WHITE PAPER


# VERTICAL FARMING USING INFORMATION AND COMMUNICATION TECHNOLOGIES

Manoj Kumar Gupta and Sreedhar Ganapuram

## Abstract

Vertical farming is an energy intensive system of crop production involving integration of multiple technologies such as big data analytics, robotics, internet of things, artificial intelligence etc. so that crops can grow well without any agronomic constraint. Vertical farming structures rely on comprehensive solutions to support different hardware integration, data collection, data analysis and automatic control of the installed devices within the structures. Considering the economy of vertical farming, it is not a viable option for growing field crops or low value crops because returns on investment are not enough to justify the worth.

Energy efficient structures, diversified crop production and production cost are some of the important criteria to prove the worth of vertical farming. IT companies have a significant role to make the technology feasible for crops cultivation by integrating domain specific solutions, relevant hardware and devices for real time data collection, data analysis, and automatic application of actuators. IT can also help to optimize different operations carried out in a vertical farm to make the crop production more competitive and profitable.

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## Introduction

The global population is anticipated to grow up to 9 billion by 2050, this growth in population is expected to cause immense pressure on the available natural resources (Hanjra and Qureshi, 2010) and demand more food which makes it imperative to intensify agricultural production (Tilman et al., 2011). Moreover, the growing purchasing power of people and changing consumer preference for example demand for organic or pollution free food is also growing due to health consciousness. Apart from this, the pollution and environmental degradation caused by traditional farming practices are leading researchers and practitioners to come up with alternate farming practices that are much more environment friendly such as greenhouse/shade net farming, terrace farming, urban farming (Farah, 2013; Specht et al., 2014) and vertical farming (Despommier, 2013; Farah, 2013). Among these, vertical farming is one such alternative, which holds the promise of addressing the issues of environmental degradation (Banerjee and Adenaeuer, 2014) and the growing demand for food as it can lead to more food production with fewer resources.

Vertical Farming is a novel method of growing crops by artificially stacking plants vertically above each other either in skyscrapers or by using the third dimension of space. This might help to solve many of future's problems like malnutrition, polluted food etc. that could become evident along with food scarcity. In this kind of farming there is huge scope to acquire more agricultural produce as this practice allows a huge amount of crops to be grown in a much lesser space, when compared to traditional farming and other alternatives like permaculture, biodynamic and agro-ecological farming (Fenton, 2012; Padmavathy and Gopalswamy, 2011), thus reducing the use of agricultural land. Furthermore, this practice recycles and reuses other natural resources such as water and nutrients and creates less waste as plants grow in soil-less media. As a result, vertical farming leads to smaller carbon footprint and causes much less pollution to the environment (Hamilton, 2016).

The History of Vertical Farming dates back to 1915 when the American geologist Gilbert Ellis Bailey wrote a book called Vertical Farming. Though the book primarily dealt with the topic of using particular types of soils to grow crops, the idea of Vertical Farm came from the theory of this book (Bailey G, 1852). The concept of Vertical Farming has been there for decades; however, the demand for more food production, pollution free produce and inclusion of modern technologies would drive farmers, farming societies, and commercial companies to take up vertical farming in large scale. The first vertical farm came in existence in 1950s to grow cress indoors at a large scale. Today many biotechnology companies and startups have taken this concept to the next level making vertical farming an economically viable model (NFIB, 2015) considering the pollution free or organic cultivation.

Researchers claim that vertical farms might be expensive to construct but once built they are actually less expensive to run compared to land based farms (Cho, 2011). They also claim that produce acquired from vertical farms is generally of better quality and pollution free as it grows mostly using water and nutrients. Thus, these crops can fetch premium price. Traditional farming puts farmers to multiple odds such as weather disasters, long hours of labor, yield uncertainty, vulnerability of crops to pest and disease, lower return on investment. Vertical farming might be a welcome change, as it will give ease of operation and higher yield percentage (Yildiz, 2016).

Many vertical farming companies such as GE & Mirai (Mellino, 2015), AeroFarms (Baranuik 2017), Ecopia Farms (Jung, 2012), Nuvege, Plant Lab (Cho, 2011) are mushrooming across the urban parts of many countries that are having limited agriculture land, trying to change the way vegetables are grown. In these farms, nutrients, air temperature, humidity and lights are controlled to meet the exact specifications as per the crop grown for optimum plant growth. Vertical farming provides opportunities to sustainably grow crops by minimizing use of water through water recycling, increasing productivity per unit of area, reducing use of fertilizer/ pesticide to maintain ecosystem health, and protecting crops from weather related disasters (NFIB, 2015; Banerjee and Adenaeuer, 2014). Considering the benefits of this farming system, environmentalists, sustainable developers, and futurists advocates growing crops using vertical farming structures in cities.

