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Entrepreneurship in Urban Jungles through High-Tech Vertical Farming

Suaad Jassem and Mohammad Rezaur Razzak

Abstract

Demographic movements forecasted by the United Nations indicates that, over the next few decades greater portion of people will be concentrated in and around large cities of the world. Such population dynamics in parallel with emerging phenomena such as global pandemics and impact of climate change are posing threats to the supply chain of agricultural production. The reliance on traditional open-field cultivation and transportation of fresh products to distant urban locations are coming under threat. This has been further exposed by the current pandemic (Covid-19) that is impeding farm production along with movement of people and goods. A viable solution lies in vertical in-door farming driven by advanced technologies. The use of high-tech solutions to grow vegetables, fruits and flowers close to consumption centers has taken off successfully in many locations around the world. However, majority of such projects have been set up by investors; with access to substantial capital. In order to mitigate the possibilities of food shortages in densely populated cities, initiatives need to be undertaken to foster growth of large-scale entrepreneurship by individuals that can venture into this field on a smaller scale and with less capital outlay.

Keywords: vertical farming, indoor farming, high-tech farming

1. Introduction

In 2015, the United Nations, committed to end “World Hunger” by 2030, as one of its Sustainable Development Goals. However, two converging phenomena are driving the likelihood of major implications for urban planners in terms of achieving such a goal [1]. The first is the fact that concentration of people in the world’s urban centers is witnessing a dramatic rise. According to recent estimates by the United Nations Fund for Population Action, by the year 2050 over 9 billion people are forecasted to be residing in urban centers [2]. It is estimated the rise in urban population will dramatically increase the demand for food, and considering the impact of climate change and reduction in arable land for cultivation, there is likelihood of food shortages [3]. Furthermore, the economic disparity between rural and urban dwellers is also expected to drive younger people from rural farming communities, to seek better lifestyles in large cities, rather than continue on the footsteps of their predecessors [4]. This trend is already having an impact on availability of farm workers in rural communities in countries such as China, Thailand, Vietnam and India [5].

The second phenomenon is a more recent manifestation that is the global pandemic in 2020 attributed to the nouvelle coronavirus (Covid-19) that has brought about unprecedented changes in socioeconomic order of human society, with greater impact on people residing in crowded urban centers [1]. The pandemic severely impacted distribution of fresh products from farms to centers of consumption. Additionally, in many countries such as USA, the lockdown prevented farm workers to work in the fields, which led farmers to destroy large portion of their crops [6].

A recently published study in *The Lancet* indicates that future occurrences of virus-borne diseases will evolve and continue to emerge in rapid succession [7], while the movement of people looking for better economic opportunities will increase pressure on large cities to accommodate more influx of such people, thus driving them into urban concrete jungles [8].

One of the major fallouts of above two converging trends will show up in the disruption of food supply chains, thus impacting food security [9]. Particularly, demand for fresh perishable products (e.g., vegetables and certain types of fruits) will be difficult to cope with [10]. The economic prosperity that are expected to drive growth of urban jungles will also increase demand for transporting people and goods, thus creating severe traffic congestions making the situation more dire [8]. The time taken to transport fresh food items and the corresponding cost of transportation from far away farms will render the supply of such products from distant locations less feasible.

One sustainable solution to ensuring reliable fresh products supply within urban jungles could be through vertical farming in unutilized urban spaces using some of the technologies that have been developed for urban centers [11]. Some of the latest advances in vertical farming technology are driven by advanced hyper-connected systems aligned with technologies that drive Industry 4.0 (such as AI and IoT) [12]. These emerging technology applications in agriculture are also driving down capital cost of in-door farms that can be set up in small spaces.

The large concentration of people in major metropolises is likely to create pressure on availability of horizontal space, making them prohibitively expensive to use for agriculture [13]. Ironically, however it appears that one of the scarcest resources in large cities, idle space, is also widely available in the form of vertical space in most large cities, but out of the view of most people [14]. For instance, there are many abandoned warehouses, underground structures underneath tall skyscrapers, rooftops, underground shelters beneath railway stations, unutilized factory spaces, unused space at stadiums and government buildings, parking lots, etc. These spaces may be used for installing self-contained vertical farms in controlled environments [11].

