Vertical Cultivation: Moving Towards a Sustainable and Eco-friendly Farming

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Abstract

Vertical farming, popularly known as sky farming, is a recently emerging technology for cultivating many herbacious crops. As the world's population increases exponentially, arable land is diminishing. The vertical farm concept was developed to remedy the spatial land utilization crisis. This method utilizes conventional farming methods such as hydroponics, aquaponics and aeroponics to gain greater productivity. Design, layout and configuration of these high-tech farms provide optimal light exposure, precisely measured nutrients for each plant and ability to grow in a controlled, closed-loop environment. These farms eliminate the need for harmful herbicides and pesticides, maximize nutrition and increase food value in produce. Vertical cultures under protected structures also enhance taste to cater to consumers preferences. In horticultural crops like berries, leafy vegetables, spinach and some crucifers, this technique has already been adopted. It provides a tremendous yield, improved quality assurance and sustained production capacity. Start-up costs are higher than traditional options, but these can be quickly overcome with increased productivity providing profit. Scientists are continuing to modify technologies to boost profits to users. Indoor horticulture production systems can be advanced and automated by vertical farming techniques to enhance organic farming concurrently with improved soil health and sustainable farming.

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20.1 Introduction

Crop production is under threat as a result of extreme weather variables, biotic and abiotic factors and diminishing land resources. The global resources of land and clean water are diminishing daily. By 2050, predictions indicate a 60% increase in food production will be required (Tilman et al. 2002; Green et al. 2005; Alexandratos and Bruinsma 2012) to feed the projected human population of 9.5 billion. This will not be possible using conventional technologies; hence a fundamental change in food production is needed (Corvalan et al. 2005; Healy and Rosenberg 2013; Thomaier et al. 2015; Despommier 2010). Supply must meet the demand of an expanding population. Crop productivity must be enhanced significantly to achieve this goal. Undernourishment remains a hurdle to face globally (FAO 2020). As per a 2019 UN report, the number of people living in urban areas will rise to more than 6 billion with 90% of the demographic shift in developing countries. Recurrent, unprecedented population explosion and growth of mega-cities worldwide could prove unsustainable and ecologically disastrous (Banerjee and Adenaeuer 2014). In 2000, the world's mega-cities accounted for just 2% of land surface of Earth, but they consume roughly 75% of industrial wood and 60% of water to produce almost 80% of human-produced carbon emissions (UNPD 2008). Expanding human population and urban residency have a destructive influence on the environment. Urban centres concentrate service industry options for quick and affordable goods and services; this demand tends to increase vehicular emissions. Adoption of efficient tools and techniques can provide a means of maintaining the environmental and anthropogenic harmony.

Vertical gardening in urban and semi-urban areas could be an efficient method to merge food production and consumption locally (Al-Kodmany 2018b). Land becomes a vital resource due to limited availability and higher cost. Using novel food production specially might provide city dwellers with quality, poison-free, farm fresh produce that is less expensive. Recent advances in greenhouse technologies, soil-less farming, aeroponics, hydroponics and aquaponics have provided a promising future to the vertical farm concept. These high-tech systems represent a paradigm shift in farming and food production systems that offer sustainable and efficient methods for city farming by minimizing maintenance and maximizing yield. Reduction in application of poisonous agrochemicals in this type of farming also increases interest in health cautious communities. Rooftop farms using vertical concepts could feed a family size of 3–5 by meeting daily vegetable needs. This technology is in a juvenile stage and gaining interest from businesses, scientists and young people engaged in prototype development, with high resource use efficiency, low labour hinderance and greater productivity.

20.2 What Is a Vertical Farm?

The term vertical farm is self-explanatory with a literal meaning of farming vertically, up from the ground surface. Conventional farming can be broadly considered horizontal farming. Vertical is farming up rather than farming out (Fig. 20.1). There are three main types of vertical farming (Despommier 2014; Touliatos et al. 2016; Muller et al. 2017; Al-Kodmany 2018b) based on construction. The first type of vertical gardening is preferred by many industries and involves the construction of tall structures containing several levels of growing beds, often lined with artificial lights. Multi-coloured LED (Light Emitting Diode) lights are commonly used for crop-specific phenophases. The second type of vertical farm is built on the rooftops of old and new buildings. These may be constructed on commercial and residential structures, such as restaurants and grocery stores (Despommier 2014; Touliatos et al. 2016). The third type of vertical farm is a visionary, multi-story building with automated monitoring systems and fewer human interventions. The third type is the most advanced form of vertical gardening technology, but it is relatively rare. Vertical farming is the practice of growing or producing crops in vertically stacked layers. These farm comes in different shapes and sizes, from simple two-level structures or wall-mounted systems to large warehouses several stories tall. Vertical farming typically uses a mix of natural and artificial light. Artificial lighting is often LED-based and may be driven by a renewable power source such as solar power or

