**Vertical Farming for Future Food Requirement – Problems and Prospects**

\*Vidya, V. S.1, Sushma, N.2, Tilak, K.3, Manasa, S. R.4, Jeevan, H. R.5 and Sathwik, M. N. Raj6

1. Ph. D. scholar, Department of Agronomy, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India
2. Department of Soil science, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India
3. Ph. D. scholar, Department of Agronomy, University of Agricultural Sciences, Bengaluru, Karnataka, India
4. Ph. D. scholar, Department of Agronomy, University of Agricultural Sciences, Dharwad, Karnataka, India
5. *M. Sc.(Agri)* scholar, Department of Agronomy, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India
6. Ph. D. scholar, Dept of Agricultural microbiology, University of Agricultural Sciences, Bengaluru, Karnataka, India

\*corresponding author Email ID: vidyavs1611@gmail.com

**Abstract**

Vertical farming can feed the ever growing population under limited resource condition mainly the urban population. The concept foresees the cultivation of fruits, vegetables, medicinal, fuel producing plants and other plant products in the cities and their sales directly within the cities, thereby reducing the transportation costs and efficient utilization of land and water resources. Though the vertical farming involves huge amount of establishment and maintenance costs, it can be a boon for effective recycling of city waste and water effluent. It can provide nutritious and chemical free food.

**Keywords:** Vertical farming, Hydroponics, Aeroponics, Aquaponics, Skyscrapers

**Introduction**

 Most challenging task for agricultural scientists today is to ensure continuous and enough supply of food to growing human civilization. Urban centres throughout the world have experienced substantial increase in population; this growth is accompanied with change in food habits and rising concerns for food quality. Here, food quality refers to the optimum levels of the nutrition in the food along with the minimized amount of the chemical (pesticides/fertilizers) residues used in the production of the crop. The logic of vertical farming is to reduce the overall amount of resources (Despommier, 2010).

 According to the estimates of UN population projection, world population could reach 9.15 billion by 2050, thus the expected rate of increase in the world population will be 2.25 percent over next forty years and thus provides for a potentially huge market for food grains and food production needs to be doubled to meet this demand (USDA, 2017). It is projected that to feed the global population by 2050 require 70 per cent increase in global food production with food production from developing countries need to be doubled. Environmental stress (climate change) and shortage of water and land resources are major constraints haunting this task. Thus, recent trend in agriculture has seen rise in organic agriculture, vertical farming and intensive agriculture to accommodate the demands of increasing world population and address the rising concern for environmental issues.

 **Vertical farming**

Vertical farming can be generally defined as a system of commercial farming where by plants, animals, fungi and other life forms are cultivated for food, fuel, fiber or other products by artificially stacking them vertically above each other. Vertical farming is a step ahead technology from green houses as it involves harnessing of resources in vertical arrays and can feed the demands of food supply with the resources of mega cities. In the second category, vertical farming is done in open air or in mixed use sky scrapers. This is sustainable type of farming for personal or community use and it may not be for commercial purposes. A modified form of this concept involves cultivation of crops in the periphery of sky scrapers to provide them ambient amount of light. Third category involves cultivation of plant and animals in the sky scrapers in closed system for large scale cultivation. These systems under trails at various location (Singapore, Canada, London).

**History of vertical farming**

In 1915, Gilbert Ellis Bailey coined the term “vertical farming” and wrote a book titled “Vertical Farming”. He introduced the concept of underground vertical farming, presently followed in Netherlands. In the early 1930s, William Frederick Gerick pioneered hydroponics at the University of California at Berkley. “Tower Hydroponicums” experiments were done in Armenia prior to 1951. In 1964, the Vienna international horticulture exhibition had exhibited vertical farm concept. The modern concept of vertical farming was proposed in 1999 by Dickson Despommier at Columbia University.

**Need for vertical farming**

* To feed the ever growing population
* Reduction in area of cultivable land
* Climate change and it’s bad effect on agriculture
* Problem of migration to cities
* Irregularity in monsoon rainfall
* Drastic reduction in natural resources
* Agriculture labours problem
* Disasters like floods, cyclones, droughts *etc.,*
* Need for supply of sufficient and nutritional rich food

**Systems of vertical farming**

It includes majorly

1. **Hydroponics**

The cultivation of plants in nutrient–enriched water, with or without the mechanical support of an inert medium such as sand or gravel (Harris, 1992). The word “hydroponics” was derived Greek word *hydro* means water and *ponos* means labour i.e., working with water.Terrestrial plants may be grown with their roots in the mineral nutrient solution only or in inert medium, such as perlite, gravel or mineral wool. This system helps to face the challenges of climate change and also helps in production system management for efficient utilization of natural resources and mitigating malnutrition.

