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# Controlled Plant Growth in Vertical Farming Systems

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***Abstract*— The traditional methods of growing crops, such as in greenhouses and open fields, have lately been put to the test by a contemporary invention called vertical farming. According to the amount of the output, the crops are usually stacked shelves and stacked vertically using this method. In order for crops to develop well without any agronomic restrictions, vertical farming integrates a number of technologies, including big data analytics, robotics, the internet of things, artificial intelligence, etc. Structures for vertical farming depend on complete solutions to support the integration of various hardware, data collection, data analysis, and automatic control of the installed devices. Future vertical urban farms will not only boost crop yields or lower production costs, but also vastly enhance the quality of the agricultural goods offered to city inhabitants, minimizing the unfavourable effects of urbanization on the environment. Due to their independence from climatic factors and reduced water requirements, vertical farms can serve the same purposes wherever they are, and locals can gain comparable advantages. The paper presents vertical farm systems as a whole and also a minimum and ideal setting for a vertical farm as a means of increasing food availability and yields, all while ensuring sustainability and environmental protection.**

***Keywords—controlled environment, vertical farming, plant growing, sustainable agriculture***

## I. INTRODUCTION

The world's population is projected to grow to 9.8 billion persons by the year 2050. Nonetheless, the proportion of accessible land that is used for agriculture has been stable over the past 50 years (circling around 37%), and no significant changes in that percentage are expected in the near future. When viewed in this light, it is simple to understand why governments are beginning to give food security a top priority. A UN report from 2013 found that the world's food supply would need to rise by almost 70% merely to keep up with population growth by the time the population reached 9.6 billion [1,2].

Presently, 80% of the world's arable land is in use, while the other 20% is wasteland, whose potential for agriculture has all but vanished in recent decades due to subpar land management. Therefore, the necessity to apply new solutions in the fields of bio-architecture and agro-urban planning is brought on by intensive urbanization, population movement to cities, and a lack of fertile lands. In order to combat climate change, the human population must develop a new kind of space that will not only preserve but also enhance the quality of the environment [3].

In each of the climatic zones, there is a propensity to build vertical farms using different methods and scales. Due to their independence from climatic factors and reduced water requirements, vertical farms can serve the same purposes wherever they are, and locals can gain comparable advantages [5].

Crops can be shielded from hostile settings with fluctuating weather by being grown indoors in normal or vertical systems. In addition to providing shelter from the exterior elements, isolation keeps out pests like weeds and insects that harm crops [2]. The quality of crops is greatly influenced by the weather and fertile soils in conventional farming. As indoor farming is not reliant on soil, local weather, or sunlight, production might occur everywhere and all year round [3]. This method can be used to produce fresh veggies and herbs all year long in places like Sweden where the growing season is short. One advantage of vertical farming in urban areas is that there is no need for extensive transportation because production can take place close to where the products are consumed [6].

Vertical crops can be grown and harvested in clean environments, free of contact with external contaminants and without the need of plant protection chemicals, in extremely polluted parts of industrial and post-industrial towns. Notwithstanding the many advantages of urban vertical farming, there are some practical challenges with their implementation. For example, building restrictions, as installation and management costs should be considered when planning, designing, and constructing vertical farms in modern cities [7-9].

This article aims to present a series of equipment and methods for the growth of plants in controlled environment in the context of current needs to increase food production in a sustainable and safe manner.

## II. MATERIALS AND METHODS

Vegetables can be grown in a controlled environment anywhere in the globe, efficiently using minimal space, regardless of the outside temperature. This is done in part to alleviate traditional agriculture as well as to supply the rising demand for food. Also, long transit routes are removed, which results in lower $CO_2$ emissions, thanks to the circular economy. On the other side, there are also some who oppose the idea, viewing indoor or vertical farming as more unnatural agriculture. Particularly, artificial lighting and the corresponding energy needs are frequently criticized [10].

**Advantages**

- Shorter transport routes and smaller space required.
- Constant production regardless of climate.
- Relief of traditional agriculture land.
- The process can be automated and optimised.
- Low water consumption thanks to the closed water cycle.
- Low to zero use of chemicals and pesticides, making organic cultivation is therefore also possible [10-11].

**Disadvantages**

- Artificial lighting leads to higher energy requirements.
- Necessity to use microorganisms and nutrients.
- LED lamps are difficult to dispose of.
- High risk when there are power outages.
- In some cases, manual natural pollination is necessary and is time-consuming and expensive.