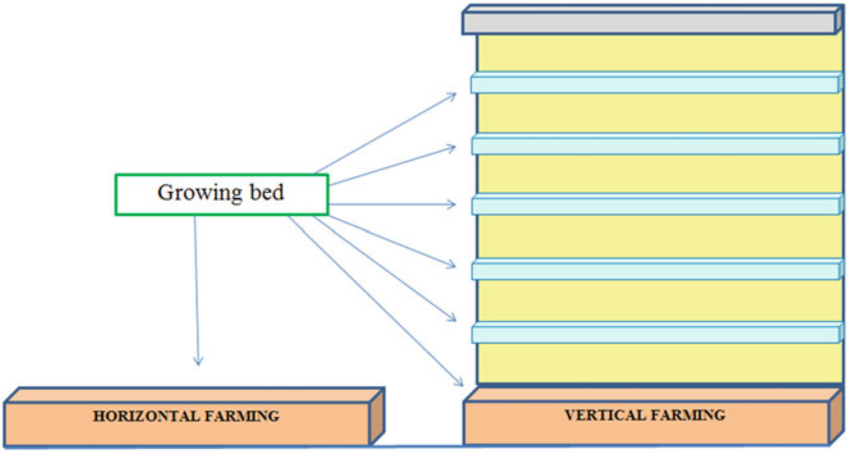

Fig. 20.1 Generalized view of vertical garden versus horizontal garden. Horizontal gardening involves crops grown in soil as a single bed system, but vertical gardening increases the number of growth beds per land plot to accommodate more plants and potentially increase yield per plot

wind turbines. It may be very simple system and function only with available natural resources (outside greenhouse). The system may be highly sophisticated and driven by use of LED, aeroponics, hydroponics and aquaponics, including fully controlled growth conditions, automated irrigation, fertigation, plant health management, sensor-based harvesting operations and other technologies. Depending on human intervention, vertical gardens can be of two types. “Mixed used skyscrapers” developed by Ken Yeang have both plants and humans living together in natural environments. “Despommier skyscrapers” by Despommier contain plants grown in fully controlled environmental conditions with less human intervention. There are also two main types of growth media or root holding chamber used. One type comprised of multiple levels of traditional horizontal growing platforms, and the other type with crops grown on a vertical surface (Beacham et al. 2019). Using advanced greenhouse technologies such as soil-less culture, hydroponics, aquaponics and aeroponics, the vertical farm could theoretically produce the daily human requirements for fish, poultry, fruit and vegetables (Despommier 2010). The vertical farm is considered to promote sustainable agricultural practices beyond conventional farming, which relies on large scale, outdoor agriculture engaging heavy irrigation, intensive tillage and excessive use of fertilizers, pesticides and herbicides (Healy and Rosenberg 2013). Vertical farming provides adequate amounts of high quality foods and helps the environment by reducing agrochemicals and recycling water regularly.

20.3 Historical Background of Vertical Farming

Vertical farming is not an entirely new prospect. Examples of it can be traced back to the Hanging Gardens of Babylon in ancient era, one of Philon’s Seven Wonders of the Ancient World which was built around 600 BC. The term “vertical farming” was coined by Gilbert Ellis Bailey in 1915 who also wrote a book titled “Vertical Farming”. He also argued farming hydroponically in a controlled vertical environment would provide economic and environmental benefits. In the early 1930s, William Frederick Gericke of University of California at Berkeley pioneered hydroponics and became the father of that technology. In the 1980s, Ake Olsson, a Swedish ecological farmer, also proposed vertical farming as a means for producing fresh vegetables in cities. He is known as the inventor of a spiral-shaped rail system for growing plants (Corvalan et al. 2005; Healy and Rosenberg 2013; Thomaier et al. 2015; Despommier 2010, 2013, 2014). Around the turn of the century, Dickson Despommier, an American ecologist and professor of public health, passionately revived the concept of vertical farming. He described the vertical farm as “the mass cultivation of plant and animal life for commercial purposes in skyscrapers.” In India, vines are grown on rooftops, as shown in Fig. 20.2, as a very beautiful example of vertical-green wall.

Fig. 20.2 Growing of cucurbits on the roof of thatch house in India. Figure adopted from https://www.outlookindia.comtravellermpvisual-escapephoto-gallerytraditional-architecture-madhya-pradesh

20.4 Concept and Technology Involved in Vertical Farming

Vertical gardening started in earnest during the 1990s and has expanded to metropolitan areas globally. Food production businesses searched for less intensive but highly profitable production systems. Vertical gardening became one viable option. Despite being an emerging technology, the diverse workability and expansion potential do not hamper it. Numerous organizations have proposed prototypes, such as Vertical Farm stands of Suwan in South Korea, the plant vertical farm of Chicago, Nuvege plant factory of Japan, Vertical harvest plans 2 of USA, eroFarms of New Jersey and the recent addition Plantagon, Urban Kissan of Hyderabad, India, City Greens of Ahmedabad, India. Designs differ, but vertical farm concepts remain the same with the general idea of growing crops in an upward direction rather than horizontally. Hydroponic, aeroponic, aquaponic and soil-less farming techniques are integral methods for holding and feeding vertical garden plants. The new technology is built on its theoretical concept. Vertical farming aims to increase crop yield per unit area of land, and this idea is currently gaining momentum (Agrilyst 2017). Here are a few common questions. (1) Can conventional farms growing crops only vertically be called vertical gardens? (2) Are all crops suitable for this technique? What about the other perennial crops like mango, jackfruit, persimmon and apple?

