POLICY PAPER 89

# Vertical Farming

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI
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# Preface

Due to limited access to land for farming, there is a need to explore potential alternatives to pave the way for adding to food requirements especially for the continuously expanding urban population. Recently, the application of Vertical Farming into cities has emerged as an option to land based farming for cultivation of vegetables and ornamental plants in high rise buildings the world over. It appears that the concept of the vertical farm in the urban areas could solve a lot of issues related to safe and nutritious food production and environmental degradation. Vertical gardens are being taken up enthusiastically in Indian metros too by growing plants in various soilless medium. Optimally, vertical farming is required to be a cost effective, sustainable and efficient system to be adopted on a large scale in peri-urban areas.

In order to critically examine the potential of vertical farming in Indian agriculture with prevailing technologies, the National Academy of Agricultural Sciences (NAAS), New Delhi organized a Brainstorming Session on Vertical Farming on April 11, 2019 under the Convenership of Dr Brahma Singh. The main stakeholders, experienced scientists and representative of public and private sectors, research and development planners and NGOs participated in the deliberations. Issues related to availability of fresh food in bulging urban areas, possibility of indoor production of food and associated crops, and limitations of long distance transportations of perishable items were discussed and debated in this Session. The policy paper on Vertical Farming gives an overview of current status of vertical farming in the country and future course of action to popularise it in the wake of continuous decline in land and water resources coupled with growing demand for quality food items.

On behalf of the Academy, I express my gratitude and sincere thanks to the Convener, Prof Brahma Singh, Dr T. Janakiram, ADG (Hort.) & Co–Convener, Dr Gyan Prakash Mishra, Associate, NAAS, Reviewers, Dr S.K. Pandey and Dr Bijendra Singh, all the other experts, stakeholders present both from public and private institutions for their valuable inputs, besides Dr V.K. Bhatia and Dr Kusumakar Sharma for their editorial support.

**(Panjab Singh)**
President, NAAS

# Vertical Farming

## 1. INTRODUCTION

Only one fourth (nearly 27%) is the total land mass on the planet earth rest being water (nearly 73%). Out of this land mass, only three fourth is productive rest being high mountains, cold and hot deserts, etc. Over the years mankind has been able to convert nearly 57% of productive land for cultivation of various crops for food, often on expense of forest and grasslands (43%). With rising urbanization a worldwide phenomena, it has been estimated that most of the world's population (>60%) by 2030 will shift to cities for urban dwelling. Interestingly in the same period (by 2030), the human population is expected to reach 8.6 billion from the current 7.6 billion, and expected to rise further exponentially to 9.8 billion by 2050 and explode to 11.2 billion by 2100. The rapid urbanization on the other hand is putting pressure on the meagre available land resources that is witnessing gradual but continuous decline in the cultivated land worldwide (Ali and Srivastava, 2017). Urbanization has resulted in innumerable small and large concrete structures mostly to accommodate the ever rising population at the expense of farm land. The sky-line in major metros is now dotted with high rise structures but one hardly sees the peri-urban agriculture growing vegetables and other food. The population of cities would obviously keep on multiplying and put pressure on food production where in several crops it has already plateaued. In many regions, the cultivable land has almost exhausted and there is hardly any scope for further adding the area to the crop cultivation. In India too, the cultivable area is almost constant for last several years. Whatever land area is reclaimed, almost same productive area goes to construction and other infrastructure development. Cultivable land has become a limiting factor and land prices are skyrocketing in recent years. The transportation of food to cities from rural production sites will add to the problem, compounded further in perishable and semi-perishable food especially from horticultural crops having shorter shelf life. One innovation that has potential to partly manage the above problem is by production of food items in cities itself in residential buildings, roof tops, public spaces, etc. Whereas the present improved agriculture practices put immense pressure on finite resources with diminishing returns on land, water, energy, etc., the innovative technology of vertical farming is expected to relieve this pressure to a large extent.

Considering the above, year round production of large quantities of nutritious food from vertical farming within a limited space/area appears to be a revolutionary approach. Vertical farming generally refers to the growing of crops mostly vegetables, ornamentals, and herbs on stacks of indoor shelves using artificial light and nutrient solutions, without much sunshine and soil. Such farms are not dependent on seasons/controlled environment and have ability to enhance production round the year with little risk of crop failure. Further they give fresh quality produce without depending on favourable climate, healthy soil, high water consumption and above all saves on labour, a scarce commodity today**.** Vertical farming has potential to sustain ever increasing world population especially in the urban areas with nutritional supplement thus providing food security. Vertical production of mushrooms, hydroponic green fodder, some vegetables and fruits and even poultry birds are either already in vogue or at advanced stage. Vertical gardens in ornamental horticulture, a component of vertical farming are also known as green walls, living walls, bio walls or vertical garden (Jain and Janakiram, 2016). It is a free-standing space or part of a building that is partially or completely covered with attractive vegetation luxuriantly growing in an organic or inorganic medium and in some cases soil also.