## Types of vertical farming

Type and processes used classifies different vertical farming systems. There are three types of vertical farming systems i.e. 1) Despommier Skyscrapers 2) Mixed Use Skyscrapers and 3) Stackable Shipping Containers (Despommier, 2013).

In addition to these, there are three processes usually adopted in the vertical farming systems viz., 1) Hydroponics, 2) Aeroponics and 3) Aquaponics (Farah, 2013). The details of the above types and processes are discussed in the below sub-sections.

1. **Despommier Skyscrapers:** Dickson Despommier, a microbiologist at Columbia University, believes that traditional farm practices, which are already using 41% of the planet's land, will not be able to support the food requirements of the exponentially increasing population. So, he envisions skyscrapers where crops can be grown in vertically stacked shelves, mass produced within closed and controlled environments that are not influenced by the external climate. As a result, these skyscrapers can be built anywhere regardless of any agronomic constraint. One school of thoughts claims that vertical farming requires less energy and causes less pollution than some those of traditional farming practices because vertical farms can be integrated with renewable energy technology. Solar panels, wind turbines and hydroelectric power can be used respectively or in combination with one another to satisfy energy requirements of these structures. Vertical farming has a scope to create huge employment opportunities as local inhabitants can work in these vertical farms to make a living (Venkataraman, 2008).

2. **Mixed Use Skyscrapers:** These type of skyscrapers is the brainchild of architect Ken Yeang These skyscrapers integrate traditional agricultural activities with vertical farming concept. Instead of growing crops in completely controlled and closed environment, in these skyscrapers, crops are grown in natural sunlight such as top floors of an office building that receive the most sunlight. The advantage of Mixed Use Skyscrapers over Despommier Skyscrapers is that they require less initial investment compared to Despommier Skyscrapers, which requires the entire environment within the building to be controlled and monitored according to the crop's requirements (Yeang, 2002).

3. **Stackable Shipping Containers:** This method of vertical farming uses shipping containers to grow leafy green vegetables, gourmet mushrooms and strawberries. These stacked recycled shipping containers can be used in urban settings. Companies such as Freight Farms and Podponics are using shipping containers fitted with hydroponic components, LED lighting, heating and ventilation systems for climate control, and sensors to monitor the environmental condition inside the containers (Markham, 2015).

## Processes used in Vertical Farming

**1. Hydrophonics:** Hydroponics is the predominant growing system used in vertical farms. In this system, plants are grown in nutrient solutions, free of soil. The plant roots are grown in the nutrient solution contained in a grow tray such that the roots are submerged in the solution. The grow tray is filled with a nutrient solution few times a day by using a reservoir below the tray, a water pump, and a timer. The timer is set based on the parameters such as the size of the plants, the water and nutrient requirements of the plants, the growth cycle of the plants as well as the air temperature. Based on the time set by the timer, the grow tray is filled with the nutrient solution until it is flooded using the water pump. After the tray is flooded, due to gravitational force, the excess solution is drained back to the reservoir where it sits until the next flood cycle (Figure 1). The essential nutrients used in a hydroponics system are calcium nitrate, potassium sulphate, potassium nitrate, mono potassium phosphate, and magnesium sulphate. Micronutrients used include boron, chlorine, copper, iron, manganese, sodium, zinc, molybdenum, nickel, cobalt and silicon (Epicgardening, 2017).