The goal of this chapter is to present emerging entrepreneurship opportunities through vertical farming in unutilized spaces in crowded cities around the world (interchangeably referred to as urban jungles in this study). The chapter starts by presenting a description of vertical farming along with an overview of technologies that are presently driving them, followed by discourse on advantages and disadvantages of vertical farming based on economic, social and environmental impact. The following section presents some of the challenges faced by entrepreneurs that have ventured into the business of vertical farming in urban spaces. Finally, the chapter discusses several cases related to the different models of vertical farming being implemented around the world. These models are expected to serve as potential roadmaps for tech-savvy youth that will be entering the job market over the next few decades. Such educated workforce may be incentivized to consider entrepreneurial forays into the field of high-tech vertical urban farming.

2. Vertical farming

The concept of vertical farming on a domestic scale has been around for quite some time; however, the modern concept of vertical farming on a commercial scale using advanced technologies is relatively recent. It represents the application of technology in controlled environments to grow agricultural plants such as vegetables, fruits and flowers [11]. Such farming techniques have been applied using abandoned ocean shipping containers where empty space is available, and also inside buildings such as abandoned warehouses, environmentally damaged land space, underground or rooftops of structures of existing buildings, in dilapidated buildings and even under railway stations [15]. In general, such farming can be done in any unutilized space whether the space is in a closed or open environment [16].

2.1 Classification based on technology

Although the approach to vertical farming comes in different sizes and shapes, one common factor is that they all grow plants without soil and use the height of a structure effectively in growing such plants. The plants are supplied with nutrients mainly through three systems: hydroponics, aeroponics and aquaponics [13]. Each system is contained inside an environment where the amount of light, temperature and supply of nutrients is controlled based on the type of plant that is being grown. Multiple layers of plant-beds are stacked parallelly above each bed, thus making best use of vertical rather than horizontal space [17]. Such environments are usually free of insects, weeds and pests thus allowing the plants to grow without any damage [18].

2.1.1 Hydroponics

The application of modern hydroponics is credited to a California based scientist, Willaim F. Gerrick about 100 years ago [19]. The system utilizes water as a base for the roots of the plants where the fluid is filled with the optimum balance of nutrients required for the plants to grow. The present-day application of hydroponics uses computerized systems to control the nutrient solution in which the base of each plant is submerged. The plants do not require any inert media to support them such as sand or gravel (see **Figure 1**).

The hydroponics method has relatively low maintenance cost as it does not require tilling, soil removal, fertilizers, etc. The water is recycled, and the composition of the nutrients including oxygen is controlled by automatic feedback loops. Depending on which vegetable or fruit is to be grown, the nutrient solution is controlled by computer software with customized settings for each type of crop [12].

2.1.2 Aeroponics

In 1990, NASA worked to develop a system to substitute soil for a spray of nutrient rich mixture of air and mist so that astronauts on missions to space stations can grow their own food [12]. Aeroponics is considered a technological leap forward in high-tech farming [20]. In fact, while hydroponics uses water solution as a growing medium, aeroponics does not require a growing medium. The mist that is sprayed over the roots is sufficient to enable the plant to grow in a healthy manner (See **Figure 2**) [11].

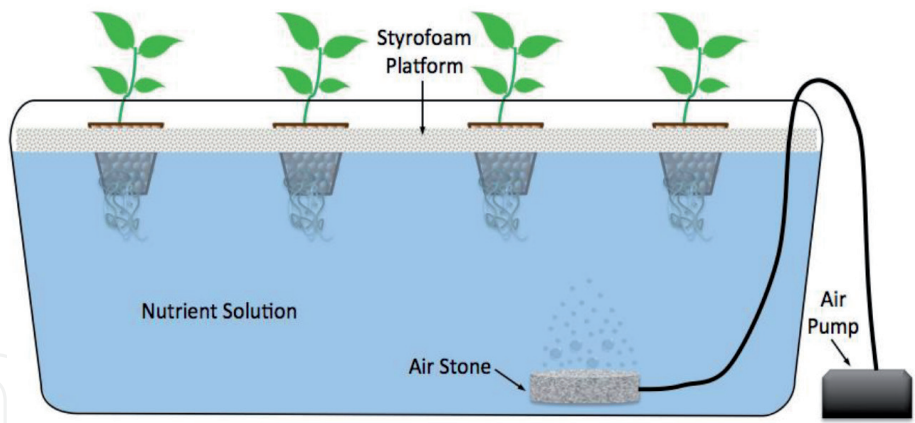


Figure 1.
Illustration of a basic hydroponic system. Source: [20].

