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Implementation of Dutch Farming for the Cultivation of Tomatoes in South India

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Sommario

Le crescenti problematiche legate ai cambiamenti climatici, alla scarsità d'acqua e alla limitata disponibilità di terreni coltivabili hanno evidenziato l'urgenza di soluzioni agricole sostenibili, in particolare nelle aree tropicali come il Sud dell'India. Questa tesi descrive la progettazione, lo sviluppo e l'efficacia di un sistema idroponico passivo integrato in una struttura di coltivazione protetta, pensato per la produzione durante tutto l'anno di colture ad alta richiesta come pomodoro, lattuga, spinaci e basilico. Lo studio si basa su ricerche condotte in paesi in via di sviluppo e utilizza materiali disponibili localmente, substrati di coltivazione a basso costo e tecniche manuali di gestione dei nutrienti per garantire un sistema sostenibile, accessibile e scalabile per coltivatori di piccole e medie dimensioni.

La ricerca ha incluso la selezione del sito, la progettazione di una serra passiva adattata al clima, la scelta delle colture e delle tecniche idroponiche, e la gestione delle prestazioni delle piante in ambienti climatici controllati passivamente. Sono stati misurati e analizzati parametri chiave come altezza delle piante, resa, assorbimento dei nutrienti, efficienza nell'uso dell'acqua e incidenza dei parassiti. I risultati mostrano evidenze significative che i sistemi idroponici passivi possono produrre ortaggi di alta qualità con un uso d'acqua molto ridotto e un minore impiego di input chimici rispetto ai metodi di coltivazione tradizionali in suolo. Inoltre, l'integrazione di pratiche di gestione dei parassiti, del microclima e del distanziamento tra le piante ha migliorato la salute e la produttività delle colture.

L'idroponica passiva in condizioni protette rappresenta un'alternativa intelligente per il clima, economicamente sostenibile ed ecologicamente vantaggiosa rispetto all'agricoltura tradizionale nelle regioni tropicali e semi-aride. Essa offre soluzioni tecniche praticabili, oltre a favorire l'agricoltura urbana, la coltivazione verticale e la produzione continua, contribuendo direttamente agli Obiettivi di Sviluppo Sostenibile (SDGs) delle Nazioni Unite, in particolare quelli relativi a Fame Zero, Consumo Responsabile e Azione per il Clima. Si raccomanda pertanto di espandere tali sistemi integrando componenti automatizzati, fonti di energia rinnovabile, riciclo dei nutrienti e strumenti di politica agricola più efficaci per supportare sia le aree rurali che urbane.

Parole chiave: Idroponica passiva; Coltivazione protetta; Sicurezza alimentare; Obiettivi di Sviluppo Sostenibile (SDGs); Agricoltura a basso costo; Gestione integrata dei parassiti; Agricoltura in ambiente controllato (CEA)

ABSTRACT

The increasing issues of climate change, water scarcity, and limited arable land have highlighted the need for sustainable agricultural solutions, especially in tropical areas like South India. This thesis has outlined the design, development, and effectiveness of a passive hydroponic system integrated into a protected cultivation structure for the high demand growing of tomatoes, lettuce, spinach and basil all year round. The study builds upon research conducted in developing countries using available materials, inexpensive growing media, and low-tech manual nutrient management solutions, to maintain sustainability that is accessible and scalable for small and medium-sized growers.

The research comprised site selection, designing a passive climate-adaptive greenhouse system, crop selection, choosing hydroponic techniques, managing crop performance in passive climate environments. Key parameters including plant height, yield, nutrient uptake, water-use efficiency, and pest counts were measured and reported. The findings show significant evidence that passive hydroponic systems can produce high-quality vegetables with much lower water use and fewer chemical inputs, to be able to grow food in comparison to traditional soil-based cropping systems. The integration of pest management practices, climate management practices, and plant spacing also improved crop health and yield.

Passive hydroponics under protected conditions is a climate-smart, economically viable, and environmentally friendly alternative to traditional farming in tropical and semi-arid regions. It offers viable technical options, plus an opportunity for urban agriculture, vertical farming, and year-round production, alongside creating a direct contribution to the UN Sustainable Development Goals (SDGs); more specifically the goals applicable to Zero Hunger, Responsible Consumption, and Climate Action. It is therefore recommended that the systems be scaled, including automated components, renewable source energy, waste nutrient recycling, and greater policy tools to support farming in rural compared to urban areas.

Keywords: Passive hydroponics; Protected cultivation; Food security; SDGs (Sustainable development Goals); Low-cost farming; Integrated pest management; Controlled environment agriculture (CEA)

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NOMENCLATURE

CEA	Controlled Environment Agriculture
EC	Electrical Conductivity (measured in mS/cm)
IPM	Integrated Pest Management
NFT	Nutrient Film Technique
pH	Potential of Hydrogen; acidity or alkalinity scale
DO	Dissolved Oxygen
ppm	Parts Per Million
DWC	Deep Water Culture
LED	Light Emitting Diode
TDS	Total Dissolved Solids
Substrate	Medium that supports plant roots in hydroponics (e.g., cocopeat)

1 Introduction

Agriculture has undergone significant developments since the earliest cultivation, evolving alongside human societies and technological advancements. Around 10,000 BCE, during the Neolithic Revolution, early humans began domesticating plants and animals, marking the transition from a hunter-gatherer lifestyle to settled farming. The domestication of crops like wheat, barley, rice, and maize, along with animals such as cattle, sheep, and goats, played a crucial role in food security and population growth. This transformation led to the establishment of permanent settlements, fostering economic and social structures that shaped early civilizations. One of the earliest known land management techniques was fire-stick farming, used by indigenous communities such as Australian Aboriginals. This method involved controlled burning of vegetation to clear the land, to encourage the growth of specific plants, and attract animals. Similar techniques, such as slash-and-burn agriculture in tropical regions and terrace farming in hilly terrains, were practiced worldwide to enhance soil fertility and optimize land use. As civilizations advanced, irrigation-based agriculture emerged in Mesopotamia and Egypt, enabling large-scale food production in arid environments. The medieval period saw the introduction of crop rotation and mixed cropping to maintain the soil fertility, while the Industrial Revolution brought mechanization, including tractors, harvesters, and chemical fertilizers, significantly boosting agricultural productivity. Agriculture has always been an ever-changing system, adapting to environmental conditions and human needs. In the modern era, technological advancements such as precision farming, biotechnology, and climate-resilient crops have revolutionized food production. The use of GPS, drones, and AI-driven analytics has optimized resource use, while organic and regenerative agriculture promote sustainability. Despite these advancements, challenges such as climate change, soil degradation, and water scarcity pose significant threats to global agriculture. India, being an agriculture-based country, has a rich farming history dating back to the Indus Valley Civilization (around 3000 BCE). The Green Revolution in the 1960s and 1970s introduced high-yield varieties (HYVs) of wheat and rice, significantly increasing food production and making India self-sufficient in grain supply. Other agricultural revolutions, such as the White Revolution (dairy production), Blue Revolution (aquaculture), and Organic Farming Movement, have contributed to the country's agricultural diversity. Today, Indian agriculture faces multiple challenges, including the climate variability, declining soil health, and the need for sustainable farming practices. However, the integration of modern technology, policy support, and eco-friendly innovations will be key to ensuring food security and economic growth in the coming decades. (Afroz Alam, 2014)

1.1 HISTORY OF AGRICULTURE IN INDIA

In India, agriculture started around 9000BC as a consequence of early farming of plants, crops along with the animal domestication. Almost immediately people established life with the implication of practices developed for agriculture. Due to the occurrence of double monsoon harvesting were done twice a year. Barley, wheat and jujube were cultivated in the Indian subcontinent by 9000 BC. Varieties of tropical fruit like muskmelon and mango were indigenous to the Indian subcontinent. The Indians also domesticated hemp and rice which was cultivated in the Indus Valley Civilization. It was also stated that rice cultivation was started during second millennium BC in Kashmir and Harrappan regions. The basis of farming in Indus valley economy was mixed farming. The development of irrigation was made in the Indus Valley Civilization about 4500 B.C. Due to the development of irrigation prosperity grew in Indus valley civilization and eventually these leads to more sophisticated settlement of make use of drainage and sewers. In Vedic period the ploughing of top soil was done several times and seeds were spread. Definite succession of cropping was made from time to time. Cow dung was usually utilized in the form of the preferred fertilizer. Irrigation was adept accordingly in this period. The cultivation of jute was also done in India and was used to make rope and cordage in this period. During ancient Mauryan-Empire (322–185 BCE) meteorological observations were made and categorization of soils were made for agricultural use. In this period facilitation like construction and maintenance of dams were done along with provision of horse-drawn chariots.

High Middle Ages (200–1200 CE):

Early Common Era in High Middle Ages for sustained agriculture methodical ploughing, weeding, manuring, irrigation and crop safeguard was implemented. Water storage systems were also developed during this era. A dam named Kallanai was built during (1st- 2nd century CE) on river Kaveri during this period, and it is considered as one of the oldest water regulation structures in the world still in use.

Traditional Agriculture: A Sustainable Farming System

Traditional agriculture has evolved over the last 10,000 years, forming the foundation of farming practices across various civilizations. It is a sustainable and stable farming system that has been passed down through generations, ensuring food security while maintaining harmony with the environment. Unlike modern industrial agriculture, which focuses on mass production, traditional farming systems emphasize local knowledge, ecological balance, and biodiversity. Many communities, especially in developing regions, continue to practice traditional agriculture, as it remains resilient, organized, and environmentally friendly.

Traditional farming systems were developed through the interaction of societal and ecological systems, incorporating natural wealth, biological diversity, and alternating practices to sustain food production. This method relies on local resources, organic fertilizers, crop diversity, and natural pest control mechanisms rather than chemical-based interventions. Farmers practicing traditional agriculture focus on techniques that help preserve soil fertility, prevent soil erosion, retain water in the soil, and ensure stable harvests. One of the key characteristics of this farming system is its high degree of biodiversity, which enhances resilience against pests, diseases, and climatic fluctuations.

1.2 Types of Traditional Farming Systems in India

1. Forest-Gardening

   Forest gardening is considered one of the oldest agro-ecosystems, primarily a plant-based food production system. In this system, indigenous communities identified and protected useful trees and plant species while eliminating fewer desirable ones. Over time, they improved certain plant varieties through selection and breeding. These cultivated trees and plants were then integrated into household gardens, creating multi-layered ecosystems that provided food, medicinal herbs, firewood, and shelter. Forest gardening is a sustainable method that maintains soil fertility, promotes biodiversity, and enhances food security while requiring minimal external inputs.

Figure 1: Forest gardening

Figure 2: Goals and achievements of Forest gardening (Source - Researching Forest Gardening 2021.,)

2. Agro-Pastoralism

Agro-pastoralism is a farming system that combines crop cultivation and livestock rearing. In India, this practice was characterized by threshing, planting crops in strips (either two or six strips), and storing harvested grains in granaries. The integration of livestock allowed farmers to use manure as natural fertilizer, improving soil fertility. Animals like bullocks and horses were also employed for ploughing fields and transporting goods, enhancing farm productivity. This system provided multiple sources of income and food, ensuring resilience against crop failures.

Figure 3: Agro pastoralism farming

Figure 4: Pastro Farming benefits

3. Mixed-Farming

Mixed farming was the foundation of the Indus Valley economy, where crop cultivation was combined with livestock rearing to create a sustainable agricultural system. This method allowed farmers to use cattle dung as manure, enriching the soil and increasing cereal production. In mixed farming, horses and cattle were raised for ploughing and transportation, while bullocks pulled carts and Plows. The integration of crops and livestock provided farmers with multiple benefits, including a steady food supply, improved soil fertility, and risk diversification in case of crop failures.

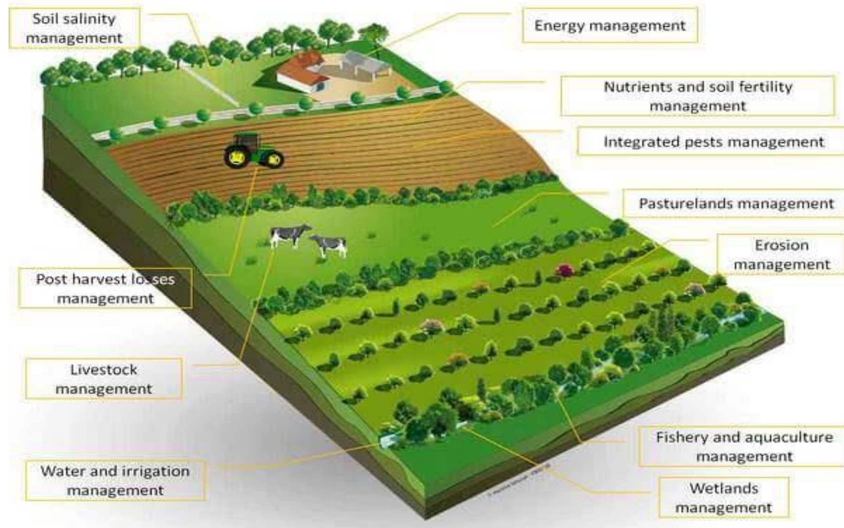


Figure 5: Mixed farming (Sustainable agriculture)

4. Shifting Cultivation (Slash-and-Burn Farming)

Shifting cultivation, also known as slash-and-burn farming, is an ancient technique practiced in forested areas. This system involves cutting and burning trees and vegetation to clear land for farming. The ashes left behind enrich the soil with nutrients, supporting crop growth for several years. Once the soil loses its fertility, farmers leave the plot fallow and move to another area, allowing the forest to regenerate naturally. This subsistence-based agricultural method requires minimal technology and external inputs and is still practiced by indigenous communities worldwide. Shifting cultivation is often associated with transhumance livestock herding, where farmers relocate seasonally to find fresh grazing land for their animals.

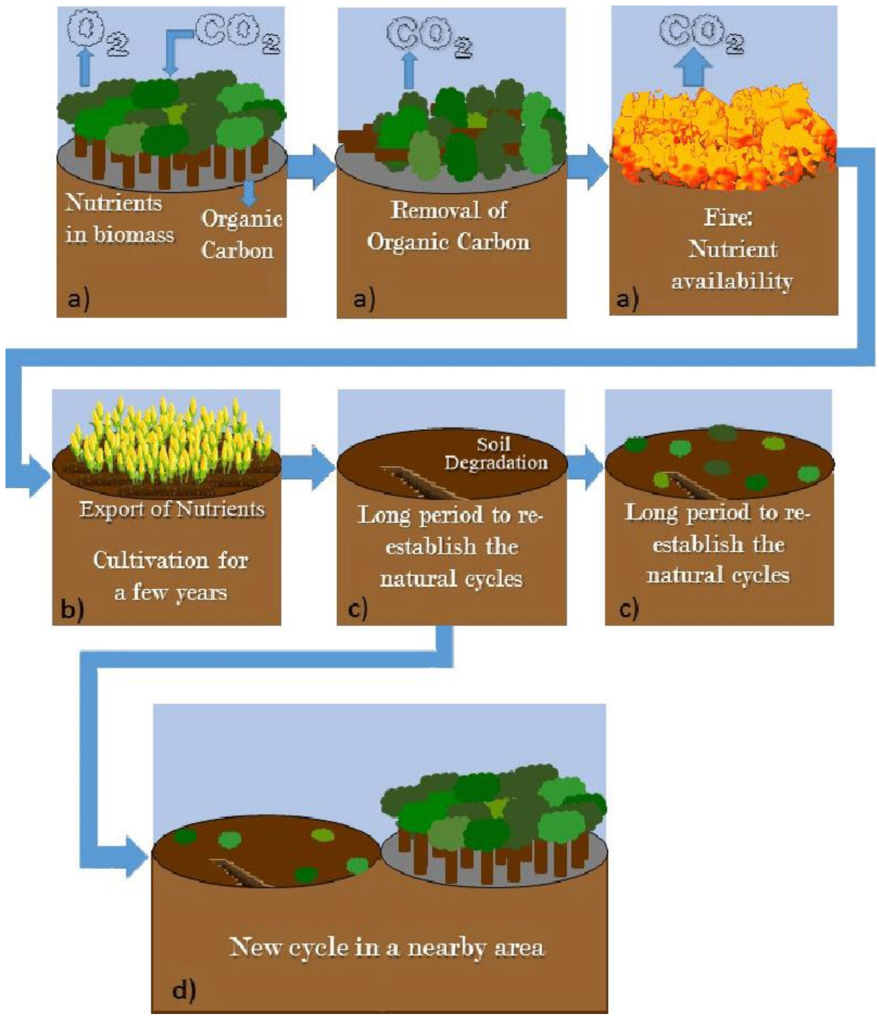


Figure 6: Shifting cultivation technique (Source from Sustainable productive intensification for family farming in developing tropical countries, 2019.,)

1.3 DISADVANTAGES OF TRADITIONAL FARMING

(a) During the old days, agricultural technology was not well developed compared to now. People did not use any machinery to farm their land, machinery which are much more efficient replaced those animals used in the agricultural.

(b) Previously, farmers had to be depended on land suitability, climate factor and the availability of adequate water supply before planting a crop that suited those criteria.

(c) In the old days, farmers worked on their land to produce crops for their own domestic use because with the methods used in traditional agriculture were not very effective to produce enormous number of crops. The crop yield was really low according to the population in traditional agriculture.

(d) Pest management and disease management were not so effective in traditional agriculture.

(e) Due to environmental factors and undeveloped techniques overall production was low in traditional farming.

2. NEW FARMING SYSTEM

Due to many challenges in traditional farming system, new techniques come into play now a day. The new technique includes Drip irrigation system, Organic farming, genetically modified crops, Vertical farming, Hydroponics, Polytonal farming, greenhouse farming, Livestock farming and multi-crop farming. Majorly used techniques are described.

2.1 ORGANIC FARMING SYSTEM

Organic farming is a holistic agricultural approach that focuses on sustainability, soil health, and biodiversity while avoiding synthetic inputs. Instead of relying on chemical pesticides and fertilizers, organic farmers use natural alternatives such as compost, manure, and crop rotation to maintain soil fertility. They also adopt biological pest control methods, such as introducing beneficial insects or using neem-based sprays, to manage pest populations without harming the ecosystem. This approach not only ensures safer food production but also reduces environmental pollution and soil degradation, making it a sustainable alternative to conventional farming. One of the fundamental principles of organic farming is soil conservation and enhancement. Organic farmers emphasize practices like cover cropping, mulching, and minimum tillage to prevent soil erosion and improve water retention. Crop rotation is another essential method, as it helps maintain soil fertility by naturally replenishing nutrients and reducing the buildup of pests and diseases. Additionally, organic farming promotes the use of green manure and composting, which enriches the soil with essential nutrients, fostering healthier plant growth.

Another crucial aspect of organic farming is biodiversity and ecological balance. Unlike conventional monoculture farming, which depletes soil nutrients and increases vulnerability to pests, organic farming encourages polyculture—growing multiple crops together in harmony. This method enhances soil health, attracts pollinators, and creates a balanced ecosystem where pests and their natural predators coexist, reducing the need for chemical interventions. Moreover, organic farms often incorporate agroforestry—planting trees alongside crops—to improve microclimates, provide shade, and enhance carbon sequestration. Organic farming is also beneficial for human health and food quality. Since organic crops are grown without synthetic pesticides, fertilizers, and genetically modified organisms (GMOs), they are free from harmful chemical residues. Studies suggest that organically grown food often contains higher levels of essential nutrients, antioxidants, and vitamins, making it a healthier choice for consumers. Additionally, organic livestock farming prohibits the use of antibiotics and growth hormones, ensuring that meat, dairy, and eggs are free from harmful substances.

Over the years, the global demand for organic products has risen significantly due to increased consumer awareness about health and environmental sustainability. Governments and agricultural organizations worldwide have implemented certification programs, such as the USDA Organic (United States), EU Organic (Europe), and India Organic, to regulate organic farming practices and ensure product authenticity. Despite its numerous benefits, organic farming also faces challenges such as lower initial yields, higher labour costs, and the need for extensive knowledge and skill. However, with advancements in research and the growing emphasis on sustainable agriculture, organic farming is expected to play a crucial role in shaping the future of food production (V, 2012).

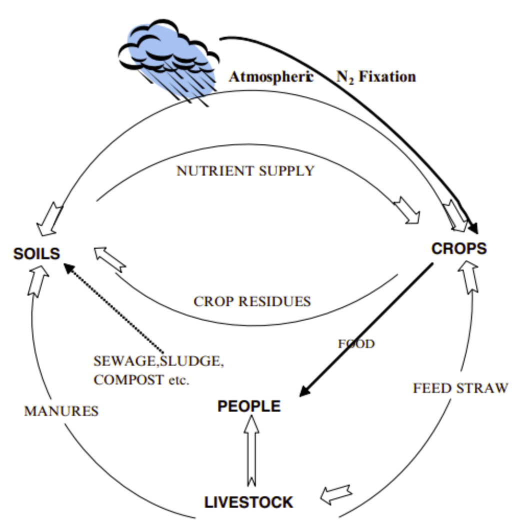


Figure 7:Organic cycle of organic farming system (Source organic farming history and technique, K.K. Behera et al)

CONVENTIONAL FARMING	ORGANIC FARMING
It is based on economical orientation, heavy mechanization, specialization and misappropriates development of enterprises with unstable market-oriented programme.	It is based on ecological orientation, efficient input use efficiency, diversification and balanced enterprise combination with stability.
Based on the philosophy to feed the crop and environment.	Feed the soil not to the plant is the main motive of organic farming
Supplementing nutrients through fertilizers, weed control by herbicides, plant protection measures by chemicals and rarely combination with livestock.	Cycle of nutrients within the farm, weed control by crop rotation and cultural practices, plant protection by non-polluting substances and better combination of livestock
Low input: output ratio with considerable pollution	High input: output ratio with no pollution
Production is not integrated into environment and more imbalances	Production is integrated into environment with balanced conditions for plants and animals.
Economic motivation of natural resources without considering principles of natural upgradation	Maximum consideration of all natural resources through adopting holistic approach.

Table 1: Difference between conventional farming and organic farming

DISADVANTAGES OF ORGANIC FARMING

1. In 1998, there was an increased risk of E. COLI infection via consumption of organic food rather than inorganic food which was published by Dennis Avery of the Hudson Institute.

2. The father of Modern Green Revolution, Norman Borlaug says that the organic farming practices are capable of catering to the demands of very small consumer fraction, the expanding cropland is dramatically destroying world ecosystems.

3. Organic agriculture is hardly able to address or combat global climate change. Through regenerative organic farming practices are recognized as effective strategies for reducing CO2 emissions ton an extend, the impact is not dramatic.

