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Review Article

Integration of Vertical Farming and Hydroponics: A Recent Agricultural Trend to Feed the Indian Urban Population in 21st Century

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Abstract

Horizontal agriculture is confronting with major challenges and the most importantly, decrease in per capita land availability as well as agricultural production. In addition to this, the two dimensional traditional farming is unable to meet the food requirements of exponentially increasing population owing to the constant land tract and rising food demand. Consequently, there is a pressing need to switch over a new concept of farming, which is known as 'Vertical farming'. The integration of vertical farming with hydroponics has added a neoteric chapter in agricultural engineering to mitigate the problem of food scarcity for the future. Vertical farming is a practice of yielding agricultural products to produce more and more food crops in small area in vertically stacked structures specifically in the urban and peri-urban regions, where shortage of agricultural land is grimmer. It may be one of the best possible ways to yield crops to meet the food demand of urban population; whereas hydroponics is a way of cultivating plants with the use of liquid nutrient solution as a growing medium and other necessary minerals to maintain the growth of plants. The inclusion of these both innovations in mainstream agriculture may increase the yield, which can meet the rising food necessities. Although in last few years, vertical farming is being practised in Japan, Singapore, Taiwan, China, Korea and the United States of America, this concept is yet to be implemented in most of the developing countries as well as in India. Hence, the paper aims to deliver pros and cons of these agricultural technologies, its economic viability and the hope of its success in Indian background. It also acts as a curtain raiser for the introduction of this method of farming with adjustments to suit the Indian context.

Keywords: Horizontal; Vertical Farming; Hydroponics; Mitigate; Liquid Nutrient

Introduction

Food is one of the vital as well as indispensable requirements to sustain the life on the earth and the history of the evolution of human civilisation revolves around the agricultural practices. The early age of the human development and agricultural activities were in embryonic phase and as the ages passed on; these all have been replaced by the scientific and technical innovations. Expansion in population and increase in human necessities are the driving forces to introduce technical advancement and modernisation to meet the needs. Rapidity in urban sprawl and global urbanisation, increasing population growth and decrease in available arable land have collectively set a platform to rapid demand of more agricultural land, food requirement in addition to this growth in agricultural research. Increase in agricultural productivity, by embracing techniques in conventional farming, is confronting with a major challenge of ceiling in food production. Intensive use of chemical fertilizers, pesticides and herbicides seem unable to boost the agricultural production and these elements are posing a great threat to the environment as well as to the human health. Loss in food crops owing to the violent form of the nature and climate change have deteriorated the situation and have made the conditions grimmer. Hence, it is a challenging task before the agricultural scientists to ensure uninterrupted and sufficient supply of nutritious, healthy and uncontaminated foodstuff to the growing population.

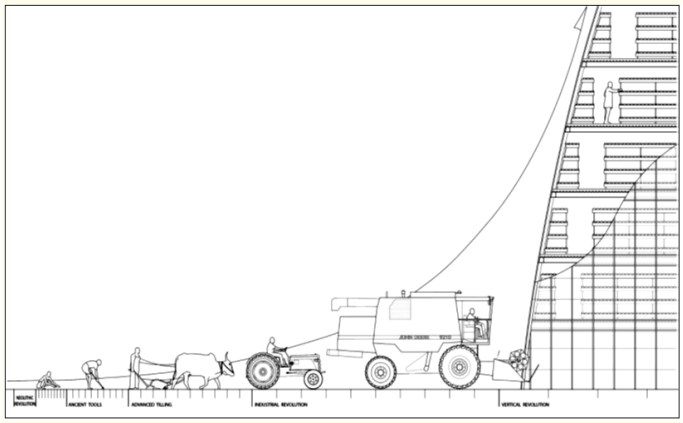

Figure 1: "Agriculture's evolution" Gordon James Graff for Sky farming.
Source: https://www.academia.edu/7655922/Vertical_Farming_Concepts_for_INDIA

According to the United Nations Department of Economic and Social Affairs (UN DESA) report the current population of the world is 7.3 billion, which could reach 9.7 billion in 2050 and 11.2 billion in 2100 [1] and approximately, 80% of world's settlements would be concentrated in and around urban areas [1]. This mounting population will create an immense pressure over to the current agricultural practices and the existing resources and huge land parcels would be required to feed the populace. The father of Vertical farming 'Dr. Dickson Despommier' claims that "An estimated 109 million hectares of new land (about 20% more land than is represented by the country of Brazil) will be needed to grow enough food to feed the world population in 2050 if conventional farming practices continue. At present, throughout the world, over 80% of the land that is suitable for raising crops is in use" [2].