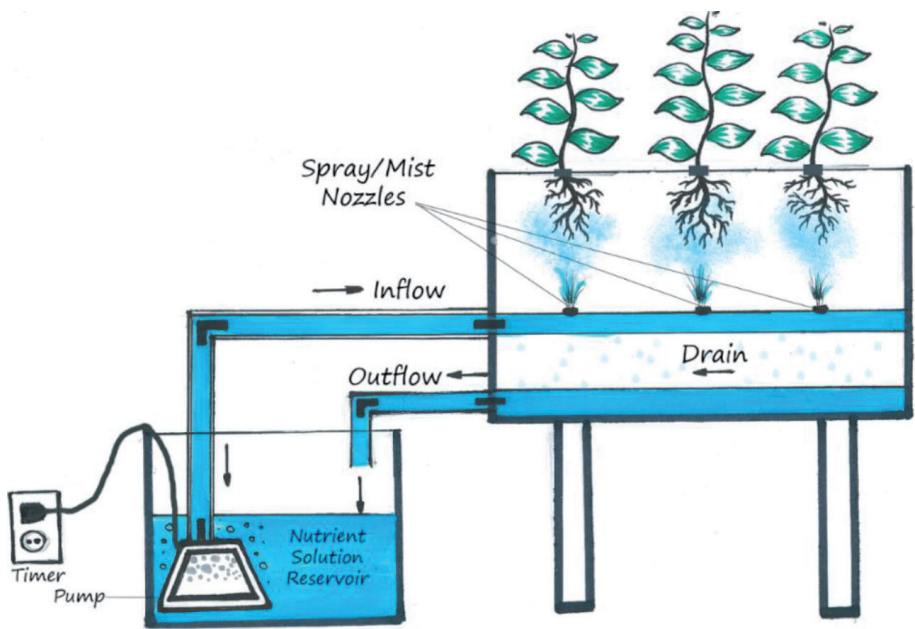


Figure 2.
Illustration of a basic aeroponic system. Source: [12].

The technology has now been commercialized and is used by pioneering companies such as Aero-Farms in USA. The system is revolutionary because it uses 90% less water than hydroponics. Plants grown with aeroponics technology have shown to have higher uptake of vitamins and other essential minerals such as potassium and magnesium required for healthy human bodies. This technology is now widely applied in arid regions of the world where water is scarce and costly to provide such as hot places in the Middle East and extremely cold places such as Antarctica [21] .

2.1.3 Aquaponics

This system differs from hydroponics because, the water solution where the plants are submerged, are also used to grow certain variety of fish (such as tilapia and perch) that thrive in such an environment [22]. In fact, the fish and the plants have a symbiotic relationship, where the waste produced by the fish serve as a natural source of organic fertilizer for plants, and in return the plants purify the water from the waste. Typically, aquaponics requires substantially more water supply than hydroponics. However, the additional cost of supplying water to

aquaponic systems is made up through the availability of two kinds of cash crops, vegetables and fish [6]. The diagram in **Figure 3** shows a basic aquaponic system.

2.2 Classification based on structure

Vertical farming can also be classified based on the type of structure they are housed in. Two of the most popular structures are: (i) building-based vertical farms and (ii) shipping-container vertical farms [23] .

2.2.1 Building-based vertical farms

Such farms are situated inside abandoned warehouses and buildings, new buildings in the basement or rooftops, unused basement parking space, abandoned subway stations, etc. The spaces occupied for the farming projects are closed and controlled through special HVAC systems and LED lighting [24]. Once the environment is built and vegetables are planted, the system requires minimum human involvement during the growth stage of the vegetables. Human labor is involved only during picking the vegetables and packing, and for re-plantation [25].

A new trend in such farming has also been initiated where such farms are set up close to large hypermarkets, restaurants and hotels that have a daily requirement for large amounts of fresh products such as leafy green vegetables, tomatoes, cucumbers, etc. For the customers, the proximity of the farms to the customers reduces transport cost, inventory cost and also ensures that extremely fresh products that are available 24/7 (see **Figure 4**). For the farmers, they have ready customers close by that will buy their daily production.

