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Vertical Farming: An Option in Modern Food Production: A Review

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Review Article

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ABSTRACT

Meeting the food needs will be one of the major problems, as farmland is being lost due to causes including soil contamination, water scarcity, and climate change, among others. In this situation, a workable alternative to manage this perennial problem is provided by vertical farming, an energy-efficient, environmentally friendly agricultural technology that does not use soil. Vertical farming could indeed be an important factor in the production of crops and vegetables in regions with

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scarce soil and water resources. With modern technology such as hydroponics, aeroponics, and aquaponics, the idea of a vertical farm appears to have a promising future. In times of pandemics like COVID-19, it has emerged as a viable option for growing a wide range of food crops to suit the dietary needs of the growing world population.

Keywords: Aeroponics; aquaponics; climate change; hydroponics; vertical farming.

1. INTRODUCTION

The soil fertility has been negatively impacted by rapid urbanization, climate change, natural disasters, unrestricted use of chemicals, and pesticides. Aside from that, the size of land that is available to each individual has dropped and the fertility of soil and productivity have consequently decreased [1]. The water resources of the watershed are challenged by factors such a changing climate, rising temperatures, frequent dry spells and the unpredictability of climate. A few threats to the water resources of the watershed include excessive irrigation water use, unregulated water contamination, and a downward trend in groundwater levels [2].

In order to produce additional 50% food by year 2050, when the population is predicted to exceed 9 billion, however additional arable land will be needed [3]. About 75 % of the world's population is anticipated to reside in urban areas due to the world's increasing urbanization [4]. Food production is currently a major concern due to the serious threats these issues pose to traditional soil-based agricultural production systems. Systems of soilless farming could provide a solution to these contemporary problems. Vertical farming methods may be used in place of soil-based farming systems as a supplementary approach to help address the current scarcity of fertile arable lands and water. In simple terms, vertical farming (VF) is a method of large-scale food production in high-rise structures that allows for rapid growth and planned production by managing environmental factors and nutrient solutions for crops grown in hydroponic systems, aeroponics and aquaponics systems using cutting-edge greenhouse techniques and other advanced technologies [5,6]. In accordance with Perez's [7] research, VF combines both engineering and natural science disciplines and has a wide range of uses in both society and the environment.

2. CONCEPT OF VERTICAL FARM

Vertical farming saves water and does away with the need for soil by growing crops inside of buildings (such as a skyscraper or a neglected warehouse). A vertical farm's ability to produce food is unaffected by weather or other natural phenomena. To enable indoor food and pharmaceutical manufacturing, it is possible to artificially control temperature, humidity, light and gases. Vegetables are grown vertically using modern agricultural techniques called "vertical farming," which integrates farms into high-rise buildings in urban areas. This method involves intentionally stacking plants, fungi and other living things vertically on top of one another in order to produce them for food, fuel, and fibre while maximising the use of available land [5,8]. Many nations are currently utilising vertical farms. These farms currently produce a wide range of crops primarily inside of cities. Modern concepts of vertical farming make use of indoor farming methods and controlled environment agriculture (CEA) technology where all atmospheric factors can be artificially controlled, including light, humidity and temperature. Biofortification, or breeding crops to increase their nutritional value is also a part of these modern concepts.

3. BRIEF HISTORY OF MODERN VERTICAL FARMING

The earliest known method of growing plants vertically is the hanging garden of Babylon. Gilbert Ellis Bailey, an American geologist, first proposed the idea of using big, multistorey buildings for indoor cultivation in 1915. The idea of "vertical farming" was created in the most recent years (1999) by Dickson Despommier, an Emeritus Professor of Microbiology at Columbia University, using technological advancements. He explained that hydroponic vegetables may be produced on the higher floors, while poultry and fish that consume plant waste would be more appropriate on the lower floors [9].