**Processes used in Vertical Farming**

The most common growing method utilized in vertical farms is **hydroponics** (Fig. 1). Plants are cultivated in nutrient solutions in this technique instead of in soil substrate. In order for the plant roots to grow, the nutrient solution in a grow tray must be deep enough for the roots to be submerged. A reservoir beneath the grow tray, a water pump, and a timer are used to fill the grow tray with a nutrient solution a few times each day. The timer is set based on various factors, including the size of the plants, their water and food needs, their development cycles, and the ambient temperature [13,14].

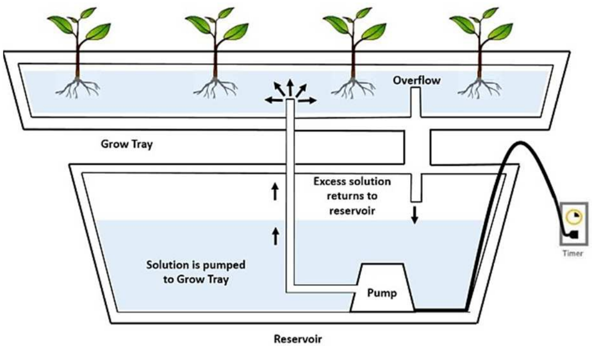


Fig.1. Schematic diagram of a hydroponic system [1]

**Aeroponics** - In an aeroponic system (Fig. 2), an environment lacking soil and abundant in air with very little water or mist are used to grow plants.

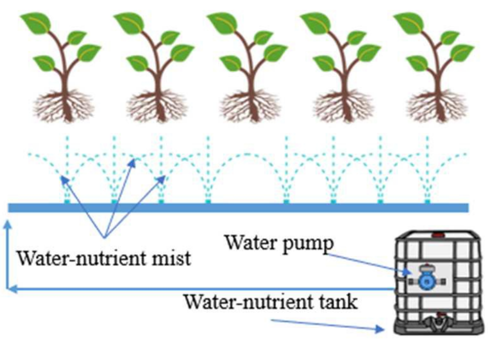


Fig.2. Schematic diagram of an aeroponic system

The roots of the plants are suspended in the air in this system. Therefore, to ensure that the roots of plants grown receive enough nutrients, the root zones are continuously misted with a nutritious solution using a small sprayer [13-16].

**Aquaponics** (Fig. 3) combines hydroponics and aquaculture in a single habitat. Fish raised in aquariums produce waste that is rich in nutrients that can be used as a fertilizer supplement to help plants develop in grow trays. On the other side, the plants act as a natural filter for the water that the fish habit. The grow tray receives circulation of the ammonia-rich water from the fish tank. Ammonia is first transformed to nitrites, then to nitrates, and lastly to vermicompost, which the plants can utilize as bio fertilizer, by nitrifying bacteria that thrive in the growth bed where the plants are growing [17-20].

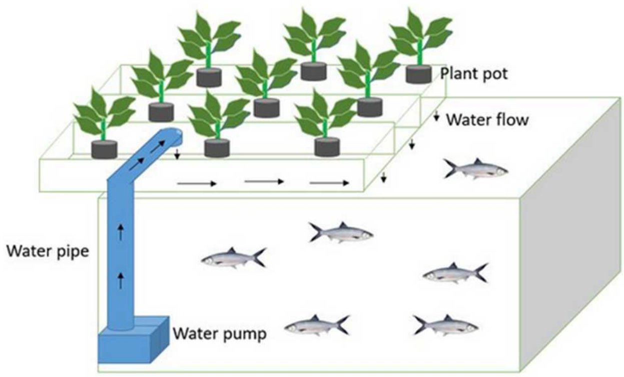


Fig.3. Schematic diagram of an aquaponic system [12]

## III. Results

Depending on the particular crops being grown, the vertical farm's scale, the tools and technologies being employed, and other factors in the workflow for a vertical farm can change. A general description of the process for a typical vertical farm is presented as follows:

1. *Planning and Design*: Creating a plan and design for the farm's layout is the first stage in establishing a vertical farm. This entails deciding which plants will be grown, developing the growth systems (such as hydroponic or aeroponic systems), and figuring out the ideal lighting, temperature, and humidity levels for each plant.
2. *Installation and setup*: After the planning and design stage is over, the farm's equipment and technologies must be installed and set up. Installing the growing systems, lighting, irrigation, and sensors to track the growing conditions are part of this stage.
3. *Seeding and germination:* Seeds must be sown and germinated before crops may be grown in the vertical farm. In order to encourage healthy seedling growth, this might be done in a separate seeding and germination room or part of the farm with specialized lighting and growing conditions.
4. *Planting*: Once the seedlings are ready, they are transplanted into the growing systems in the vertical farm. This may be done manually or using automated planting equipment.