2.2.2 Shipping-container vertical farms

This type of structure has become quite popular mainly due to the mobility offered by such a system. Basically, 40-foot ocean shipping containers are refurbished with drip irrigation, lighting and HVAC systems controlled by computers. These containers can be moved into any space where the containers can fit into

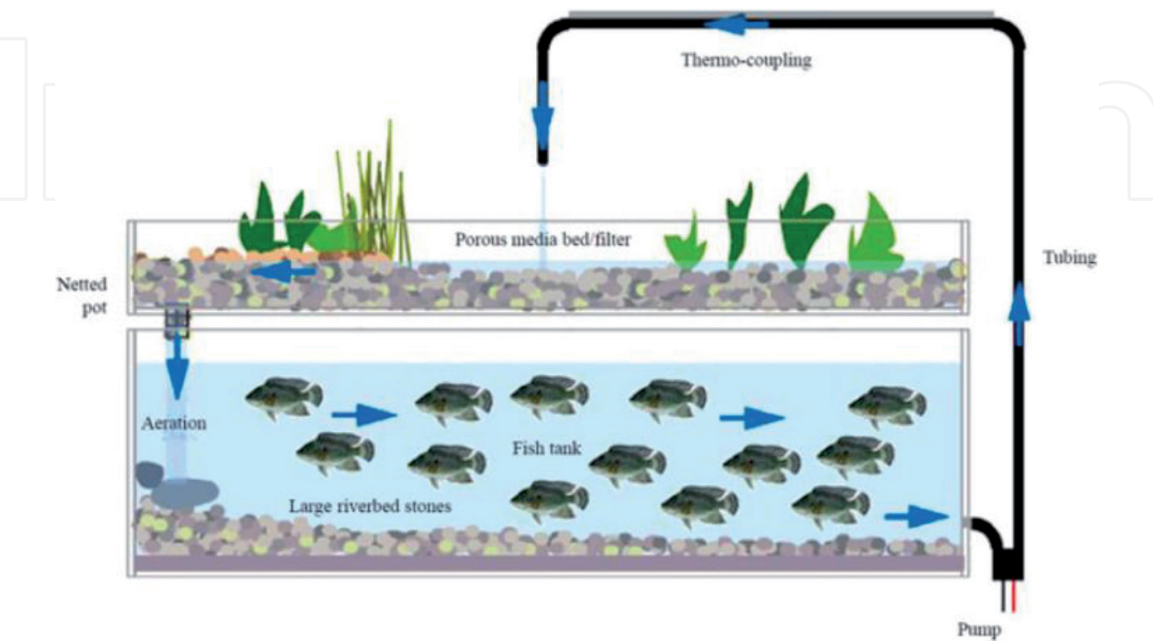


Figure 3.
Illustration of a basic aquaponic system. Source: [6].

smaller spaces such as empty car parking lots, environmentally damaged land spaces, or even in places where the weather is harsh such as deserts or extremely cold places. Such structures can also be moved to places where there are military bases on large groups of people residing temporarily (see **Figure 5**).

2.3 Advantages and disadvantages of vertical farming

2.3.1 Advantages

Vertical high-tech in-door farming has numerous advantages over traditional open field horizontal cultivation. Traditional cultivation requires vast amount of arable space where large equipment such as tractors that run on fossil fuel are required, along with large quantity of farm workers. Furthermore, the open-field cultivation requires synthetically produced chemicals such as urea-based and phosphate-based fertilizers that over a period of time diminish the land’s ability to



Figure 4.
Vertical farm housed inside a commercial building. Source: [26].



Figure 5.
A vertical farm inside a shipping container. Source: [27].

sustain crops. Most agricultural lands are developed by destroying forests, such as in Brazil where the Amazon rain forests are reduced each year to create for space for planting agricultural products. This not only contributes to displacements of indigenous flora and fauna, but also contributes to global warming [28] .

Additionally, the yield per meter-square from open field cultivation is much lower than that of vertical farming [29]. Open field crops are susceptible to weeds, pests and adverse weather conditions. Finally, products such as vegetables need to be transported a long distance from the fields to urban centers thus increasing fuel consumption and other related costs factors.