Hydroponics and vertical farming address the need of safe and healthy, pesticide/ acaricides/ insecticide free, natural antioxidant rich produce with low carbon and water foot print (Pant *et al.,* 2018).

## 2. HISTORY OF VERTICAL FARMING

Vertical farms have come to lime light on the agricultural front only in the last decade, however the concept behind this innovative farming technique is not new as is evident from the following:

### Pre - 20th Century

**600 BC -** Perhaps the earliest example of a "vertical farm" is the legendary ***Hanging Gardens of Babylon***, built by King Nebuchadnezzar II, more than 2,500 years ago. The gardens consisted of a series of vaulted terraces, stacked one on top of the other planted with several different types of trees and flowers. Reaching a height of 20 meters, the gardens were irrigated probably by another early engineering innovation known as a chain pumps. These pumps may have used a system of buckets and pulleys to bring water from the ***Euphrates River*** flowing at the foot of the garden to a pool at the top.

**1150 AD -** Nearly a thousand years ago, Aztec people used a form of hydroponic farming known as "***chinampas***" to grow crops in marshy areas near lakes. The swampy soil in these areas was not suitable for agriculture; the Aztecs instead constructed rafts out of reeds, stalks, and roots and covered them with mud and soil from the lake bottom. These rafts were then drifted out into the lakes. The structural support provided by the rafts allowed crops to grow upwards letting the roots grow downwards into the water. Often, many of these rafts were attached together to form floating "fields."

**1627 -** The first published theory of hydroponic gardening and farming methods appeared in the book ***Sylva Sylvarum***, by the English scientist and statesman ***Sir Francis Bacon***.

In this book, ***Sir Bacon*** established and explored the possibility of growing terrestrial plants without soil.

**1699 -** English scientist ***John Woodward*** using spearmint refined the idea of hydroponic gardening with a series of water culture experiments. ***Woodward*** found that the plants grew better in water having impurities than in distilled water. This led to his important finding that the plants derive important nutrients from soil and other additives mixed into water solutions.

## Twentieth Century and Beyond

**1909 -** ***Life Magazine*** published the earliest drawing of a "modern" vertical farm. The sketch shows open-air layers of vertically stacked homes set in a farming landscape, all cultivating food for consumption.

**1915 -** The term "vertical farming" is coined by American geologist ***Gilbert Ellis Bailey*** in his book of the same name. Interestingly, ***Bailey*** focused primarily on farming "down" rather than "up." That is, he explored a type of underground farming where farmers used explosives to reach deeper, increasing their total cultivable area and thus allowing for crops to be grown in larger area.

**1929 -** ***William F. Gericke***, an agronomist at the University of California, Berkeley, is credited with developing modern hydroponics. In his article "Aquaculture: A means of Crop-production," published in December 1929, ***Gericke*** first outlined the process of growing plants without soil in sand, gravel, or liquid, using added nutrients.

**1937 -** The term "hydroponics" however has origin in an article published in ***Science magazine,*** derived from the Greek words "hydro," or water, and "ponos," or labor. The term was suggested to ***Gericke*** as an alternative to "aquaculture" (which was already in use to describe fish-breeding techniques) by the botanist ***William Albert Setchell***, his associate in the University of California.

**1940 -** The hydroponic system of growing crops on large scale was used for the first time in modern history during World War II. More than 8,000 tons of fresh vegetables were produced hydroponically on South Pacific Islands to feed the allied forces stationed there (Kojai *et al.,* 2015).

**1964 -** At the Vienna International Horticulture Exhibition, a vertical farm in the form of a tall glass tower was displayed.

**1989 -** Architect and ecologist ***Kenneth Yeang*** created a vision of mixed-use of buildings that are seamlessly integrated with green spaces, allowing plant life to be cultivated in buildings in the open air. ***Yeang*** described this as "***vegetated architecture***." Unlike many other approaches to vertical farming, his vision was based on personal and community use rather than large-scale production and marketing.