(3) What is the growth media used in this type of farming? Is it different than soil? Many additional questions related to crop environment, irrigation, nutrition and plant growth will depend on the questioner's interest and knowledge. To answer, vertical cultivation is growth of short duration crops in a climate controlled, fully automated environment using sensors and employing highly skilled workforce. In general, mango or any perennials are not cultivated in this method, but greens, vegetables, small berries, annuals and other herbaceous plants are cultivated. Because hydroponic, aeroponic, aquaponic and soil-less farming techniques are integral part of this system, these methods provide plant anchorage, nutrient uptake and water uptake. The vertical farm must provide optimal conditions for crops to transition from seedlings through germination, vegetative, reproduction and harvest phases. A major prerequisite is temperature and relative humidity-controlled growth chambers. Additionally, controlled and elevated CO_2-levels have been shown to maximize biomass yield. The closed system can filter out contaminants and trace gases, such as ethylene, which are released into the air by plants.

20.5 The Musts in Vertical Farm

This technology is new and outside general cultivation practices of traditional or conventional farming. Full expertise limits failures of technology. Certain listed critical factors determine cost effectiveness of vertical farming.

- Evaluate feasibility of vertical farming technology for climate/geographical areas
- Prioritize technologies by their type prior to establishment
- Become knowledgeable regarding vertical farm implementation
- Analyze availability of space, electricity, instruments, other resources
- Maintain hygienic and use of low weight, soil-less media
- Understand crop phenology and environmental requirements
- Find urban or semi-urban location with good transportation and water availability
- Obtain storage unit and start the cropping with few prior bookings
- Streamline the sell to catch the market
- Accommodate the maximum number of crops rather than one
- Find skilled and semi-skilled labours

20.5.1 Factors Affecting Design of Vertical Garden

The various factors which might affect the design and structure of vertical garden are listed here.

- Available materials for structural construction—locally available materials like bamboo, lumber, must be used for the early period with the growth of the farm they can be replaced by costly materials like stainless steel.

- Local preferences—crops suitable for the particular locality must be considered first. They should be tested in trial runs. If there is no profit, farm must shift to alternatives.
- Creativity and imagination—construction of the farm depends on maximum use of land and solar radiation.
- Crop management—care in selecting space for each crop.
- Resources—available energy or electricity. Determine need for solar system or any other source of energy.
- Space—total land availability.
- Climate—conditions of locality and more.

20.6 Environment and Plant Response to Vertical Garden

Environment plays a crucial role in all aspects of plant growth and development. Plant behaviour is the result of the climate in which it is grown. Light, humidity and temperature are the fundamental modifiers of plant responses. Plants grown in humid regions will have a larger leaf for maximum transpiration compared to those grown in dry climates. Likewise, plants under cold conditions preserve more food in the hard stem. Evergreens growing in tropical regions receive good amounts of solar temperature. Plants with poor irradiation are slightly pale green in colour compared to those grown under full solar light. Most vertical farming photosystems differ from the normal solar radiation used in greenhouses. The maximum impact of photon energy on variation of growth is prominent, including modification in plant physiology, biology, morphology and photosynthesis. Temperature variation is prominent moving in the vertical direction, making plant response to vertical farm raised temperatures a general concern. Therefore, the following subheadings highlight crop responses under vertical farming with various alternations in morpho-physicochemical activities inside and outside the plant.

20.6.1 Photo-biology

Plant biological processes are highly regulated through different light spectra. Photoreceptors function as light-absorbing molecules that determine the wide range of light or photo spectra and utilize them for specified plant responses. Photoreceptors are light-sensing proteins containing a chromophore molecule sensing and responding to specific wavelengths of light. Examples of these molecules include cryptochromes, zeitlupes, phototropins, phytochromes, UV RESISTANCE LOCUS 8 (UVR8) and too many others to list. Vertical farming allows for full control over plant light supply. Manipulation of light spectrum intensity and timing may help obtain or regulate specific plant physiological processes (Pattison et al. 2018). Plant use different photoreceptors to detect various spectra of light (Table 20.1). Research into the signalling role of individual photoreceptors is ongoing (Sanchez et al. 2020). The interplay and the crosstalk among the

Table 20.1 Specified photoreceptors for different light spectrum (Smith et al. 2017)

Sl. No.	Designated light spectra	Photoreceptors
1	Blue	Cryptochromes, phototropins and zeitlupes
2	Red: far red	Phytochromes
3	Green light	Cryptochromes and unknown receptor
4	UV-A, UV-B	UV RESISTANCE LOCUS 8 (UVR8)

photoreceptors require more scientific attention. Light adjustments generate vertical farming possibilities, for example blue-red light opens of stomata, red light initiates photosynthesis, far red promotes stem elongation and blue light triggers floral induction (Sharath Kumar et al. 2020). In some short-day or long-day plants, floral induction is started by proper photon spectra. The dynamic role of light may boost yield and crop quality with proper implementation, using plant circadian clock mechanisms that regulate translational and transcriptional feedback loops (Sanchez and Kay 2016).