India Food Banking Network's report on Hunger in India explicates that although India, with a population of over 1.2 billion, has seen tremendous growth in the past two decades and the GDP (Gross Domestic Product), the per capita consumption and the food grain production have increased by 4.5 fold, 3.0 fold and 2.0 fold respectively, yet it is unable to provide access to food to a large number of people, especially women and children [3]. According to latest FAO (Food and Agriculture Organisation of United Nations) estimates in "The State of Food Insecurity in the World, 2015" report, 194.6 million people are undernourished in India. By this measure India is home to a quarter of the undernourished population in the world.

In addition to this, the two dimensional traditional farming is unable to meet the food requirements of exponentially increasing population owing to the constant land tract and rising food demand. Therefore, vertical farming along with hydroponics may be a great substitute to alleviate the problem of food scarcity for the future. Vertical farming is one of the best possible ways to yield crops to meet the food demand of urban population; whereas hydroponics is a way of cultivating plants with use of liquid nutrient solution as a growing medium and other necessary mineral to maintain the growth of plants. The inclusion of these both innovations in mainstream agriculture may increase the yield, which can meet the rising food necessities.

Some of the developed countries i.e. Japan, Singapore, Taiwan, China, Korea and United States of America are practicing vertical farming, but the scenario in developing nations is little different. These nations are confronting with shortage of financial assistance along with the lack of technical advancement. Consequently, this concept is yet to be implemented in most of the developing countries as well as in India and unfortunately the problem of malnutrition and starvation is more severe in these countries than the developed one.

In this context, to defeat the battle of food insufficiency, well-designed farms that utilize space vertically rather than horizontally, can eliminate the pressure on an already overburdened earth and can help to create a cleaner environment in urban areas [4]. Hydroponics and Aeroponics are the major technologies, which are employed in vertical farming to grow food crops in vertical stacks with the use of liquid nutrients in a controlled atmosphere, created in membrane, made of Ethylene tetraflouro ethylene translucent plastic. Besides meeting the food requirements, vertical farming and hydroponics can lessen the loss created by environmental extremes.

Objectives

Practices of vertical farming on a large scale has not been noticed in India so far, but some government and non-government organisations such as Indian Council of Agricultural Research (ICAR), New Delhi and Vertical Farming Association (VFA), Mumbai are working to elevate vertical farming in India. Hence, the certain objectives of the paper are as follows:

- To be familiar with the technologies of vertical farming and hydroponics.
- To deliver pros and cons of these agricultural technologies, its economic viability in the country.

- To explore the hope of its success in Indian background
- And also, to act as a curtain raiser for the introduction of this method of farming with adjustments to suit the Indian context.

Research design

Vertical farming is relatively a new concept in India and it is in the budding stage in the country. ICAR experts are making effort to launch this concept in Indian metropolitan cities (i.e. New Delhi, Mumbai, Kolkata and Chennai) to grow food corps in soil-less conditions on multistoried buildings. Therefore, in the lack of primary data an intensive study of various published materials related to vertical farming and hydroponics has been incorporated to get the genuine techniques of the innovative agricultural practices. Various government and non-government official websites (such as ICAR, VFA and Association of Vertical Farming) have also been explored to authenticate the information. Thus, the study is completely based on secondary data.