4. WHY VERTICAL FARMS?

4.1 Food Security

An increasingly critical concern is food security. Demographers predict that in the future decades, the population of cities will grow significantly. Agronomists, ecologists, and other land experts warn of a growing shortage of farmland at the same time [10]. Due to these factors, there may be a global famine if food demand grows exponentially faster than supply. By the year 2050, the United Nations (UN) document projects that there will be more than 9 billion people on the planet. The UN predicts that by this time, 80 percent of the world's population will live in cities. Additionally, it projects that by 2050, we would require 70% more food to meet the needs of an additional 3 billion people worldwide [11]. Farmers believe that as oil prices rise and the availability of water, electricity, and agricultural resources decreases, food prices which have already risen dramatically in recent decades, will continue to rise [6]. Urban agriculture has struggled because of the lack of available land and expensive expenses. If so, vertical farming could make it possible to produce food in an effective and sustainable way, save money and energy, strengthen the economy, reduce pollution, create new job possibilities, rehabilitate ecosystems and ensure that everyone has access to wholesome food. Crops will be less vulnerable to the fluctuations of the weather, pest infestation, nitrogen cycle, crop rotation, contaminated water runoff, pesticides, and dust in a controlled environment. As a result, growing food indoors might provide a healthier atmosphere [12]. Indoor farming has a great potential to produce higher yields and external income because it is year-round and weather-independent. Additionally, by bringing much-needed "green collar" occupations to urban areas, vertical farming could improve regional economies [13].

4.2 The Ecosystem

Through indoor vertical farming, it is very much possible to restore biodiversity and lessen the consequences of climate change. Vertical farms might provide food on only 10% of the land that cities currently occupy, lowering CO_2 emissions just enough to encourage the creation of novel technologies that would eventually benefit the environment [14]. If fertilizer runoff were removed, coastal and river water quality would improve, and wild fish populations would increase. The most compelling argument in favour of switching the majority of food production to vertical farming seems to be the possibility of restoring ecological services and functions [15].

4.3 Climate Change

Climate change is causing a decrease in the amount of arable land. Large expanses of valuable farmland have been destroyed by drought, flash floods, storms and hurricanes which has detrimental effect on the world economy [16,17]. The frequency and severity of weather-related disasters are expected to rise as a result of human-caused global warming. Large tracts of cultivable land will become unusable as a result of these events. In that case, vertical farming has emerged as a good alternative to combat these issues because it saves water, does not require soil, and allows crops to be grown throughout the year without suffering the negative effects of climate change.

4.4 Health

Traditional farming methods seem to affect the natural and human surroundings Soil erodes, becomes contaminated, and a lot of water is lost as a result of traditional farming systems. According to studies by the WHO, more than half of all farms in the world still use raw animal manure as fertiliser, which can attract flies and serve as a source of weed seeds or diseases that can infect plants [18]. Consuming such food is harmful to people's health. Additionally, if crops were produced in a controlled indoor environment, the usage of herbicides and pesticides which cause damaging agricultural runoff, may be decreased [19]. The demand for water rises as urban populations rise, which may have a significant effect on the amount of water available for agricultural use. With appropriate and efficient irrigation, indoor vertical farming uses around ten times less water than conventional farming [14].

4.5 Economics

The food produced by the vertical farm will be offered at reasonable pricing. Due to increased input costs, the cost gap in traditional farming is fast decreasing. Vertical farms, for instance, might be advantageously located in metropolitan areas so that product can be sold directly to the consumer, decreasing costs by about 60% [20]. Vertical farms can increase production by an order of magnitude in addition to the utilisation of cutting-edge technologies and intensive agricultural techniques. Scientists have spent years studying several aspects of indoor farming, including light intensity and colour, temperature, CO_2 concentrations in the air, soil, water, and humidity levels [20]. Vertical farming can also help the local economy. Wasted urban structures can also be converted into vertical farms to supply needy communities with fresh food. Growing vegetables indoors might also be more pleasurable due to its high-tech nature. Thus, a more technologically competent younger generation has been interested in the practise, giving rise to a new generation of farmers [14].

5. HOW DOES VERTICAL FARMING WORK?

There are four critical areas in understanding how vertical farming works:

5.1 Physical Layout

Firstly, since generating more food per square metre is the main objective of vertical farming, crops are piled vertically to grow.

5.2 Lighting

A proper amount of both natural and artificial light is employed to maintain the ideal lighting level in the room. Utilizing technologies such as rotating beds improve the efficiency of illumination.

5.3 Growing Medium

Vertical farming employs hydroponics, aeroponics, or aquaponic growing mediums in place of soil. Hydroponics involves submerging plant roots in nutritional solution. In vertical farming, peat moss, coconut husks, and other similar non-soil mediums are frequently used.

5.4 Sustainability Features

To reduce the energy cost of farming, the vertical farming technique makes use of a number of sustainability aspects. In comparison to conventional farming, vertical farming generally consumes 95% less water.