5. *Crop maintenance*: after the plants are introduced in the system, crop maintenance actions need to be taken. Irrigation, fertilization, ventilation, pest control activities are part of this stage. Crops are constantly monitored in order to ensure that there are no problems in the system and the plants are growing in a healthy manner.
6. *Harvesting*: When a crop is mature, it is harvested using specialized instruments like mechanized harvesting machines or hand-held harvesting implements.
7. *Packaging and distribution*: After the crops are harvested, they are supplied to the public in a variety of packages. The vertical farm may occasionally sell directly to customers or eateries, while other times it may sell the products to wholesalers for further distribution.

For starting a vertical farm, a minimal design (Fig. 4) can be employed, setting the farm in a standard container (L 12 m x W 3 m). To be noted that in this case, seeding and germination are not included in the design. The seeding and germination phase can take place in shed or even a covered open space ensuring that no pests can reach the pots / raw materials.

The container for plant growing / storing / packaging can be divided into the following separate rooms:

• Entry buffer with insect trap for personnel decontamination;

• Vertical Farming room where the plants are grown, fitted with AC for ensuring the required temperature and ventilation;

• Packing room;

• Cold room provided with a compressor for ensuring 4-6 ºC;

• Delivery room with insect trap that also functions as a delivery SAS.

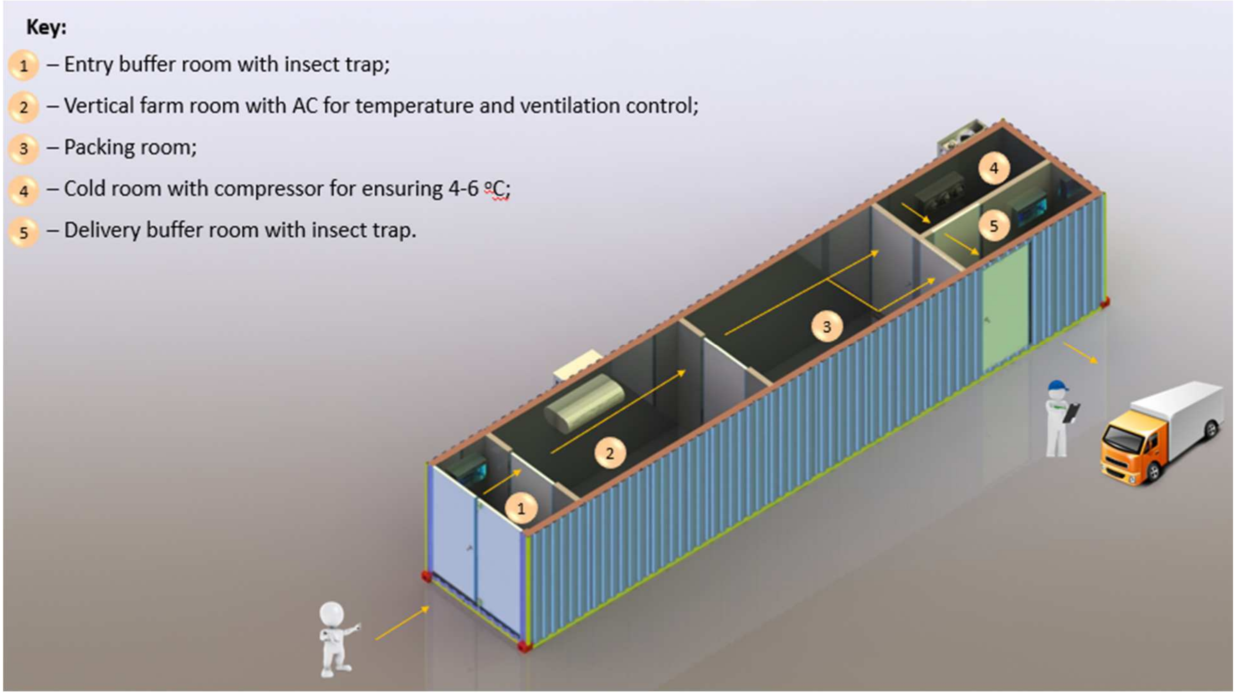


Fig.4. Minimal design for a vertical farm

The arrows in Figure 4 represent the directions of movement in the container, thus having a closed and monitored system that ensures that plants are not contaminated by viruses, bacteria, fungi and pests. From the packing room, the plants can be either stored in the cold room, or can be directly taken out through the delivery room to the delivery truck, depending on the situation.