20.6.2 Photomorphogenesis

Photomorphogenesis refers to plant morphological responses induced by light. Plants intercept light, and efficient utilization depends on crop morphology specifically leaf morphology. Larger leaf surfaces intercept more light for photosynthetic processes. That results in more photosynthate and dry matter production to improve yield and quality. Not only leaf size but also its orientation, or phyllotaxy, impacts the efficient use of light energy by the plant system. Spectral effects of light have a major impact on dry matter partitioning which can improve the harvest index (HI) of crop plants. Morphogenesis and metabolic processes provide a holistic approach for improving yield (Fernie et al. 2020) as do important hormones responsible for flowering like florigen and gibberellin (Eshed and Lippman 2019). Hormones can modify plant architecture, synchronous flowering, fruiting and yield of crops for vertical farming.

20.6.3 Photosynthesis

Light is the major factor in plant photosynthetic processes both in spatial and temporal distribution. The importance of the light energy is well known in both horizontal and vertical farming plants. In vertical farming where solar radiation is the sole source of light, plant growth is reduced in lower layers due to reduced light. Photosynthesis enhancement is essential, but practical application is limited to balanced source and sink strength at the whole-plant level. Although leaf photosynthetic efficiency of green light is usually lower than that of red and blue due to higher reflection, green light penetrates deeper leaves and canopies benefiting crops. Additionally, far-red may play a role in photosynthesis and has been proposed to be photosynthetically active radiation (Zhen and Bugbee 2020). Vertical farms will enable us to grow plants at continuously saturating CO_2 to obtain greater production in less time, but most research has been conducted at ambient or moderately elevated CO_2.

20.6.4 Secondary Metabolites Production

Secondary metabolite production is not part of the general plant response. Certain conditions like extreme weather, temperature and light spectrum produce those plant metabolites. These are reported to be highly beneficial, rich in nutraceutical, dietary value and enhanced quality. LED lighting in vertical production system could enable exposure to diverse light spectrum, helping produce of these compounds, even with short illumination before harvest. Biosynthesis and breakdown of secondary metabolites depend on light-regulated transcriptional factors (Sharath Kumar et al. 2020). For example, light-regulated transcriptional factor R2R3- MYB for phenylpropanoids (Liu et al. 2015) and phytoene synthase activity (PSY) for carotenoids (Llorente et al. 2017) are already well described. Ntagkas et al. (2018) reported that the production of this metabolite is directly linked with photosynthesis and respiration or indirectly to subsequent effects on sugar availability. Photosynthates or sugars can serve as substrates and signalling molecules for secondary metabolite biosynthesis (Sharath Kumar et al. 2020).

20.6.5 Thermomorphogenesis

Vertical farming grows compact plants. In this system, diel temperature patterns, i.e. more temperature in night than day temperature or specific light spectra needed for particular growth could provide dense plant growth (Sharath Kumar et al. 2020). It is already known that PhyB acts as a thermosensor and PIF4 is a transcription factor serving as a central regulator of thermomorphogenesis (Casal and Balasubramanian 2019). The morphogenesis of any plant is a result of interaction of light spectra, photoperiod and temperature (Sharath Kumar et al. 2020). Temperature in vertical farming must be adopted based on the crop grown and its growth stage.

20.7 Proposed Design of Vertical Farm

The design and working principles of vertical farm are numerous. There are also many types of vertical farms and prototypes. Here is a generalized design for a vertical garden proposed by the authors. This vertical farm consists of the desired numbers of growing beds constructed under a highly controlled and automated greenhouse. For raising plants, the vertical trays (in hydroponics) or the bed (in drip system; as shown in Fig. 20.3) is used. The laterals from the submain line