4. Organic farming often requires more labor, time, and resources than conventional farming. Farmers must invest in natural fertilizers, organic seeds, and manual labor for weed and pest control. The cost of organic certification and compliance with regulatory standards can also be expensive, making organic farming less accessible for small-scale farmers.

5. Since organic crops do not contain chemical preservatives, they tend to spoil faster than conventionally grown produce. This reduces storage and transport flexibility, making it challenging to distribute organic products over long distances.

6. Farmers switching from conventional to organic farming face a long transition period, often lasting 2-3 years, during which the soil needs time to rebuild its natural fertility. During this time, yields may decline, and farmers may face financial losses before their farms become fully productive under organic systems.

Figure 8: Disadvantages of Organic farming

2.2 INTRODUCTION TO NEW FARMING TECHNIQUE (DUTCH FARMING FOR TOMATO CROP)

The increased importance of tomatoes in the worldwide market has been a driving force to expand the average and export share for many countries, especially for those located close to the major importing countries. Originating in Central and South America, tomato is today more consumed in the USA, Europe and India than in the rest of the world. The world crop area of tomato has increased by 164% in 40 years and the world consumption of tomatoes has increased by 314%. In recent years, tomato consumption quantity increased at the average rate of 3% annually. Along with the increase in consumption, product quality which has been improved. Production of tomatoes during the hot-wet season in tropical and subtropical climates is limited by unfavourable conditions, Examples include extreme temperatures, flooding, severe winds, and a high illness incidence. Over the last several decades, protected growing of tomato crops has been the most effective way to acquire high-quality fresh tomatoes for both domestic and international markets. The growing time under covered horticulture may be prolonged throughout the year; however, the main constraint is the high temperature within the greenhouses generated by the heating effects of high irradiation. To optimize tomato production in the tropics, it's important to examine the many climates and production systems that impact the region.

Individual qualitative features of tomato fruit are valued differently in the fresh and processed industries. The development of automated harvesting, as well as the need for enhanced health value in processing goods, has altered the importance of fruit quality traits in tomato processing. The progress in studies on the genetics and physiology of certain fruit quality qualities, such as solid content, colour, taste and flavour, and health considerations in tomato fruits, is encouraging. Improving raw material quality is likely to be the most significant problem for tomato processing management in the near future. Quality criteria include fruit integrity, firmness, maturity stage, chemical and physical properties, nutrient content, flavour, and pesticide residues. The significance of the varied raw material needs for commercial products should not be underestimated. Climate, soil, and crop management are the three most important elements influencing tomato fruit quality. Crop management is based on farm organization and industry agreements. It should cover variety selection, technical methods, crop planning, harvest, and post-harvest management. Trade flows vary according on tomato kind and season. Tomato production regions have expanded in recent years, but the unorganized supply chain leads prices to plummet, resulting in the import-export of a bad product. In order to become more competitive, producers and processors need collaborate to create a productivity pricing scheme. This approach allows producers to focus on boosting yields, reduces unit costs for processors, and includes the creation of commercial strategies and technology to guarantee the worldwide market's quality criteria. In the tropics, environmental limitations limit both production and postharvest stages. High temperatures, humidity, and bugs all pose challenges throughout the entire chain. These may be regulated throughout production by protected cultivation, automated greenhouses, pest integrated management, and cooling systems, as well as postharvest through refrigeration techniques at harvest and distribution, and sanitation during processing. To standardize the chain, it is required to develop criteria for production, processing, and distribution that can be arranged for both the fresh market and the processing sector while ensuring safety and quality. Global food markets have grown more competitive, and trade in high-value foodstuffs has slowed as more of them are produced domestically. For this reason, it is critical to increase the quality of tomatoes cultivated in tropical regions (S. Nicola, 2009) .

2.3 VERTICAL FARMING TECHNIQUE WITH HYDROPONICS

Vertical farming is a technique that uses no soil and little water to grow crops in vertically stacked layers. As the global population is growing, and traditional farming practices has many challenges. Vertical farming can produce food around the clock and save up to 90% of water. In the near future, vertical farms and industrialized farming within buildings will supplement alternative agricultural production systems by providing a product with precise specifications that is produced under controlled conditions. However, they will not completely replace traditional agriculture. This product is adaptable and will change to meet the evolving needs of urban residents. Modelling many design options for cities that are continuously changing is made possible by combining urban vertical farms into a multi-dimensional (multi-scale, multifunctional) system. Newly developed vertical urban farms will not only boost harvests and reduce production costs in the future, but they will also greatly improve the quality of agricultural items given to city people, mitigating urbanization's negative environmental impacts.

Figure 9: Vertical Farming with hydroponics

3 Literature Review

The goal of this literature review aims to establish a comprehensive understanding of the fundamental concepts and current trends in vertical farming of Tomatoes. This foundational knowledge will set the stage for a more in-depth exploration of sustainable business model innovation within the vertical farming sector. Specifically, the research will then pivot towards addressing the unique challenges and opportunities faced by vertical Dutch farming of tomatoes in South India (Small and Medium scale farmers). Despite the global advancements in vertical farming, there exists a significant knowledge gap and a dearth of information in the existing research literature concerning the Indian vertical farming industry, particularly regarding the sustainability practices and business model innovations employed for small and medium scale farmers in this region.

3.1 INTRODUCTION AND OBJECTIVE OF HYDROPONICS (VERTICAL FARMING)

Today, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 and 593mha of land will need to be turned into agricultural land to fulfil the estimated calorie demands of the worldwide population. Furthermore, the occurrence of second-generation problems, such as over-mining of soil nutrients, decline in factor productivity, lowering of groundwater tables and pest build-up, such as weeds, diseases and insects poses serious problems. To mitigate these problems, intensification and vertical expansion of agricultural land has been regarded as the only viable options in near future for meeting the rising food demands. Globally, 70% of water usage goes towards agricultural production, largely due to unsustainable irrigation practises (Worldbank.org). In this context, soil-less cultivation i.e., hydroponics, might be inaugurated successfully and considered as an alternative option for growing quality food plants, crops or vegetables. One of the most important advantages of hydroponic farming is the ability to grow crops in near optimal conditions using Controlled Environment Agriculture (CEA) technology. It can be grown anywhere on the world at any time of year, regardless of weather, accessible cultivable land, or soil quality. Crop production can be kept in a controlled environment, allowing trained personnel to optimize water (saving up to 70% of water) nutrients and light to the plants using advanced climate control technologies. Light inputs are also optimized to ensure maximum plant absorption and yield outputs. Vertical farms increase upwards instead of outwards on a horizontal plane, allowing farmers to grow 2 to 10 times more crops in the same amount of space as unlike conventional farms. By stacking horizontal racks on top of each other, hydroponics increases the amount of space available on the ground. In a traditional farm, identification of pests, diseases in the field are much more difficult. But in hydroponics, the modular design allows for a highly efficient separation of diseased or dying crops, as well as a quick and easy neutralization of compromised plants. Most hydroponic systems operate automatically to control the amount of water, nutrients and photoperiod based on the requirements of different plants.

3.2 GROWTH AND DEVELOPMENT

Due to improvements in farming practices and rising consumer demand for premium, greenhouse-grown veggies, the worldwide hydroponics market has experienced significant expansion in recent years. With a compound annual growth rate (CAGR) of 6.39% from 2015 to 2020, the global hydroponics crop market was estimated to be worth USD 18.8 billion in 2014 and reached USD 27.29 billion by 2020. Furthermore, the market for hydroponics equipment was anticipated to increase at a compound annual growth rate (CAGR) of 16.8% to reach USD 395.2 million by 2020. The market comprises a variety of crop kinds, including peppers, lettuce, leafy greens, tomatoes, and cucurbits (melons and cucumbers). In 2018, tomatoes held a dominant 30.4% share. Because of its sophisticated farming methods, Europe continues to be the region with the highest adoption of hydroponics, however demand has also increased in Asia-Pacific. Because of its sophisticated farming methods, Europe continues to lead the world in the adoption of hydroponics, but Asia-Pacific has also seen an increase in demand as a result of growing consumer knowledge of the advantages of produce cultivated in greenhouses. Higher yields, resource efficiency, urban agriculture, and controlled environments that lessen reliance on weather and pests are some of the elements driving this industry growth. The market for hydroponics is anticipated to keep growing as consumers place a greater value on sustainability and quality, helped along by developments in technology and the growing popularity of soilless growing techniques.

The second-largest hydroponics market is Asia-Pacific, and it is anticipated to expand steadily. The USA, Canada, Israel, France, England, Australia, and the Netherlands are the leaders in hydroponic technology. The Netherlands leads the world in commercial hydroponics, with 13,000 hectares planted to tomatoes, capsicum, cucumbers, and cut flowers, which make up half of the total value of all fruits and vegetables grown in the nation (Netherlands Department of Environment, Food, and Rural Affairs, NDEFRA). According to the Rural Industries Research and Development Corporation (RIRDC), Australia's hydroponic system for growing vegetables, herbs, and cut flowers is worth between $300 and $400 million, or 20% of the country's total value of vegetable and cut flower production.

In addition to producing more strawberries than the USA and nearly as many cut flowers, Australia is the world's largest producer of hydroponic lettuce. Commercial hydroponic systems are also being used to expand the area in Canada and Spain. In order to feed its population, Japan has begun producing rice using the hydroponics technique. Because of its dry and arid climate, Israel produces a lot of bananas, citrus fruits, and berries. The need for hydroponic farming has grown recently in both industrialized and developing nations. Hydroponics can be used on a number of wasteland tracts in India that have good soil but lots of water. Nowadays, residents of several large cities, including Delhi, Chandigarh, Noida, and Bangalore, grow little herbs, spices, and leafy greens on their balconies and rooftops for fresh consumption (Dr. Madhavi D. Jangilwad, 2020).

3.3 HYDROPONICS

Hydroponics farming refers to a method of growing plants without the use of soil. Plant roots are submerged in liquid solutions containing macronutrients like nitrogen, phosphorus, sulphur, potassium, calcium, and magnesium, as well as trace elements like iron, chlorine, manganese, boron, zinc, copper, and molybdenum, in hydroponic systems. In addition, to provide support for the roots, inert (chemically inactive) mediums such as gravel, sand, and sawdust are used as soil substitutes. Hydroponic farms offer a viable solution towards a more sustainable food production while avoiding hazardous chemicals due to controlled environments and strict certification laws. Hydroponic farming is already integrated into sustainable agriculture in order to meet rising global food demand.

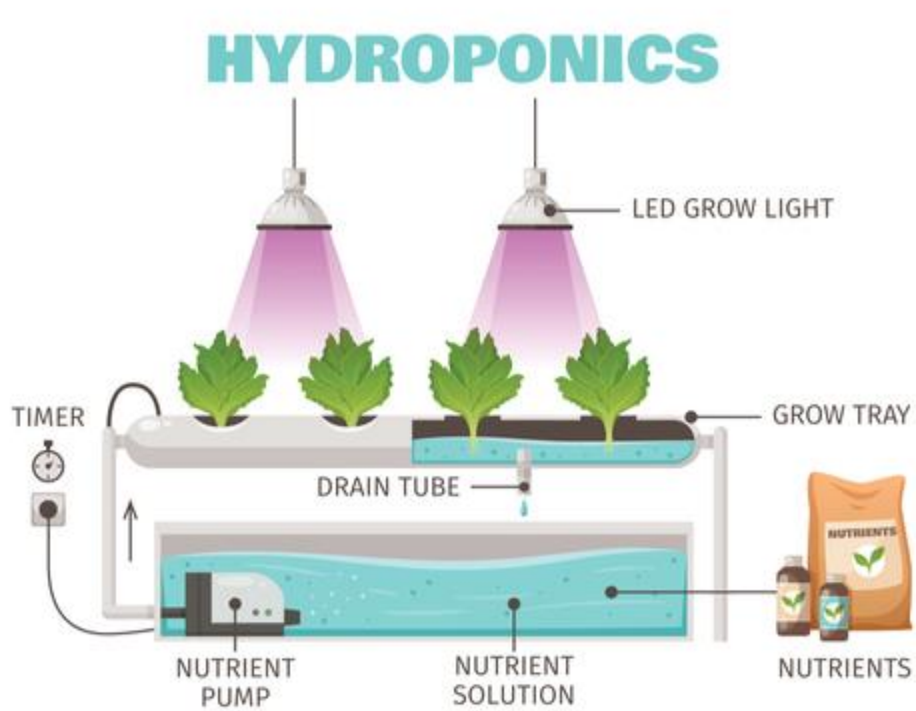


Figure 10: Hydroponics system

3.3.1 MEDIA USED IN HYDROPONICS

The term "medium" refers to a substance that is used to sustain plants and replace dirt. The growth medium plays a crucial role in getting water and dissolved nutrients into contact with the plants and aids in anchoring them so they do not topple over roots. The most common media include expanded clay pellets, rockwool, coco-peat, vermiculite, sand, perlite, and lightweight, porous, and reusable, offering excellent drainage and aeration. Rockwool, derived from molten basalt rock, retains moisture well and provides good root support, though it requires pH balancing before use. Coco-peat, made from coconut husks, is an organic medium that retains water efficiently while maintaining aeration, making it a popular choice for various hydroponic systems. Vermiculite is another moisture-retaining medium that also helps in buffering pH and nutrient absorption. Perlite, a volcanic glass, is lightweight and improves aeration, often mixed with other media for better drainage. Sand, although inexpensive and widely available, is heavy and does not retain nutrients as effectively as other media. Gravel, while offering excellent drainage and stability, is primarily used in larger hydroponic systems where frequent watering ensures nutrient availability.

Each kind of medium works best with a particular hydroponic system. For example, rock wool or perlite are frequently used in deep water culture (DWC) and nutrient film technique (NFT) systems, whereas gravel or expanded clay pellets are effective in ebb and flow systems. The type of plant, the hydroponic technique, and the surrounding environment all influence the medium selection, which guarantees ideal development and nutrient absorption (Dr. Madhavi D. Jangilwad, 2020).

Figure 11: Media used in Hydroponics

SOIL-LESS MEDIA	BULK DENSITY (kg/m3)	Total porosity (% v/v)
Coco peat	80-100	90-95
Perlite	80-120	85-90
Vermiculite	90-150	90-95

Rock Wool	80-90	95-97
Expand Clay	600-900	85-90

Table 2:Bulk density and Porosity of Important Soil – Less Media

3.3.2 ESSENTIAL COMPONENTS OF HYDROPONIC SYSTEM

1. Growing Tray
2. Nutrient Management
3. Water management by Submersible Pumps
4. Aerators or Air Pumps
5. Grow Lights
6. Substrates
7. Monitoring and Control Tools

GROWING TRAY

A grow tray is a container designed to hold plants in a hydroponic system while keeping them safe and secure. Depending on the type of hydroponic system, trays may include leach valves for draining excess water from the growing medium. On a small scale, hydroponics can also be cultivated in pots. The grow tray is crucial because it directly houses the plant roots in the nutrient-rich hydroponic solution. This setup provides plants with immediate and continuous access to essential minerals and nutrients, eliminating the need for roots to grow extensively in search of sustenance, as they would in traditional soil-based farming. As a result, root growth is more compact, while shoot development is significantly accelerated, leading to higher productivity and faster crop cycles. The controlled environment of the growth tray also minimizes the risks of soil-borne diseases, enhances nutrient absorption efficiency, and contributes to consistent and uniform crop yields.

Figure 12: Grow trays inside Nursery

NUTRIENT MANAGEMENT

Hydroponics is a soilless growth technology in which plants get their nutrition from a precisely adjusted nutrient solution. Nutrient solution formulation is crucial to plant growth and productivity because it assures the availability of important macronutrients and micronutrients.

Significance of Nutrient Solution

The development of nutrient solutions has been important in hydroponic research. The Hoagland solution, formulated by Dennis R. Hoagland and Snyder (1933) and later refined by Hoagland and Arnon (1938), which remains one of the most widely used nutrient solutions in hydroponics (Hoagland & Arnon, 1950). It provides a balanced composition of essential nutrients, making it suitable for a wide range of plant species. Several modifications of the Hoagland solution exist to cater to specific crop needs, pH stability, and salinity control.

Hydroponic nutrient solutions must be tailored to meet plant-specific requirements. Research has shown that deficiencies or excesses of certain nutrients can adversely affect plant metabolism and development. For example, potassium deficiency leads to stunted growth and reduced disease resistance, while excess nitrogen can contribute to excessive vegetative growth at the expense of fruit or flower production. Macronutrient and micronutrients Macronutrients play a major role in increasing crop yield, growth, and quality. These nutrients are termed as ‘macronutrients since they are required by the plants in a larger quantity. Each macronutrient has its functionality involved in various beneficial activities and metabolic processes of the plant during its lifecycle. Further, they contribute support to the plants to protect themselves from various biotic stress such as attacks by different pathogens, pests, etc., and are also helpful to recover from abiotic stress like heavy metal intake, drought, UV radiation, excessive heat, salinity, etc., Macronutrients are classified into two groups: primary macronutrient and secondary macronutrient. The primary macronutrients are the ones that are required in larger quantities like nitrogen (N), phosphorus (P), and potassium (K), whereas the secondary macronutrients are usually required in moderate measure compared to the primary macronutrients, some of these are calcium (Ca), magnesium (Mg), sulphur (S), and carbon (C) . Micronutrients have their role in all the metabolic and cellular activities of the plant. They are essential for plant growth but are needed in minimal quantity than the macronutrient. Required micronutrients include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), sodium (Na), cobalt (Co), silicon (Si), and vanadium (V). However, the last four elements rarely influence plant growth. Obviously, there is a tolerance concentration limit for each nutrient in the hydroponics medium. This tolerance limit depends on the plant species and their origin. Therefore, understanding the tolerance limit of each nutrient against the plants that are grown hydroponically is much required. Also, the hydroponic medium has to be replenished periodically to improve the yield of the cultivation. So, the hydroponic medium is monitored using total dissolved solid content and pH in regular intervals.

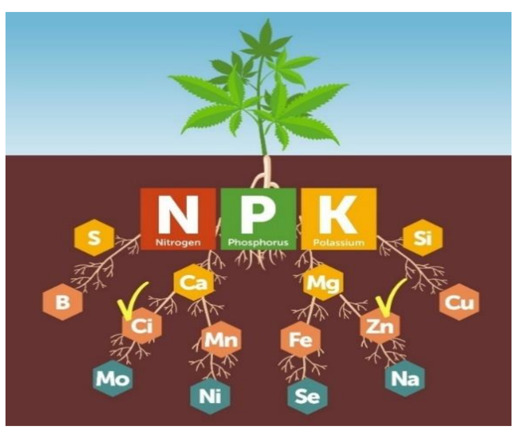


Figure 13:Macro and Micro Nutrients for Plants

COMPONENT	STOCK SOLUTION (SS)	(SS) in 1000 ml water
	Source for Macronutrients	
Potassium nitrate (KNO_3)	202 g/L	2.5 ml
Calcium nitrate ($Ca(NO_3)_2$)	236 g/0.5L	2.5 ml
Fe (II) ethylenediaminetetraacetate (Fe-EDTA)	15 g/L	1.5 ml
Magnesium sulphate ($MgSO_4$)	493 g/L	1 ml
	Source for Micronutrients	
Boric acid (H_3BO_3)	2.86 g/L	1 ml
Manganese II chloride ($MnCl_2$)	1.81 g/L	1 ml
Zinc sulphate ($ZnSO_4$)	0.22 g/L	1 ml
Copper II sulphate ($CuSO_4$)	0.051 g/L	1 ml
Molybdic acid (H_2MoO_4)	0.09 g/L	1 ml
Sodium molybdic acid (Na_2MoO_4)	0.12 g/L	1 ml
	Source for Phosphate	
Potassium phosphate (KH_2PO_4)	136 g/L	1 ml

Table 3:Constituents present in the basic Hoagland solution (Monisha k et al.,2023)

WATER MANAGEMENT BY SUBMERSIBLE PUMPS

In hydroponic systems, a submersible pump plays a serious role in delivering nutrient-rich water from a reservoir to the plant roots, ensuring efficient hydration and nutrient absorption. These pumps are essential for maintaining continuous water circulation, preventing stagnation, and evenly distributing nutrients to the plants. The choice of pump depends on factors such as system size, water flow rate, and the height at which water needs to be lifted (head height). Hydroponic irrigation methods vary based on the system type. Among them, sprinkler irrigation is considered highly effective for certain hydroponic setups, especially aeroponics and drip systems. In aeroponic systems, the nutrient solution is sprayed as a fine mist directly onto plant roots, maximizing oxygen availability and nutrient uptake. Drip irrigation, on the other hand, uses controlled emitters to deliver precise amounts of nutrients to each plant, reducing water wastage and optimizing absorption.

Different watering techniques and pumps are used in different hydroponic systems. An air pump and air stone oxygenate the nutrient solution in deep water culture (DWC), enabling direct oxygen uptake by the roots. The Nutrient Film Technique (NFT) uses a shallow channel to gently and continuously run nutrient-rich water over plant roots. In order to replicate natural wet and dry cycles, ebb and flow (flood and drain) devices regularly pump water into the grow bed and then drain it back into the reservoir. Commercial hydroponics frequently uses drip systems, which minimize waste by delivering nutrients via regulated drippers. Aeroponics is a cuttingedge technique that suspends roots in air and supplies them with nutrients using high-pressure misting devices. Pump maintenance is essential to the success of hydroponics. Regular cleaning prevents algae buildup, clogging, and pump failure. Using a filter can help keep debris out of the system, ensuring smooth operation. Choosing an energy-efficient, durable pump with an appropriate flow rate is key to maintaining optimal nutrient delivery, supporting healthy plant growth in hydroponic environments.

Figure 14: Submersible Pump used in Hydroponics

AERATORS OR AIR PUMPS

In hydroponic systems, where plants are cultivated without soil, oxygen is especially important for plant growth. Roots in conventional soil-based farming naturally take up oxygen from soil air pockets. However, in order to avoid suffocation, root rot, and anaerobic conditions that promote dangerous bacteria, oxygen must be delivered directly to the root zone in soilless hydroponics. Healthy root development, effective nutrient absorption, and quicker plant growth are all facilitated by adequate oxygen levels. To oxygenate the nutrient solution and guarantee that plant roots receive adequate dissolved oxygen, air pumps are crucial in hydroponic systems. Air is forced through an airline tube that is attached to an air stone or diffuser that is submerged in the nutrient reservoir in order for these pumps to function. By spreading tiny bubbles throughout the water, the air stone ensures even distribution and increases the surface area available for oxygen exchange. In addition to supporting aerobic bacteria that aid in the breakdown and uptake of nutrients, this process helps avoid water stagnation.