**1999 -** The concept of the modern vertical farm was given shape developed in a class led by ***Drs Despommier and Carter***, Professors of Environmental Health Sciences, Columbia University during 2011. ***Despommier*** and his students developed the idea of a multi-story building in which layers of crops could be grown on each floor to feed the population of New York using only urban rooftop agriculture- in other words, a contemporary vertical farming tower. (*Despommier has since become the world's foremost expert on and proponent of vertical farms*). In the year 2010, he published a book entitled *The Vertical Farm: Feeding the World in the 21st Century*, wherein he laid down the principles and practices of modern vertical farming around cities, and inside buildings, instead of horizontal expansion on the ground. Unfortunately his technique is still not practised on large scale worldwide. However, India has made a beginning in 20$^{th}$ century mainly producing lettuce, few leafy vegetables, strawberry and herbs on small scale, besides hydroponic fodder, mushrooms and poultry.

## 3. IMPORTANT FEATURES OF VERTICAL FARMING

- Vertical farms enable the producer to:
  - Grow food 24 hours a day, 365 days a year
  - Protect crops from unpredictable and harmful weather
  - Re-use of water collected from the indoor environment
  - Provide jobs for residents/communities
  - Minimize use of pesticides/fertilizers/ herbicides
  - Drastic reduction and dependence on fossil fuels
  - Prevent crop loss from storage/shipping/ long transportation
  - Stop agricultural runoff, water saving up to 90%
- Pride of producing food – an euphoric feelings
- Education and training to school children in food production

## 4. INNOVATIONS IN VERTICAL FARMING

Some of the following vertical farming innovations have potential to support, supplement and improve existing agriculture techniques and technologies.

1. Hydroponics – Growing plants without soil or soilless production.
2. Aeroponics – Growing plants with no soil and very little water and nutrients in the form of mist or fog.

3. Aquaponics – An ecosystem-one drop two crops- crop and fish farming together with more or less same inputs (feed to the fish).
4. Lokal – Serving fresh food right where it is being grown.
5. AeroFarms– Another smart vertical farming innovation - the technology of growing greens without sun or soil under controlled environment.
6. Plantscapers – A building that provides food for its occupants.
7. VertiCrop – A sustainable farming technique for urban areas.
8. Modular Farms – Produce fresh produce virtually anywhere in the world.
9. Cubic Farming Systems – The next-generation sustainable farming system- working with conveyor rotation and automated nutrient delivery system.
10. Zip Grow – Vertical farming for the modern farmers involving conveyor rotation, automated nutrient delivery and LED lighting.
11. Bowery – The most technologically, sophisticated commercial indoor farm in the world. The technology automatically generates ideal conditions for the plants, while collecting the data as they grow. The data help in providing the plants with the exact amount of light, nutrients and water.
12. Sky farm – A wind-powered vertical farming tower.
13. Sky Greens – The World's First Hydraulic Driven Vertical Farm. The Singapore-based company Sky Greens has developed a revolutionary vertical farming system which is also the world's first low carbon, hydraulic driven farm. The vegetables are planted on shelves that keep on rotating throughout the day.

The vertical farming has advanced abroad, providing positivity to space farming, which would be in demand even on other planets inhabited with either short or long periods (Kheir Al-Kodmany, 2018).

## 5. SUSTAINABLE VERTICAL FARMING VENTURES IN VOGUE IN INDIA

### 5.1 Mushroom Production

Mushrooms do not require lots of light to grow and are nutritious food that cycle up organic waste. Mushroom producers have been using vertical farming much longer than the plant producers. It is amenable to urban or indoor farming in vertical beds and is being practiced in several metros and peri-urban areas. Mushroom production is an apt example of successful, economical and sustainable vertical farming.

## 5.2 Poultry Production (Broiler and Eggs)

Poultry birds, mainly the layers (egg producers) and broilers (meat bird), are raised either in multi-storey buildings on floors or in battery cages. Battery cages accommodate more number of birds making the venture more profitable. Though popular both in urban and rural areas, the animal welfare organizations have serious reservations and do not support it.

## 5.3 Garden Wall/Bio Wall

Garden wall–a type of vertical farming (garden) is popular throughout the world including India. Vertical gardens can be seen on public places mainly on airports, metro pillars/stations, river bridges, elevated roads, etc., in many metro cities in India. Multicolour evergreen foliage plants are preferred, although flowers and even leafy vegetables find place in these wall gardens. However, their maintenance is costly and proving un-sustainable. Orchids, which do better on tree trunk and its branches, can be grown vertically under controlled climatic conditions especially in temperate and sub-temperate climate. Garden walls with seasonal leafy vegetables are the best option for indoor gardens. Availability of all season plants, growing media, fertilizers and watering are issues that need to be addressed for their commercialization.