In order to have an ideal setting for a vertical farm (Figure 5), the following should be ensured:

-A **facility for plant germination and products reception** from suppliers equipped with:

•Deposit room for substrates (soil, pearl stone), fertilizers, seeds, pots, consumables in general;
•Locker rooms for personnel;
•Toilets for personnel;
•Room for seeding and watering pots;
•Germination room where plants are watered and monitored until germination – ensuring certain temperatures and ventilation;
•Buffer rooms for personnel decontamination before entering the process and when taking the germinated pots out towards plant growing.

-A **facility plant growing and packaging**, equipped with:

•Room for the reception of raw material (germinated pots);
•SAS rooms for personnel decontamination before entering the process;
•Locker rooms for personnel;

•Toilets for personnel;

•Room for depositing fertilizers and spare parts necessary in the growing process;

•CLEAN ROOM – where the vertical module / modules are installed and operated and plants grow until harvesting / shipping, ensuring the right temperature, air humidity and ventilation;

•Refrigeration room – between 4-6 ºC where plants are stored before packaging;

•Packing room – where plants are packed and prepared for shipping;

•Delivery buffer room – ensuring a final decontamination before shipping.

The ideal setting of a Vertical Farm is presented in Figure 5.

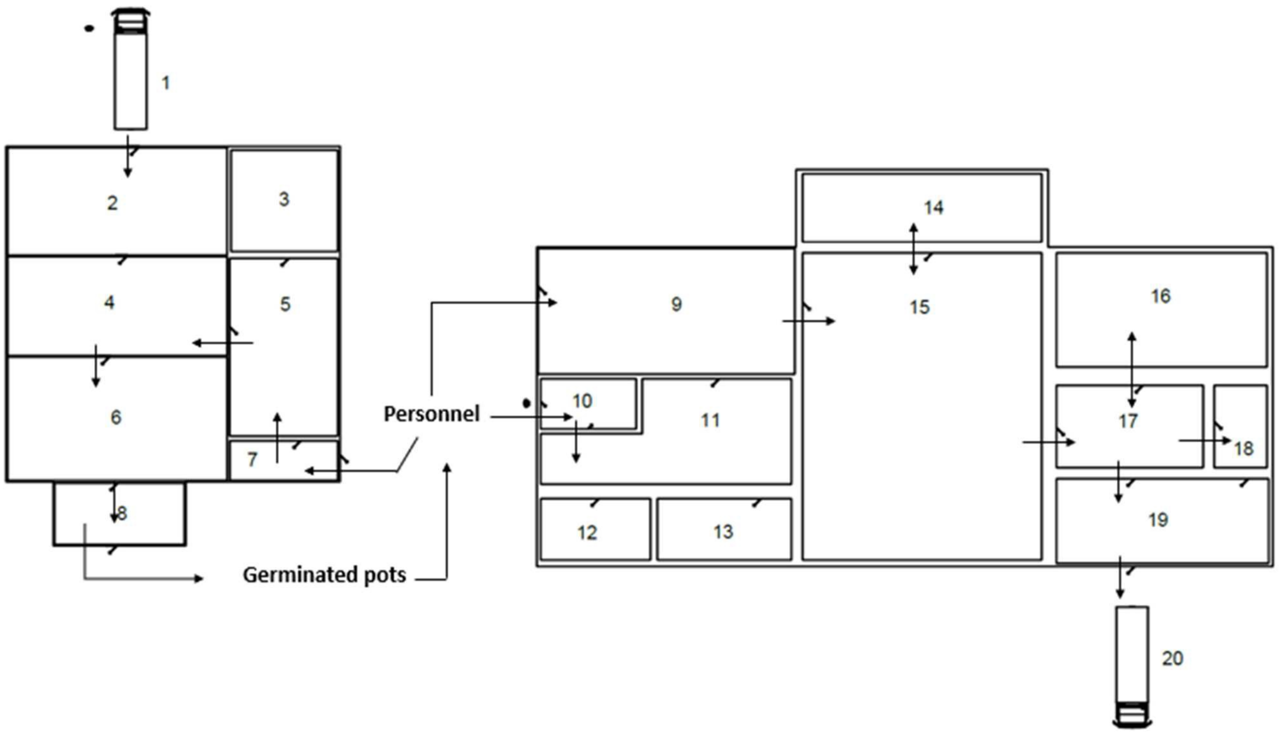


Fig.5. Ideal setting for a vertical farm *(1 - Suppliers; 2 - Deposit substrates fertilizers, seeds, pots, etc.; 3 - Toilets; 4 - Seeding & watering; 5 - Locker room; 6 – Germination room; 7,8,10 - Buffer; 9 - Raw materials reception buffer room; 11 - Locker rooms; 12,13 - Toilets; 14 - Deposit fertilizers & spare parts; 15 - CLEAN ROOM (plant growing room); 16 - Refrigeration deposit; 17 - Packing; 18 - Deposit Packed materials; 19 - Delivery buffer room; 20 - Finished products transport).*

The arrows in the figure represent the directions of movement in the facility, thus having a closed and monitored system that ensures that plants are not contaminated by viruses, bacteria, fungi and pests.

For the actual growing of plant, various options can be employed:

- **Fully automated individual modules** can perform particular tasks in a farm or greenhouse without the need for human intervention. These modules frequently have sensors, cameras, and other technologies built in so they can monitor their surroundings, evaluate data, and take action based on what they detect.
- **Stacked vertical shelves** can boost farm output due to their effective use of space and are a common component of vertical farming systems. Typically, these shelves are organized in a vertical column with several plant layers stacked on top of one another.
- **Cylindrical columns** involve growing crops in a series cylindrical containers or columns. Each container or column typically contains multiple levels of plants, with the irrigation coming from the top and the excess water draining into the next levels. This allows for efficient use of water and nutrients, as well as maximizing the use of space in a vertical farming environment.