Different hydroponic systems utilize air pumps in various ways. Deep Water Culture (DWC), one of the most oxygen-dependent systems, requires a continuous supply of aeration to keep the roots submerged yet well-oxygenated. In Nutrient Film Technique (NFT), the thin film of nutrient solution is naturally oxygenated as it flows, but additional aeration can further enhance oxygen availability. Ebb and Flow (Flood and Drain) systems periodically expose the roots to air between watering cycles, but air pumps can still be used to enhance oxygenation in the reservoir. Plant health depends on maintaining appropriate oxygen levels. Maintaining the reservoir temperature between 18 and 22°C (64 and 72°F) helps maximize oxygen retention since warmer water stores less dissolved oxygen. Even oxygen distribution is ensured in larger systems by using multiple air stones. Effective oxygenation is ensured and clogging is avoided by routinely cleaning air stones and air pump filters. In order to maintain oxygen levels within the ideal range, dissolved oxygen meters can assist in monitoring them. In advanced hydroponic setups, some growers use oxygen-enriched water or oxygen injection systems (such as ozone generators or liquid oxygen supplements) to further boost plant growth. Proper oxygenation not only prevents diseases like Pythium (root rot) but also enhances overall nutrient uptake efficiency, leading to stronger, healthier plants with higher yields.

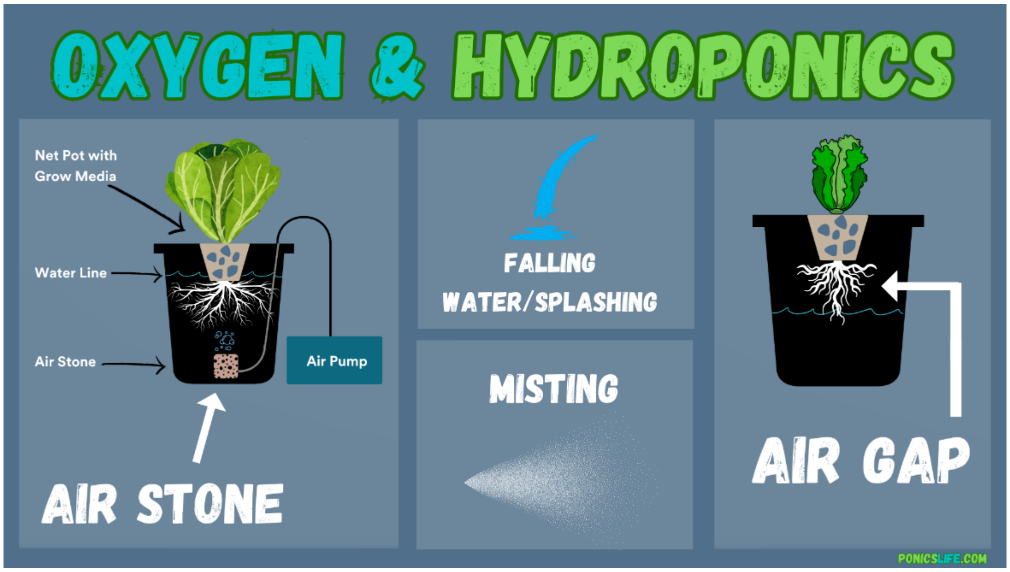


Figure 15: Aerators or air pump

GROW LIGHTS

Light with photosynthesis is a thing that you need to provide in hydroponic systems for plant growth. As so many hydroponic systems tend to the indoors growers have to maximize the light with natural sunshine, artificial grow lights, or a combination of both. At this point, artificial lights, such as LED, HID, and fluorescent lights are being used. LED grow lights are extremely energy efficient and produce only a little heat and the ability to customize the light spectrums for what growth stage a plant is currently in. HID (MH / HPS)– High-Pressure Sodium and Metal Halide are the older styles of bulbs, producing a lot of light but only covering a lot of area with light as well. MH lights produce a lot of blue light, encouraging dense vegetative growth while HPS lights produce more reddish/orange light spectrum encouraging flowering. Fluorescent lights (for example, T5 or CFL) are lower in intensity, making them a good candidate for seedlings and leafy greens.

Different light spectrum is needed at each stage of plant growth. Blue light (400-500 nm) promotes the development of the root system and leaves, preventing spindly stems, while red light (600-700 nm) fosters flowering and fruiting, making it most suitable for crops such as tomatoes and peppers. Far-red light (700–780 nm), which promotes stem elongation and flowering, is also beneficial, for cultivars such as cannabis and orchids. Furthermore, UV light (100–400 nm) can enhance plant responses to pests and stimulate the yield of essential oils in aromatic plants. Green light (500-600 nm) penetrates deeper in shade inside of the canopy, and stabilizes growth.

Specific periods of light (photoperiods) are needed by distinct plants in order to facilitate optimal growth. Some need 14-18 hours of light, such as long-day plants like lettuce and spinach, while others, like strawberries and cannabis, prefer short-days or 12 hours or less. Day-neutral plants, like tomatoes and peppers, thrive best when treated to 16-18 hours of light every day. Photosynthetic Photon Flux Density (PPFD) is important in particular, but too much light promotes heat stress and leaf burn, while too little results in weak, leggy plants. Best to optimize the light in hydroponics, for example, growers will often utilize reflectors or grow tents to optimize efficiency, modify heights of lights to reduce burning or shading, or combine different light spectrums to replicate natural sunlight. Timers also create accurate photoperiods that are vital for healthy plant growth. Improvements in LED technology allow hydroponic growers to optimize light intensity, spectrum and duration more cost-effectively, enabling greater yields and healthier plants.

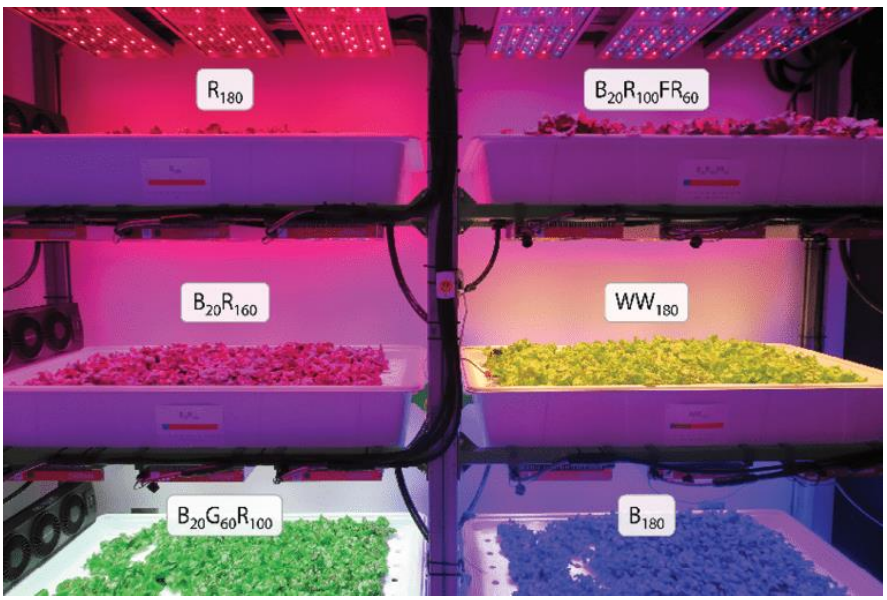


Figure 16: Grow lights in Hydroponic system

SUBSTRATES

Hydroponic setups provide a nutrient solution for the plant roots, however, support must also be provided to the growing plants, as well as aeration. While hydroponic substrates do not supply natural nutrients like soil would, they serve three main purposes of moisture retention, oxygen flow, and site of root anchorage. Substrates are selected for their ability to retain water, aerate the substrate, and decompose at the appropriate rate.

A frequently used set of substrates is of perlite, pumice, and vermiculite. We use these lightweight, porous volcanic stones to help retain moisture and provide enough airflow around the roots. Perlite is produced from volcanic glass that is heated, resulting in an excellent drainage medium ideal for a hydroponic system that needs to require high aeration. Pumice, a naturally occurring type of volcanic rock, is similar to perlite but a bit denser, with decent water retention. Another mineral-based medium that retains more moisture than perlite is vermiculite, which is often mixed with other substrates to balance aeration and water-holding capacity.

In hydroponics, organic substrates like rice husk, wood fiber, and wool are also frequently used. Source of rice husk is an agricultural waste produced as the by-product of rice milling, which is a sustainable and biodegradable medium that decomposes very slowly but retains aeration for the roots. Wood fiber, which comes from shredding wood, is aerated well and supportive of roots but needs to be properly prepared so it doesn't break down too quickly. Substrates made from wool (e.g., sheep's wool) are conducive to water retention with good oxygen availability to roots making them suitable for hydroponic cultivation.

Another widely used alternative is rock wool, which is produced by heating, and then spinning, basalt rock to create fine filaments in a sponge-like structure. Highly durable, highly moisture-retaining, and great at keeping roots insubstantial. But rock wool does not break down naturally, and in its fibrous form needs careful handling as it is irritating to work with. It is commonly used in commercial hydroponic farming because of its consistent structure and ability to hold both water and air.

The choice of the substrate will depend on the type of plants grown, the hydroponic system and the environmental conditions. Certain substrates may produce more aeration, some might retain more moisture, and a mix of different media will ensure plant growth. A substrate is the medium that supports the growth of plants, and selecting the right one is essential for the best results in hydroponic farming.

Figure 17: Substrates used in Hydroponic system

PERLITE

This is the small glassy bits produced from drawn out volcanic stone when it has been superheated before you make it. It can be applied loosely or contained within plastic sleeves submerged within water for short periods of time depending on the application. Perlite is also known to be used in potting soil mixes to lighten the soil, reduce density, and improve drainage. Typically, perlite provides a higher air-to water ratio. If it's flood and drain feeding, then it can even float if it's not contained. Several different types of rocks are combined to create it.

Figure 18: Perlite in Hydroponics

VERMICULITE

This hydrated mineral cluster with a smectite structure is recognized for its high-water retention capacity and the abundance of potassium (K) and magnesium (Mg) in its structure, the two important nutrient elements for plant growth. Potassium promotes flowering, fruiting and disease resistance, and magnesium is required to produce chlorophyll and photosynthesis. Vermiculite is an excellent moisture retainer and therefore aids in maintaining the root zone hydrated with less irrigation frequency. It also increases drainage and aeration in growing media but is less durable than substrates like sand and perlite.

Though its fine particles can pack down, when blended with perlite, sand or organic matter, it balances water-holding capacity and aeration. The layer structure of smectite minerals allows them to absorb cations, improving the cation exchange capacity (CEC) for plants and limiting leaching losses of nutrients. It's not as popular as the other hydroponic media; however, they are helpful in hydroponic drip systems, soil amendments, and using in arid conditions as water retention medium linked with better root formation and nutrient management with healthy plant growth.

PEAT MOSS

Peat moss is one of the most popular growing mediums because it retains water very well, making it an ideal component of both potting mixes and hydroponic systems. Peat moss is harvested from peat bogs, where sphagnum moss has partially decomposed and built up over thousands of years. It provides the spongy structure needed to retain moisture and keep roots aerated. This gives it a very advantageous property in potted plants, seed starting, and hydroponic setups that require a consistent water supply.

Peat moss is one of the main components of pre-packaged potting soil, and is frequently mixed with perlite, vermiculite, or compost to improve drainage and nutrient retention. This conditioner is particularly useful for moisture-loving plants, like ferns, orchids and tropical, which prefer high-humidity environments. Tropical plants (think philodendrons, calatheas, and monsteras) need both warm temperatures and high humidity to grow successfully, and peat moss helps retain the moisture that their growing medium needs.

Peat moss is also often mixed with fertilizers or organic matter due to its low nutrient content. Moreover, its slightly acidic pH (3.5-4.5) makes it perfect for acid-loving plants such as blueberries, azaleas, and hydrangeas, but for other crops pH adjustments may be required. Peat moss retains water efficiently and contributes to soil structure but its non-renewable nature has encouraged sustainable alternatives such as coco coir, which provides similar water retention benefits with a lower environmental impact. Proper use of peat moss in gardening, hydroponics, and plant care ensures improved moisture control, healthier root development, and optimal plant growth.

Figure 19: Peat moss in hydroponics substrate

ROCK WOOL

Rock wool, also known as mineral wool or stone wool, is another popular substrate that is known to retain water and provide aeration to plant roots. It is made by melting natural basalt rock and spinning it into fine, hairy filaments that create the spongey structure. It's an inherently fibrous medium with high capillary-accessibility that very effectively retains water while allowing oxygen to get to the bottom of the pot (plant root zone), so is suitable in both free drainage and recirculating hydroponic systems.

Rock wool is inert, it won't react with the nutrient solution, it is also not susceptible to microbiological degradation, making it a long-lasting option in hydroponics. It is especially good for germinating seeds and rooting cuttings, because it provides a consistent environment that promotes strong root growth. Pros Cons Rock wool: Absorbs moisture for plants, non-flammable and insect proof, reusable and durable, good air permeability Not biodegradable, should be handled sensitively to avoid irritation from fine fibres.

Moreover, due to its high pH, it may require adjustment to ensure compatibility with a wider range of plants. Overall, rock wool's ability to retain moisture, provide excellent aeration, and support consistent root health makes it a preferred medium in commercial and for home hydroponic setups.

Figure 20: Rock Wool in hydroponics

MONITORING AND OTHER TOOLS IN HYDROPONICS

Hydroponic farming considers the nutrient solution composition, requires maintaining proper pH levels, a high dissolved oxygen concentration, and is highly regulated. Soil-based cultivation allows natural processes to provide buffering of nutrient availability, but in hydroponics the plants rely completely on the grower to control their environment. Different instruments maintain the optimum growing conditions by monitoring the **electrical conductivity (EC) of nutrient solution, monitoring the pH, monitoring dissolved oxygen with electrodes**. These tools prevent nutrient imbalances, deficiencies and toxicities, ensuring plants grow efficiently and healthily.

ELECTRICAL CONDUCTIVITY (EC) METERS (MEASURING NUTRIENT CONCENTRATION)

An electrical conductivity (EC) meter is one of the most basic devices in hydroponics that is used to monitor the level of nutrients present in the solution. To clarify how EC does this, EC meters analyze the concentration of dissolved salts in the water, which directly correlates to the availability of nutrients. And because minerals such as nitrates, phosphates, potassium, calcium and magnesium turn into charged ions in the solution, the EC meter measures how well the solution conducts electricity and returns a number in millisiemens per centimeter (mS/cm) or micro siemens per centimeter (µS/cm).

Maintaining the proper EC level is essential since too low a concentration can result in deficiencies that limit plant growth, while too high a concentration can cause nutrient toxicity, which can cause salt build up and damage to roots. For instance, fruiting plants like tomatoes, cucumbers, peppers etc., need a greater EC range of 2.0–3.5 mS/cm, whereas leafy greens like lettuce and spinach thrive in an EC range of 0.8–1.8 mS/cm. Using an EC meter on a regular basis guarantee that plants get enough nutrients without accumulating too much salt. To maintain the accuracy, EC meters must be calibrated regularly using standard calibration solutions (e.g., 1.41 mS/cm solution). If readings deviate from the expected values, growers can dilute the nutrient solution with distilled water to lower EC or add nutrients to raise EC levels.

Figure 21: Electric conductivity meter

pH METERS: ENSURING OPTIMAL NUTRIENT ABSORPTION

A pH meter is another critical tool used in hydroponic farming to measure the acidity or alkalinity of the nutrient solution. The pH scale ranges from 0 to 14, whereas the 7 is neutral, value below 7 indicate acidity, and values above 7 indicate alkalinity. Most hydroponic plants thrive in a slightly acidic pH range of 5.5 to 6.5 this is the range which ensures optimal nutrient uptake.

If the pH of the nutrient solution deviates from the optimal range, certain nutrients may become unavailable to plants, leading to deficiencies or toxicities. When the pH is pH is too high (above 7.5), the availability of essential nutrients such as iron (Fe), manganese (Mn), and phosphorus (P) decreases, which can result in poor growth, yellowing leaves, and nutrient deficiencies. On the other hand, if the pH is too low (below 5.0), the solubility of toxic elements like aluminium (Al) increases, potentially damaging root systems and inhibiting plant growth. To regulate pH, growers use pH adjustment solutions—to increase pH, they typically use potassium hydroxide (KOH) or potassium carbonate, while to lower pH, they use phosphoric acid (H_3PO_4) or nitric acid (HNO_3). Maintaining accurate pH readings requires the regular calibration of pH meters using buffer solutions (pH 4.0, pH 7.0, and pH 10.0). A properly maintained pH meter ensures precise measurements, allowing growers to make necessary adjustments to maintain an optimal growing environment for their plants.

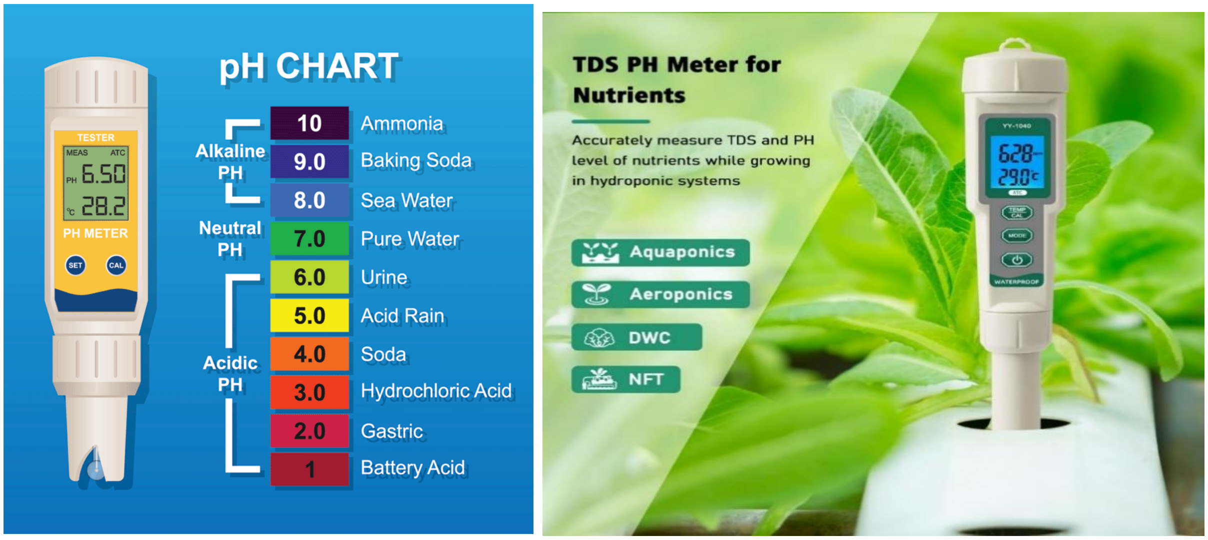


Figure 22: pH meter

OXYGEN ELECTRODES (Dissolved Oxygen Meters): MAINTAINING OXYGEN LEVELS

Oxygen electrodes, which is also known as dissolved oxygen (DO) meters, that measures the oxygen concentration in the hydroponic nutrient solution. Oxygen is essential for the plant root respiration and nutrient uptake. Unlike soil-based plants, which receive oxygen from air pockets inside the soil, hydroponic plants completely rely on dissolved oxygen in water.

Without proper aeration, the root system suffocates as oxygen levels drop too low, stunting growth and causing nutrient deficiencies, rot. Hydroponic solutions should have dissolved oxygen levels between 5–8 mg/L, with <3 mg/L resulting in stress and a greater chance of contracting diseases due to anaerobic bacteria and fungi.

Growers can enhance oxygen availability through:

- Air pumps and air stones: These appliances release tiny bubbles of oxygen into the solution.
- Maintaining low water temperatures: Cooler water retains more dissolved oxygen (target range 18–22 °C).
- Installing water circulation systems: Stagnation is avoided and oxygenation is improved with moving water.

Dissolved oxygen meters allow growers to track the amount of oxygen in the nutrient solution and make adjustments as needed to maintain optimum root health.

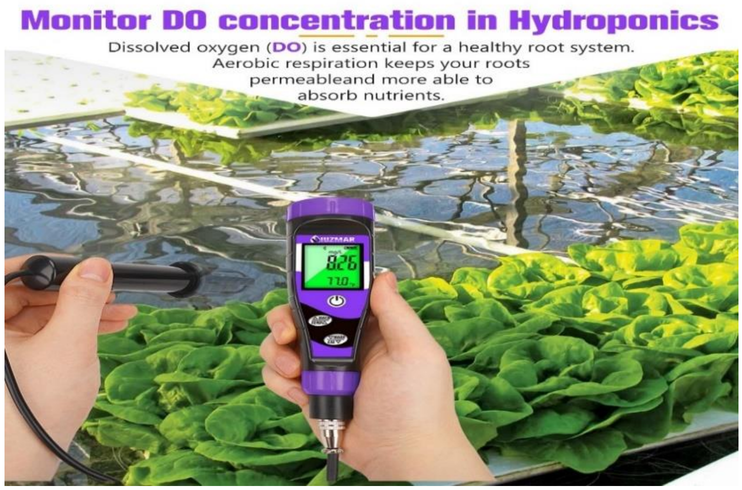


Figure 23: Oxygen meter to monitor dissolved oxygen in hydroponic system

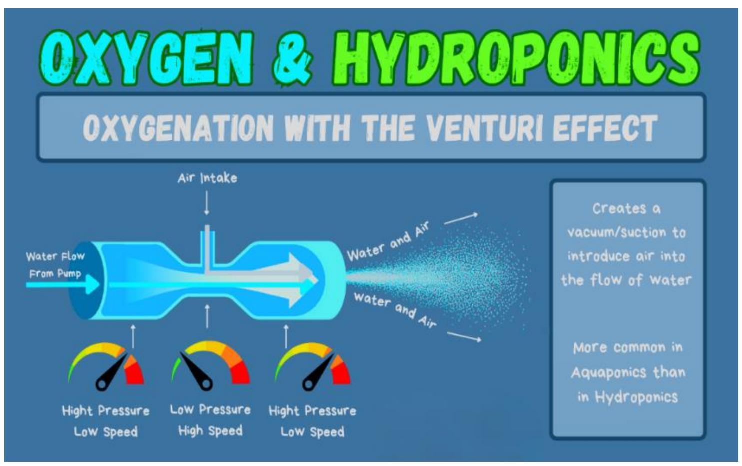


Figure 24:Oxygenation with venturi effect

Measuring Spoons, Graduated Cylinders, and Digital Scales: Accurate Nutrient Mixing

Precise nutrient measurement is essential for hydroponic systems, as incorrect dosages can lead to imbalances that harm plant growth. Tools such as measuring spoons, graduated cylinders, and digital scales are used to ensure accurate mixing of liquid and solid fertilizers, pH adjusters, and supplements.