6. VERTICAL FARMING METHODS

In an effort to increase the production of sustainable food, researchers have developed a variety of urban and vertical farming techniques. Modern farming techniques have the potential to produce crops having more yields while using significantly less water. These high-tech farms' architecture, design, and setup would give each plant the ideal amount of light and precisely calculated nutrients. By growing in a controlled, closed-loop environment, these farms would eliminate the need for harmful pesticides and herbicides while improving nutrition and food value. Vertical farming includes different methods which are being discussed below:

6.1 Hydroponics

According to Savvas et al. (2017), hydroponics is a technology for growing plants in soilless conditions with their roots submerged in nutrient solution. It is a technique to grow food without needing soil utilising mineral nutrient solutions in water [21]. The definition of hydroponics according to Encyclopaedia Britannica is "the growing of plants in nutrient-enriched water, with or without any mechanical support of an inert media such as sand or gravel" [22]. This term is originated from the Greek word’s hydro and ponos, which means “water doing labour” or “water works”. The paintings on the walls of the more than 4,000-year-old Egyptian temple Deir El Bahari are among the earliest examples of hydroponics [23]. In Babylon during the VI century BCE, hydroponics was utilised to grow primarily ornamental plants [24]. National Aeronautics and Space Administration (NASA) experts have recognised hydroponics as a promising technique for growing food in space. They have had success growing various vegetables including radishes, lettuce, and onions. Overall, scientists have improved the hydroponic technique by making it more fruitful, reliable, and water-saving. In industrial agriculture nowadays, hydroponics is frequently used and offers a number of benefits over conventional soil-based farming. The ability of this approach to prevent or at least significantly lessen soil-related cultivation issues is one of its main benefits (*i.e.,* the insects, fungus, and bacteria that grow in soil). Insofar as weeding, tilling, kneeling, and dirt removal are not difficulties, the hydroponic approach is likewise reasonably low-maintenance.

Additionally, the hydroponic technique offers a less labour-intensive alternative to manage higher production areas [25]. To meet daily consumer demands for healthy, fresh products in and around densely populated areas, hydroponics can produce a higher yield than traditional farming by utilising both the horizontal surface area and the vertical space above it. This effectively increases the number of plants per unit area [26]. Additionally, hydroponics allows for the year-round harvesting of several crops while utilising less water and land than conventional open-field agriculture and without indiscriminate chemical or fertiliser discharges into the environment. In fact, hydroponics optimises the use of water and chemicals to reduce potentially dangerous waste and residuals by utilising smart greenhouses outfitted with a variety of technologies to regulate essential parameters for proper plant physiology [27]. Growers believe that only hydroponic systems allow for continuous production, meaning that plants may be grown everywhere, including in small places with a controlled atmosphere throughout the year and during a short growing season [28]. Many growers respond that hydroponics always enables them to produce more and with higher yields without being limited by climatic or environmental factors [29].

6.2 Different Hydroponic Systems and Their Operations

In hydroponic systems, nutrient solution and supporting medium can be recycled and reused, allowing for customization and change. The most popular systems include deep water culture, nutrient film technique, drip, ebb and flow method, and wick.

6.2.1 Deep water culture

The platform that supports the plants is made from Styrofoam. On top of the nutritional solution, it floats. In deep water culture, plant roots are suspended in nutrient-rich water, and an air stone {Fig. 1. (a)} delivers air directly to the roots. The typical example of this technology is the hydroponic bucket system. The roots of the plants are suspended in nutrient solution and placed in net pots, where they grow rapidly and in a mass. Algae and moulds can grow quickly in the reservoir; thus, it is essential to monitor the oxygen and nutrient concentrations, pH and salinity [30]. This method is good for larger fruit-producing plants, particularly cucumber and tomato, which thrive under it. For this system's growing medium, water and a Styrofoam platform ideal for leafy plants like lettuce are used.

6.2.2 Nutrient Film Technique (NFT)

The nutrients are injected into the growing tray using tubes or pipelines. Then they drain away after flowing over the plant roots {Fig. 1 (b)}. Dr. Alen Cooper developed this technique in the 1960s to address the issues with the ebb and flow system. This system uses a water pump without a timer to circulate water or a nutrient solution throughout the entire system and into the growing tray [30]. A system that is slightly slanted allows the nutrient solution to pass through the roots and then return to the reservoir. Plants grown hydroponically have roots that hang from a tube or channel. The roots are susceptible to fungal infection even when they are constantly submerged in water or nutrients. This technique may be used to successfully cultivate a variety of leafy greens, including lettuce, which is why the commercial lettuce sector uses it so frequently.