Vertical farming

Indoor farming is an open secret and the concept is no newer now, per se, greenhouse-based farming has been in practice for years and various herbs, food plants, such as strawberries, tomatoes, cucumbers etc., can be seen in supermarkets to consume year round. The operation of producing vegetables, fruits and herbs are exercised in predominantly single-storied structure in a monitored and regulated atmosphere but it is unable to meet ever increasing food requirements. Therefore, this conventional farming has been replaced by the concept of vertical farming propounded by Prof. Dickson Despommier to produce more yields to feed the burgeoning population [5].

History of vertical farming

The term 'Vertical Farming' was coined by US geologist Gilbert Ellis Bailey in his book 'Vertical Farming' in 1915 but the needed technology was yet awaited. In the year 2010, an American scientist Dickson Despommier, published a book, "The Vertical Farm: Feeding the World in the 21st Century", and in this book, he clarified the principles and practices of modern vertical farming. Prof. Despommier designed the high-tech vertical farms as an alternative to feed the people, especially in megacities, thus he is acknowledged as the founding 'Father of Vertical Farming'. In course of time new technologies like hydroponics and aeroponics developed; which made it possible to cultivate almost anything indoors [1].

Used Technology

Vertical farming (VF) can be judged as an extended form of indoor farming, which is exercised in multi-storeyed buildings of urban or peri-urban areas. The concept facilitates the cultivation of fruits, vegetables, medicinal, fuel producing plants and other plants in vertical stacks in cities [8], where the shortage of arable land strips is the major cause of concern. VF also assists to reduce transportation cost, cuts the emission of greenhouse gases and utilizes small tracts of land efficiently and further, it promotes the reduction in food prices and the consumers may get fresh fruits and vegetables at their door step in mega cities. Vertical farming includes three types of farming:

1. Mr. Gilbert discussed the utopian concept of vertical farming and introduced the notion of underground vertical farming, presently followed in Netherlands [6].
2. In the second category of VF, Malaysian architect and eco-designer Ken Yeang proposed the idea of mixed-use skyscrapers, which is performed in open air for climate control and consumption instead of hermetically sealed houses [7]. It is a farming for personal or community use, not for the commercial purposes.
3. Third category of VF is accredited as Despommier's skyscrapers which involves farming of plants in the sky scrapers in the closed system for large scale cultivation [7].

A vertical farm of 9300 m^2 (roughly the size of a city block) with 30 stories should provide food around 15,000 people with 2000 kcal of nutrition per day [6]. The multi-storey vertical farms can enhance the production of food crops if it is integrated with and nourished by hydroponics/aeroponics systems and illuminated by LED-based illumination system.

Hydroponics

Hydroponics or hydro-culture is a soilless indoor farming in a controlled atmosphere. Plants are supplemented the nutrients, which are dissolved in sterile water and the solution of nutrients passes through the routes of the plants and inundate them regularly. According to the experts, the growth rate of the plants are higher in hydroponic cultivation system because the nutrients are engrossed by the plants immediately. Accessibility of fresh vegetable, off season production, high nutrition value, least use of water are the few attributes, which make hydroponics indispensable to vertical farming. It is a unique example of agricultural engineering and has engaged thousands of acers land tract world over to grow food crops using vertical stacks.