Hydroponics was practiced many centuries ago in Babylon, Egypt and China**.** Later, when plant physiologists started to grow plants with specific nutrients, they gave the name “nutri-culture”.In 1929, Dr. William F. Gericke of the university of California grown tomato vines of 7.5 m height in nutrient solution. In India, hydroponics was introduced in the year 1946 by an English scientist, W. J. Shalto Duglas and he established a laboratory in Kalimpong area, West Bengal. During 1980s, many automated and computerized hydroponics farms were established around the world. Home hydroponics kits became popular during 1990s.

1. **Aeroponics**

Aeroponics is the process of growing plants in air or mist environment, without soil and very little amount of water (Cooper, 2013). The word “aeroponics” is derived from Greek word *aero* meansair and *ponos* means labour. Aeroponic culture differs from conventional hydroponics, aquaponics and *in-vitro* (plant tissue culture) growing; aeroponics is conducted without a growing medium. F. W. Went in 1957 who first coined the term “Aeroponics”, for growing coffee plants and tomatoes. Stoner is considered as the father of commercial aeroponics.

Aeroponics uses the application of nutrient dissolved mist over exposed plant roots which enable growth without soil. The suspended plant roots are enclosed in sealed chamber and the plant canopy is exposed to outside. The plant grows vigorously in an aeroponic system due to the sterile environment and abundant oxygen present in the chamber. Aeroponic systems are more water resource efficient than hydroponic system. Growing in soil is no longer a sustainable way to grow food for the 7 billion people on the earth. Aeroponics reduces water usage by 95%, fertilizers 60% and increases the crop yields by 45 to 75% (Agrihouse, 2011). The aeroponics system is widely used for NASA space research programmes.

1. **Aquaponics**

Aquaponics is the union of hydroponics (growing plants without soil) and aquaculture (farming fish or other aquatic organisms) for a fast, efficient method of producing both plant and fish crops, thus provides dual income. Fish waste from aquaculture portion of the system, is broken down by bacteria into dissolved nutrients (e.g. nitrogen and phosphorus compounds) that plants utilize.

 The remainder of the waste is excreted as fecal matter, undergoes mineralization which occurs when heterotrophic bacteria consumes fish waste, decaying plant matter and uneaten food, converting to ammonia and other compounds. The plants readily take up the nitrites and nitrates in the water and in consuming it, help to keep the water clean and safe for the fish.

**Components of vertical farming**

1. **Green house**

 A greenhouse is a structure with walls and roof made chiefly of transparent material, such as glass, in which plants requiring regulated climatic conditions are grown. These structures range in size from small sheds to industrial-sized buildings. The interior of a greenhouse exposed to sunlight becomes significantly warmer than the external ambient temperature, protecting its contents in cold weather. Many commercial greenhouses have high-tech production facilities for growing vegetables or flowers. The greenhouses are filled with equipment including screening installations, heating, cooling and lighting.

1. **Folk wall**

 The folk wall is a construction with the dual functions of growing plants and purifying waste water. It was designed by Folke Gunther in Sweden. The basic design is a wall of hollow concrete slabs, with compartments opening on one or both sides of the wall. The hallows are filled with inert material like gravel, expanded clay aggregate, perlite or vermiculite.

1. **Grow light**

 A grow light is an artificial light source, generally an [electric light](https://en.wikipedia.org/wiki/Electric_light), designed to stimulate plant growth by emitting an electromagnetic spectrum similar to that of the sun, or to provide spectrum that is more tailored to the needs of the plant being cultivated. Grow lights are used where there is either no naturally occurring light or where the available hours of daylight may be insufficient for the desired plant growth, lights are used to extend the time the plants receive light.Depending on the type of plant being cultivated, stage of crop (e.g. germination/vegetative phase or flowering/fruiting phase) and the photoperiodic requirements of the plant, specific range of spectrum, luminous efficacy, color and temperature desirable for use with specific plants and time periods. The normal range of light intensity utilized in closed growing system is 50-200 mol m-2 s-1 (Kalantari *et al*., 2017).