6.2.3 Ebb and flow (flood and drain culture)

These systems work by abruptly flooding the grow tray with nutrient solution, which is then drained back into the reservoir by a pump controlled by a timer {Fig. 1 (c)}. This is the first commercial hydroponic system that uses the flood and drain technique. A tray with plants in it receives regular fills of nutrient-rich water pumped up from a reservoir below. The water is recycled by the system by using gravity to restore it to the reservoir. In addition, it is feasible to grow many crops, however root rot, algae, and mould problems are frequent [31], thus a modified system with a filtering unit is needed**.** Rocks are used as growing media and gravel or granular rockwool are used for vine crops.

6.2.4 Drip systems

The type of eco-farming system most commonly used worldwide is probably the drip system. Each plant has a short drip line that is dripping nutrient solution onto the base of the plant {Fig. 1 (d)}. Both commercial and residential growers frequently employ the drip hydroponic technique. Each plant root receives the correct amount of water or fertilizer solution from the reservoir with the help of a pump [32]. In order to make the nutrient solution drip slowly, plants are typically placed in growth medium that is only moderately absorbent. With increased water conservation, wide range of crops can be cultivated. This technique uses drip line that is ideal for vine crops as the growing medium.

6.2.5 Wick system

It is entirely static. Fig. 1 (e) shows how nutrients are transferred into the growing media using a wick and a feed tank. The simplest hydroponic system available today does not require an electric pump or aerators [33]. The roots of the plants are connected to a reservoir of nutrient solution by a nylon wick, which is placed in an absorbent media such as coco coir, vermiculite, or perlite. Plants receive water or fertiliser solutions by capillary action. This approach is good for small plants, herbs, and spices but ineffective for plants that require a lot of water. Perlite, Vermiculite can be utilized as growing media for this system and Coconut Fiber suitable for vine crops.

6.3 Aeroponics

The practise of growing plants in the absence of soil or another aggregate medium in the presence of air or a fine mist is known as aeroponics. The fundamental idea behind aeroponic growing is to grow plants hung in a closed or semi-closed environment by spraying the plant's lower stem and dangling roots with an atomized or sprayed water solution that is rich in nutrients. Aeroponic gardening is best for growing tubers and roots. Aeroponic systems don't have a growing medium, whereas hydroponic systems do, and this is the main difference between the two. Aeroponics eliminates the need for water-holding trays or containers by using mist or nutrient solutions instead of water. It is a successful and efficient method of cultivating plants since it uses little water (95 per cent less water than conventional farming techniques) and little land [34].

The key benefit of this method is that it does not need an airing system because oxygen is carried in the fertiliser solution that is sprayed [26]. Plant boxes can be piled in practically any environment, including a warehouse or basement. Plants can easily grow upward and downward because the stacking arrangement of the plant boxes is designed to sustain the top and bottom of the plants in the air. A fine mist of a nutrient-rich, water-mix solution feeds the plants. The fertiliser mix is completely recycled because the system is enclosed, which results in significant water savings. Therefore, this technique is especially useful in areas with a water shortage. The aeroponic approach also has the benefit of not using pesticides or fertilisers. In a real aeroponic system, plants have complete access to CO_2 concentrations for photosynthesis that range from 450 ppm to 780 ppm. High crop growing rate and 70% less water use than hydroponics [9].