In contrast, high-tech vertical farming has several advantages as noted below:

- i. The most obvious advantage of vertical farming is the relatively small amount of horizontal space required to produce multiple varieties of fresh crops (e.g., vegetables, flowers and certain variety of fruits) in the same space. Vertical farming on the other hand enables utilization of unused vertical space in urban centers where typically horizontal space is an expensive resource.
- ii. The system ensures that crop production can be done round the year even in harsh weather conditions. In fact, in dry arid places with plenty of sunshine, the energy needed to operate the equipment inside the system can be run on solar power, thus reducing dependence on electricity from the power grid.
- iii. This type of farming does not require use of pesticides and herbicides as they are in closed environments. As a result, the products are free of toxins.
- iv. Unlike open-field cultivation, vertical farming does not require too many farm workers to be present all the time. Finally, the environment within vertical farming enclosures, are typically safer for people compared to open field cultivation.
- v. Entrepreneurs can conduct market feasibility and locate their farms close to the market centers where the products can be sold quickly after plucking them without having to preserve them. This is a great value proposition for both the buyer and seller, as buyers do not need to maintain large inventories, and the time and cost of transporting the products to the retailers is much lower.
- vi. Finally, application of advanced technologies, enable people to get real-time feedback on the plants in terms of their stage of growth, health and available finished goods inventory.

2.3.2 Disadvantages

The vertical in-door farms nevertheless have some disadvantages also:

- i. The first disadvantage of vertical farming in urban metropolises is the availability of space. Horizontal space in crowded cities, are typically a costly resource. Nevertheless, due to closure of manufacturing industries in places like United States and Western Europe, substantial amount of space is becoming available for alternative uses such as indoor farming. However, in cities that are on a high economic growth trajectory such as cities in Asia: Shanghai, Shenzhen, Singapore, Taipei, Tokyo, etc., it would be very

difficult to find sufficient horizontal space to establish such farming projects (except for vertical and roof-top farming).

- ii. Second, the consumption of energy and water are quite high, and can prove to be prohibitive in certain cities unless the government subsidizes the electricity tariff for such projects, or there is access to renewable energy sources such as solar power.
- iii. In order to compete with traditional farm cultivated products, the present vertical farms are promoting their products as organic, as they do not use pesticides and herbicides. However, in some countries they face obstacles due to government regulations to promote their products as organic. For instance, the USDA (US Department of Agriculture) is very stringent in certifying such products as organic because the nutrients used are not completely organic. The present definition of organic products according to agencies such as the USDA is much wider, that includes systems that promote biodiversity and biological cycles.
- iv. Another limitation of vertical farming is that they can offer a limited range of products that have quick turnover cycles such as leafy greens, cauliflower, tomatoes, bell pepper, eggplants, strawberry, etc., while producing grains is not feasible.
- v. Finally, since insects are excluded from the environment, there is no natural pollination. Hence, pollination has to be done by human hands, thus requiring workers for this purpose. Although, new technology is being developed to use insect drones to do the pollination.

3. High-tech vertical farming projects

The following are three large scale high-tech vertical farming projects depict how these farms are being managed for producing high-yield fresh products:

3.1 Green spirit farms

The Green Spirit Farms (GSF) first project was established in 2011 in an abandoned plastic factory in Buffalo, New York. The project has been set on a 44,000 square-feet built-up space. Currently, GSF's business model is to locate abandoned commercial and industrial buildings and set up their vertical farming projects through long-term lease agreements with the building owners. The company enters into these spaces and sets up their farming project through agreements with equipment suppliers on the basis of pay-as-your-earn. Therefore, GSF sets up vertical farms without much initial capital investments in structures and equipment, which allows them to focus on their core competency, that is to be a provider of fresh non-GMO (genetically modified) high-value products such as kale, basil, peppers, stevia, spinach, brussels sprouts, tomatoes, strawberries, etc. They select locations that are close to large-scale customers such as hotels, fresh products wholesale markets and major urban centers. Besides, selling farm products inside the United States, due to the proximity of their farm sites to the Canadian border, they are also able to service customers in Ontario, Canada [26].