Graduated Cylinders: For liquid fertilizers, nutrient concentrated, and pH adjustment solutions. They come in different sizes and provide precise nutrient ratios.

Measuring Spoons: Utilized to measure small amount of powdery or granular nutrients. They assist to keep the nutrient solutions consistent in mixing.

Digital Scales: More for testing the weight of dry nutrients to assure you prepare just how to formulate when preparing your custom nutrient for use in Hydroponics or Deep-Water Culture.

Accurate measuring tools ensure you avoid the pitfalls of over-fertilizing, leading to nutrient toxicity and root burn, or under-fertilizing, resulting in slow growth and poor yield.

IMPORTANCE OF REGULAR MONITORING AND ADJUSTMENTS

Maintaining a balance in the nutrient solution through regular monitoring and adjustments is essential to a stable and productive hydroponic system. Among the key maintenance tasks are:

Daily EC and pH Check to Make Sure Your Plants Are Getting the Proper Quantity of Nutrients

Testing DO levels in order to avoid root suffocation.

Replenishing the nutrient solution regularly to avoid excess salts and nutrient imbalances.

By recalibrating meters and sensors for ensuring the accuracy of readings. By integrating EC meters, pH meters, oxygen electrodes, and precise measuring tools, hydroponic growers can maintain optimal conditions for plant growth, leading to higher yields, improved quality, and reduced nutrient wastage. These tools play a crucial role in sustainable hydroponic farming, enabling efficient nutrient management and reducing environmental impact.

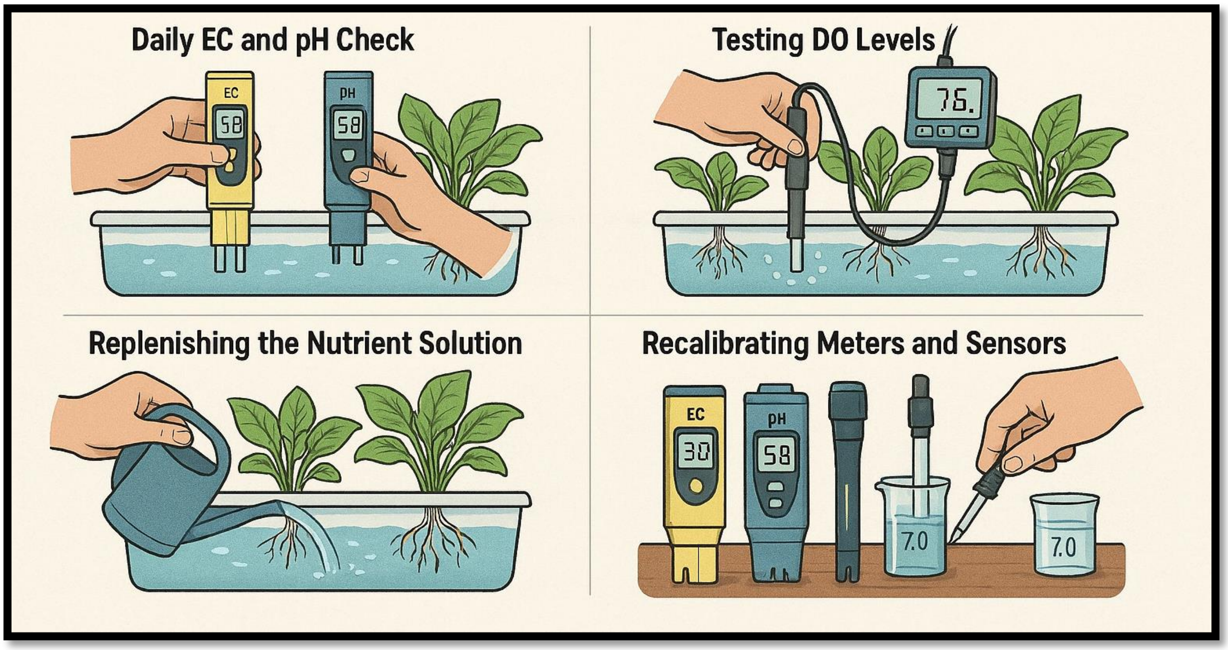


Figure 25 Regular Monitoring and adjustments

4 METHODOLOGY

This whole section outlines the research methodology used to study the HYDROPONIC SETUP IN SOUTH INDIA which aims to design and execute a hydroponic production system in South India, which has a tropical climate, within a protected structure enabling year-round vegetable production. As my study focuses on assessing and modelling the growth of mainly tomato and lettuce, spinach, basil crops, which have shorter growth cycles due to their consistent demand among local markets in South India hence, these are chosen as the crops for this study because they are popular with consumers and profitable to grow hydroponically. The present study emphasizes the Design, Execution, and Evaluation of a hydroponic vegetable production system specific to the climate of South India. Hydroponics is the growth of plants in nutrient-rich water instead of soil and has emerged as a modern solution to the ecological problems arising in agribusiness in tropical countries. This study mainly aims to establish a sustainable and scalable hydroponic system in a protected structure (a polyhouse or a climate-controlled greenhouse) for selected crop with the objective of growing crops continuously for the whole year. This approach is particularly pertinent in South India, where conditions of climatic variation, availability of limited arable land along with increasing demand for fresh produce in urban areas necessitate innovative farming solutions. These crops are not only popular among South Indian consumers but also it offers good market value, especially when cultivated in clean, pesticide-free environments like hydroponic farms. Their quick turnaround time makes them ideal for experimentation and scaling which allows multiple harvest in a single year which increases the profitability and efficiency.

The design phase of the hydroponic system involves creating a setup that supports optimal plant growth while being energy and water efficient. Key components which include grow channels for leafy crops containers for larger fruiting plants, and an irrigation system with sensors to control nutrient flow and water distribution. The nutrient solutions will be carefully prepared and they are adjusted according to each crop type and growth stage, with a continuous monitoring of pH and EC (Electrical conductivity) to ensure proper nutrient absorption. Environmental parameters such as temperature, humidity, and light exposure will also be regulated within the greenhouse to create ideal growing conditions.

To evaluate the success of the system, growth data will be collected and analyzed at every stage of the crop lifecycle. Parameters such as germination rate, plant height, number of leaves, yield per plant, nutrient and water usage, and time to harvest will be monitored closely. These data points will help in modelling crop growth trends under controlled conditions and in comparing the performance of hydroponically grown vegetables with those cultivated through conventional farming methods. This data driven approach ensures the system can be optimized based on the practical results.

It also includes the analysis of the system's sustainability and economic feasibility to assess the systems real world applicability. Key factors such as water use efficiency, nutrient recycling, operational costs, crop yields and market returns is thoroughly assessed. It will also determine the potential of hydroponic farming which can serve as an economically viable and environmentally sustainable solution, which is particularly for the small and medium-scale farmers in South India. Furthermore, the research will explore the scalability of the hydroponic model in urban and peri-urban areas, aligning with broader goals of promoting food security, income generation and sustainable agricultural practices in the region.

Figure 26: Hydroponic system

The primary objective of this study is to design, implement, and evaluate the hydroponic vegetable and fruit production system which is suitable for the tropical climatic conditions of South India, with the aim of enabling year-round cultivation within the controlled environment. This research mainly focuses on Tomato and then on Bell pepper, cucumber, lettuce, spinach, basil etc., which are selected for the high consumer demand and shorter growth cycles and profitability in hydroponic system. It also aims to assess both the technical performance and economic viability of hydroponic farming for small to medium scale applications in south Indian region.

The specific objectives of the study are as follows: -

1. Designing and development of a hydroponic system within a protected cultivation structure which is suited for tropical conditions, incorporating appropriate irrigation, nutrient delivery, and with climate-controlled mechanism.

2. Selection and cultivation of key crop such as tomato, bell pepper, cucumber, lettuce, spinach etc., based on their suitability for hydroponic farming and their market relevance in South India.

3. Monitoring and evaluation of crop growth parameters which includes plant height, yield, nutrient uptake and water consumption as well as to compare performance across the selected crop.

4. Analysing the resource use efficiency which includes water and nutrient use and assess environmental impacts such as reduction in pesticide and fertilizer dependency.

5. Conducting a cost-benefit and sustainability analysis to evaluate the economic feasibility and environmental sustainability of the hydroponic model in which particularly focuses on small and medium-scale farming operations.

6. Exploring the scalability potential of the system in the urban and peri urban settings to support local food system and to contribute to sustainable development goals related to food security and climate-resilient agriculture.

7. Evaluating the crop quality such as leaf texture, colour, taste, nutritional value, to assess the market readiness and consumer appeal of hydroponically grown produce.

8. Estimation of carbon footprint reduction through minimized use of synthetic fertilizers and pesticides and efficient water and land use in hydroponic system rather than the traditional one.

4.1 Introduction to Hydroponic Cultivation

4.1.1 What is a Protected Cultivation

It is the practice of growing plants without soils. Plants can be grown in plain nutrient solution or in sterile substrates such as coco peat, perlite, vermiculite, or rock wool. In this system, all the essential nutrients required for the plant growth are directly delivered through water-based solution, ensuring precise control over the nutrient intake. The absence of soil helps to eliminate many soil borne pests and diseases, thereby reducing the need for chemical pesticides and herbicides. Additionally, the method also supports year around production under controlled conditions, independent of seasonal limitations, which greatly enhances food security and sustainability in urban and peri-urban regions.

Figure 27: Protected cultivation

4.1.2 Importance of protected cultivation

1. Protected cultivation helps the farmers grow crops in a controlled environment, protecting them from bad weather like heavy rain, strong winds, and extreme heat.

2. It also allows crops to be grown all year round, even in off-seasons, leading to more continuous production.

3. By controlling temperature, humidity, and light the plants grow healthier, faster, and produce better yields.

4. It saves water and nutrients by using them more efficiently compared to open-field farming.

5. Crops grow under protected cultivation are usually of better quality and fewer pest and disease problem.

6. Farmers can grow high-value crops like exotic vegetables, flowers and herbs earning more income.

7. It reduces the need for chemical pesticides, making the produce safer and eco-friendly.

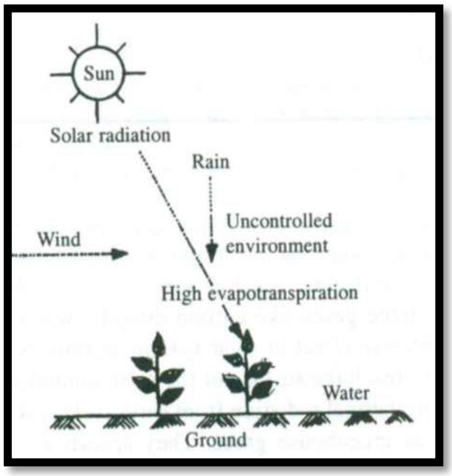
8. Protected cultivation is very important for food security, especially in areas with poor soil or changing climatic conditions.

9. Overall protected cultivation supports sustainable agriculture and helps meet the growing food demands in day-to-day world.

Figure 28: Protected cultivation with passive hydroponics

Comparison between crops under sunlight and crops under greenhouse

CROPS UNDER OPEN SUNLIGHT



CROPS UNDER GREENHOUSE

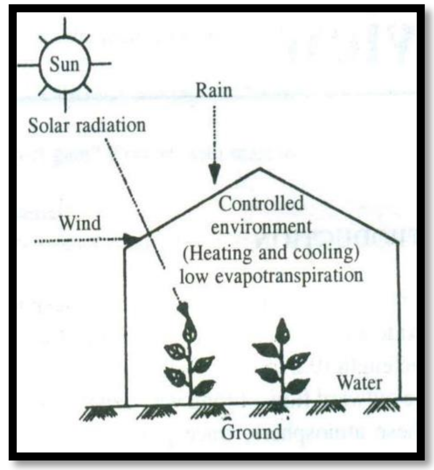


Figure 29: Crops under sunlight and greenhouse

4.1.3 Types of Green houses

- **Lean-to Type greenhouse**

It is a structure that is built directly against an existing building, utilizing one of the buildings walls as a part of the greenhouse itself. This type of greenhouse shares a wall with another structure, saving on construction material and heating costs. It is suitable for small spaces and is commonly used for household or personal gardening. Its limited space can restrict the variety and quantity of crop that should be grown.

- **Even-Span Greenhouse**

It's a freestanding structure characterized by two roof slopes of equal length, forming a symmetrical shape. It offers a spacious growing area and better sunlight distribution. They are typically larger and are used for commercial farming where uniform temperature and efficient use of space are important. This type allows the installation of the modern equipment like automated irrigation and ventilation system.

- **Uneven-Span Greenhouse**

It's a type of freestanding structure where the two roof slopes are of unequal length, typically designed for sloped or mountainous terrains. This design helps maximize solar energy utilization on sloping land by adjusting the roof angles according to the land's gradient. They are not common today but it was once historically useful for farming in hilly regions where flat land was unavailable.

- **Ridge and Furrow Greenhouse**

It is formed by connecting multiple greenhouses along their ridge (peak) lines, creating a large contiguous farming area under a single cover. It reduces construction costs and heating requirements because multiple greenhouse shares sidewalls. It creates a large continuous production space ideal for commercial-scale vegetable, flower or ornamental plant cultivation.

- **Saw Tooth Shaped Greenhouse**

It is a structure with a roof designed like the teeth of a saw, incorporating vertical openings for natural ventilation. It improves the air circulation by allowing hot air to escape through vertical openings without needing of powered fans. It is particularly beneficial in tropical and subtropical regions where heat management is critical for healthy crop growth.

- **Quonset-Shaped Greenhouse**

This greenhouse features a semi-circular or hoop-shaped design made of metal or PVC pipes covered with plastic films. This economical structure is easy to build and maintain, making it ideal for small farmers. It is effective against strong winds and snow loads, but may have limitations in sidewall height, restricting the growth of tall crops.

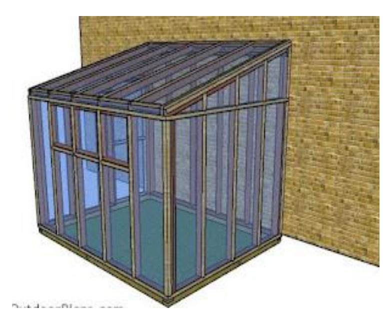


Figure 30: LEAN-TO-TYPE

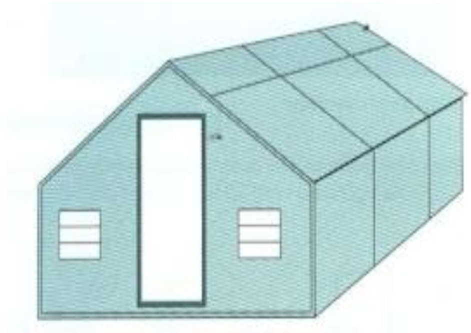


Figure 31: EVEN SPAN

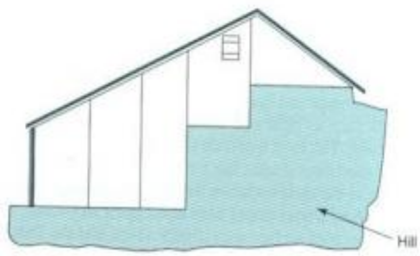


Figure 32: UNEVEN SPAN

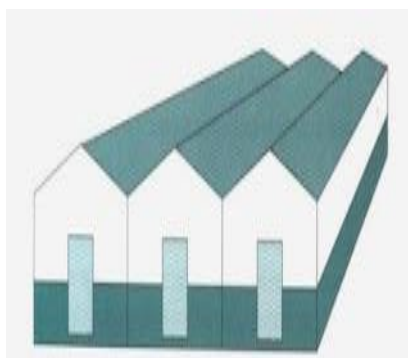


Figure 33: RIDGES AND FURROW

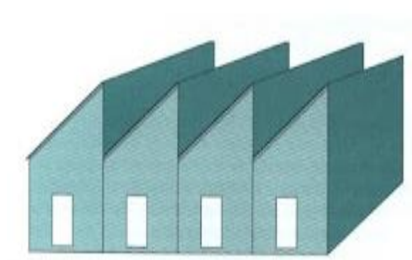


Figure 34: SAW TOOTH SHAPED

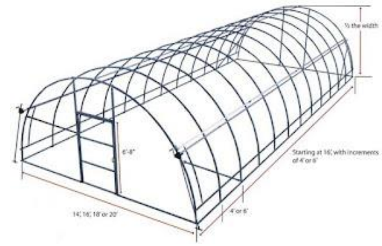


Figure 35: QUONSET SHAPED

4.1.4 Why Greenhouse yields more

- U.V film does not allow harmful U.V rays to enter the greenhouse thus protecting the crop
- Inside environment remains under control
- 8-10 times more food production than the open field condition –C02
- Long wave radiations are absorbed and retained for a longer time inside the green house.

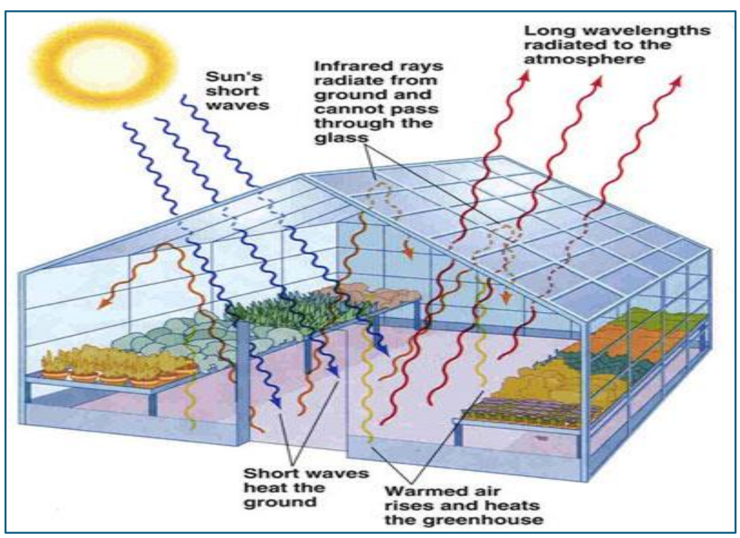


Figure 36: GREEN HOUSE RADIATION DEMONSTRATION

4.1.5 Potential Crops

Potential crops are those plant species that are best suited for the growth under specific cultivation conditions such as temperature, humidity, light, and protection systems ensuring high productivity, economic value and market demand. Overall, the careful selection of potential crops ensures better resource utilization (like water, nutrients, and space), increases farmers' income, and contributes to sustainable agriculture practices, especially in climate-sensitive regions like South India.

Figure 37: MAJOR POTENTIAL CROPS

HYDROPONICS

Figure 38: HYDROPONIC SYSTEM IMAGES

4.1.6 TYPES OF HYDROPONICS

1. **Active hydroponics:** An ACTIVE system does recirculate the nutrient solution with a pump.

   Example - Ebb and Flow, NFT, Deep water culture, Drip system.

2. **Passive hydroponics:** A PASSIVE system does not recirculate the nutrient solution with a pump.

   Example - Cocopeat, Coco chips, Perlite, Vermiculite.