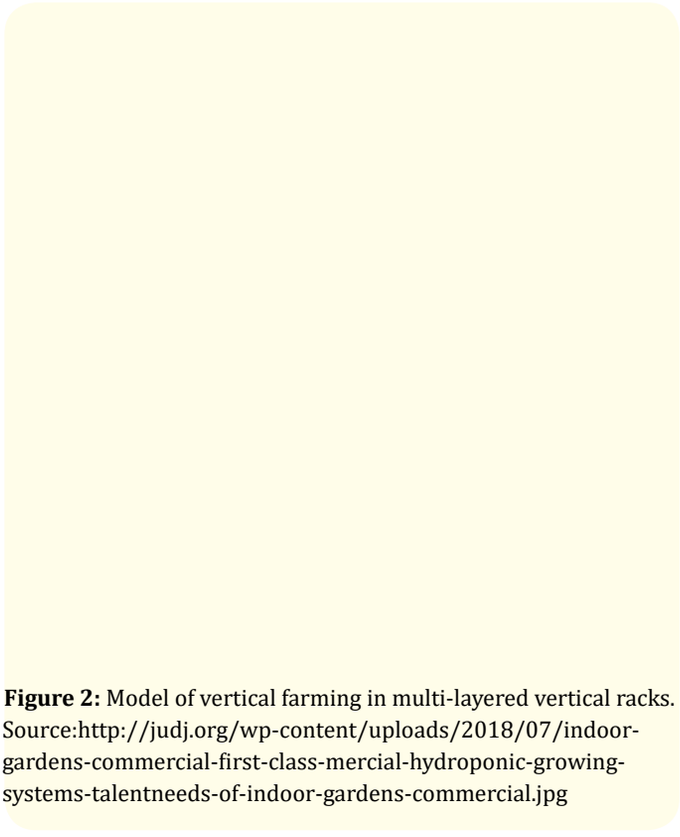

Figure 2: Model of vertical farming in multi-layered vertical racks. Source:http://judj.org/wp-content/uploads/2018/07/indoor-gardens-commercial-first-class-mercial-hydroponic-growing-systems-talentneeds-of-indoor-gardens-commercial.jpg

History of hydroponics

The manuscripts related to hydroponics narrate that the new form of gardening has been in practice for centuries in Amazon, Babylon, Egypt, China and India, where cucumber, watermelon and other vegetables were yielded using dissolved manure [1]. Dr. William Gericke of the University of California is accredited (1929) as 'Father of modern Hydroponics' owing to his remarkable contribution and he coined the term hydroponics which stands for 'Hydro' and 'Ponos'. In Latin, hydro reflects 'water' and ponos represents in Greek 'working', therefore, it literally means 'Working with water'. Since then, hydroponic farming is gaining popularity and owing to the integration with vertical farming, it may touch new horizons to feed the urban population in 21st century.

Used Technology

In this soilless cultivation, plants are grown using liquid nutrients and the nurturing cum developing process of the saplings and grown up plants pass through various steps. At the very first, an artificial atmosphere in a greenhouse is needed to be built to nurture the plants and for that, steel frames and Ethylene tetra-flouro ethylene (ETFE) membrane can be assembled to construct the conservatory. ETFE is a translucent plastic polymer membrane and it has much better qualities than glass. Light emitting diode (LED) bulbs would be a better option for the illumination of the poly-house. Plastic greenhouse tray, full of sterile coco peat and soaked with liquid nutrients, can be used to germinate seeds and after attaining a certain growth, the saplings should be rooted out carefully and the roots of young plants must be washed with running water gently. Now, these new plants are all set to be planted into mesh net pot cups, which is full of pea gravel and finally the net pot may be transferred into tote tub, which is full of liquid nutrients. Pea gravels act as an anchor to provide support to the roots and provide an excellent porous medium for the roots to heave and grow. The solution of the nutrients is prepared depending on the requirements of the plants. Usually, seventeen elements are needed for the proper growth of the plants, nine of these elements are macro nutrients (i.e. carbons, hydrogen, oxygen, sulfur, phosphorus, calcium, magnesium, potassium, and nitrogen) and are required in comparatively large amount, whereas the staying eight elements are trash elements and known as micro nutrients and needed in minute amounts, these are as follows: iron, zinc, copper, manganese, boron, chlorine, cobalt, and molybdenum [1].