### *5.3.1 Plants suitable for bio/ living walls*

For garden walls, selection of suitable plants is the single most important factor in its success. Plants thriving well in local climate are the best option. Besides, they should have compact growth providing thick and dense cover. Plants having short growth habit, shallow fibrous root system and longer life cycle are best suited for this purpose. They also need to be capable of coping both full sun and full shade according to the location. Most commonly used plants in bio/living walls are:

#### 5.3.1.1 Green facades

Climbers having faster growth and dense variegated foliage from ground to top, are the best like *Hedera helix, Parthenocissu squinquefolia, Parthenocissus tricuspidata (Japanese creeper), Hydrangea anomalapetiolaris (climbing Hydrangea), Lonicera japonica, Jasminum officinale, Aristolochia spp., Clematis paniculata, Cissusrhom bifolia (Grape Ivy) Ficus pumila (Creeping fig) , Bignonia unguiscatii (Cat's-Claw Vine) , Polygonum baldschuanicum, Passiflora caerulea,* etc.

#### 5.3.1.2 Living wall

Plant species with dwarf nature, limited root volume, fibrous roots, resistant to wind, and good growth habit are ideal, e.g., *Dracaena marginata, Dracaena sanderiana, Phalaenopsis* spp., *Hibiscus* spp., *Gardenia* spp., *Nephrolepsis, Asparagus sprengeri, Kalanchoe* spp., *Fittonia* spp., *Scindapsus aureus, Asplenium nidus, Maranta* spp., *Cordyline* spp., *Chlorophytum* spp., *Haworthia* spp., *Tradescantia* spp., *Hydrangea, Nasturtium, Wisteria, Petunia, Clematis, Selaginella, Daisies, Bromeliads* and even few vegetables like tomato, chillies, cucumber, pea, lettuce, etc.

#### 5.3.1.3 Exterior wall

Selected plants should perform well under full sun shine or partially shade conditions, e.g., *Lavendulaangus tifolia, Thymus serpyllum, Rosmarinus or Salvia splendens,* for full sunlight. *Rex begonia, Arum, Davallia, Asplenium nidus, Fuchia for* shady conditions.

#### 5.3.1.4 Interior wall

Selected plants should perform well both under full shade or partially shade conditions, e.g., *Philodendron, Epipremnum, Aeschynanthus, Columnea, Saintpaulia,* many species of *Peperomia and Begonia* or different ferns *like Nephrolepis* and *Pteris.*

## 5.4 Hydroponic Fodder

An age-old technology for the multiplication of green fodder to meet daily requirements of cattle is continuously being updated and popularized by public and private sectors. It involves climate-controlled cabins with trays vertically arranged and fed hydroponically through nutrient film technique. Barley, oat and maize are commonly used for hydroponic green fodder production. Not only the hydroponics technology for fodder production has been successfully developed, evaluated and certified by Ministry of Agriculture for various fodder crops, the fodder is being produced in Ayurvet Pro Green Hydroponics Machines. Fodder banks equipped with Certified Hydroponics Machine (both all-weather and make shift) need to be supported at village and farm levels for providing round the year (24 x 7) value added green fodder for animals.

## 5.5 Strawberry Vertical Farming

Strawberries are commercially grown in environment controlled structures in different gutter systems by keeping distance between two gutters approximately 100 cm. A gutter system enables correct amount of drainage water to irrigate.

## 5.6 Cucurbits Trained Vertically

Viny cucurbits spread on ground occupy huge space with low productivity. In vertical gardens, vines are trained to climb a trellis or garden netting, accommodating a larger plant population leading to multiple productivity under open field condition. Same is done under protected conditions in soil or soilless medium. It is best suited to indeterminate varieties of tomatoes, yard long cow pea and several beans. The important cucurbit crops for vertical farming include cucumber, bottle gourd, sponge gourd, ridge gourd, snake gourd, and bitter gourd.