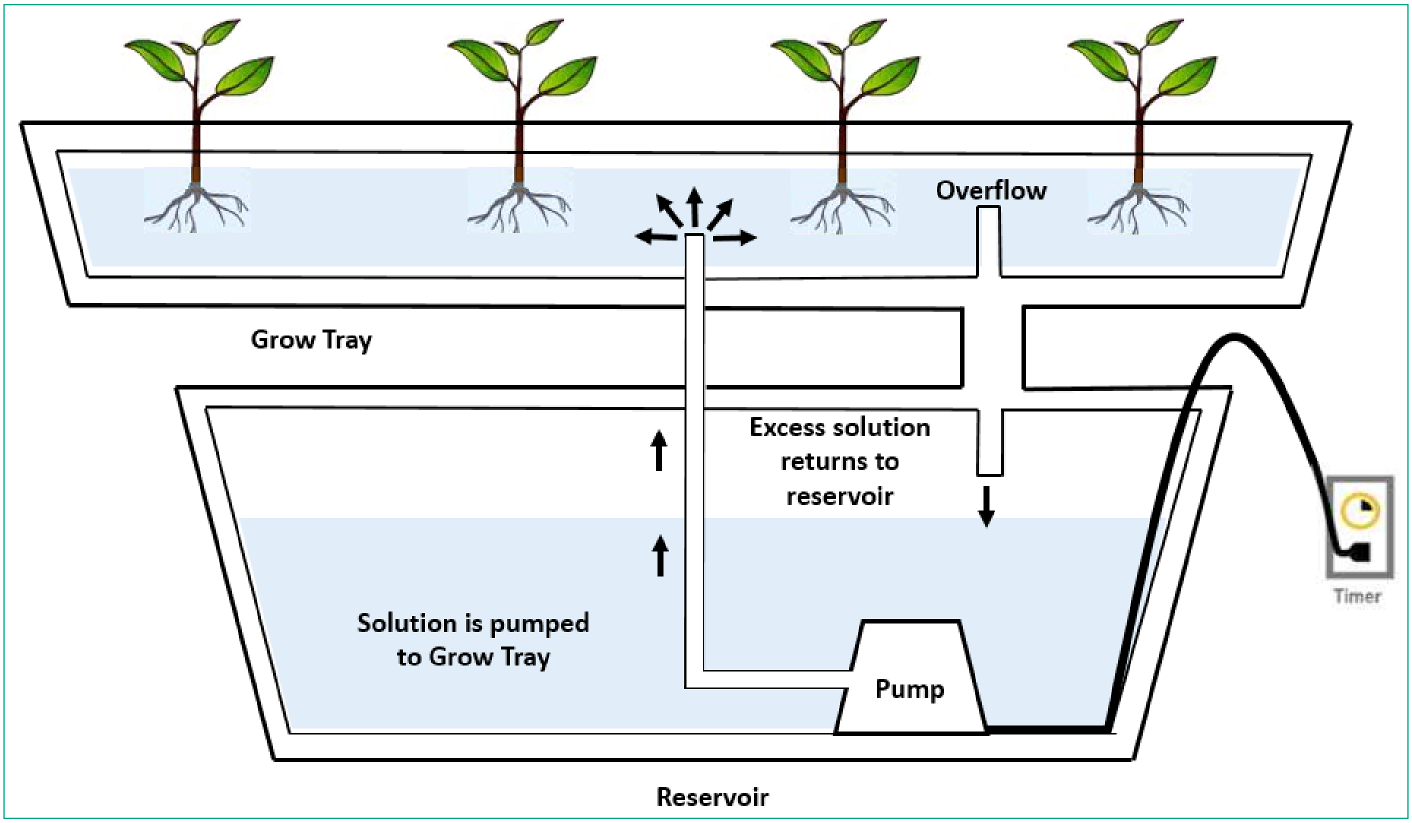


***Figure 1*** *Schematic diagram of a hydroponic system*

**2. Aeroponics:** In an Aeroponic system, plants are grown in an environment where air with very little water or mist and without soil are used. In this system, the plant roots are suspended in air. So, the roots are nourished by misting the root zones with a nutrient solution on a continual basis by using a fine sprayer to ensure that the roots get sufficient oxygen (Figure 2). This system is the most efficient vertical farming system, as it uses 90% lesser water than the most efficient hydroponic systems (Agrihouse, 2011) and it has been observed that plants grow quicker than in other types of hydroponic systems. Moreover, the fertilizer usage is reduced by 60%, while the crop yields increases by 45 to 75% (Agrihouse, 2011). Plants grown in these systems have also been shown to uptake higher concentrations of minerals and vitamins, making the plants healthier and potentially more nutritious (Banerjee and Adenaeuer, 2014; Epicgardening, 2017).