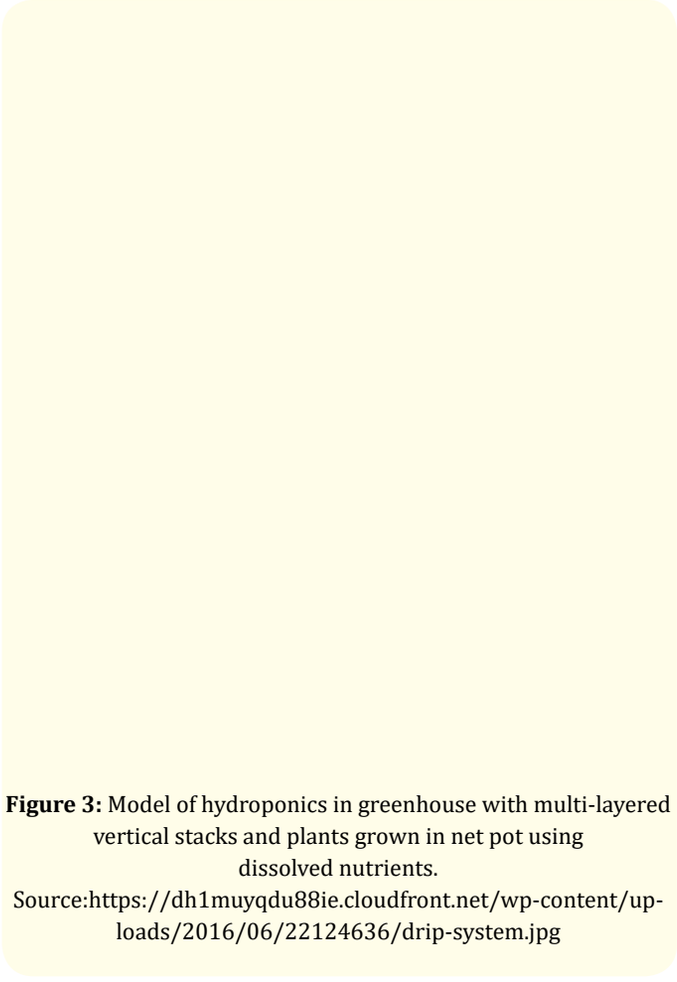

Figure 3: Model of hydroponics in greenhouse with multi-layered vertical stacks and plants grown in net pot using dissolved nutrients.
Source:https://dh1muyqdu88ie.cloudfront.net/wp-content/uploads/2016/06/22124636/drip-system.jpg

Further, the tote tubs can be placed on multi-layered vertical racks and dissolved nutrients can be supplied through conduits with the help of water pumps. All the tote tubs can be interconnected with each other with the ducts to transport the nutrient water from one tub to another and finally, a tube will lead to the tank, in which the solution of the nutrient has been kept. Regular measurement of electrical conductivity (EC)/ total dissolved solids (TDS), pH value and supply of nutrients can facilitate the plants to grow vigorously. To regulate the temperature of the greenhouse, exhausts fans and windows with net can also be put in place to expel hot air out and for cross ventilation respectively. All these methods lead to create an artificial and pollution free atmosphere to grow plants and the products of the plants are uncontaminated, nutritious, non-toxic, fresh and free from soil borne diseases. Various vegetables such as; cucumber, tomato, chili, lady's finger, coriander, spinach etc. can be yielded in this soilless cultivation medium. Besides these vegetables, mushroom cultivation and its yielding can be enhanced by using vertical farming cultivation, but hydroponics do not play any role in mushroom cultivation. The energy requirements to illuminate the greenhouse and other activities, can be furnished by the integration of solar energy, which is available in abundance and for that solar panels can be easily placed on the roof top, existing terrace and balconies as well.

Advantages and limitations of vertical farming and hydroponics

The burgeoning population, speedy urbanisation, reduction in arable land tract and decrease in limited resources have collectively brought the two dimensional horizontal farming under a great stress and the conventional farming is unable to meet the drastically escalating requirement of foodstuff. As a result, the role of vertical farming with hydroponics has turned out to be more vital and it has number of advantages. The advantages of vertical farming as envisioned by Prof. Despomier, include: 'year-round crop production, elimination of agricultural run-off, significant reduction in the use of fossil fuels for operation of farm machines and transport of crops, cut into the emission of greenhouse gases, utilization of abandoned or unused properties, reduction in weather-related crop failures, sustainable food supply for all urban centres, conversion of black and grey-water into drinking water, addition of energy back to the grid via methane generation or plasma arc gasification, creation of new urban employment opportunities, reduction of the risk of infection from agents transmitted at the human–agricultural interface, and return of farmland to nature, thereby helping to restore ecosystem functions and services [4].