## 5.7 Micro Greens

Micro greens and baby greens are a relatively new specialty becoming popular among nutrients conscious urbanites. These crops consist of vegetables and herbs that are consumed at a young growth stage. Several species of micro greens also contain high concentrations of health-promoting phyto-chemicals. Micro greens can be produced by vertical farming indoor, outdoor, on and off season, in home and on farm. They are preferred by chefs and consumers to enhance the flavour, colour, and texture of a dish. Oflate, micro greens of the genus *Brassica* mainly broccoli have become popular due to their ease of germination, relatively short production time (7 to 21 days), and offering of intense flavours, colours and medicinal values. Commercial growers are currently producing micro greens in greenhouses in vertical system using soilless media in trays. Micro greens are also produced hydroponically using capillary mats placed in troughs, similar to those used in a nutrient film technique system.

## 5.8 Aquaponics

Aquaponics combine the fishes and plants in one ecosystem, wherein fishes grow in indoor ponds producing nutrient-rich waste that acts as a food for the plants grown in vertical farms. The plants purify and filter the waste water that is recycled directly to the fish ponds. There is need of using Re-circulatory Aquacultures System (RAS) in the Vertical Farming. The pisciponics - cultivating fishes, prawns and snails with plants (vegetables, fruits, herbs or flowers) in a symbiotic environment with RAS in vertical farming is coming up in Kerala. This closed-cycle system has potential to become popular in coming days.

## 5.9 Farm Containers

The soilless cultivation, mostly of leafy vegetables, in controlled environment can be done in mobile or static containers. The high cost and care are major impediments in popularization of such farming.

## 5.10 The Structures and other Engineering Inputs in Vertical Farming

Vertical farms need to be safe, efficient, durable, elegant, economical and ecologically sustainable. The structure should meet optimum physiological and behavioral needs of the intended life forms with adequate micro-climatic control and access to appropriate nutrition. Heating, ventilation, and air conditioning (HVAC), uniformity of the environment, optimal delivery of carbon dioxide ($CO_2$), shelf spacing and design and smart lighting are important engineering components in environment controlled vertical farms allowing optimum interaction of crops and surrounding climate. Since seed germination, rooting, vegetative growth, flowering, fruiting, flavour and colour development are directly related to photo period, its duration, intensity, spectrum, etc., are crucial to maximize yield and quality of produce. LED, red and blue light alone and their combinations have direct influence on the crop growth. The energy intensive lighting and HVAC systems account for nearly one third of the overall operational costs. The growing beds are suitably designed to utilize maximum space combining ease of irrigation/fertigation and other operations.

## 5.11 Commonly Grown Crops in Vertical Farming

Although possible to grow any plant completely indoor, economics limits to few crops in vertical farming that have small growing habit (*for maximizing the number of plants that can be grown in a limited space*), are prolific producers (*e.g. indeterminate tomatoes*), or can be grown and sold rapidly (*such as micro greens*). Compatible crops for vertical agriculture today include lettuce, broccoli, spinach, chard, chive, palak (beet leaf), mustard greens, amaranths, parsley, coriander, mint, kale, basil and other herbs (rosemary, fennel, thyme, oregano and others), strawberries, mushrooms, micro greens and sprouts, summer squash, peppers, eggplants, tomatoes, cucumbers, muskmelon, algae, crop nurseries, ornamental foliage and flower plants.

## 5.12 Growing Medium

The type of growing media, providing needed nutrition to the relatively shallow depth/ limited volume in containers, is the most important component in vertical farming. Field soils are generally unsatisfactory for the production of plants in containers. Mixing coco peat, vermiculite and perlite in the ratio of 3:1:1 on volume basis was observed to be one of the best growing media. However, to bring down cost locally available inert media needs to be standardized.

## 5.13 Water and Nutrient Management Efficiency in Vertical Farming

In vertical farming, the elevation difference between first row (*bottom one*) and top row (*upper one*) is considerable and this difference affects the water emission rate from dripper. Since success depends on the relation between head and discharge, the network of pipes and dripper discharge need to be such that all plants get uniform water irrespective of their location. For quality production, irrigation water needs to be free from undesirable chemicals and pathogens, while fertigation can save as much as 60% fertilizers. Appropriate design of irrigation/ fertigation system is important to maintain the pressure and discharge requirements. Essentially the drainage and recirculation of water/ nutrients solution needs to be monitored for its electrical conductivity (EC) and pH.