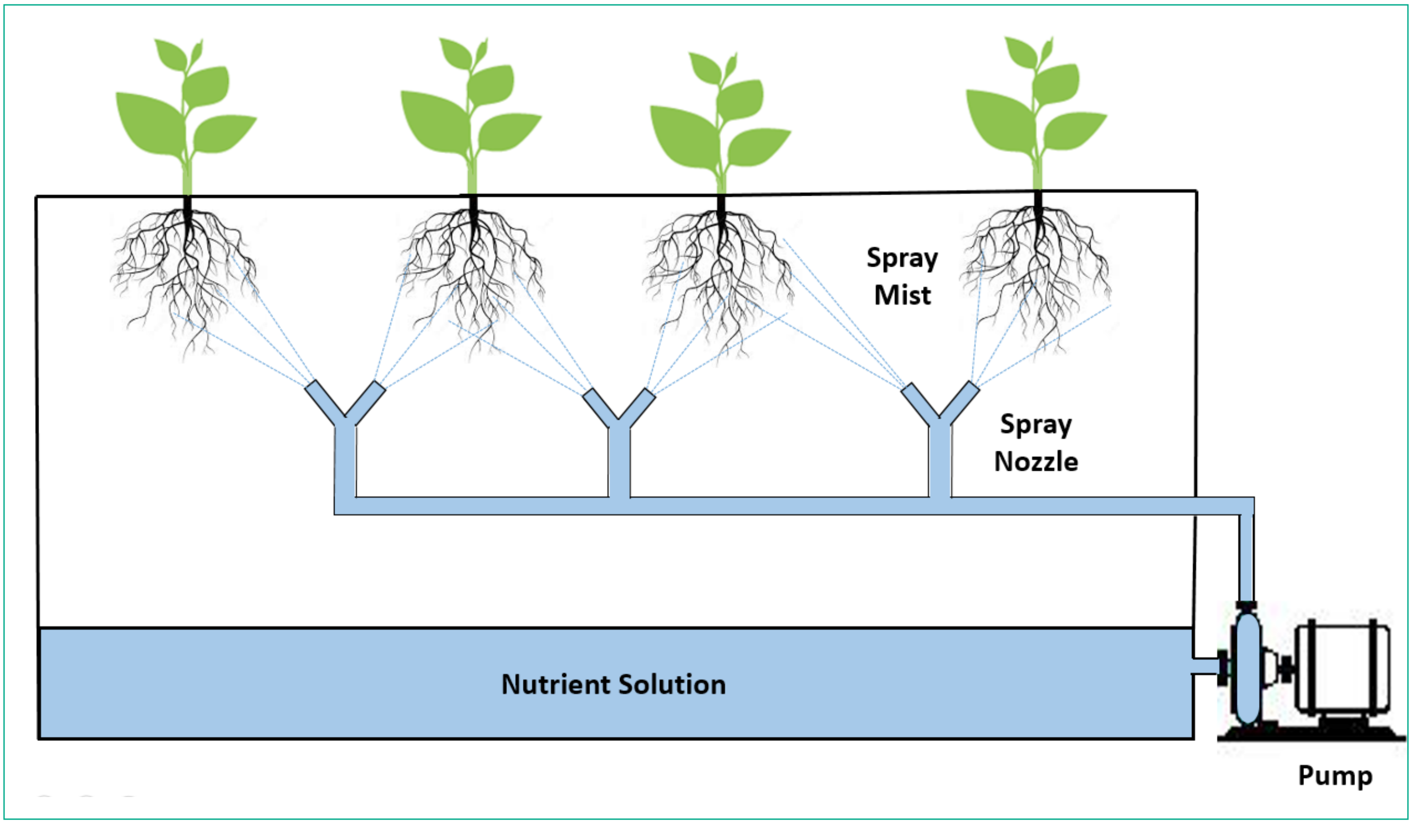


***Figure 2*** *Schematic diagram of an aeroponic system*

3. **Aquaponics:** It combines aquaculture (raising of fish in tanks or ponds) and hydroponics in the same ecosystem. Fish grown in fish tanks, produce waste that are high in nutrient content, which can be used as nutrient suppliant to grow the plants in a grow tray. The plants on the other hand naturally filter the water in which the fish live. The water from the fish tank, which is rich in ammonia, is circulated to the grow tray. There nitrifying bacteria, which thrives in the growth bed where the plants are growing, convert the ammonia first to nitrites, then to nitrates and finally the solids are converted to vermi compost, which can be used by the plants as bio fertilizer. This water, which has all the wastes decomposed and used up by the plants as nutrients, is recycled back to the fish tank (Ellingsen & Despommier, 2008). The major advantage of an aquaponics system is that it has to be carefully monitored for the first month, but once the system is established, only pH and ammonia levels have to be monitored every week (Banerjee and Adenaeuer, 2014; The Aquaponic Source, 2017).