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Besides it, the modern format of farming can mitigate the problem of food scarcity because in a small area huge amount of food crops can be grown i.e. 1 acre of vertical farm is equal to 10-20 acres of soil based traditional farms depending on crops. The whole world is facing an acute problem of fresh water and a significant amount of water is consumed by traditional agricultural practices, but an efficient greenhouse hydroponics system uses five percent of the water required in the outdoors and can deliver multiple times the yield of farming outdoors. According to Professor Despommier, a vertical farm can deliver the same yield again, using a fraction of the water the greenhouse system requires [8]. The food is consumed to nourish our health and to make us healthy as well as strong, but if that food makes us sick, it becomes a big question mark? According to the available data from WHO the growing problem of food borne illness is global and people are getting sick worldwide from contaminated food. Pesticides, chemical fertilizers used to grow crops are reaching in human body via food chain, but the hydroponic farming is free from pesticides, herbicides and fertilizers, and hence, these foods are non-toxic and chemical free. In addition to this, the plants grown on roof top, in balconies and at the outer wall of the multi-storey buildings, may decrease the temperature of the apartments and it can further reduce the consumption of electricity, use of air conditioners, which emit harmful greenhouse gases.

Having so many advantages, vertical farming with hydroponics is not ultimate, it has some limitations too. Even though the technologies are available, they are not up to reach to most of the developing countries and they are restricted to the regions/ countries where vertical farming are being practised. Some other confines of the agricultural technology are as follows [4]:

1. Limited vegetable crops have been identified for the purpose. However, vegetable crops in vogue are being grown without any scientific validation.
2. No varieties/hybrids have been exclusively bred for the purpose of vertical farming. As a result, yield and quality of the produce cannot be guaranteed.
3. Production technologies and Good Agricultural Practices for these crops have not been standardized.
4. Presently, the high-rise inclined buildings are not built to suit vertical farming. There is a need to reengineer the existing buildings by providing additional structures to suit the purpose.

The above limitations are the matter of research and in smart cities/green cities the high-rise buildings should be planed and constructed in such a way it could suit better for vertical farming purposes.

Feasibility and suitability of these technologies in Indian background

Vertical farming in soilless conditions are in practice in the US, Europe, Japan and Singapore but its introduction and implementation in India on a large scale, is yet to be recruited. To integrate vertical farming with mainstream cultivation, a herculean effort is needed. Most of the agricultural activities are practiced to earn livelihood only, farmers are not technologically sound, and owing to its capital-intensive nature, it is not economically viable for everyone.

Although, the above conditions are not in our part but as the times will gone by, vertical farming would be a necessary need because of decrease in cultivable land tract. Seeking the scenario, scientists from the Indian Council for Agricultural Research (ICAR) are working at Kolkata on a module to grow vegetables and fruits in multi-storied structures [9]. If the project of the ICAR gets success, people of urban India would be able to consume daily dose of fresh vegetables and fruits grown next to their residences. The Deputy Director General (Crop Science) ICAR explains that, "ICAR is looking into the scope of vertical urban agriculture. This could cater to the need of fresh vegetables in the cities, which are growing in terms of height with numerous multi-storied buildings cropping up. And this farming would be done soil free".

Conclusion

Unquestionably, the concept of vertical farming (VF) and hydroponics carries number of advantages and it is beneficial for both; human beings and the planet, but at the beginning, it must be kept in mind that VF and hydroponics are not the panacea to all farming woes. Traditional farms cannot be substituted by VF. Hence, it is the need of time to explore more alternatives to feed the growing population. One of the main drawbacks of hydroponics is dedication of time and workforce, which are indispensable to get success. The soil free cultivation is more challenging and rigorous than traditional farming. Therefore, a novice horticulturist should start the project with uncomplicated steps and the knowledge and comfort increase; they can switch over to the more sophisticated system of VF as well as hydroponics.

The importance of the advanced farming cannot be overlooked and familiarity along with expertise to the technologies are prerequisite. It is a pressing need to grow more and more crops in a sustainable way to provide food everyone on the earth and VF and hydroponics are one of best alternatives to be integrated into mainstream farming to feed the urban population in 21st century.

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