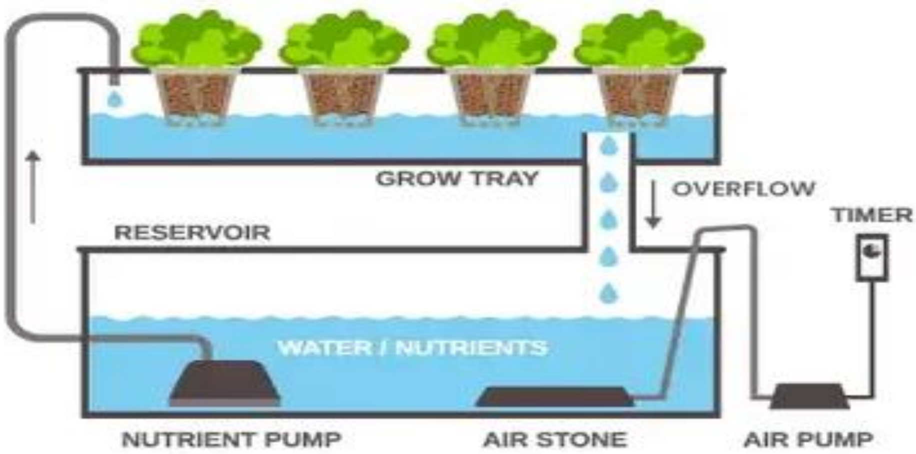


Figure 39 EBB AND FLOW SYSTEM

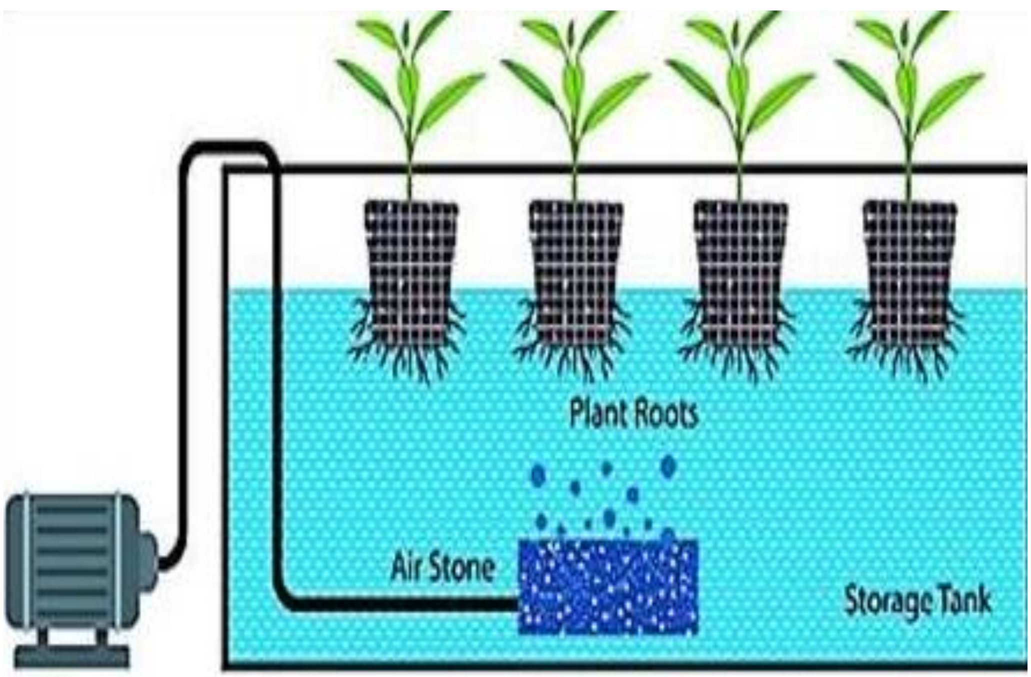


Figure 40 DEEP WATER CULTURE

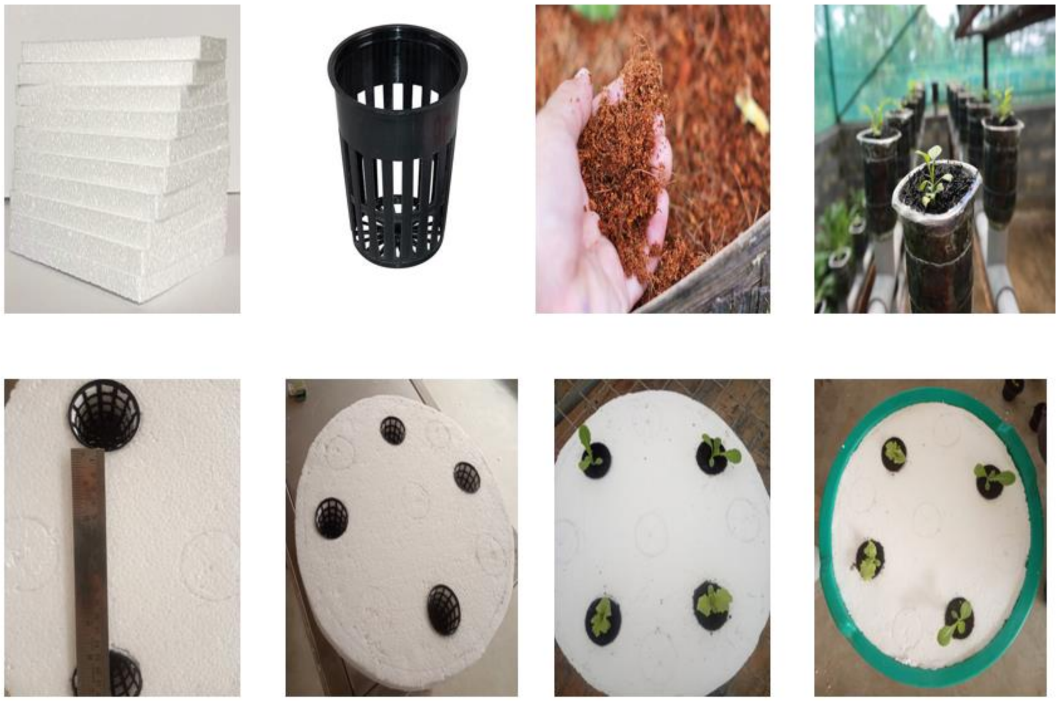


Figure 41: EQUIPMENTS USED IN HYDROPONICS

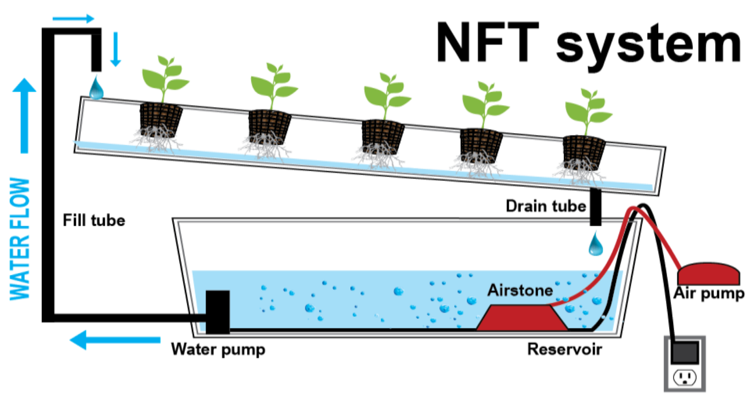


Figure 42 NUTRIENT FILM TECHNIQUE

Figure 43:NFT (A COMPLETE SYSTEM IMAGE)

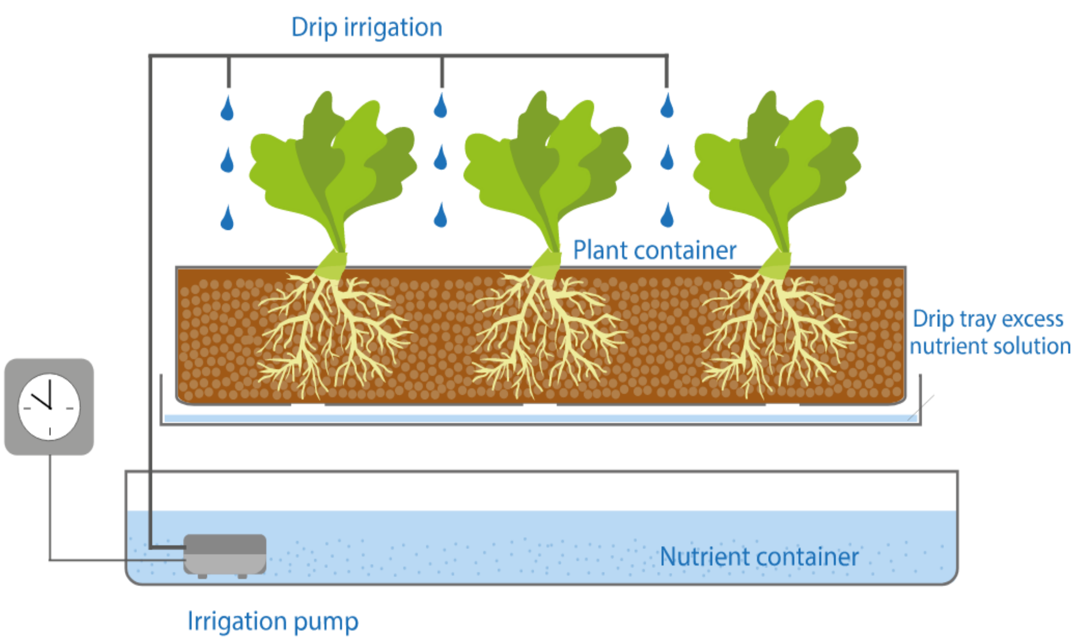


Figure 44 DRIP SYSTEM

Figure 45 DUTCH BUCKET SYSTEM

4.1.7 PASSIVE HYDROPONICS

Passive hydroponics also known as semi-hydroponics or passive sub-irrigation, is a method of growing plants without soil where the nutrient solution is delivered to the plant roots through capillary action or natural wicking, without the use of active mechanical pumps or aerators.

Figure 46: PASSIVE HYDROPONICS SETUP

Growing Media for Hydroponic Cultivation

Figure 47 Growing Media for Hydroponic Cultivation

4.1.8 Grow Bag System

The grow bag system is a type of soilless cultivation method commonly used in greenhouse and protected farming setups. It involves growing plants in flexible, lightweight plastic or fabric bags filled with a suitable growing medium such as cocopeat, perlite, vermiculite, or a mixture of these. This system is especially popular in hydroponic and organic farming for its simplicity, cost-effectiveness, and efficient space utilization.

Grow bags are particularly suitable for crops like tomato, cucumber, capsicum, strawberries, and leafy greens, which benefit from controlled root conditions. These systems are highly adaptable to rooftop gardens, greenhouses, and vertical farming due to their mobility and scalability.

The advantages of the grow bag system which includes:

- Improved root aeration
- Reduced soil-borne diseases
- Efficient use of space and resources
- Ease of setup and maintenance
- Enhanced control over crop nutrition

This system also supports sustainable practices by using biodegradable or reusable bags and optimizing water and nutrient use.

Figure 48 Grow Bag System

4.1.9 Trough System

The trough system is a popular hydroponic cultivation method in which plants are grown in long, shallow channels or containers called troughs that holds the nutrient solution and support plant roots. In this system, plants are arranged in rows along the troughs, and their roots are either suspended in a flowing nutrient solution (in active systems like NFT – Nutrient Film Technique) or embedded in a growing medium such as cocopeat or perlite (in passive systems). The nutrient solution is either recirculated continuously or supplied intermittently using a drip irrigation system with proper drainage and collection mechanisms. This system is especially well suited for leafy vegetables, herbs, strawberries and vine crops such as tomatoes and cucumbers.

Figure 49: TROUGH SYSTEM

4.2 Cocopeat Grow Slabs Systems

The cocopeat grow slab system is popular method for soilless culture (used in NFT, hydroponics and Hi-tech cultivation) It requires plants to be grown in compacted bricks of cocopeat, a natural biodegradable medium made from coconut husks. Cocopeat (coir pith) is well-recognized for its water holding capacity, aeration properties, and capacity to stabilize the root zones, and is thereby an excellent substrate for crops.

In such a system, pre-filled cocopeat slabs are inserted into polythene sleeves/grow bags that have pre-cut planting holes and drainage slits. These plates are normally placed on benches or the floor in greenhouses or polyhouses. They are fed using a drip irrigation system to give water and nutrients directly to the plant roots for a specific period of time. Unabsorbed solution drips out of the slits, which may be collected and reused or disposed.

Cocopeat grow slab system works best for fruiting vegetables e.g. tomatoes, capsicum, cucumbers, strawberries etc that need constant moist to the roots and nutrients supply for best growing.

Figure 50: COCOPEAT GROW SLAB SYSTEM

4.2.1 Aeroponics

Plant roots are suspended in the air and are misted with the nutrient solution continuously. The misting interval is fairly short, done by a pump controlled by a timer. It has own advantages and disadvantages

Advantages:

- Plenty of oxygen for plant roots.
- Little to none growing medium used.
- Efficient water use

Disadvantages:

- More expensive than other types
- More vulnerable to dryness caused by the power outrages

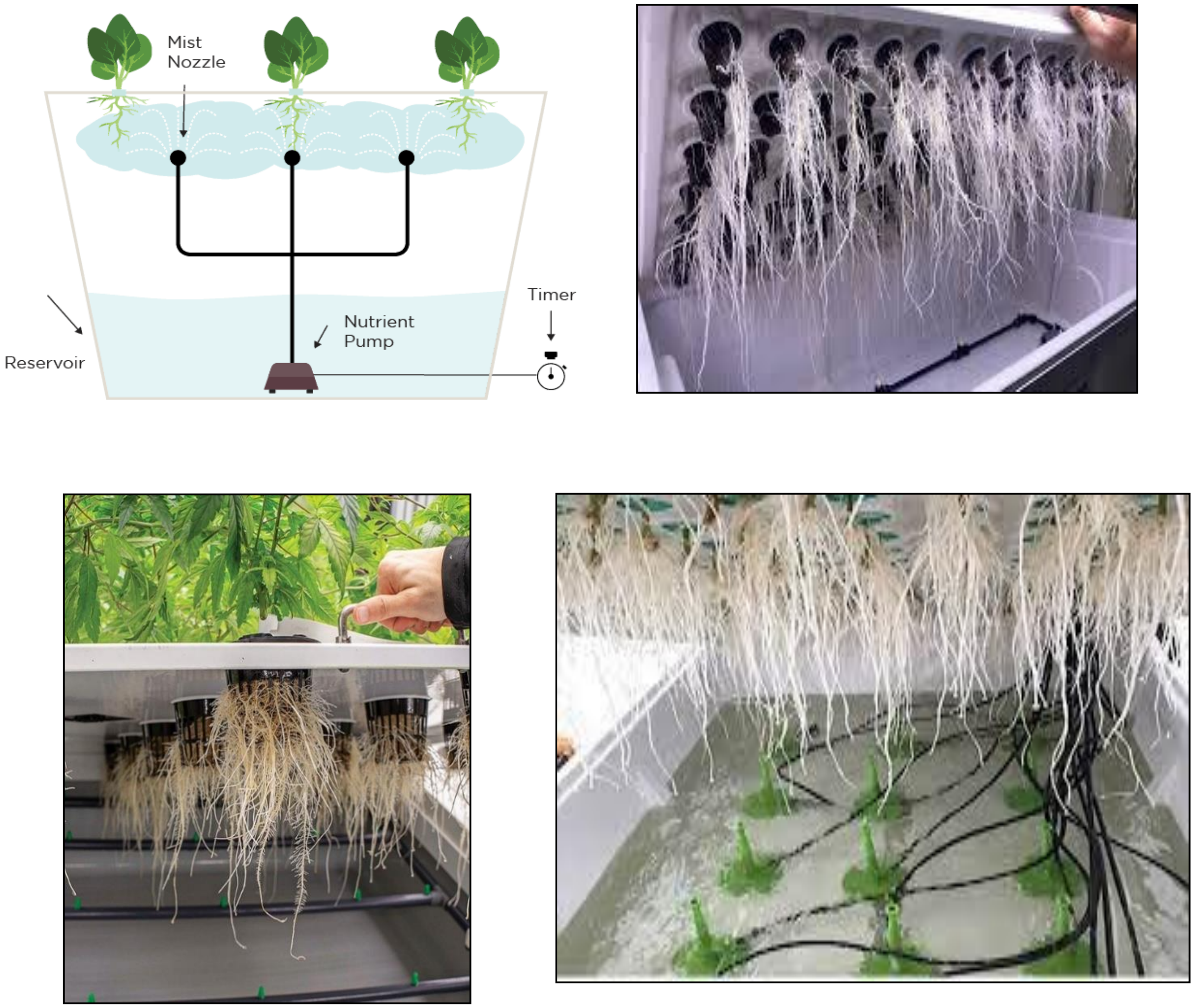


Figure 51: AEROPONICS SYSTEM

4.2.2 Aquaponics

A system of aquaculture in which the waste produced by farmed fish or other aquatic creatures supplies the nutrients for plants grown hydroponically, which in turn purify the water.

Advantages:

- Organic fertilizers.
- Two Incomes for Commercial Aquaponics Farmers.

Disadvantages:

- More plants growth then more requirements of fish
- Not balanced food for plants so more deficiency observed in plants

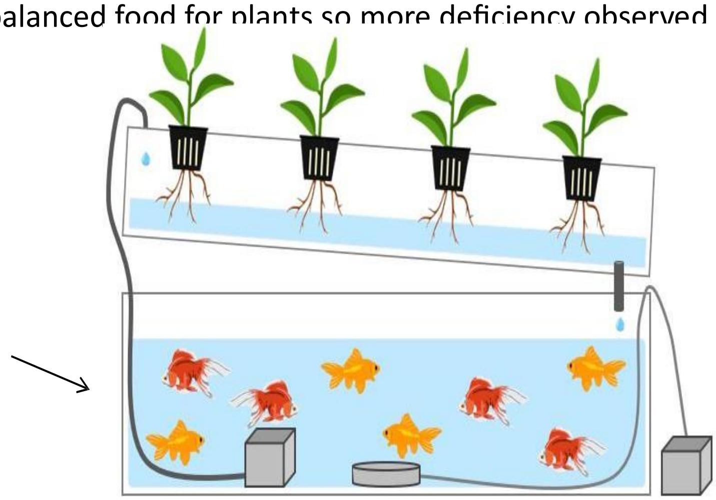
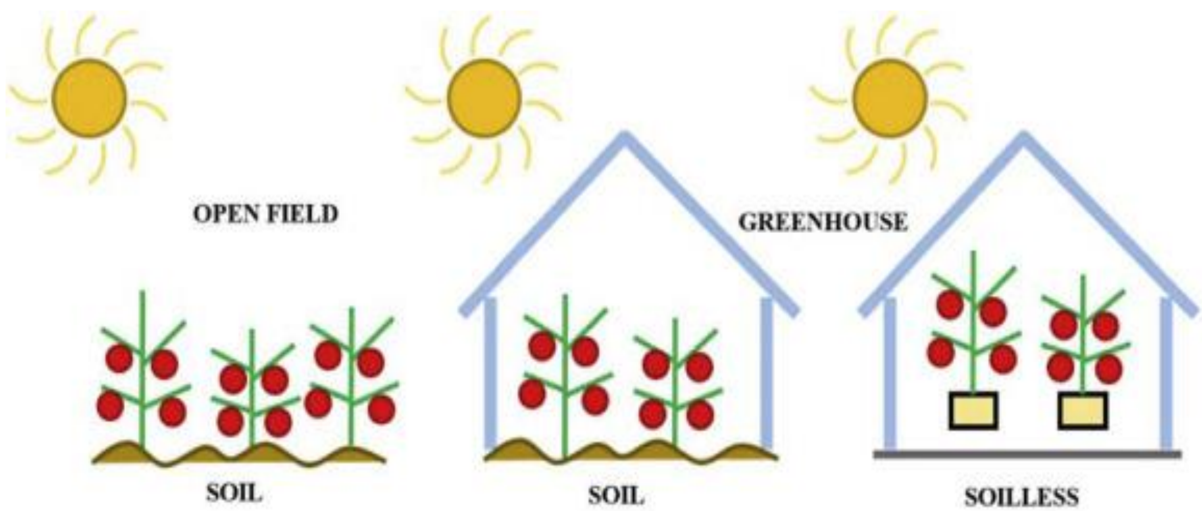


Figure 52: AQUAPONICS WITH FISH CULTURE

4.2.3 Open Field and Green house Plant growth comparison



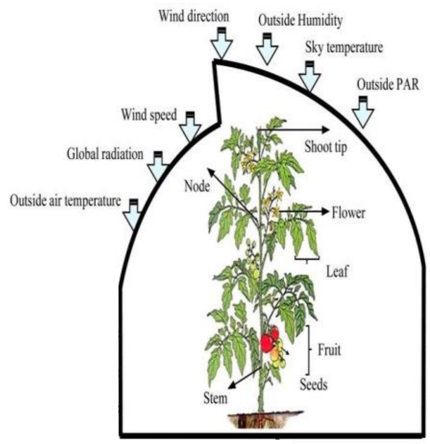


Figure 53:DEMONSTRATION OF PLANT INSIDE GREENHOUSE

4.2.4 COMPARISION BETWEEN SOIL BASED AND HYDROPONIC FARMING

Components	**Soil- Based (Traditional Farming)**	**Hydroponic farming**
Fertilizer	Average	Very efficient
Water Use	Poor	90% less than traditional farming
Growth Speed	Average	30% Fast growth than traditional farming
Yield and Productivity	Low to average	25%-50% more than traditional farming
Workload	Less intensive than hydroponics	Intensive
Sustainability	Poor	Very efficient
Pest & Disease	More interfere	Less interfere

Table 4: SOIL BASED AND HYDROPONIC FARMING DIFFERENCES

Open cultivation – High evapotranspiration, low yield

Green house cultivation – Low evapotranspiration, high yield

Vegetables	Tomatoes	Capsicum	Cucumber, leafy vegetables
Fruits	Strawberries	Blueberries	Melons
Flowers	Rose	Orchids	Carnation (Dianthus caryophyllus)

Table 5: CROPS GROWN IN HYDROPONICS

4.2.5 CRITERIAS TO START A GREENHOUSE

If we want to build a greenhouse, you need to have a decent spot where there is plenty of sun light, good drainage and is accessible to small vehicles and is out of the deadly wind. We must have decent facilities such as a reliable water supply, electricity and appropriate climate control systems. It is important to have solid financial workout, which consists of calculating your initial investment, gathering funds/loan grants, and planning for operational costs. The choice of crop should be market driven and suitable for greenhouse cultivation, employing good planting material. Expertise in greenhouse management, pest control and modern farming methods in addition to the above fields, however, know-how in the domaine of pest control in greenhouse is useful. Technical knowledge in greenhouse operations, pest management, and modern farming methods is vital, along with necessary training or expert guidance. Regulatory compliance through licenses and approvals is required, especially when applying for subsidies. Finally, a strong marketing and sales strategy, including logistics and potential tie-ups with buyers, ensures commercial success.

Figure 54: GREENHOUSE STRUCTURE

4.2.6 Establishing the greenhouse based on agricultural venture

Figure 55: STEP BY STEP PROCESS FOR ESTABLISHING A GREENHOUSE BASED AGRICULTURAL VENTURE

The image illustrates the step-by-step process of establishing a greenhouse farming venture. It begins with thorough research on crops, climate suitability, market demand, and available technologies. Once a clear plan is developed, the next step is to apply for a bank loan to secure the necessary funding, followed by applying for any available government subsidies to reduce investment costs. With the financial backing in place, an order is placed with a greenhouse construction company to build the required infrastructure. After construction, suitable plant varieties are grown, and cultivation begins using proper cultural practices such as irrigation, fertilization, and pest management under controlled conditions. Finally, the harvested produce is marketed through appropriate channels to ensure profitability and sustainability of the business.

4.2.7 Research and establishment of greenhouse

Figure 56: THE PROCESS USED FOR GREENHOUSE SETUP

4.2.8 Key Criteria for Site selection for protected cultivation

- The soil should have pH of 5.5-6.5.
- Availability of continuous source of quality water with pH of 5.5-6.5.
- Good supply of electricity.
- A ground slope for drainage is an important factor to divert surface water way from the green house.
- Greenhouse should be located away from the building and trees to avoid obstruction to sunlight and should be pollution free.
- Facility of good rood transport to near markets
- Laboures availability is also important
- Communication facility should available at the site.

4.2.9 Structure of the Greenhouse

- Orientation: Could be in any direction when they are in single span.
- Multi span greenhouses should be oriented in **north –south** direction to avoid continuous shading of certain portions of the green house by its structural components.
- The maximum dimension (length) of greenhouse should be perpendicular to the wind direction especially in summer.

Figure 57: Greenhouse view

- Size:50m*50m/45m*65m
- Height: Maximum height we can provide is 8m
- Gutter height: 4-to-4.5-meter, top height- 2.5-3 meters
- Each bay should have fixed open top roof ventilation. (Vent opening 1 meter.)
- Direction of top ventilation: East west, last top should be in opposite direction to reduce wind impact
- Bay width:9 m/8 m/9.6m/11.2 m
- Maximum size if one GH: Indian climatic condition: 1 acre so that there will be an issue of ventilation
- Other contries:10 acre or 15 acre-weather is mostly winter, they don't want very frequent ventilation
- Minimum:200 sq m, but it has to be feasible

Figure 58: Structure representation

- Insect net :1.2-to-2-meter height from the ground, mesh size:40 micron. Higher microns: barrier to air movement
- Sanitization room size: Based on requirement. Std: 9m*4m
- Polythene cover: UV stabilized greenhouse film.
- Flowers: 205N (code of polyfilm): Slight yellow
- Yellow sheet: Rs.54+GST/sq m
- Vegetables: Drip lock cool: White
- White sheet: Rs. 53+GST/sq m
- Change cover: 3 years once; water droplets blocks.