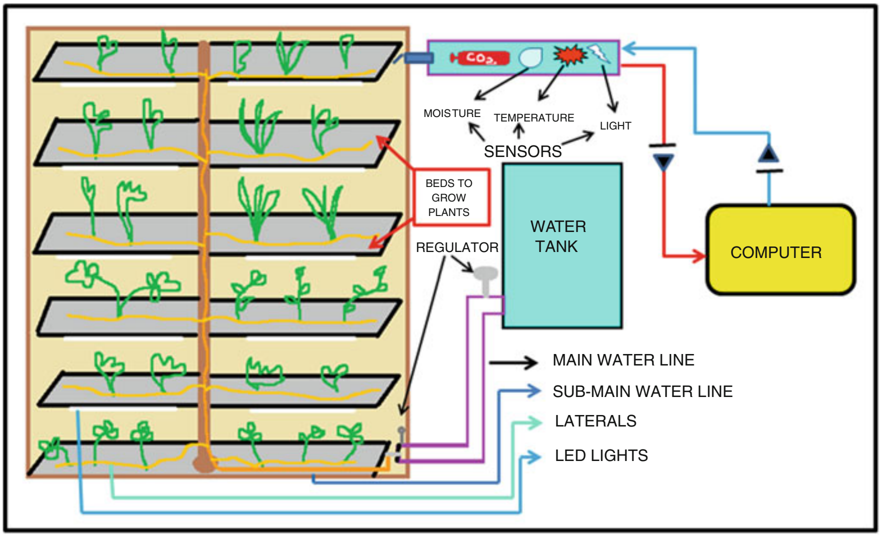

Fig. 20.3 Proposed model of an automated vertical garden design (drawn by author)

are spread on the bed with a sufficient number of emitters placed at equal distances. Plants are fed with the nutrient solution as fertigation at frequent intervals. The greenhouse or farm has sensors to detect humidity, plant root zone moisture, temperature, CO_2 concentration and light intensity and can be modified to any desired level using computer programs. LED lights provide even and specific distribution of light for each crop growth stage. Energy must be harvested from renewable energy sources for maximum economy. Crop residue might be composted or used to generate hydro energy by burning.

20.8 Sources of Photosystem and Importance of Green Energy

Vertical farming needs artificial lightning as irradiance is plentiful in the upper growing bed but decreases sharply moving down in the beds. Various sources of energy like electricity, solar energy, wind energy or hydro energy will fulfil the desired light requirement in the farm. LED technology is the best for artificial lighting as it emits a low level of thermal radiation, contains no hot electrodes and no high-voltage ballasts. LED also has a long operating life that makes it a practical alternative for long-term use like vertical farming. Most importantly, it is possible to modify the irradiation output to approximate the peak absorption zone of chlorophyll. Furthermore, LED can be operated in a shutter sequence to save power. A shutter sequence means LED is frequently turned on and off with a defined frequency. Investigation in plant response has shown shuttering of LED do not affect plant growth and development but can drastically reduce required electrical energy (NASA 2004). Green energy referrers to energy with zero pollution. That includes the solar energy, wind energy or hydro energy. A highly automated greenhouse requires more energy. Non-renewable sources are diminishing at a rapid rate. Adoption of green energy could minimize electricity cost and simultaneously reduce environmental pollution. The efficiency of green energy to operate and illuminate the vertical farm needs research and development.

20.9 Is Vertical Farm Viable?

The viability of any business depends on work environment, functioning and efficiency. To consider farm viability in present context, a discussion of vertical farm establishment and advantages follows with a conclusion concerning long-term viability.

20.9.1 Why Vertical Farming Must Be Adopted?

Adaptation of vertical farming is a means to cope with land degradation, climate change, the need for sustainable farming, demand for quality food, providing local food security and increasing cultivable land. Selected consideration of future food production issues follows with a detailed description.

20.9.1.1 Climate Change

Climate change is a major factor contributing to the reduction of arable land. Both natural disasters like flooding, hurricane, storms, drought and man-made hindrances such as over use of fertilizers and agrochemicals decrease valuable agricultural land drastically, thereby damaging the global economy (Despommier 2010; Muller et al. 2017; UN 2017; Kalantari et al. 2017). Climate change and adverse weather conditions are present today and might occur at an increased rate in the future. Over time, these events might render arable land useless for farming. Prioritization of productivity over sustainability has left the soil simultaneously hungry and thirsty. Popularity and provision of crop insurance subsidies by government following natural catastrophes might help traditional farms to plan outside the current scenario (Sanye-Mengual et al. 2013; Thomaier et al. 2015; Padmavathy and Poyyamoli 2016). Traditional farming requires more fossil fuel, more manpower and more human interventions to conduct agricultural operations. Traditional farming faces problems of pest management and low productivity. Distance travelled by crops or "food miles" contributes to environmental pollution and reduces food freshness. On average, food travels 1500 miles from farm to dining table (Despommier 2013; Astee and Kishnani 2010). A study conducted during 2008 at Carnegie Mellon concluded food delivery is responsible for 0.4 tons of carbon dioxide emissions per household per year (FAO 2013). Sadly, resulting greenhouse gas emissions from food transport and agricultural activities have contributed enormously to climate change. Adaptation of indoor gardening and roof top gardening with vertical technology or vertical farms in urban and semi-urban areas carries the possibility of minimizing these effects.