## 5.14 Electrical Conductivity (EC) and pH

The EC and pH are two key important parameters for hydroponic's success. Although crop specific, the EC values range from 1.5 to 2.5 ds/m for hydroponics depending on environment. Higher EC increases osmotic pressure and hinders nutrient uptake while lower EC severely affects the plant growth and yield. Reduction in water uptake is strongly and linearly correlated to EC. The pH value determines the nutrient availability for the plants; therefore, it needs daily adjustment due to the lower buffering capacity of soilless systems. Regulation of pH can also be carried out by using nitric, sulphuric or phosphoric acid, either individually or in combination.

### 5.15 Aeration for the Roots

Not only oxygen is essential for cell growth and activity, the roots require oxygen to absorb water and nutrients. Therefore, aeration, is an important factor that influences root and plant growth in hydroponic system. Maintenance of proper balance of water and oxygen in plant roots is very important in vertical farming and requires standardization.

## 6. RESEARCHABLE ISSUES IN WATER AND NUTRIENT MANAGEMENT

### 6.1 Standardization of Water and Micronutrients

Crops differ in their requirement for water and major/minor trace elements. Nutrient solution, therefore, needs standardization in different media for crops and their varieties for better output.

### 6.2 Modification in Irrigation Schedule

Irrigation schedule needs to be appropriately modified and standardized as water holding capacity differs in soils and soilless media. Similarly, there is need to standardise the timings of exposure of plant roots to nutrients solution and air in situations where no medium but only nutrients solution is used. Thus, irrigation requirement for different stages of crop growth needs optimization. In aquaculture, where roots are submerged in water/ nutrients solution all the time, aeration in solution needs attention. The frequency and duration of nutrients solution exposure in aeroponics need to be worked out in vertical towers and inclined horizontal stacks (Hota *et al.,* 2018).

### 6.3 Development and Standardization of Drip Irrigation and Fertigation

There is need to develop and standardize the drip irrigation and fertigation schedules in vertical farming enabling crops to optimally use water and nutrients. In aquaponics, the standard monitoring systems for nutrient supply to plants and water quality to fishes needs to be worked out depending upon plant and fish species used in the region.

## 6.4 Bio-stress and Vertical Farming

Prevention and management of bio-stress in vertical farming is as important as in any other farming system. The major biotic stresses include spider mites, thrips, aphids, whiteflies, fungal gnats (*Bradysia* spp.), powdery mildew, downy mildew, grey mould, root rot, etc., while high humidity and excessive fertilizers aggravate the stress. Deficiencies of nutrients in general are the common abiotic stress in vertical farming. The management of these stresses involves following three sub-systems:

1. *Prevention or avoidance*: Good Agricultural Practices (GAP) protocols involving strict preventive measures as per buyer's requirements are nowadays available. Exclusion of the infested area, pots, troughs, planting trays, etc., and maintaining general hygiene of irrigation water, plants, workers and accessories are important.
2. *Monitoring and regulation:* Regular monitoring and surveillance of the pestilence during the crop growth and quarantine protocols for imported seeds and other planting material are important factors. Tools like yellow sticky traps, delta traps and other modern devices are very helpful while monitoring of disease-spreading plant material requires strict surveillance at all levels.
3. *Intervention or control measures*:
   (a) Mechanical controls like manual or physical destruction, removal, termination, pinching, pruning, burning and destruction of pest sites or propagules are essential to avoid building of high pest populations.
   (b) Physical control includes management of temperature from seedling stage to harvesting, shading and cooling management, aeration, carbon dioxide enrichment, oxygenation of substrate for suppressing anaerobic pathogens, particularly fungi like *Pythium*, $CO_2$ enrichment for more effective photosynthesis.
   (c) Chemical control includes use of crop and pest specific bio-rationales and biologicals as per need, use of need based effective chemicals with care, attention and caution and use of integrated pest management practices for biotic stresses.

# 7. RESEARCHABLE ISSUES

Vertical farming is in infancy in India. Although vertical farming units for production of crops like strawberry, lettuce and other leafy vegetables, foliage and flowers are functioning in major metros of India, the organised vertical farms for production of food crops are not available. However, production of button mushrooms and orchids on large scale in vertical system are success stories. Lack of research on hi-technologies involved in vertical farming system is meagre, particularly in public sector. Most of the components require support both in terms of human resource and infrastructure. Vertical farming being highly technical requires intensive research on:

a. Designing cost effective structures for vertical farming.
b. Media for production of plants and suitable crop varieties.
c. Standardization of required plant nutrients of different crops and their varieties.
d. Optimum water need of hybrids/varieties in different methods of vertical farming.
e. Plant protection including preventive and management practices.
f. Role and efficacy of different indoor lights for crops, seasons and growing environments.
g. Harvest index and harvesting tools.
h. Packaging, transport and storage.
i. Automation and touch screen operations.
j. Value addition.
k. Marketing.