4.3 Inputs and Tools used in Greenhouse


Figure 59: INPUT FANS IN GREENHOUSE


Figure 60:STRINGS ATTACHED TO THE PLANTS FROM TOP

Figure 61:DRIP IRRIGATION SYSTEM IN PASSOIVE HYDROPONICS

Figure 62:STICKY TRAPS TO ATTRACT INSECTS

4.3.1 TOOLS USED IN HYDROPONIC SYSTEM

Figure 63 TOOLS USED IN HYDROPONIC SYSTEM

4.3.2 BANK LOAN AND SUBSIDY

Applying for bank loan for ventures such as polyhouse construction, hydroponic farming offers several significant advantages beyond mere financial assistance. Firstly, many of these loans are supported by government subsidy NABARD or MIDH, which can reduce the effective cost of investment and encourage farmers to adopt advanced technologies. These loans usually come with lower interest rates and flexible repayment options tailored to agricultural cycles, helping farmers manage finances more efficiently. Additionally, there are tax benefits associated with agricultural loans, and repayment of these loans can improve a farmer's credit profile, opening doors for future funding. Some loans also include insurance coverage for the structure and crops, providing financial security against unpredictable events such as extreme weather or pest outbreaks. Furthermore, banks often collaborate with Agri-experts and consultants, offering technical guidance and support to ensure the success of the project. Access to formal credit enables farmers to scale their operations, diversify crop choices, and tap into more profitable markets, contributing to long-term sustainability and income generation.

Below is the list of documents required and the banks which offers:

A) List of documents required in the bank

- Detailed Project Report – Introduction of farmer, need, technical analysis, economic analysis
- 8 "A" land Report
- 7/12 of land Report
- Estimate of poly house
- Blueprint of poly house
- Estimate of plants
- Estimate of Irrigation
- Soil and water analysis report

B) List Of the Bank Providing Horticulture Loan

- State Bank of India
- Bank of Baroda

- Bank of India
- Maharashtra Bank
- IDBI Bank
- Canara bank

4.3.3 Apply for Green house Subsidy

<u>Before applying subsidy following document required</u>

- Detailed Project Report
- Certified Copy of record of rights over the piece of project-land
- loan sanctioned letter issued by the bank with complete terms & condition.
- Estimated total cost of naturally ventilated green house for 4000 Sqr meters: Rs. 35 to 36 lakhs
- Green House construction cost: Rs.700 to 1000 per square meter
- Estimated total cost of Fan and Pad system green house for 4000 Sqr meters: Rs. 56 to 60 lakhs
- Green House construction cost: Rs.1400 to 1500 per square meter

For vegetables and flower crops

- 50% subsidy.

4.3.4 Advantages of Hydroponics

Water is food, is life.

No water, no food!

- Hydroponics uses less than 1/10th - 1/5th of the water used in soil cultivation.
- Hydroponics can reduce irrigation water usage by 70% to 90% by recycling the run-off water.

Figure 64: HYDROPONIC PLANT

4.3.5 Labor Management

- Weeds are a major problem in Soil cultivation and calls for the use of harmful herbicides. Most farmers spend an enormous amount of money on labor for weeding.
- All labor input associated with soil management, such as digging and weeding are eliminated with hydroponics.
- The system is less labour-intensive method compared to the soil cultivation method.

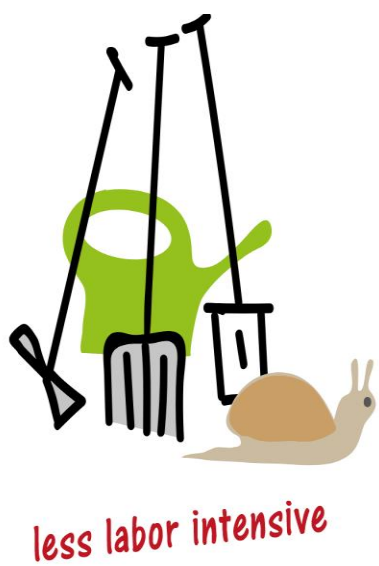


Figure 65 Labor Management

4.3.6 Nutrient use efficiency

- Nutrient solutions can be tailored to the plant's requirements, whereas in the field there is a tendency to over or under- fertilize.
- Nutrients in the soil are often fixed as insoluble compounds that are not available to plants and therefore a loss to the grower.
- Uneven nutrition is ensured by virtue of leaching and sloping of land gradients.

Figure 66 Nutrient use efficiency

Table 1: percentage of water and fertilizer consumption, vegetables yield percentage and the percentage of water productivity for different new farming systems as compared with conventional farming system.

Parameters	Hydroponic system				Aeroponics	Aquaponics
	Media Soilless system		Nutrient solution system			
	Open	Closed	Open	Closed		
% Irrigation water saving	80	85	85	90	95	%85-80
% Fertilizer saving	55	80	68	85	85	%99-85
% Productivity increase	100	150	200	250	300	%150-100
% Water productivity	1000	1600	2000	3500	8000	1000-1600

Table 6: PERCENTAGE OF WATER AND FERTILIZER CONSUMPTION (adopted from agrotie).

4.4.5 Climate Management

- Greater control of the environment, temperature and humidity can be maintained, Root zone temperatures are maintained as is ideal to ensure good growth.
- Production in the Off Season is possible when market prices are highest.
- Off season production in which crops can be grown during unfavorable outdoor conditions, enabling year around cultivation and ensuring consistent supply.
- A protected environment lowers the risk of pests and diseases, reducing the need of chemical pesticides.
- It supports efficient water and nutrient management, reducing waste and improving sustainability.
- Producing crops during off seasons allows farmers to sell at premium prices when supply is low and demand is high.
- Stable root zone temperature can be maintained at ideal temperatures, improving nutrient uptake and overall plant health.

Figure 67 Climate Management

4.3.7 IPM - Integrated Pest Management

- The use of **Integrated Pest Management (IPM)** in protected environments is ideally suited, which can virtually eliminate the need to use toxic and expensive chemical pesticides.
- Diseases and pests from neighboring farms can cause spread of diseases in one's field crops.
- Reduced chemical dependency by integrating IPM, the reliance on toxic and expensive chemical pesticides is drastically reduced, making greenhouse farming more environmentally friendly and economically sustainable.
- Improved Biosecurity which access control and sanitation protocols can be effectively implemented in greenhouses, preventing the introduction and spread of pests and diseases.

Figure 68 IPM - Integrated Pest Management

Sample Yield Numbers (Conservative)

Crop	Yield (soil) per acre	Yield (hydroponics) per acre
Lettuce	9-10 tons	150 – 200 tons
Strawberries	20 – 25 tons	50 tons
Cucumber	15 – 20 tons	50 tons
Tomato	10 – 12 tons	70-80 tons
Bell Pepper	10 – 12 tons	40-50 tons

Figure 69 Sample Yield Numbers ((Conservative (Adopted from AGROTIE))

Preparation before Transplanting

Figure 70: ENSURE WEEDS FREE IN AND AROUND GREENHOUSE

4.3.8 Sanitization of Green House

Sanitization room:

- Hand sanitization –Ehanol-60%
- Leg sanitization- Potassium paramanganate-2-5ml/l
- After every crop cycle sanitize whole green house with
- Profenofos 3 ml/lit
- Lamda cyhalothrin 1ml/lit
- Copper sulphate 2 g/lit
- Streptomycin sulphate 0.3 g/lit
- Close GH for 3 days

Figure 71 Sanitization of Green House

- **Cleaning inside GH**: Old crop removal, dust cleaning, side net and polythene sheet cleaning with water
- Removal of old sticky traps
- Clean tutu traps
- **Drip cleaning:** Phosphoric acid 3-4 lit /25 lit of water
- **Grow bags**: Formaldehyde 10 ml/l

4.3.9 Cocopeat

Coco peat, also known as coir pith or coir dust, which is a widely used growing medium in passive hydroponics due to its excellent water retention, aeration, and sustainability for the plant growth. Derived from the husk of coconuts, coco peat is organic, lightweight, and biodegradable. In hydroponic systems, it serves as a supporting substrate that anchors plant roots while facilitating optimal moisture and nutrient availability. Cocopeat can absorb and retain water up to eight to nine times its weight, ensuring continuous moisture supply to plant roots while maintaining proper aeration, which is essential for healthy root development. It has a neutral to slightly acidic pH (5.5–6.5), making it ideal for most hydroponic crops. The material is lightweight, porous, and free from harmful pathogens, reducing the risk of soil-borne diseases. In hydroponic systems like drip irrigation, Dutch buckets, and grow bags, cocopeat supports robust plant growth by allowing efficient nutrient uptake. Additionally, it is reusable for multiple crop cycles if properly sterilized and buffered to remove excess salts. Being biodegradable and environmentally friendly, cocopeat is a preferred alternative to peat moss, especially in sustainable and organic farming systems.

Specifications of cocopeat

- Density <0.1
- Electrical Conductivity <0.5 mS/cm
- pH<5.9-6.5
- Water holding capacity <8-9 times
- Pore space >90%
- Expandability > 6 times of the compressed volume

Figure 72: COCOPEAT

Advantages of Cocopeat

- Excellent water retention properties. Cocopeat needs less watering (up to 65%) as compared to the peat moss. It holds water rather than shedding it like the traditional peat moss.
- The rapid re-wet ability and quick draining characteristic of Cocopeat also reduces the loss of nutrients through leaching.
- The pH content of Cocopeat is neutral to slightly acidic, and is therefore very beneficial for plants
- The coconut peat is a better natural soil conditioner; with good porosity.
- The coconut peat is resistant to bacterial, weed, fungal growth, and is truly pathogen free.
- Naturally high lignin content promotes the development of favorable micro-organisms.
- Cocopeat are entirely organic. There are no harmful effects on the environment when disposed of.
- Cocopeat is physically stable and is very slow to disintegrate.
- Cocopeat is reusable and recyclable for up to two years.

Figure 73:COCOPEAT IN PASSIVE HYDROPONIC SYSTEM

4.4 How media pH affects availability of nutrients to plants

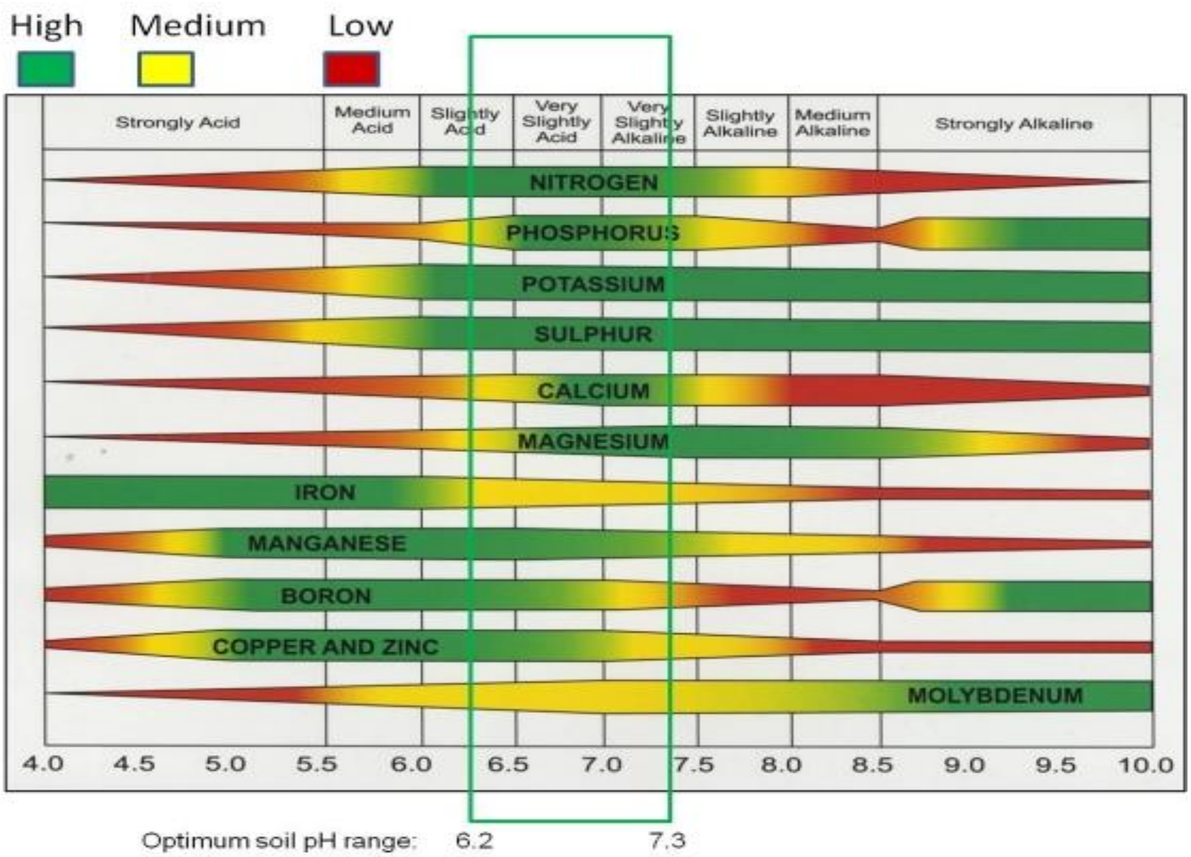


Figure 74 How media pH affects availability of nutrients to plants

Here the image shows the relationship between soil pH and the availability of essential plant nutrients. The uptake of nutrients is directly affected by the soil pH, where there is an optimal range for most crops between pH 6.2 and 7.3, shown with the green shading. These are the available (easily utilizable) macro-nutrients like NPK, calcium, sulphur, phosphorus, and magnesium. Their availability also decreases outside this range, particularly in very acid or alkaline soils, with a consequent detrimental impact on plant growth. Outside of this range, particularly in very acidic or alkaline soils, their availability decreases, which can in turn limit plant growth. Equally, micro-elements such as iron, manganese, boron, copper, zinc and molybdenum will have varying ability to availability according to the pH range. For example, iron and manganese are more soluble in acidic soils, whereas molybdenum is more soluble in slightly basic conditions. The correct pH range for root growth and optimum plant nutrient uptake is essential in both hydroponic and soil farming to ensure maximum nutrient absorption and healthy plant development.

4.4.1 How media EC affects the plants

Stabilization:

High media PH: add acid- nitric acid

Low media PH: add any alkali (Na carbonate/bicarbonate)

Recommended PH: 5.5 to 6.5

High media EC: flush media with RO water

Recommended EC:<0.1 dS/m

The stabilization of growth media is critical for successful plant growth in hydroponic platforms. The media pH and EC should be closely carefully maintained at optimal levels. pH If the media is too high in pH, it will need to be corrected with some kind of acid in most application, nitric acid. Conversely, if the pH is too low, it should be increased by adding an alkaline material such as for example sodium carbonate or sodium bicarbonate. The optimal pH range for hydroponic media is 5.5 to 6.5 which is great for most crops. Regarding EC, EC, which indicates the concentration of soluble salts in the media, high EC levels can be injurious to plant roots and restrict plant growth. If the EC of the media is too high then it can be flushed well with RO water to remove excess salts. The EC level of the media is preferably less than 0.1 dS/m, such as to provide a balanced root-zone environment, conducive to optimal nutrient availability, and to provide for healthy plant growth.

Figure 75 EC affects the plants

4.4.2 Types of bags used in passive hydroponics

Figure 76 Bags used in passive hydroponics

Figure 77 Bags used for passive hydroponics

In Passive hydroponics, various types of bags are used to support plant growth by holding the growing medium and allowing for capillary movement of water and nutrients without the use of active pumps. Commonly used grow bags include fabric grow bags include fabric grow bags, which are made from breathable materials like non-woven fabric or recycled PET, these promote air pruning of roots and offer excellent aeration. Poly grow bags made from UV-resistant polyethylene are also widely used for their durability and cost-effectiveness. Another popular option is cocopeat grow bags, which come pre-filled with coco coir and are ideal for crops like tomatoes and cucumbers due to their good water retention and root support. Perforated drain bags, often made of woven plastic or fabric, are used to improve drainage and moisture control, especially when filled with media like clay pellets or perlite. Additionally, DIY passive grows bags made from reused plastic bags or sacks with added drainage holes are commonly used in home or small-scale hydroponic setups. Each type of bag offers specific advantages depending on the crop and the growing environment.

4.4.3 HYDROPONIC PRODUCTION SYSTEM IN A PROTECTED STRUCTURE

1. Nursery and Seedling Management
2. Greenhouse Management for Hydroponic Plantation
3. Nutrient deficiency management
4. Integrated Pest Management
5. Pest issues on plants
6. Disease management

Nursery and Seedling Management

Selection of appropriate germination medium (e.g., Cocopeat, rockwool, perlite)

Seed treatment methods to prevent damping-off and fungal infections

Environmental conditions required for optimal seedling development

Transplanting timing and hardening of seedlings.

Maintenance of nursery hygiene and disease prevention practices.

Raise healthy seedlings.

Young plants require a lot of care.

Protected from adverse environmental condition.

Figure 78: PLANTS IN PROTRAY

4.4.4 Nursery Structure

Figure 79: Nursery structure for seedling stage

Selection of the Nursery Site

When selecting the site for a nursery, we need to look at the following factors:-

1. Availability & quality of water: It is much recommended to have the water analyzed before deciding to use a location.

2. Surrounding: We cannot control our neighbours. If in the neighbourhood crops are grown that are full of insects and viruses this will surely create problems.

3. Light: There should be no trees or buildings blocking the light.

4. Air: There should be no obstacles like walls or other greenhouses blocking the airflow into the nursery.

5. Access: You will need easy access to the site.

Nursery tables

Figure 80 Nursery tables

Pro trays

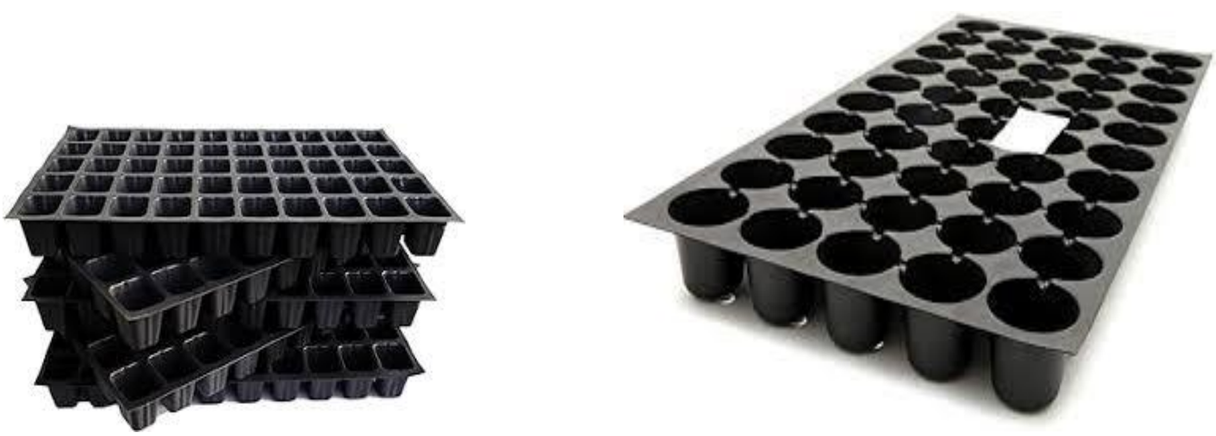


Figure 81 Pro Trays

- Shape
- Size
- Number of cavities (36, 50, 72, 98)

Figure 82: 36 Cavities

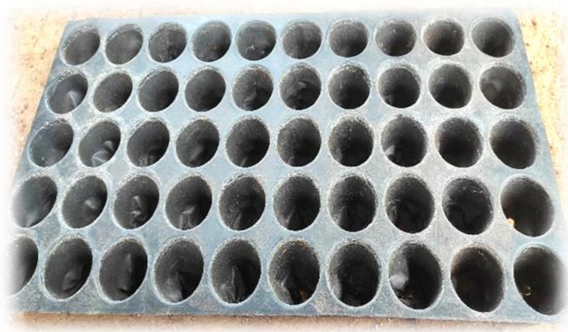


Figure 83: 50 Cavities

Figure 84: 70 Cavities

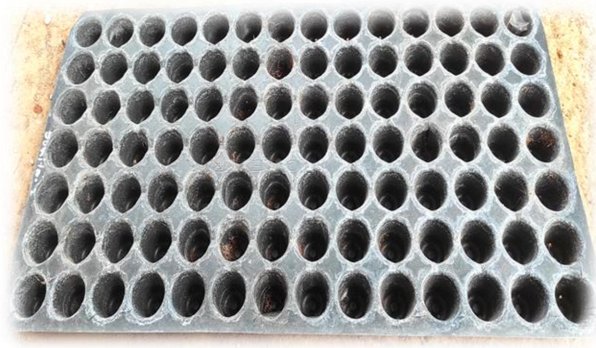


Figure 85: 98 Cavities

Advantages

- Slow growth of seedlings occurs, if transplanting is delayed
- Has less space
- More number of seedlings

Disadvantages

- Less space available for proper root development
- Coiling of root occurs
- Uptake of water and nutrients is competitive

4.4.5 Cocopeat

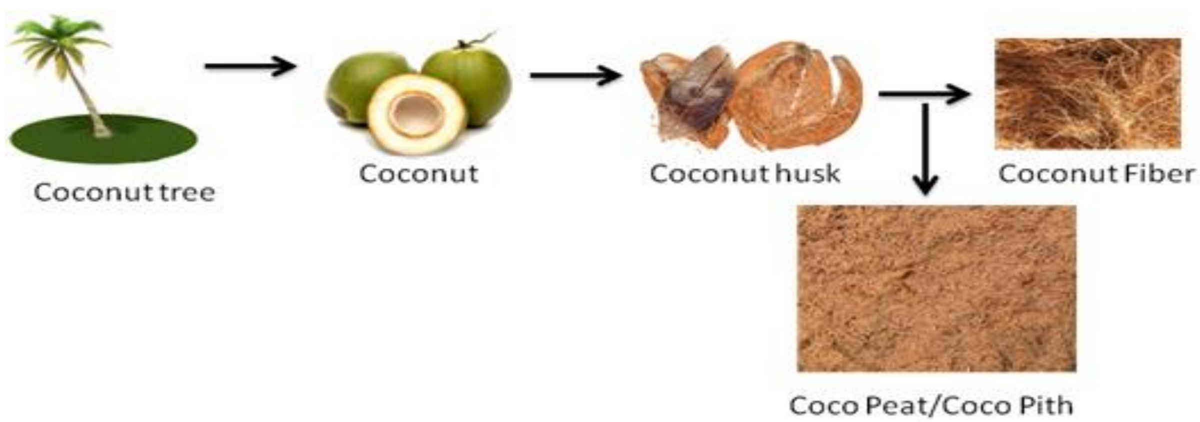


Figure 86 Cocopeat

- Sterilized
- Stabilized -EC- 0.1 dS/m
- pH -5.9-6.5
- Fibrous

Figure 87:Cocopeat

Figure 88: Tomato seeds

4.4.6 Sanitization of Nursery

Figure 89 Sanitization of Nursery

- Profenofos – 3ml/ L
- Lamda cyhalothrin – 1ml/L
- $CuSO_4$ – 2g/L
- Streptomycin SO_4 – 0.3 g/L

4.4.7 Germination and Plant growth stage

1st Stage Stacking

Figure 90:FILLING OF COCOPEAT TO PROTRAYS

Figure 91:SOWING OF SEEDS

- Stack portrays and place in **dark room** (2-3 days) – 7 trays can be stacked at a time
- Semi shade condition
- Nursery (at 2 leaf stage)

Figure 92:PLACE TRAYS IN THE DARK ROOM

Crops	Days taken for germination	Days taken for transplanting after sowing
Tomato	5-8 days	25-30 days
Capsicum	5-8 days	30 days
Cucumber	2-3 days	12-15 days
Gourds	4-5 days	15-20 days
Crucifers	2-3 days	30 days

Table 7: CROPS, GERMINATION DAYS

Figure 93:SEED STARTS TO GERMINATE

Figure 94: SHIFTING TO NURSERY

Figure 95: GERMINATION STAGE OF PLANT

Figure 96: TWO LEAF STAGE

Figure 97:THIRD SET OF LEAF

Figure 98:FOURTH SET OF LEAF

Figure 99:FIFTH SET OF LEAF

Figure 100: SEEDLINGS READY FOR TRANSPLANTING

4.4.8 Nursery Process of Plant growth

The nursery phase of a plant's life cycle includes a series of precisely programmed stages to achieve the production of healthy and vigorous seedlings for tree planting. It starts with seed choice of high quality, free from disease. This is then proceeded by seed treatment: soaking, priming or fungicidal treatment in order to improve germination and resist pests. Seeds are sown in trays / seedbeds / pots containing a suitable growing medium such as coco peat, compost or soil sand mixture. The germination stage proceeds under ideal temperatures, moisture, and light levels. When the seeds germinate the baby plants are in the vegetative stage and need to be watered regularly and checked for pests and diseases and sometimes thinned so that too many plants don't grow and crowd the growing area. After the seedlings develop a strong root system and a few true leaves, they are hardened by gradually exposing them to outdoor conditions to increase their tolerance to stress. Finally, the healthy young plants are transplanted into the main field or a hydroponic system for further growth and production. This nursery phase plays a crucial role in ensuring uniform crop establishment and higher yields.