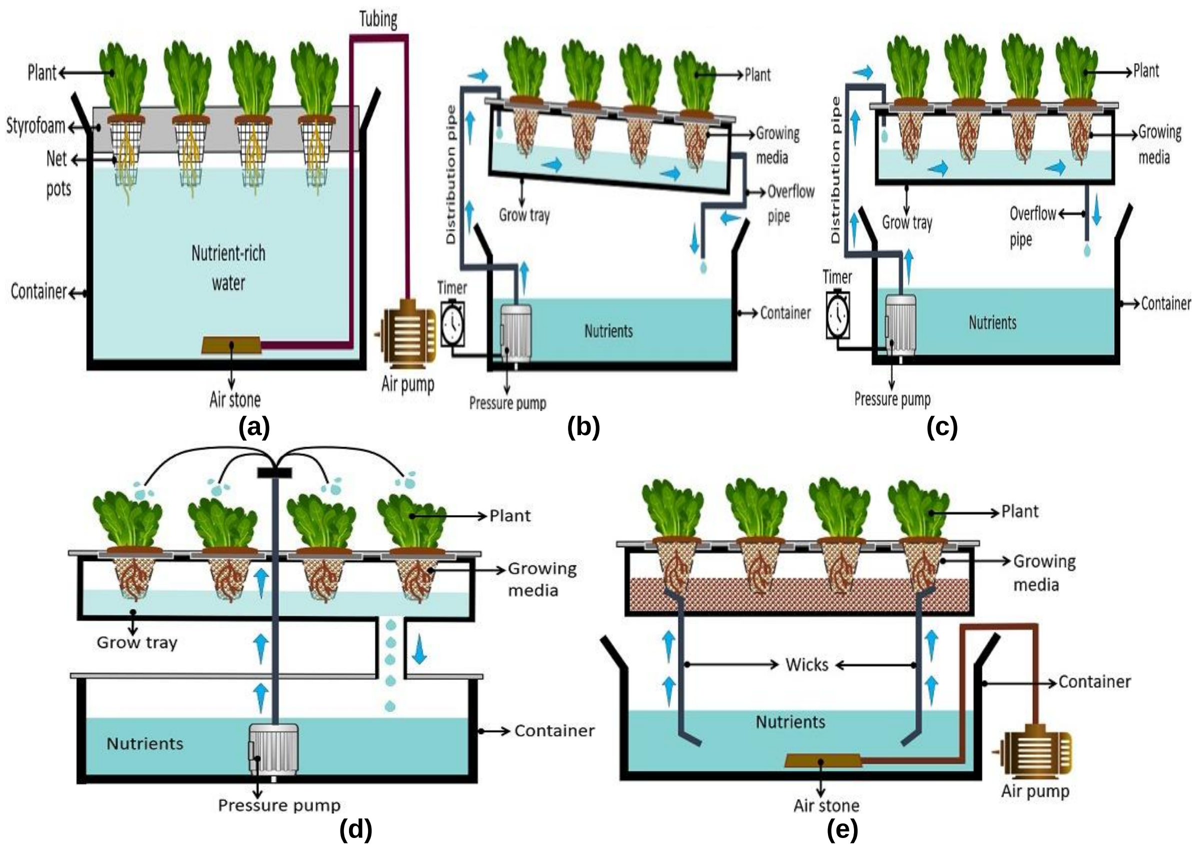

Fig.1. Various types of Hydroponics systems. (a) Deep water culture (b) Nutrient film technique (c) Ebb and flow (d) Drip system (e) Wick system
(Source: https://biologyreader.com/types-of-hydroponic-systems.html)