GSF mostly utilizes hydroponics technology such as Rotary Vertical Growing Stations (RVGS) that has a high level of efficiency in terms of use of water and

energy. In fact, GSF claims to use 90% less land, 80% less water and 40% electricity compared to conventional hydroponics farms [11]. The company has received strong support from state and federal agencies through public-private partnerships in the United States for having high social and environmental impact. The company has not only created employment in the local communities, but it has also fostered development of small entrepreneurs who are service providers in terms of food delivery, supply of chemical nutrients, maintenance of facilities, etc. Among the most lasting social impacts is the availability of fresh products throughout the year within a range of 75 km from any of their facilities [11].

3.2 Plenty farms

The company was set up in 2015 in Seattle, Washington with investment from Jeff Bezos of Amazon [30]. Plenty is one of the few companies in this business that has received a USDA certification as an organic food supplier. The company sells large quantity of its products to retail chains such as Whole Foods and Good Food. In fact, the company claims to be providing 6% of all the fresh products in the greater Seattle area [31]. The technology adopted by the company uses hybridized technology combining aeroponics and aquaponics. The project is housed on a space of 100,000 square-feet. Therefore, the company produces fresh organic products and also fish. The company uses sophisticated technology to produce large quantities of multiple varieties of fresh vegetables and fruits in the same site. The farm grows algae, which serve as feedstock for the fish, while the waste produced by the fish serves as organic fertilizer for the plants [31].

The company has recently raised additional capital for expansion from new investors such as Google's Eric Schmidt. The farm has proven to be instrumental in ensuring regular supply of fresh products and sweet water fish to supermarkets especially during the Covid-19 pandemic that hit Seattle area quite hard. Had the city relied on supplies from conventional sources such as farms in California, there would have been massive food shortages [31].

3.3 Aero-farms

This company was established in 2004 in the New Jersey area through joint collaboration between IKEA, David Chang, SoftBank and the Ruler of Dubai [32]. The \$100 Million project is the largest aeroponic farms in the world that uses state-of-the-art agricultural technologies such as AI, aerial drones, IoT and climate control technology [33]. The farm has reported yields that are 390% higher than conventional open cultivation fields. The farm has also enabled agricultural researchers to team up with engineers and scientists to experiment with some of the most sophisticated technologies in the world. The technology is now being replicated in arid regions of the world such as UAE, Qatar and Saudi Arabia in collaboration with MIT and King Abdullah University of Science and Technology by using seawater (instead of fresh water), which is abundantly available in those regions [34].

4. Challenges for entrepreneurs without access to substantial capital

The vertical farm projects described in the previous section are all fairly large-sized investments that make them highly capital intensive. Despite the fact the output of such projects has readily available markets there are numerous challenges for entrepreneurs to get into this business without having substantially deep pockets. Some of these challenges are:

4.1 High initial capital requirements

Even when space is available on lease, the initial investments in preparing the space to make it suitable for installing equipment along with arrangements for water and electricity involves substantial capital. Furthermore, the equipment used in building a controlled environment requires large investments in systems that are made by a limited number of vendors. The other initial investments are in deposits required for leasing space, deposits for obtaining commercial utility connections, permits, etc.

4.2 Reluctance of banks to fund vertical farming projects

Most commercial banks and financial institutions are typically reluctant to provide capital to small entrepreneurs entering into a new field. Banks usually look at the worst-case scenario in assessing loan applications for such projects. For example, if the business fails to meet its goals, then for the bank to recuperate their investments it would be difficult to liquidate the assets of the company.

4.3 Lack of training facilities for entrepreneurs

The operation of high-tech vertical farms requires knowledge and experience with insights into the critical aspects of managing such a business. For new entrepreneurs without exposure to such businesses it will be difficult to develop and sustain such as venture. Without availability of training facilities to prepare them it may turn out to be a risky venture for new entrepreneurs without substantially deep pockets.

4.4 High operational expenses due to cost of energy

These projects consume substantial amount of electricity due to lighting and temperature control. Current developments in renewable energy technologies are trying to bring down operational costs of such projects through recycling biomass gas produced by the plants. Nevertheless, the operating costs related to energy, water supply, equipment maintenance and chemical composition of the plant-bed (fluid base) require sufficient working capital.