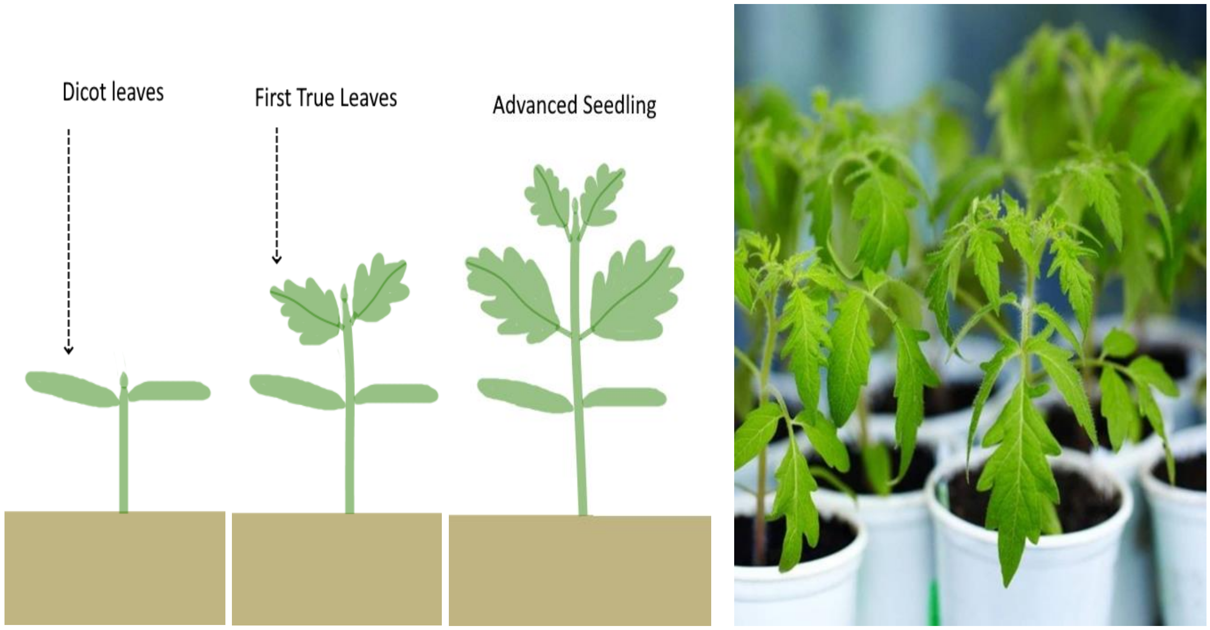


Figure 101: Seedlings ready for transplanting

5 Constraints in nursery plantation process

Avoid compaction of media while filling of trays

- Compaction may occur
- if the labour is pressing media too much into the trays
- Increased Cost of substrate
- Less air
- Poor root growth

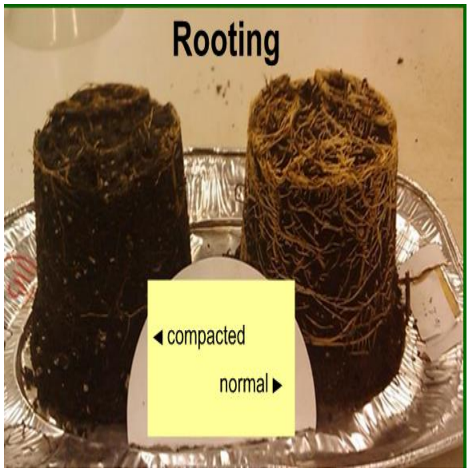


Figure 102 Avoid compaction of media while filling of trays

Under filled Trays

- Usually happen when substrate is too dry while filling
- trays after irrigation settles down
- Which may result in settling of media
- uneven germination

Figure 103 Underfilled Trays

Overfilled Trays

- Increased substrate cost
- Roots spread across cell
- difficult to separate while transplanting
- Damaged roots

Figure 104 Overfilled Trays

Uneven filling of trays

- Uneven germination
- Uneven drying of substrate
- Uneven growth
- More grading required – more labour- more cost

Figure 105 Uneven filling of trays

Hardening

- The last 4-5 days the plants should be hardened of by reduced RH and full sun.
- If necessary, put the seedlings outdoors to get used to the out-door circumstances.
- Before planting the trays can be drenched in a fungicide solution to help to protect the damaged roots from getting diseased.

Climatic conditions, foggers

- Sanitation should be done before shifting the germinated trays
- Maintain 25-to-26-degree Celsius temperature
- 55 to 60 % relative humidity
- Use top white shade net
- Avoid shade for vegetative growth
- If high temperature: close the top shade net to avoid seedling tip burning.
- Foggers can be used to cool the air and there by high temperature and maintain the RH in the nursery
- The water droplets should not reach the crop, but evaporate in the air.
- Water droplets size should be less than 0.5 micron and give only for 2 to 3 seconds
- We should not increase humidity too much, because this makes weak plants.

Air movement to activate plants

Functions of ventilation:

- Temperature control is most important for ventilation
- Humidity control
- Activate the plant
- CO2 import from outside

We can improve ventilation by:

- Having a greenhouse with good ventilation.
- Open up the sides
- Clean the net. Dirty net will reduce ventilation by 30% or more
- If needed, use fans.

Seed Storage

For the storage of all vegetable seeds counts:

- The colder the better
- The dryer the better
- An air tight package in a refrigerator will do fine.
- Don’t leave seeds in a hot or humid place.

If there is more sunlight there will be lackness of seedlings.

Figure 106: Lackness of seedlings

Problems associated with second hand coco peat

- Lower aeration and less drainage
- Higher risk of pest and diseases
- Water scheduling problem
- Higher media EC risk
- Can't depend on drip and drain percentage
- Mandatory to drench COC at the rate of 2 g per lit and Dichlorvos 76% EC 1ml/ltr
- If we use 3rd hand Cocopeat it is mandatory to add Perlite 40g/bag & Peatmoss 20g/bag & drench COC 2g/ltr.

Figure 107 pH and EC balance in coco peat

- High media PH: add acid- nitric acid
- Low media PH: add any alkali (Na carbonate/bicarbonate)
- Recommended PH: 5.5 to 6.5
- High media EC: flush media with RO water
  Recommended EC:<0.1 ds/m

Nutrient Management

Essential nutrients – 17

- Macro nutrients – Primary macronutrients – N, P, K
  Secondary macronutrients – Ca, Mg, S
- Micronutrients – Fe, Cu, Zn, Mn, Mo, B, Cl

Fertigation Recipe and Fertigation Schedule

In 100 L of water

A tank

Calcium nitrate – 1.65 kgs

Iron – 10.8 g

B tank

Potassium nitrate – 614 g

Magnesium nitrate – 670 g

Mono potassium nitrate – 340 g

Potassium sulphate – 340 g

Zinc sulphate – 2.6 g

Manganese sulphate – 3.1 g

Copper sulphate – 3.6 g

Ammonium molybdate – 0.3 g

Borax – 4.5 g

- From the initiation of two leaves stage start giving fertigation.
- Start fertigation with the EC of 0.5 dS/m.
- For every 5 days, increase EC of 0.2 dS/m.

EC can be- 0.7, 0.9, 1.1, 1.3 and 1.5 dS/m up to transplanting.

- 15 days after sowing drench with MAP (12:61:00) 1g/lt of water
- 20 days after sowing, drench with 19:19:19,1g/lt of water
- 25days after sowing drench with 13:40:13,1.5g/lt of water
- 30 days after sowing drench with MPP (00:52:34) 1.5g/lt of water
- 35 days after sowing drench with 6:12:6, 2g/lt of water.
- From 2 leaf stage drench MAP (12:61:00) with concentration 0.25 g/lt then change concentration every 5 days by increasing 0.25g till it reaches 1 g/lt
- Then drench with 19:19:19, with concentration 0.5g/lt of water.

Spray Schedule

- 12 days after sowing drench with Lessenta (Imidacloprid+fipronil) o.3g/litre of water
- 18 days after sowing spray with actara (Thiamethoxom) @0.3g/litre of water
- 24 days after sowing spray with tracer (Spinosad) @0.3ml/litre of water
- 31 days after sowing spray with abamectin @0.4ml/litre of water
- 35 to 40days old seedlings before planting, dip the seedlings roots with trichoderma
- Before planting/Immediately after planting one preventive spray can be taken up.

Procedure for Nursery Plantation

Figure 108: Filling of Trays with cocopeat without pressing it into the cells

Figure 109: Making of holes (with the help of dibbler) for placement of seed)

Figure 110: Placing the seed at right depth and centre of the cavity

Figure 111:Covering of seeds with a layer of cocopeat

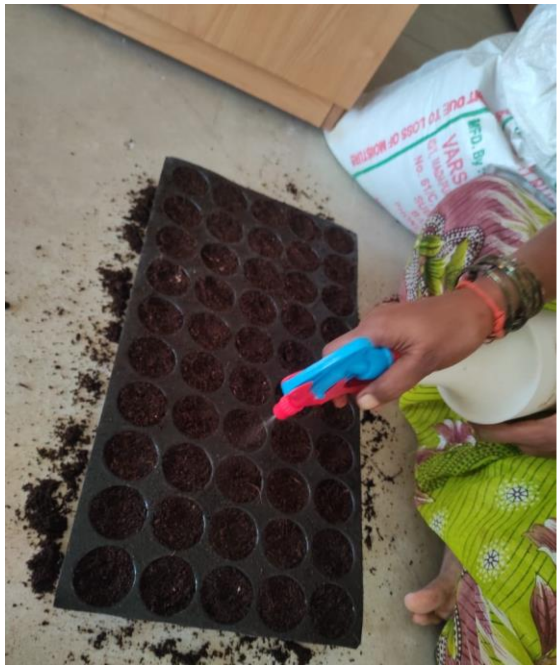


Figure 112: Light watering for already sown trays

5.1 Technical Considerations for Greenhouse-Based Passive Hydroponic Systems

The comprehensive guidelines for setting up, managing, and maintaining a greenhouse system, specifically for passive hydroponic cultivation. It begins with the removal of old crops, cleaning of the greenhouse, including weed and drain mat cleaning, and proper drip line alignment and bag placement. For growing media, the use of second-hand coco peat is the big drawback (e.g., poor aeration, high pest risk) and treatment protocols using COC, Dichlorvos, and supplements like perlite and peat moss if using third-hand coco peat. It also covers how to balance pH and EC levels in the media, ensuring ideal growing conditions. Essential equipment's checks include placing sticky traps, temperature and RH meters, and ensuring the fertigation system and climate control tools are operational before transplanting. The transplanting method emphasizes media preparation, proper placement of seedlings, and immediate care such as plant tying and coco peat support. The presentation also details climate management (temperature: 21–30°C, humidity: 60–65%) and coping strategies for common problems, such as extreme temperatures (using screens, foggers, and fans), humidity (and/or rainfall) (using artificial means to control humidity), and wildlife intrusion. Planting density is also suggested e.g. for capsicum (3.1/m²), tomato (2.5/m²) and cucumber (2.5/m²), with consideration of the best branch structure with most advantages for yield.

It also provides fertigation schedules for all the crops, timing, quantities for applications, as well as drip and drain calculations that are suitable for the seasonal circumstances. Primary indexes are the moisture (60-70%) and drain EC control. Other plant-related recommendations include a crop walk to look for pests, nutrient problems, structural concerns, and ensure system health.

5.1.1 Transplanting method

- Don't give water to seedlings on previous day of transplanting.
- Media should be EC and PH balanced
- Evenly spread the media
- Media should be moistened before 1 day of transplanting
- Media should not cross collar region of the plant while planting

Figure 113 Transplanting method

5.1.3 Plant density

- Recommended density of tomato plants: 2.5 per square meter
- Recommended density of cucumber plants: 2.5 per square meter
- Recommended density of capsicum plants: 3.1 per square meter
- Recommended branch per plant: 2. Max 3 (Bachata/ yellow capsicum)

Higher plant density disadvantages:

- No aeration
- Low light penetration
- Competition for space
- Fungus problem
- Easy speared of diseases
- Difficulty in doing intercultural operations

Lower plant density disadvantages:

- Rapid water and nutrient loss from the media
- Direct sun light to media, fruits and flowers
- Less productivity

Four stems per plant disadvantages:

- Less space for fruit growth
- Uneven shape
- Less weight of fruit

EC requirement	**Tomato**
Initial stage water/fertigation requirement	1.5 to 2.2
Flowering to initial fruiting stage	2.2 to 2.4
Full fruit bearing stage	2.8 to 3.0

Table 8: FERTIGATION PROPOTION FOR TOMATO PLANTS

Fertilizer	Quantity: 100 lit RO water
A tank	
Calcium nitrate	16.5 kg
Fe-EDTA (13%)/EDDHA/DTPA	108 g
B tank	
Potassium nitrate (13:0:45)	10 kg
Magnesium sulphate (MgSo4)	6.7 kg
Mono Potassium phosphate (0:52:34)	3.4 kg
Sulphate of potash (0:0:50)	3 kg
Manganese sulphate (MnSo4)	31 g
Zinc Sulphate	26 g
Copper sulphate	36 g
Sodium molybdate/Ammonium molybdate	3 g
Borax	45 g

Table 9:STAGE OF FERTIGATION

CUCUMBER		
A tank	**100 lt (stock)**	**quantity**
Calcium nitrate	18.5	kg
Fe-EDTA (13%)/EDDHA/DTPA	125	g
B tank	**100 lt (stock)**	**quantity**
Potassium nitrate (13:0:45)	13.8	kg
Magnesium sulphate (MgSo4)	7.4	kg
Mono Potassium phosphate (0:52:34)	3.4	kg

Sulphate of potash (0:0:50)	600	g
Manganese sulphate (MnSo4)	34	g
Zinc Sulphate	29	g
Copper sulphate	4	g
Sodium molybdate/Ammonium molybdate	3	g
Borax	50	g

5.1.4 FERTIGATION FOR CUCUMBER

Growth stage	**EC**
Initial stage	1.4 to 1.7
Flowering to initial fruiting stage	1.8 to 2.2
Full fruit bearing stage	2.3 to 2.5

Water Requirement for plants

Water requirement	**Quantity**
Initial stage water/fertigation requirement	300-400 ml/plant/day
Flowering to initial fruiting stage	400-450 ml/plant/day
Full fruit bearing stage	700-750 ml/plant/day

- Ideal moisture content: 60 to 70%
- Drain EC: 20% more than input EC

Figure 114:MOISTURE AND EC TEST METER

Figure 115:FERTIGATION AND IRRIGATION

	% drainage	Ec drainage higher than input	Time
			1st irrigation 1 to 1.5 hours after
1st	5	0.5 to 0.8	sunrise
2nd	10	0.4 to 0.7	
3rd	15	0.3 to 0.7	
4th	25	0.2 to 0.4	
5th	25	0.2 to 0.4	
6th	30	0.2 to 0.4	hottest part of the day
7th	30	0.2 to 0.4	
8th	25	0.2 to 0.4	
9th	25	0.2 to 0.4	
10th	25	0.2 to 0.4	
11th	25	0.2 to 0.4	
12th	20	0.2 to 0.4	
13th	15	0.2 to 0.4	Last irrigation 1.5 hours before sunset

Table 10: Ec DRAINAGE TABULAR PRESENTATION

5.1.5 Crop Walk

Crop walk is vital routine in passive greenhouse cultivation, aimed at monitoring the overall health and development of the plants. During the walk close attention is given for pests and diseases, such as thrips and mites and evidence of fungal diseases such as powdery mildew, during the walk. Leaf colour, texture and plant structure can be the first clues to nutrient deficiencies or toxicities. Also make sure to look for any imposed mechanical damage to the plants that could occur from maintenance. Moisture content and electrical conductivity (EC) of the growing media should be measured to control water and nutrient levels. It is also important to analyse the structural aspects of the greenhouse, such as bags, drip lines and support systems, to avoid possible problems that could compromise the development of your plants. Water issues such as leaks or clogged drippers should be resolved as quickly as possible. Crop walks help to spot problems before they become established, allowing for timely remedial action.

Do scout for

- Pest and diseases
- Nutrient deficiency
- Manual damage
- EC problem
- Structure damage
- Water related issues

Figure 116: CROP WALK

5.1.6 Best practices in Protected Cultivation of Tomato

Protected cultivation is a modern technique in which crops are grown under a protective environment. This protective environment can be of any nature and form and is used to shield crops from undesirable growing conditions. Covering three horticulture crops namely, tomato, capsicum and cucumber, in greenhouse conditions with special reference on varietal choice, intercultural operations and climate management. In tomatoes, single and double-stem systems are used to grow varieties with cherry, beefsteak and intermediate clusters. Correct training and support with staking and trellis is important to prevent plant injury and promote the upward growth. Some of the best practices are specific to regular pruning for plant shape/veg harvest balance and hand pollination to ensure consistent fruit set and thinning fun show/thin harvest for quality yield. Harvesting is scheduled after 60 days of transplanting and fruit weight is the criterion for grading.

Cucumber are particularly parthenocarpic types, are ideal for protected environments as they do not require pollination. These varieties produce only female flowers and are harvested daily to maintain quality. Early fruit removal, along with side shoot management, helps focus the plant's energy on healthy vine growth and consistent production. Varieties such as mini cucumbers and English cucumbers are chosen for their tender skin, crisp texture, and market appeal.

Tomato Type	Fruit Bearing	Avg Fruit wt. (g)	No of Fruits/cluster
Beefsteak	Cluster	180 – 200	2 – 3
Intermediate	Cluster	140 – 160	5 – 6
Round Cherry	Cluster	14 – 16	12 – 14

Table 11: Tomatoes and types in hydroponics

5.1.7 Tomato Varieties

1. Beefsteak: Valouro
2. Intermediate Cluster: Cibellia, Disten, Dyvine & Waad
3. Plum Oval: Nowara
4. Cherry: Maggino, Fortesa, Confetto & Pareso

Figure 117: Tomato Varieties

Tomatoes		
Growth stage	**Number days**	
Nursery days	25	DAS
Stacking	5 to 7	DAT
Flower initiation	27 to 30	DAT
Fruit initiataion	40 to 45	DAT
Cherry harvest	60	DAT
Bigger tomato harvest	75	DAT
Harvest interval	2	Weekly
Total life span	1	Year
Harvest days	9	Months

Table 12:Tomato crop growth

5.1.8 Tomato Growing Practices

Figure 118: Single stem system

Figure 119: Double Stem system

Special Requirement of growing tomatoes in a hydroponic greenhouse

1. Regular pruning of leaves and side shoots
2. Trellising/staking with thread & hook
3. Pollination by shaking or by vibrating; morning 7 to 9 everyday

4. Fruit thinning / flower thinning is essential
5. Lowering down

Stacking in Tomatoes

- Give wire support to plants within one or two days after transplanting
- Avoid physical damage by giving support
- Do not give turning very tightly
- One turn per one internode

Figure 120: Stacking of tomatoes

Flower removal in Tomato

- Remove inflorescence up to 100 cm height of the plant
- Do not damage the plant while removing inflorescence; hence remove it in medium growth

Figure 121 Flower removal in Tomato

Leaf and side shoot removal in Tomato

- Every week- 2 new leaves
- Maintain only 13- 14 leaves per plant
- Maintain balance between vegetative and reproductive growth
- Remove extra branch coming up from each node
- Do not damage the plant/truss

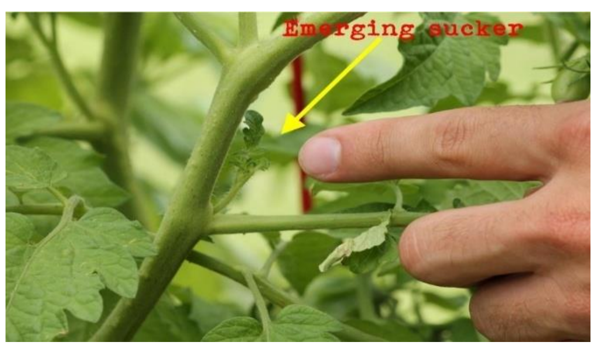


Figure 122: Leaf and side shoot removal in Tomato

Pollination in Tomatoes

- Do pollination early morning; 7 am to 8 am
- Improper pollination- improper fruit set

Figure 123: Pollination in Tomatoes

Flower or fruit thinning in Tomatoes

- Leave the cherry tomatoes truss as usual- based on nutrient management
- Hybrid tomatoes- 6 fruits/ truss

Figure 124: Flower or fruit thinning in Tomatoes

- It gives first yield 60 days after transplanting
- 50-60% color development - harvesting
- Yield /plant – Cherry tomato – 4.7 kg/plant

Bigger tomatoes – 7 kg/plant

- Grades –

Cherry tomatoes - > 8g/ fruit – A grade

6 – 8g/ fruit – B grade

< 6g/fruit – C grade

Intermediate tomatoes – Yakamoz - > 100-150 g/ fruit – A grade

< 100 g/ fruit – B grade

Red plum 7010 - > 80-100 g/fruit – A grade

< 80 g/fruit – B grade

Beefsteak tomatoes- > 160-200 g/fruit – A grade

< 160 g/fruit – B grade

Climate management

- Temperature: 21 to 30 degrees
- High temperature: loss of water from media, more transpiration- plant droops, high thrips and mites' problem
- Solution: Foggers, use top screens
- Required humidity: 60 to 65 per cent
- High humidity: Water droplets on leaves, disease like powdery mildew can attack
- Low humidity: pest problem- thrips, mites
- Solution: Foggers – humidity low, Fans- when humidity high
- Rain: close top screen and side screens

5.1.9 Nutrient Requirements

- **Mobile:** The elements which move throughout the plant are called mobile elements

  Eg: Nitrogen (N), Phosphorous (P), Potassium (K), Magnesium (Mg).