India is yet to undertake major initiative on much needed research projects of vertical farming or urban farming. Being highly populated with continuous migration of people to cities/urban areas, India would no longer be a country of villages but of cities and metros. Hence due emphasis on urban farming/vertical farming is needed both by research as well as development organizations/ ministries. Vertical farming engages multiple disciplines of natural sciences (mainly horticulture), architecture and engineering and affects both people and the environment. The two major problems have been financial and technological feasibility in its popularization and spread. Since vertical farming or indoor farming requires contemporary building materials and renewable energy systems such as light shelves, light pipes and fibre optics, which deliver natural light deep into buildings to provide energy for photosynthesis, and skilled workers to run it, therefore, its rate of return does not seem profitable to investors. Whereas on the other hand, conventional farming does not require either of it, but if one sees from the point of future then Z-farming (Zero-Acreage) and vertical farming can become the lucrative option for potential investors too.

## 8. VERTICAL FARMING A POSSIBLE REPLACEMENT TO CONVENTIONAL FARMING IN FUTURE

The length of distance that food travels in cities from source of production will increase many folds in future, if cities continue to depend for food on rural farming (most of the food in cities is imported from far off places). In this scenario, future cities would have to produce their own food. However, conventional land farming would not be possible in cities and peri-urban areas with prohibitive land prices. The vertical or roof top farming (also called zero-acreage farming) would be the only possible future approach and solution for providing food/nutrition to cities.

## 9. MAJOR CHALLENGES IN ADOPTING VERTICAL FARMING

The major challenges in vertical farming include:

1. Consideration of vertical farming as supplementary agriculture.
2. Partial or no plant-nature interaction.
3. Cost intensive cultivation.
4. Lack of expertise and infrastructure.
5. Development of suitable varieties and/or hybrids of suitable crops.
6. Generation of unpleasant odour/smell over the period (*cannot be called a totally environment friendly technology*).

## 10. INDIAN PERSPECTIVE ON VERTICAL FARMING

The vertical farming technology today in the Indian scenario is costly and consequently, its produce also. Thus, it is difficult as of today to compete with the market price obtained from the modern geoponic agriculture. However, the produce of vertical farming do have sizeable market only in the Indian metros, mainly in the high end hotels and well-to-do (high income) population. The ground reality is that soilless vertical farms for greens (leafy vegetables, strawberries and herbs) are largely owned by hotel industry that also supply quality fresh food to other industrial houses and financially well off people.

On Research and Development (R&D) and human resource fronts, the two pillars of any successful venture, this technology is unfortunately still in infancy in India. Its status either as 'organic' or 'inorganic' is also controversial. Currently, vertical farming is not amenable to major food crops. Even with several limitations, the technology has the potential to produce 10 times more per unit area over traditional agriculture and has scope of integrating in the present and futuristic life-style of food production and consumption. Besides this technology is sustainable with several positives like requirement of reduced land, water, fertilizers, pesticides and other inputs. Vertical farming is also possible in lakes, under water/above water, in space even in kitchens (micro greens) and in all the places where humans can live and work.

## 11. WAY FORWARD

Lack of expertise, research, education, training, economics, standards and regulations are some of the major obstacles coming in the way of commercial exploitation of vertical farming in cities. Compared to Europe, USA, China and Singapore where vertical farming has shown good progress, it is still restricted to a few individually driven projects/hobbies mainly in Bengaluru, Delhi, Hyderabad and few other cities in India. In spite of numerous inherent benefits enumerated earlier, the technology needs institutional support to generate mass interest to stabilize in India. It can be used as water recycler (some of the most recent vertical farms situated in the United States are recycling waste material from the cities'- according to report of *Vertical Farming: Enter the Urban Farmer, 22 January 2017*, 19:00). This is possible by spreading awareness of its benefits and strengths, coupled with financial and technological support by government's proactive policies like incentivizing farming to attract urban dwellers. Vertical farming can serve as urban regeneration tool by giving social, economic, educational and environmental benefits to the future cities and their inhabitants**.** To tap the economic, environmental and social benefits of this technology, extensive research is required to optimise and economise the production process. Research projects on various aspects of technology, mainly engineering, hi-tech horticulture, financial and economic feasibility, can be undertaken by ICAR. An Institute on Protected Cultivation covering education and research on vertical farming (Janakiram and Bhasker, 2018) needs to be established. SWOT analysis can bring forth the weaknesses and threats to work upon and look for the opportunity to take an early advantage. Though city planners, architects and investors may be excited with the idea of vertical farming, it still has to go a long way to play a serious role in feeding the world.