4.5 Creating opportunities for entrepreneurs: less capital

Emerging smart technologies are creating opportunities for entrepreneurs who desire to venture into vertical farming with lower levels of investments. Such technologies are enabling indoor farming projects to be set up in relatively small spaces using energy efficient processes that recycle and reuse the resources deployed in the system. For instance, the new generation of LED lights is replicating the same intensity of light with significantly lower energy requirements [13]. Similarly cloud computing, SAAS (Software as a Subscription Service) and Internet of Things are enabling automation without investing heavily into computer systems [24].

Increasing demand for fresh products in urban centers and advances in innovation related to farming technology alone may not be sufficient to create viable opportunities for new individuals with limited capital who wish to commit to entrepreneurship in high-tech indoor farming. The above developments must parallelly be followed up with support from policymakers and urban planners. For instance, government-initiated programs should be channelized to such entrepreneurs through training and start-up funding. The training programs can be implemented

through business incubation initiatives managed by agencies of the government, universities and other technical instructions. Training need assessment will reveal the type of technical and management training that needs to be imparted including internship programs with established vertical farming companies.

In addition to capacity building through training, such entrepreneurial ventures should be supported with seed funding for startups followed up by financial assistance for growth. Financing for such projects will initially require subsidized soft-term lending initiatives by the government implemented through financial institutions. Once the projects gather traction and start generating revenues, they will be able to attract venture capital for further growth.

5. Conclusion

Overpopulation of urban centers around the globe calls for long-term strategies for policymakers and urban planners. In absence of measures to bolster food production close to the consumption-base there are likely to be food-shortages caused by the fallout of overcrowded cities and occasional environmental shocks due to climate change, infectious diseases, and other natural calamities. Simply relying on traditional cultivation and transporting agricultural products from distant farms to urban centers may turn out to be a recipe for disaster. The United Nations' forecast of over 9 billion people concentrated in large cities by 2050 is a matter of concern that needs proactive solutions based on innovative methods of food production and supply.

The long-term prognosis for resilience of food supply chains that depend on traditional farm cultivation also faces threats from reduction in soil fertility caused by excessive use of synthetic fertilizers. After several cycles of cultivation, the land requires time to recover as it loses its ability to support growth of plants. In this way the available land for cultivation is also getting smaller. In many countries, rain forests are being cut down to make space for crop cultivation. This practice will have an adverse impact on the environment thus further exacerbating the negative fallouts of climate change. Traditional open-field cultivation is also exposed to attacks by insects, pests and weeds where the crop needs to be protected from such attacks with the use of pesticides, herbicides and other chemicals. The toxic elements in such chemicals can seep into the underground water system with consequences for human health.

The concept of utilizing vertical space to cultivate cash crops in controlled environments, offer a viable alternative to challenges that lay ahead for traditional farming. Emerging technologies that were originally developed to support manufacturing industries (e.g., to drive Industry 4.0) are now being leveraged to drive innovations in vertical indoor farming. Such agricultural projects not only increase the yield of crops per acre, but also grow the products in close proximity to the centers of consumption, thus reducing the cost of fresh food. Furthermore, these crops are produced in environments where they are free from pests and weeds, which means they are free of harmful pesticides, making the products healthy for human consumption.

Majority of the vertical in-door farming projects around the world, were initially driven by large investors with access to substantial capital. Entrepreneurs without access to such capital find it difficult to venture into vertical farming. However, with the advent of new technological breakthroughs, it is now becoming feasible for entrepreneurs to set up such projects in smaller spaces with significantly less start-up capital. Nevertheless, several obstacles still remain that need to be addressed by public policymakers and city planners. These obstacles are mainly related to access to finance and lack of opportunities for technology transfer.

Besides the entrepreneurs being familiar with the technology and the intricacies of the business, there also needs to be availability of a large pool of human resource that are capable of working in such high-tech vertical farming projects. Therefore, programs led by public-private partnerships, government backed-support, etc. are needed to get the momentum going. The efforts from urban planners and think tanks connected to food supply resilience, need to focus on training and development of potential entrepreneurs and technical staff that can manage high-tech vertical farming, and also providing seed- and growth-funding for such entrepreneurial ventures. The future of urban jungles becoming manageable from the perspective of reliable and resilient food supply chains may depend on how entrepreneurial initiatives in vertical high-tech farming are being planned and developed by policymakers and urban planners.

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