1. **Sky scrapper**

 A skyscraper is a tall, continuous building having multiple [floors](https://en.wikipedia.org/wiki/Storey). These are used as basic structural component of commercial vertical farming under controlled conditions. These are mainly situated in the city to avoid transportation cost. Construction require huge investment and technical knowledge for smooth and easy management of farm

1. **Controlled-Environment Agriculture (CEA)**

 CEA systems are typically hosted in enclosed structures such as greenhouses or buildings, where control can be imposed on environmental factors including air, temperature, light, water, humidity, carbon dioxide, nutrient concentration and pH. The aim of CEA is to provide protection and maintain optimal growing conditions throughout the development of the crop. CEA optimizes the use of resources such as water, energy, space, capital and labour.

1. **Precision agriculture (PA)**

 Precision agriculture (PA) is a farming management concept based on observing, measuring and responding to inter and intra layers variability in crops. The goal of precision agriculture is to define a [decision support system](https://en.wikipedia.org/wiki/Decision_support_system) (DSS) for whole farm management with the goal of optimizing returns on inputs while preserving resources.

1. **Agricultural robot**

 Agricultural robot is a programmed machine deployed to carry out specific [agricultural](https://en.wikipedia.org/wiki/Agriculture) operation. It reduces the problem of labour. The main area of application of robots in agriculture today is at the harvesting stage. A possible emerging application of robots or drones is for weed control.

**Model vertical farm**

In order to support to support 15,000 people with enough food the tower is planned by Bemen in Berlin which have following configuration: A vertical farm of 0.93 ha footprint area with 37 floors, 25 of them solely for the purpose of crop production and 3 for aquaculture. Further, 3 uniformly distributed floors for environmental regulation and 2 in the basement for waste management. In addition there is one floor for cleaning of the trays, sowing and germination, one for packing and processing of plants and fish, and one for sales and delivery at the basement. This configuration results to a total building height of 167.5 meters, with a length of 44 meters. A freight elevator big enough to allow a forklift truck was planned in the centre of the building, allowing for harvest and waste to be transported down to the respective floors.



**General building plan**

**Type of crops grown in vertical farming**

|  |  |
| --- | --- |
| Type of crops | **Name of the crops** |
| Cereals | *Oryza sativa* (rice), Zea mays (maize) |
| Fruits | *Fragaria ananassa* (strawberry) |
| Vegetables | *Lycopersicon esculentum* (Tomato), *Capsicum frutescens* (Chilli), *Solanum melongena* (Brinjal), *Phaseolus vulgaris* (), *beta vulgaris* (beet), *Psophocarpus tetragonolobus* (Winged bean), *Capsicum annum* (Bell pepper), *Brassica oleracea var. capitata* (Cabbage), *Brassica oleracea var. botrytis* (Cauliflower), *Cucumis sativus* (Cucumber), *Cucumis melo* (Melons), *Raphamus sativas* (Radish), *Allium cepa* (Onion) |
| Leafy vegetables | *Lactuca sativa* (Lettuce), *Ipomoea aquatic* (Kang kong) |
| Condiments | *Petroselinum crispum* (Parsley), *Mentha spicata* (Mint*), Ocimum caryophyllus* (Sweet basil), *Origanum vulgare* (Oregano) |
| Flower/ornamental crops | *Tagetes patula* (Marigold), *Rosa berberifolia* (Rose), *Dianthus caryophyllus* (Carnations), *Chrysanthemum indicum* (Chrysanthemum) |
| Medicinal plants | *Aloe vera* (Indian Aloe), *Solenostemon scutellarioides* (Coleus) |
| Fodder crops | *Sorghum bicolor* (Sorghum), *Medicago sativa* (Alfa alfa), *Hordeum vulgare* (Barley), *Axonoponus compressus* (Carpet grass) |