20.9.1.2 Ecosystem Sustainability

Over millions of years, traditional agriculture is believed to infringe upon natural ecosystems. Over-cultivation is believed to be a primary cause of soil erosion. Dickson Despommier states, “Farming has upset more ecological processes than anything else which is the most destructive process on earth”. Brazilian rainforests recorded noticeable impact with around 1,812,992 km^2 of hardwood forest being destroyed for farmland (Corvalan et al. 2005) over the past half century or so. According to Despommier, encroachment on ancient ecosystems leads to climate change. As a consequence, indoor vertical farming could substantially reduce the harmful agricultural impact on ecosystems by conservation and restoration of biodiversity and reduction of harmful influences on climate change. According to Al-Kodmany (2018b), urban vertical farms producing merely 10% of the ground area they consume might reduce CO_2 emissions enough to sustain long-term biosphere improvement. Fertilizer runoff and pesticide residue would not hamper the ecosystem and its organism. Wood et al. (2001) summarizes this point stating, “The best reason to consider converting most food production to vertical farming is the promise of restoring the services and functions of ecosystems”.

20.9.1.3 Food Security

Food security has become an increasingly important issue in recent days. Demographers anticipate a dramatic increase in the urban population as a consequence of job migration and quality lifestyle. Land specialists viz., agronomists, ecologists and geologists warn of rising farmland shortages (Corvalan et al. 2005; Healy and Rosenberg 2013; Thomaier et al. 2015) with the potential for demand surpassing supply resulting in global hunger. The United Nation (UN) estimates a 40% increase in world’s population, exceeding 9 billion people by 2050 (UN 2017). The UN report also projects 6 billion people will reside in cities by that time. Again to feed an increased population of 60% (Tilman et al. 2002; Green et al. 2005; Alexandratos and Bruinsma 2012) requires 70% (UN 2017) increase in food production. Food prices have skyrocketed in past decades and have the potential increase as a result of the COVID-19 pandemic. Farmers predict increased prices due to in climbing oil costs and decreased availability of water, energy, farmland and agricultural resources (Despommier 2010, 2013, 2014; Touliatos et al. 2016). The logic of vertical farming is very simple, i.e. to produce more food on less land (Touliatos et al. 2016; Muller et al. 2017), with the same concept in which we prepare our buildings. Adaptation of vertical farming could provide easy access to quality foods free from residual toxicity of agrochemicals. Efficient and sustainable production system management could help address multiple concerns arising from pollution, climate change, pest load, as it simultaneously minimizes energy use, saves water, reduces fertilizer and agrochemical use, restores ecosystems, upgrades financial status, provides employment opportunities and finally helps supply good quality foods locally (UN 2017). In general, indoor farming offers a healthier environment for food growth (Healy and Rosenberg 2013; Mukherji and Morales 2010). Since indoor farming is independent of weather conditions, year-round operations could provide greater yields and income (Katz and Bradley 2013). Indoor vertical farm could help reduce travel time, cost and subsequent greenhouse gases and other airborne pollutants (Mukherji and Morales 2010; Astee and Kishnani 2010). Food costs could decrease as a result of reductions in travel and packaging cost. Vertical farming can boost the local economies by granting job opportunities (Mukherji and Morales 2010; Healy and Rosenberg 2013), and directly help address local food security. Vertical farming also helps address the problem of farmland shortages (Corvalan et al. 2005; Healy and Rosenberg 2013; Despommier 2010). According to the United Nations' Food and Agriculture Organization (FAO), there was 0.42 ha (1 ac) of arable land per person on earth in 1961. Because of population growth and urbanization, the number had dropped by nearly half (0.23 ha or 0.5 ac) in 2002 (Healy and Rosenberg 2013). An estimated 28 m^2 of intensively farmed indoor space is enough to produce food supporting a single individual in an extra-terrestrial environment. In a space station or space colony, this supplies around 3000 kcal of energy per day (Mitchell 1994). In 2011 from the global assessment of planetary land resources, the United Nations found a quarter of arable land to be highly degraded. Dickson Despommier highlighted current agricultural supply will soon become largely inadequate for the growing population. On average, every human being needs 1500 calories daily. In order to meet such demand by 2050, an area of land equal to the size of Brazil will need to be added to existing agricultural land area (Despommier 2010). Vertical farming could be one means to consider for achieving this goal.