## 12. ECONOMICS OF VERTICAL FARMING

Vertical farming envisages production of food inside walls, ensuring that cities start the process of becoming self-sustaining and less reliant on the global and national systems that provide their food. Spoilage and food waste would be reduced and fresh food would be available using recycled water. These are only a few of the environmental and social benefits that vertical farms seek to provide to city dwellers. Vertical farming in addition, would eliminate agricultural runoff that harms biodiversity in our oceans, eliminate weather and climate change related crop failures and convert farmland back to nature in rural areas (restoring ecosystems). Despite these benefits, only a few successful vertical farms have been built in India mainly due to the initial high price tag on construction and the cost of maintaining them afterwards (Banerjee, 2014).

## 13. KEY RECOMMENDATIONS

1. Vertical farming, a potential, climate combative important future farm technology, needs to be suitably promoted in India.
2. Vertical farming needs to be adopted in wide range of Indian agro-ecologies through innovative research and development (R & D) and human resource development.
3. The technology requires perfection for all (small, medium, large and no farm holders) both in urban and rural areas. It needs to cover both high rise buildings and slum

dwellers, under open as well as semi/fully controlled environment and with simple or sophisticated (LEDs, sensors, controlled environment etc.) technologies.

4. Relevant research and educational institutions (ICAR, SAUs and others) in the country must contribute and support to the development of vertical farming. The technology should aim to develop affordable production protocols vis–a-vis present agriculture practices and suitable to Indian conditions.
5. Promotion of human resource development (HRD)/ skill development of vertical farming requires due attention. Designing new academic courses for graduate and post graduate programmes focusing on increasing nutritional contents of produce/ value addition is need of the hour.
6. Flagging of researchable issues, keeping in view the Indian conditions and aiming to be globally competitive, all the disciplines of vertical farming particularly the sustainability and economics of the system need to be strengthened.
7. Vertical farming including ornamental green walls needs to be promoted with all financial and technological support both from government and non-government organizations (including PPP model). Breeding and identification of varieties/hybrids suitable for vertical farming in selected crops need to be taken up.
8. Initiation of systematic research on media, light requirements, organic inputs, sensors, robots, etc., using local material to bring down the cost of vertical farming.
9. Designing the cost effective structures for different type of vertical farming.
10. Use of non-conventional sources of energy like solar/wind power to meet the energy requirements of the system.
11. Research on pest management and safe production protocols for vertical farming.
12. Development of vertical farming models for fodder production under open fields as well as for promoting hydroponic green fodder production.
13. Promotion of cluster-approach for vertical farming to facilitate input availability and remunerative disposal/marketing of produce.
14. Vertical-walls/ bio-wall/ smart wall/food-walls, etc. should be promoted on large scale with required technology support especially in metro-cities and on major national highways.
15. Establishment of Centres for 'Innovative Horticulture' to promote emerging technologies in vertical farming.
16. Framing of appropriate policy guidelines for promotion of vertical farming for the fast-expanding urban India. To start with, the Horticulture Division of ICAR may be entrusted with the responsibility to promote vertical farming in a big way through appropriate research and development.

17. Prioritization of crops for each category of vertical farms (open vertical, semi- automated and fully- automated) should be initiated.
18. Focused attention on popularization of vertical farming through available extension techniques and institutions.

## In nutshell

1. Vertical farming is not a pie-in-the-sky, but it's not a lay-up either. Vertical gardens (bio wall, lettuce and strawberry production) are a reality, which need to be economical and environment friendly.
2. Vertical farming does offer a solution to food production in areas where conventional methods just would not work.
3. Vertical farming offers some great sustainability benefits in diminishing resources and climate change scenario on the earth.
4. More basic research coupled with applied sciences, engineering and technology needs to be done for successful vertical farming.
5. Policy on vertical farming as part of main agricultural development at appropriate level is the need of the hour in India.

### *Suggested further reading*


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# Vertical Farming

Smart Wall

Strawberry

Aeroponic tower

Button Mushroom

Strawberry, Nainital

Hydroponic Gurugram

Vertical Garden

Battery System for Birds- vertical space utilization

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Note: The designations and affiliations of the participants are as on date of BSS.

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