**SWOT analysis of a vertical farm**

The vertical farming industry remained resilient during recession, due to consistently high demand for healthy and organic produce. It does not require pesticides; requires less water and space than traditional agricultural systems. The largest reason to be unenthusiastic is the energy requirement to power the supplemental lighting and operating the environmental controls. There are many controversies in the literature regarding efficient design for optimal plant growth. Scientists are still unsure regarding the best design for a vertical farm. The strength, weakness, opportunities and threats (SWOT) analysis are summarized below:

|  |  |
| --- | --- |
| **Strength**1. Faster and high yields
2. Grows healthier crops
3. No pesticides needed
4. Saves water
5. Reuse of nutrient solution
6. Can grow round the year
7. Requires less land surface
 | **Weakness**1. High initial costs
2. Requires precision monitoring
3. Limited to low profile crop
4. Requires higher energy
 |
| **Opportunities** 1. Highly controlled environment
2. Artificial lights may be used
3. No seasonal restrictions
4. Crop need based nutrient supply
 | **Threats** 1. Failure to any system components of the vertical irrigation system may leads to rapid plant death
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**Advantages of vertical farming**

|  |  |
| --- | --- |
| Features | Descriptions |
| Year round crop production | Year-round crop production of wide range of vine crops in any regions |
| Protection from extreme weather | Crops are grown under controlled environment; therefore, crops are protected from extreme weather occurrences such as drought and floods |
| Organic crops production | The controlled growing conditions allow a reduction or total abandonment of the use of chemical pesticides |
| Water conservation and recycling | Around 70% lesser water use in comparison to open field. Urban waste water may be recycled and sewage sludge may be converted to topsoil and processed for agricultural use. |
| Environment friendly | Eliminates the use of mechanical ploughs and other equipments and reduces the burning of fossil fuel. As a result, a significant reduction in air pollution and CO2 emission, which in turn reduces the climate change and ultimately favours biodiversity |
| Human health friendly | Reduces the occupational hazards associated with traditional horizontal farming |
| Solar and wind energy conservation | Installation of solar panel and wind mills on the roof top of the vertical farm may generate electrical power to contribute in its own environmental controlling system |
| Sustainable urban growth | The technology could upgrade employment and income generating opportunities for the urban poor |
| Reliable harvests | Vertical farm systems, growing cycles are consistent and reliable, allowing commercial growers to confidently commit to delivery schedules and supply contracts |
| Minimum production overheads | Minimum overheads and grow costs are maintained through low labour costs, low water usage, reduced cost of crop washing and processing and reduced transport costs |
| Increased growing area | For the same floor area, vertical farm systems with multi-level design provides nearly 8 times more growing area than single level hydroponic or green house system or open field system |
| Maximize crop yield | The land productivity of vertical farming is more than twice as high and faster as traditional agriculture |

**Problems of vertical farming**

* Economic problems
* Energy problems
* Pollution problems
* Lack of crop varieties suitable for vertical farming
* Lack of knowledge and skills required for managing vertical farms

**Economic problems:**

 Vertical farms must overcome the financial challenge of large startup costs. In order to vertical farms to be successful financially, high value crops must be grown and costs of operating these farms must decrease. Current methods require enormous energy consumption for lighting, temperature, humidity control, carbon dioxide input and fertilizer

**Energy problems:**

 The power demands of vertical farming would be uncompetitive with traditional farms using only natural light. A hydroponic farm growing lettuce would require 15,000 kJ of energy per kilogram of lettuce produced. To put this amount of energy into perspective, a traditional outdoor lettuce farm requires only 1100 kJ of energy per kilogram of lettuce grown. Plumbing and elevator systems are necessary to distribute nutrients and water

**Pollution problems:**

 With vertical farms requiring much greater energy per kilogram of produce, mainly through increased lighting, than regular greenhouses, the amount of pollution created will be much higher than that from filed produce. Hydroponics regularly changes the water; means there is a large quantity of water containing fertilizers and pesticides that must be disposed of.

**Challenges in sustainability of vertical farms**

* Land and building cost (Fletcher, 2012)
* High operation cost due to use of energy
* Social resistance since the masses of people do not accept the alteration of traditional farming (Abel, 2010)
* Limited number of crop species

**Conclusion**

* Vertical farming can partially feed the ever growing population of urban areas
* Vertical farming provides an opportunity for effective recycling of city waste and water effluent
* Platform for production of nutritious, chemical free food in limited space

 Thus, changing demographic trends and technological advancements are delivering new innovations in the field of agriculture. These emerging technologies are required to be used judiciously to meet the growing demands from modern agriculture. Vertical farming can be adopted as the viable alternatives for the conventional agriculture to meet the changing demands of and needs of mankind.

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