- **Immobile:** The nutrients which do not move throughout the plant are called immobile or elements which stay accumulates in one place or move in very small distance

  Eg: Chlorine (Cl), Zinc (Zn) and Molybdenum (Mo), Sulfur (S), Iron (Fe), Boron (B) and Copper (Cu).

Note: Calcium (Ca) is highly immobile element.

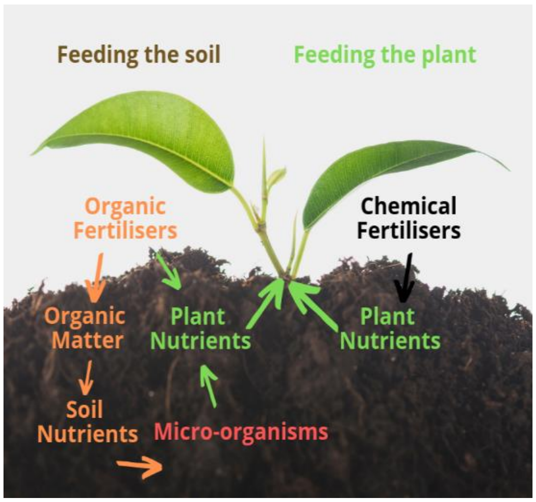


Figure 125: Organic v/s inorganic nutrient

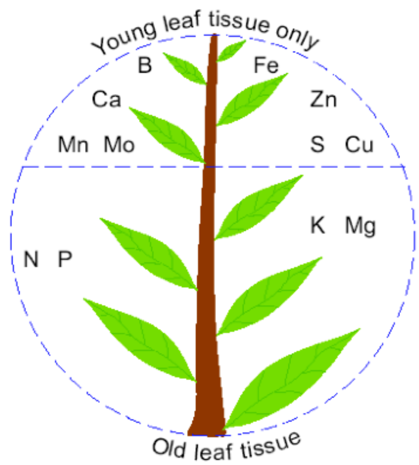


Figure 126: nutrient in old leaf and new leaf

Fertilizer Name	Nutrient(s) Supplied	Content (%)
Urea	Nitrogen (N)	46% N
Ammonium Sulphate	Nitrogen (N), Sulphur (S)	21% N, 24% S
Calcium Ammonium Nitrate (CAN)	Nitrogen (N), Calcium (Ca)	26% N, 10% Ca
Di-Ammonium Phosphate (DAP)	Nitrogen (N), Phosphorus (P_2O_5)	18% N, 46% P_2O_5
Single Super Phosphate (SSP)	Phosphorus (P_2O_5), Sulphur (S), Calcium (Ca)	16% P_2O_5, 12% S, 20% Ca
Muriate of Potash (MOP)	Potassium (K_2O)	60% K_2O
Sulphate of Potash (SOP)	Potassium (K_2O), Sulphur (S)	50% K_2O, 18% S
Magnesium Sulphate	Magnesium (Mg), Sulphur (S)	9.6% Mg, 12.5% S
Calcium Nitrate	Calcium (Ca), Nitrogen (N)	19% Ca, 15.5% N
Ferrous Sulphate	Iron (Fe), Sulphur (S)	19–20% Fe, ~10% S
Zinc Sulphate	Zinc (Zn), Sulphur (S)	21–33% Zn, ~10% S
Copper Sulphate	Copper (Cu), Sulphur (S)	24–25% Cu, ~12% S
Manganese Sulphate	Manganese (Mn), Sulphur (S)	28–31% Mn, ~12% S
Boric Acid / Borax	Boron (B)	17% B (Borax), 20% B (Boric Acid)
Sodium Molybdate	Molybdenum (Mo)	39–41% Mo
Potassium Chloride (KCl)	Potassium (K_2O)	60–62% K_2O
Chloride Salts	Chlorine (Cl)	~45–50% Cl (varies)

Table 13: Macro Fertilizers %

Micro nutrients	Prevention & treatment measures
Iron (Fe)	Correct Fe nutrient deficiency in plants by spraying damaged leaves with diluted ferrous sulfate for quick results. Iron chelates compounds (EDDHSA or EDTA) help solve the problem for a longer time.
Zinc (Zn)	Treat the damaged leaves with zinc sulfate/chelate.
Boron (B)	Fix B nutrient deficiency with diluted borax or boric acid.
Copper (Cu)	opt for copper sulfate dilution as a leaf spray.
Manganese (Mn)	Get manganese sulfate/chelate for plant leaves treatment.
Molybdenum (Mo)	Feed your crops leaves with molybdenum-containing additives.

Table 14:Micro nutrient

5.2 Insect pest management in protected cultivation in hydroponics

Pest control is important in order to assure a healthy crop growth and high productivity in protected crops, such as greenhouses. The present study is aimed at determining major insect pests occurring infrequently on tomato, capsicum and cucumber under greenhouse conditions and their relationship with their damage and integrated pest management tactics. The important pests recorded are aphids, leaf miners, spider mites, thrips, caterpillars, whiteflies, mealy bugs, Tuta absoluta. These include primarily sucking or chewing insects that cause injury to a plant's foliage, flowers, or stems that can result in loss of photosynthesis, stunted growth, leaves distortion, and poor fruit development. The aphids congregate on the lower leaves in clusters and exude honeydew, which is attractive to ants. Cotyledon leaves are damaged by leaf miners in the early stages and yellowish spots and webbing are from spider mites and mites on the leaves. Thrips, found mainly in flowers, cause low fruit set. Leaves are voraciously eaten up by caterpillars, Tuta absoluta, a major tomato pest damaging leaves and fruits. Whiteflies and mealy bugs are other sap-sucking pests that can be disease vectors.

These are organic and chemical means of controlling these pests. Organic methods such as neem oil (10,000–15,000 ppm), clove oil sprays and garlic extracts can be used. Yellow sticky traps and culling of infested parts from plants are also advised. Chemical control: Several insecticides are used against pant pests, depending on the type of pest such as, **Imidacloprid**, **Acetamiprid**, **Spinosad**, **Fipronil**, **Lambda Cyhalothrin**, **Bt formulations**, and **Cartap hydrochloride**. The study emphasizes starting with the lowest effective dose and increasing gradually if necessary. Integrated pest management (IPM) strategies, including cultural practices, biological agents, and targeted chemical application, are highlighted as essential to reduce pest pressure while minimizing resistance development and ensuring environmental safety.

Figure 127 Insect pest management in protected cultivation in hydroponics

Figure 128 Insect pest management in protected cultivation in hydroponics

Figure 129 Insect pest management in protected cultivation in hydroponics

5.2.1 Disease, Preventation and Precaution

- Cultural practices
- Biological practices
- Mechanical practices
- Chemicals

CULTURAL PRACTICES

- Selection of resistant varieties
- Crop rotation
- Variation in the time of planting
- Growing of trap crops

Figure 130 CULTURAL PRACTICES

BIOLOGICAL PRACTICES

- Antifungal- Trichoderma
- Antibacterial- Pseudomonas, Streptomycin

MECHANICAL PRACTICES

- Use of sticky traps
- Sterilize implements
- Soil solarization

Figure 131 CULTURAL PRACTICES

CHEMICAL PRACTICES

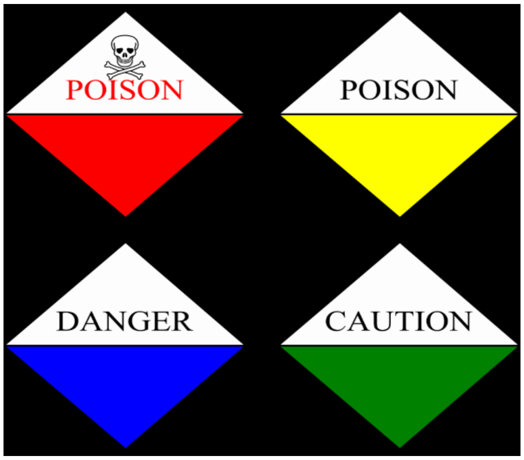


Figure 132 CHEMICAL PRACTICES

Chemical Name	Trade Name	Toxicity Classification
Benomyl	Benlate	High
Captan	Agrox, Captan, Captec	Extreme-moderate
Carboxin	Vitavax	High-moderate
Chlorothalonil	Bravo, Daconil,Terlanil	High
Coppersulfate	Basicop,Bluestone	High-moderate
Fenarimol	Rubigan	High
Fosetyl -Al	Aliette	Minimal
Iprodione	Rovral	Moderate
Mancozeb	Dithane, Fore, Manzate	High-moderate
Maneb	Maneb, Manex	High-moderate
Metalaxyl	Ridomil	Minimal
Propiconazole	Alamo, Orbit,Banner, Tilt	High-moderate
Thiram	Thiram, Spotrete	High-moderate
Ziram	Ziram	Moderate

Figure 133 CHEMICAL PRACTICES

6 Conclusions and Recommendation

To summarize, we can conclude the study that passive hydroponic cultivation with a sheltered greenhouse environment for vegetable and herb production in South India is one potential sustainable and economically profitable operation. The interplay of elements such as temperature, humidity, nutrient flow, and light offsets gains in crop yield and quality and a reduction in pest and disease occurrence. Hydroponic culture saves up to 90% of water, allows efficient nutrient absorption, and faster crop yields than conventional farming, which allows multiple harvests in some instances in one year. The results also revealed that hydroponics reduced water use mostly between 70% and 90% compared with conventional farms, and it also reduces fertilizer and pesticide concentration, thereby polluting the environment for producing healthier food. Controlled nutrient delivery and environment produce uniform growth of crops, high productivity per unit area, and an opportunity to grow crops all year round, independent of external climate conditions. This is a major concern in densely populated and developing urban zones of India, where land and water resources are under increasing stress.

The initial setup costs for these systems are considerably high; however, once running, these systems have rather low input needs and continuously produce market-quality produce throughout the year. Therefore, they work best with small and medium-scale farmers who want to enhance their incomes through high returns and average output levels.

Using the system promotes sustainability objectives because the system uses few pesticides, optimizes land use, and has a low carbon footprint. These benefits are even more promising for small- and medium-scale farmers who can adapt scalable models to take advantage of government subsidies and the emerging clean, local produce market. On top of it all, the modular characteristic of hydroponics makes the method scalable within an urban setup, thus serving as an important tool for local food systems at peri-urban/urban levels.

The sustainability perspective in this study shows that hydroponic farming aligns toward achieving some winners of the UN Sustainable Development Goals (SDGs), among which are Zero Hunger, Responsible Consumption and Production, Climate Action, and Life on Land. Thus, it can be viewed as a way toward resilient agriculture that meets the nutrition needs of the growing population while reducing environmental strain.

In conclusion, the research endorses hydroponics as a futuristic agricultural method meeting sustainable development at large, food security, and climate resilience. Given proper building capacity, technical support, and incentives, hydroponic agriculture may outrightly replace traditional agriculture approaches in the tropics to give way to efficient and less environmentally damaging food production systems. Future research would fine-tune protocols for specific crops, delve into nutrient management automation, and assess long-term implications of soilless production to further support hydroponics in the Agri-tech revolution in India.

One direction for future research to my knowledge is alteration of hydroponic models on a location base, adaptable to different agro-climatic zones of India. Whereas this study pertained to South Indian conditions, other areas may require their own forms of solutions depending on temperature ranges, humidity levels, and sunlight availability. Modular designs that take variations of scale and climatic influences into account will considerably increase the reach and pragmatic realization of hydroponic farming all over the country.

The other promising sector would be to provide hybrid solutions integrating renewable energy, mainly solar energy, to run greenhouse equipment such as foggers, fans, sensors, and water pumps. This would lessen operational costs and would also fit into the concept of sustainable agriculture by reducing carbon emissions. A solar-powered passive hydroponic system would thus serve as an excellent option in rural and off-grid situations.

Material-wise, future research should investigate different locally available media such as composted rice husk, sugarcane bagasse, and blended coco products. All could stand as cheap and environmental-friendly alternatives to commercially processed coco peat, lowering production costs and dependence on imported supplies altogether.

Education and capacity building constitute the most crucial elements fostering a sustained hydroponic promotion attempt. Development of structured training courses and the inclusion of hydroponics in agricultural curriculum at university and vocational centres would empower farmers, students, and entrepreneurs. Special consideration should be given to skill enhancement training for women and rural youth to encourage inclusive growth.

Significant opportunities exist to utilize technology and data science to improve systems performance. For example, the combination of low-cost sensors, data loggers, and AI-driven software may allow systems to identify environmental conditions, predict the needs of plants, and adjust nutrient delivery, in real time. These advancements would allow hydroponics to be more intelligent, accurate, and scalable for commercial operations.

Next, from a policy perspective, collaboration with government agencies to create environments for support for hydroponics (supported with subsidies, a robust certification framework, and market linkages for hydroponic produce) can be suggested. Government programs to encourage urban farming including rooftop systems and community hydroponic projects, with an overall intention to generate job opportunities, will help to develop food systems and the food secure city.

Further, research can also be performed on nutritional composition and consumer acceptance of hydroponic crops. Identifying consumer perceptions, pricing, and health aspects could provide size and marketing ability that would include mainstreaming hydroponic produce in domestic and internationally markets space.

7 Appendix

Sl. No.	Title	Details
1	Conventional and Organic farming	Based on philosophy (crop-focused vs. soil-focused), inputs used (chemical vs. organic), pollution levels, resource integration, sustainability.
2	Bulk Density and Porosity of Soil-less Media	Coco peat (80–100 kg/m³, 90–95%), Perlite (80–120 kg/m³, 85–90%), Vermiculite (90–150 kg/m³, 90–95%), Rock wool, Expanded Clay.
3	Constituents of Basic Hoagland Solution	Macronutrients: N, P, K, Ca, Mg, S; Micronutrients: Fe, Mn, Zn, Cu, B, Mo.
4	Soil-based vs Hydroponic Farming Differences	Soil dependent, pest prone, weather affected vs. water-efficient, controlled environment, higher yield.
5	Crops Grown in Hydroponics	Tomatoes, Lettuce, Spinach, Basil, Cucumbers, Herbs.
6	Water and Fertilizer Consumption (Hydroponics vs. Traditional)	Water usage reduced by ~70–90%, fertilizer savings of ~60% in hydroponics.
7	Germination Days for Crops	Tomato: 7–10 days, Lettuce: 3–5 days, Spinach: 5–7 days, Basil: 6–10 days.
8	Fertigation Proportion for Tomato Plants	Growth stage-wise nutrient ratios: early, flowering, fruiting stages.
9	Fertigation Stages for Tomatoes	Transplanting, flowering, fruit setting, fruit enlargement, maturation.
10	EC Drainage Values	Target EC: 2.0–3.5 mS/cm for tomatoes; monitored throughout crop cycle.
11	Tomato Varieties in Hydroponics	Cherry, Roma, Beefsteak, San Marzano, etc.
12	Tomato Crop Growth Stages	Germination, vegetative, flowering, fruit development, harvesting
13	Macronutrient Percentages	N: 10–15%, P: 3–5%, K: 10–20%, Ca: 3–6%, Mg: 1–2%, S: 1–3%.

14	Micronutrient	Fe, Zn, Mn, Cu, B, Mo with specific functions and signs of deficiency.
15	Organic vs. Inorganic Nutrients	Organic: derived from plant/animal residues. Inorganic: chemical synthesis, rapid absorption, lower environmental sustainability.
16	Mobile vs. Immobile Nutrient Elements	Mobile: N, P, K, Mg. Immobile: Ca, S, Fe, B, Cu, Zn, Mo, Cl.
17	Nutrient Deficiency Symptoms - Macronutrients	N: yellowing of older leaves, P: purpling, K: brown margins, Ca: deformed leaves, Mg: interveinal chlorosis, S: yellowing.
18	Nutrient Deficiency Symptoms - Micronutrients	Fe: interveinal chlorosis in new leaves, Zn: Khaira disease, Cu: tip whitening, Mn: grey speck, B: pollen abortion, Mo: leaf curling.

Table 15 : KEY CONCEPTS IN HYDROPONICS

Fertilizer name (Nitrogen)	**Nitrogen content (%)**
Anhydrous ammonia	82
Urea	**46**
Ammonium nitrate	**33-35**
Ammonium sulphate	20.6
Sodium nitrate	**16**
Potassium nitrate	13
Ammonium sulphate nitrate	26
CAN	**25-28**
Ammonium chloride	**26**

Table 16: NITROGEN FERTILIZER CONTENT

Fertilizer name (Phosphatic fertilizer)	**P2O5 content (%)**
SSP	**16-20**
DSP	**32**
TSP	48
MAP	12
DAP	**46**
Basic slag	14-18
Rock phosphate	20-30

Table 17: PHOSPHATIC FERTILIZER CONTENT

Fertilizer name	K2O content (%)
MOP	60
SOP	50
KNO3	44

Table 18: POTASHIC FERTILIZER CONTENT

Micro nutrients	Prevention & treatment measures
Iron (Fe)	Correct Fe nutrient deficiency in plants by spraying damaged leaves with diluted ferrous sulfate for quick results. Iron chelates compounds (EDDHSA or EDTA) help solve the problem for a longer time.
Zinc (Zn)	Treat the damaged leaves with zinc sulfate/chelate.
Boron (B)	Fix B nutrient deficiency with diluted borax or boric acid.
Copper (Cu)	opt for copper sulfate dilution as a leaf spray.
Manganese (Mn)	Get manganese sulfate/chelate for plant leaves treatment.
Molybdenum (Mo)	Feed your crops leaves with molybdenum-containing additives.

Table 19: MICRO NUTRIENTS AND MEASURES

8 Bibliography

Afroz Alam, A. H. (2014). The Changing Scenario in Indian Agriculture: A Review. *The Changing Scenario in Indian Agriculture: A Review*, 118-127.

Dr. Madhavi D. Jangilwad, D. .. (2020). Hydroponics As An Advanced Technique For Vegetable Production. 4.

S. Nicola, G. T. (2009). Tomato production systems and their application to the tropics. 9.

V, B. K. (2012). Organic Farming History and Techniques. 43.

Monisha, K., Kalai Selvi, H., Sivanandhini, P., Sona Nachammai, A., Anuradha, C. T., Rama Devi, S., Kavitha Sri, A., Neya, N. R., Vaitheeswari, M., & Hikku, G. S. (2023). Hydroponics agriculture as a modern agriculture technique. Journal of Achievements in Materials and Manufacturing Engineering, 116(1), 25–35. https://doi.org/10.5604/01.3001.0016.3395

Debangshi, U. (2021). Hydroponics – An Overview. Zenodo. https://doi.org/10.5281/ZENODO.5552644

Behera, K. K., Alam, A., Vats, S., Sharma, H. Pd., & Sharma, V. (2011). Organic Farming History and Techniques. In Agroecology and Strategies for Climate Change (pp. 287–328). Springer Netherlands. https://doi.org/10.1007/978-94-007-1905-7_12

Remiarz, Tomas., Van Der Velden., Warburton-Brown., Chris. (2021). Researching Forest Gardening practice: Current extent and potential

aveira, L. R. S., Carvalho, T. S. de, Teixeira, A. F. dos S., & Curi, N. (2019). Sustainable productive intensification for family farming in developing tropical countries. Ciência e Agrotecnologia, 43. https://doi.org/10.1590/1413-7054201943012819

Kumar Mohanty., Gaidinglungliu Gonmei., Okenmang Jamoh., Barinderjit Singh Jay Nath Patel, Lalita., (2024) Sustainable Agriculture in the 21st Century Sustainable Agriculture in the 21st Century

Taveira, L. R. S., Carvalho, T. S. de, Teixeira, A. F. dos S., & Curi, N. (2019). Sustainable productive intensification for family farming in developing tropical countries. Ciência e Agrotecnologia, 43. https://doi.org/10.1590/1413-7054201943012819

Van Gerrewey, T., Boon, N., & Geelen, D. (2021). Vertical Farming: The Only Way Is Up? Agronomy, 12(1), 2. https://doi.org/10.3390/agronomy12010002

Sonakshi Samal, Bal, P. P., Priyanshu Kumar Verma, Debansu Shekar Pattnaik, Swain, S. S. P., Kar, A., & Sahoo, J. P. (2024). Vertical Farming Revolutionizes Agriculture in India: An Overview. Unpublished. https://doi.org/10.13140/RG.2.2.14603.09760

Michael, G. W., Tay, F. S., & Then, Y. L. (2021). Development of Automated Monitoring System for Hydroponics Vertical Farming. Journal of Physics: Conference Series, 1844(1), 012024. https://doi.org/10.1088/1742-6596/1844/1/012024

Singh, S., Singh, P., Kumar, A., Baheliya, A. K., & Patel, K. K. (2024). Promoting Environmental Sustainability Through Vertical Farming: A Review. Journal of Advances in Biology & Biotechnology, 27(5), 210–219. https://doi.org/10.9734/jabb/2024/v27i5780

Nicola, S., Tibaldi, G., & Fontana, E. (2009). TOMATO PRODUCTION SYSTEMS AND THEIR APPLICATION TO THE TROPICS. Acta Horticulture, 821, 27–34. https://doi.org/10.17660/actahortic.2009.821.1