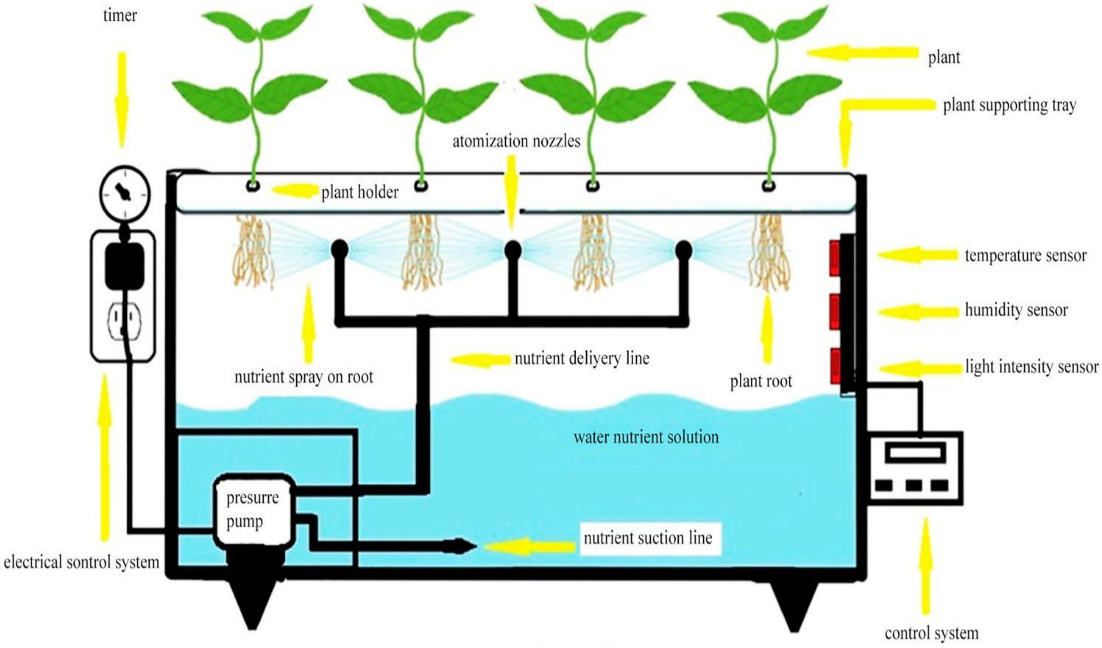

Fig. 2. Aeroponics system [35]

6.4 Aquaponics

Aquaponics is a closed-loop recirculating system that combines aquaculture (fish farming) and hydroponics (growing plants in water without soil). This method takes advantage of the symbiotic relationship between plants and animals to create a productive system where fish waste meets the nutritional needs of the plants. It accomplishes this synergy by "fertigating" hydroponic production beds with the nutrient-rich waste from fish tanks. In turn, the hydroponic beds serve as bio-filters that purge the water of gases, acids, and substances like ammonia, nitrates, and phosphates. The gravel beds also serve as habitat for nitrifying bacteria, which improve the nutrient cycle and filter water. As a result, the fish tanks can receive fresh, cleaned water through recirculation. These helpful bacteria collect in the gaps between the plant's roots and transform the sediments and fish excrement into nutrients that the plants may use to develop. The end effect is an excellent fusion of aquaculture and gardening.

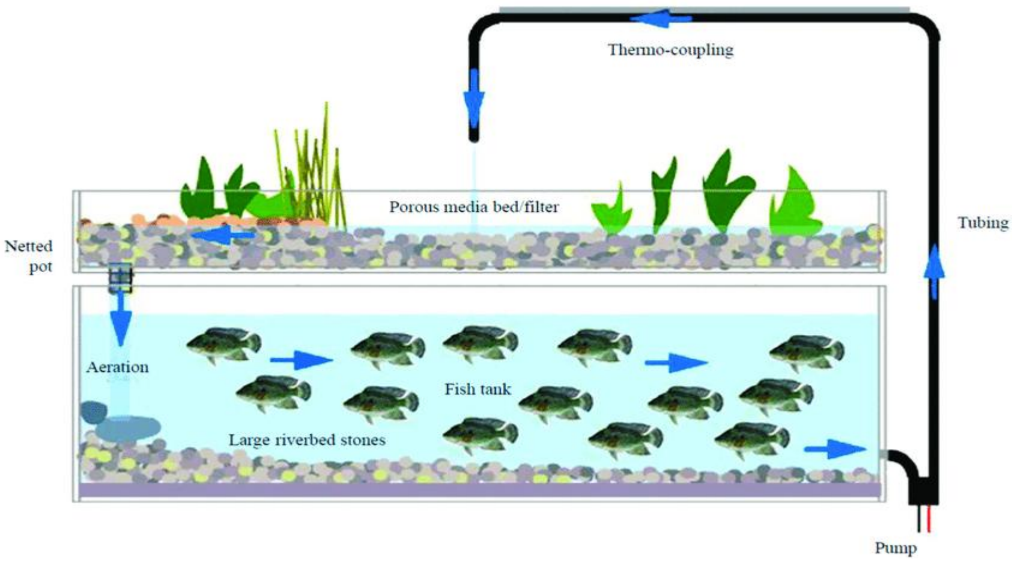

Fig. 3. Aquaponics system [36]

7. ADVANTAGES OF VERTICAL FARMING

7.1 Preparation for Future

Around 80% of the world's population is anticipated to reside in cities by 2050, and the rising population will result in rising food demand. To effectively prepare for such a scenario, vertical farming will play a significant role in enhancing food security.

7.2 Increased and Year-Round Crop Production

We can grow more crops on the same amount of land due to vertical farming. In practice, 1 acre of interior space can produce as much as 4-6 acres of outside space.

7.3 Less Use of Water in Cultivation

We can grow crops using 70 to 95 per cent less water than traditional farming methods due to vertical farming.