20.9.1.4 Health

Conventional farming stresses the economics of agriculture causing unnecessary harm to both environment and animals (Despommier 2010, 2013; Touliatos et al. 2016). Current processes depend on use of highly toxic agrochemicals *viz.*, fertilizers, fungicides, synthetic growth regulators, insecticide and other chemicals having residual impact. These practices repeatedly cause erosion, contaminate soil and generate excessive waste water. Regarding human well-being, the World Health Organization has determined that over half of the world's farms still use raw animal waste as fertilizer which may attract flies and may contain weed seeds or disease transmissible to plants (Al-Kodmany 2018a). Consequently, these practices compound negative health outcomes for people consuming such produce. Crops grown in controlled indoor environments could reduce excessive use of pesticide and herbicide to reduce risk of agricultural runoff pollutants. In a contained environment, pests, pathogens and weeds have a much harder time infiltrating and destroying crops. When excessive fertilizer nitrogen and phosphorous compounds wash into water bodies (e.g. rivers, streams and oceans), a high concentration of nutrients is created (called eutrophication). This disturbs ecological equilibrium causing dead aquatic zones (Despommier 2013). As of 2008, there were 405 dead zones counted around the world. Further, indoor vertical farming employs high-tech growing methods using little water (about 1/10th of that used in traditional farming) by offering precision irrigation and efficient scheduling (Wood et al. 2001). This significantly minimized fertilizer erosion to water bodies, diminished environmental pollution. An ameliorative effect is predicted, since demands on water increase as urban populations grow. As use of agrochemicals, pesticides and herbicide is reduced, pesticide residual toxicity concerns will diminish and provide consumers with healthy, nutritious food. Urban or semi-urban vertical farming preserves produce integrity as vegetables and fruits require less time to transportation and more time to provide fresh foods.

20.9.1.5 Urban Density and Food Production System

Vertical farming offers numerous advantages over horizontal or conventional farming. It offers more land for non-agricultural activities viz., housing, services and amenities (Despommier 2010). Urban areas are overloaded with population numbers, and there is less available arable land. The vertical farming concept could reduce pressure for land requirements for agricultural activities. Low density populations incur higher energy use and generate more air and water pollution. Serious steps are needed to feed a rising global population by 2050 requiring around 2.1 billion acres of land (Despommier 2009). Despommier suggested the space efficiency of vertical farms that a 30-story building of about 100 m high with a basal area of 2.02 ha (5 ac) would be able to produce a crop yield equivalent to 971.2 ha (2400 ac) of conventional horizontal farming around 480 times greater than the conventional farming method. The above example shows production of one high-rise farm is manyfold than conventional horizontal farms, which could produce several times more than horizontal farms.

20.9.1.6 Efficiency and Economics

Vertical farm could yield competitive food prices (Al-Kodmany 2016). The urban vertical garden may provide both jobs to support the local economy and quality foods to the neighbourhood. In certain instances, the food from these gardens would be sold locally without middlemen and rigorous transportation from production to distribution site. This transport cost constitutes a greater amount, up to 60%, of the final product price (Al-Kodmany 2016). The increasing expense of traditional farming is quickly narrowing the cost gap. For example, when vertical farms are located strategically in urban areas, it would be possible to sell produce directly to the consumer, reducing transportation costs by removing the intermediary. Start-up costs and site selection of vertical farming systems have been major constraints (Benke and Tomkins 2017), causing recent demand for streamlined government policies and intervention. Use of advance technology and intensive farming methods in these types of farms can exponentially increase production. As this technology is new, researchers have been engaged in optimizing indoor vertical farming by consideration of a wide range of variables including light intensity, light colour or spectrum, space, temperature, crop shoot and root, CO_2 contents, soil, water and air humidity (Harris 1992; Al-Kodmany 2016), etc. Abandoned, old or unused urban buildings could be converted into vertical farms to provide healthy food in neighbourhoods where fresh produce is limited. Finally, this farming technology could reconnect urban people with nature through the activity of farming (Al-Kodmany 2016). Use of advanced technology like full automation can make this farming fun and increase yield. Banerjee and Adenaeuer (2014) declared land productivity of vertical farming to be double that of traditional agriculture. With only 0.25 ha, a farm was built and recorded an increase of 516-fold in total yield compared to traditional agriculture through stacking production. In total, this leads to an estimated production of 3573 tons of edible fruit and vegetables.

Depending on the present scenario of fluctuating calamities, health consciousness, need for sustainable farming, personal economy and present and futuristic demand for food security could emphasize the need for vertical farming. Though this is an emerging technology, it still has a prominent impact on young minds. The present cost of construction for vertical farms is a concern. Scientific intervention is needed to standardize this to low-cost technology which should be region specific. Recent agriculture technology, streamlined research, technology transfer and field trials could make vertical farming a huge success. A fully enclosed and controlled environment and complete or partially automated system to monitor the crop growth and environmental parameters like humidity, CO_2 concentration, temperature and light make this technology a long-run prospect for sustainability.

20.9.2 Benefits of Adopting Vertical Farming

The following are few listed benefits of adopting vertical farming technology.

- More crop per space, as the vertical space is judiciously being used for raising more crops.
- More crop productivity or increased production per resources used.
- Year round yield for indoor or greenhouse growth condition.
- Full control over the plant growth using desired light, nutrient, moisture and CO_2.
- Minimized use of dangerous agrochemicals to stabilized climates and ecosystems.
- Reduced global carbon foot print when located at urban or semi-urban localities.
- Improved quality of food to boost healthy life.
- Less labour force, as this technology performs better in automated controlled conditions.
- Less crop loss as a result of natural calamities, invasion by insect, pests, diseases and weeds are minimized.
- Reduced transportation cost for local produce to benefit consumers, grow local economies and reduce environmental emissions.
- Protect crops from weather-related problems as well as pests and diseases.
- Minimize agricultural water requirements.