- **A-frame system** is a type of vertical farming system that involves growing crops in A-shaped structures. These structures are typically made of lightweight materials like aluminium or PVC and are designed to hold multiple levels of plants. The A-Frame design allows for maximum exposure to natural light while minimizing the amount of shading caused by the structure itself.

Vertical farming allows for a wide range of plant growing options, including:

-*Leafy greens* - the most popular crops produced in vertical farms because of their high yield and quick rate of growth. Lettuce, kale, spinach, and greens are a few examples.

-*Aromatic herbs* - A range of herbs, including basil, parsley, thyme, and cilantro, can be grown in vertical farms. These are excellent choices for use in cooking and are in high demand.

- *Strawberries* - are a good choice for vertical gardening because they are compact and thrive in soilless conditions. When grown in controlled environments, they can also yield fruit all year long.
- *Tomatoes* - trellises or other support structures can be used to produce tomatoes vertically. Increased yields can be achieved and room can be saved using this technique.
- *Microgreens* - are young herb or vegetable plants that are only a few inches long when they are harvested (before the true leaves appear). Microgreens are frequently used in salads or as a garnish because of their high nutrient richness. Microgreen examples are: broccoli, radish, peas, sunflower, basil, cress, lupine, etc.
- *Mushrooms* - shiitake and oyster mushrooms, among others, can be grown in vertical farms. These can be cultivated in trays or bags and require a dim, moist atmosphere.
- *Root vegetables* - like carrots, beets, and radishes can also be produced in vertical farms, despite being more difficult to grow in a vertical system than other vegetables. They need deeper growth spaces, as well as specific watering considerations.

## IV. Conclusions

The practice of vertical gardening is still developing. It is still working toward achieving its goal of bringing locally grown food to all people and towns by producing the freshest, best-tasting crops while using only a small percentage of the water used by a conventional farm. In addition, vertical farms use a fraction of the land that traditional farms do and none of the pesticides, synthetic fertilizers, or genetically modified organisms.

Urban vertical farms are a comparatively new idea, but as interest in this growing farming technique grows, so does the global number of vertical farms. Many different types of vertical farms are being researched globally, and new innovations and technologies are predicted to increase the energy economy and profit margins of these farms in the future. In the near future, most vertical farms will focus on high-return and short-rotation crops like salad greens, with neighbouring restaurants occasionally buying the entire harvest. Urban planners and the sustainable farming community are closely observing the ground-breaking vertical farms presently under construction or already in use, though it is unclear if vertical farms can become more prevalent in the world.

When establishing a vertical farm, it should be considered that its success depends on a variety of factors, including the availability and quantity of food, the size of the community where is set, technological development, cultural and dietary preferences, and the availability of energy and water.

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