7.4 Economics

Operations in hydroponics are sometimes less complicated than those needed in conventional agriculture. In this regard, traditional methods require for labour-intensive preparations prior to planting, including the expense of large machinery and specialised equipment, which finally may be leased. Other parts of hydroponics could allow for additional effort, typically requiring a collection of sensors and tools for an accurate follow-up of the crop condition [37-39].

7.5 Not Affected by Unfavourable Weather Conditions

Natural disasters including cyclones, flooding, torrential rainfall, and severe droughts can harm crops in a field. Indoor vertical farms offer greater harvest yield reliability throughout the year since they are less likely to take the full brunt of unfavourable weather.

7.6 Sustainability

Water evaporation, seepage, and pollution are minimised and rinse water is not required because the produce is not in contact with the soil and the nourishing solution is recycled. Additionally, a controlled environment ensures the best conditions for growth and protections against pests and diseases that affect plants, alleviating the need for chemicals and pesticides and conserving essential natural resources like soil and water [40,41].

7.7 Increased Production of Organic Crops

Vertical farming enables us to cultivate pesticide-free and organic foods because they are produced in a well-regulated indoor environment without the use of chemical pesticides.

7.8 Human and Environment Friendly

The occupational risks connected to traditional farming can be greatly reduced by indoor vertical farming.

8. LIMITATIONS OF VERTICAL FARMING

8.1 No Established Economics

This novel agricultural technique's economic viability is still unknown. Building skyscrapers for farming can be more expensive than the benefits we can obtain from vertical farming when combined with additional factors like lighting, heating, and labour. Building a 60-hectare vertical farm might cost well over $100 million.

8.2 Difficulties with Pollination

Insects are not present since vertical farming takes place in a controlled atmosphere. As a result, human pollination is required, which will be time-consuming and expensive.

8.3 Labour Costs

Due to the necessity for highly skilled professionals, labour costs in vertical farming can be very high. Therefore, the cost of labour per hour may be considerably higher than for agriculture as a whole. Additionally, the training needed for vertical farming systems will increase labour expenses.

8.4 Fewer Jobs

There may be less need for workers as a result of automation in vertical farms. In vertical farms, manual pollination may end up being one of the labour-intensive tasks.

8.5 Lower Worker Efficiency

Reaching each layer may be difficult for the employees due to the layout of a vertical farm. Inefficient employee performance is caused by the time and effort required to ascent to higher layers.

8.6 High Initial Cost

Due to the price of the necessary equipment and raw materials for the operation, the initial investment in a hydroponic system is very high.

8.7 Too much Dependency on Technology

The use of various technology for lighting, regulating temperature, and keeping humidity is highly important to the overall vertical farming industry. A vertical farm may incur significant losses if its electricity is lost for one day

9. DESIGN OF VERTICAL FARM BUILDING

These plants have conveniently been tried with success in vertical farms. They are Lettuces, Kales, Chard & collard Greens, Chives and mint, Basil (sweet, lemon, cinnamon, *etc*.), Oregano, Parsley, Tomatoes, Strawberries, Thyme, Radish, Ice berg, Spinach. The following criteria must be taken into account while designing a new structure specifically for a self-sufficient vertical farm:

1) Multi-storey construction.
2) The building might have a narrow or rectangular shape.
3) Depending on how much sunshine will be coming in, windows can be big or small.
4) Ventilation should be controlled.
5) Floors must be water-proof, heat- and vibration-resistant, and non-slippery at all times.
6) High rise structure with a core.
7) effective layout for a warehouse and storage.
8) Shipping and receiving areas at a convenient location.
9) Electrical resources can be accommodated by wind turbines (EUROWIND wind turbine).
10) Photovoltaic solar cells for renewable energy.
11) Reflector and fibre optic cable network for lighting.

10. CONCLUSION

The utilization of vertical farms could significantly enhance food sustainability in urban areas. Vertical farming has many advantages over rural farming in terms of sustainability on the social, economic, and environmental aspects. Vertical farming, which enables crops such as short-lived vegetables and preferred fodder crops like maize, potatoes, to be grown year-round in incredibly small spaces with minimal labour, can be particularly beneficial for the poorest and landless places as well as those with limited access to land and water. The vertical farm sector in India is expected to grow significantly in the future. The development of low-cost hydroponics and other vertical farming technologies is necessary to improve commercial vertical farming and lower start-up and operating costs. In the future, we will be able to control this module remotely by integrating image processing with mobile applications.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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