20.9.3 Demerits in Vertical Farming

Though this farming has numerous prospects, some shortfalls are listed here.

- Requires significant financial investment.
- Profit of this system depends directly on the patience of the grower.
- Supply of electricity 365 × 7 × 24 is a must that could be filled by installing various renewable sources.
- Disease may spread quickly through any closed system and result in 100% crop loss.
- Requires well-trained technical staff, as most of the operations are highly advanced.
- Direct marketing is possible in urban, but rural or peri-urban areas require an investment for marketing.
- Selection of crop on the basis of local demand, feasibility of growing structure must be worked out prior to installation.
- Structural integrity of the vertical frame work needs research and standardization, because frames are prone to humidity damage or rust in long run due to the controlled climate.

20.10 Insect and Pest Concern Under Vertical Farm

The vertical farm is an enclosed space, which restricts the entry or growth of harmful pests. Farming conditions are clean and maintain sanitary conditions. Crop residues are removed from the greenhouse. In total, the plant growth process begins in laboratory conditions and ends the same. For example, selected seeds are inspected and treated in laboratory conditions, grown in humid chambers and taken directly to the environmentally controlled greenhouse for planting in the vertical farm. So, there is very little chance of contamination. The entire process of farming is carried out in an organic manner (Kalantari et al. 2018). One advantage of vertical farms is significant reduction or omission of agrochemicals. Attempts can be made to find natural solutions for problems, by utilizing useful insects, i.e. predators. As previously mentioned, all vertical farms benefit from controlled conditions void of hazardous pests (Despommier 2010, 2011; Ellingsen and Despommier 2008; Germer et al. 2011) eliminating the need for pesticides. In the vertical farm, there is no need for burning fields, grass or waste for pest control, other methods of pest control can be employed. All materials are sanitized or washed prior to use. Frequent checks control the spreading of harmful organisms before they spread in the closed environment. Water may act as a contamination source and must be treated before use.

20.11 Recent Advancement

New horizons in agriculture are generally slow to emerge but to keep pace with exponential growth potential of any green revolution the grower can efficiently modify systems as he becomes acquainted with them. In the recent past industry, advances are rising to support this emerging technology. However, vertical farming is still not a common grow practice. Many industries have tried various crops (Table 20.2) and gained good results. Again this technology needs specificity in terms of locality, crops, climate, economy and more.

20.12 Conclusion

Vertical Farming is an emerging technology with huge potential for increasing crop production per unit land area in response to the pressure of population growth on agricultural production. The design, layout and configuration of these high-tech farms would provide optimal light exposure, along with precisely measured nutrients for each plant, designed to grow in a controlled, closed-loop environment. These farms would eliminate the need for harmful herbicides and pesticides, maximizing nutrition and food value in the product produced. Vertical culture in a protected structure could also enhance the taste of produce to cater to consumers preferences. In horticultural crops like berries, green leafy vegetables, spinach and some crucifers, this technique is already adopted, providing a tremendous result in terms of yield, quality and sustained production. Vertical farming is an expensive method for growing crops on designated bed, under the greenhouse or controlled environment. A combined technical approach is required to accommodate factors including lighting, growing system, crop nutrition, energy efficiency, construction and site

Table 20.2 Crops selected for growing under vertical farming system

Sl. No.	Crop	References
1	Micro greens	Growing Underground (2020), Verti Crop (2020)
2	Salad leaves	Growing Underground (2020), AeroFarms (2020), Verti Crop (2020)
3	Strawberry (*Fragaria* spp.)	Murthy et al. (2016), Saturn Bioponics (2020), Verti Crop (2020)
4	Lettuce (*Lactuca sativa*)	Sky Greens (2020), Touliatos et al. (2016), Saturn Bioponics (2020)
5	Spinach (*Spinacia oleracea*)	Sky Greens (2020)
6	Tropical leafy vegetables	Sky Greens (2020)
7	Assorted leafy vegetables	Song et al. (2018)
8	Culinary herbs	Saturn Bioponics (2020), Verti Crop (2020)

selection. This system has been shown to have a huge potential for the production of a wide range of crops but technical and economic optimizations are required. Research regarding maximized productivity and system cost reduction is in the forefront. Though start-up costs are high, increased input cost can be overcome by increased productivity. Scientists are looking to modify economic aspects of this technology. Indoor horticulture production systems can be boosted by advanced and automated vertical farming techniques to fulfil the current prospect of adaptive organic farming while concurrently improving soil health and maintaining sustainable farms.

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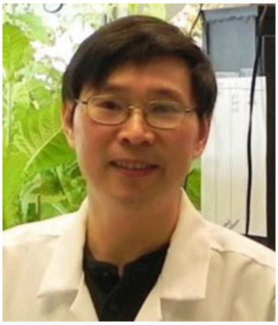

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