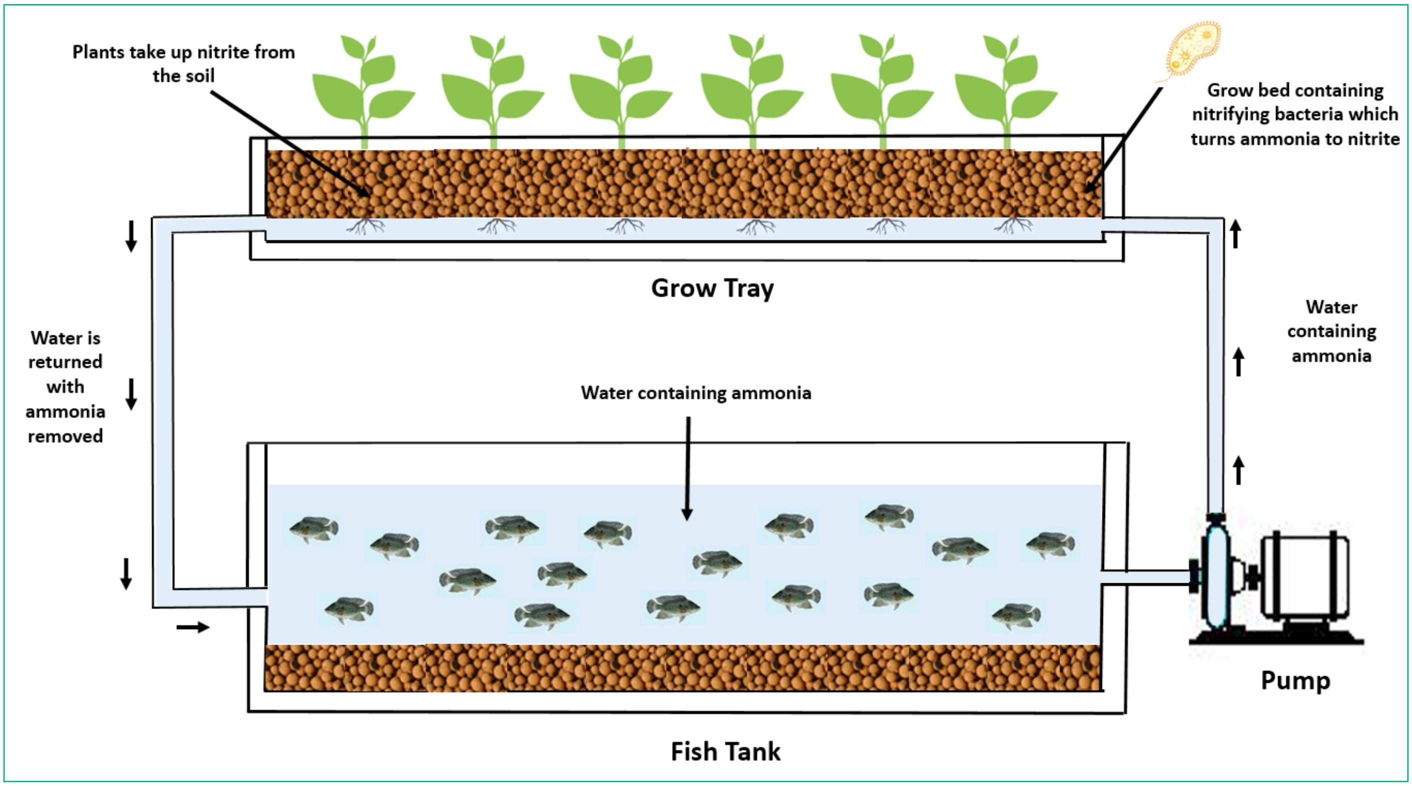


***Figure 3*** *Schematic diagram of an aquaponic system*

## Vertical farming success stories

Several companies such as GE & Mirai (Mellino, 2015), AeroFarms (Baranuik, 2017), Ecopia Farms (Jung, 2012), and Nuvege, Plant Lab (Cho, 2011) etc. have built vertical farms and are practicing farming in different parts of the world. The world's largest vertical farm, AeroFarms, has been set up in an old steel factory. The system is 75 times more productive than a traditional farm of a similar size. The system employs soil less media and consumes 95 percent less water than those of traditional farming. Their closed-loop system uses only non-GMO seeds and does not use any pesticides, herbicides or fungicides to ensure sustainable crop cultivation.

Land-strapped Singapore has opened its first vertical farm, an innovation that can increase the local food production and decrease its dependency on food imports. The experiments on vertical farm have started as early as 2009 by Sky Greens Farms. A vertical farm developed by Sky greens, consists of 120 aluminum towers that extends over 9 meters (30 feet) in height particularly for growing leafy vegetables. The entire vertical farm is capable of producing on an average 0.5 tons of vegetables per day (Dvorsky, 2012). When Japan faced a food supply shortage in 2011 due to earthquake in the East Japan region, Japanese company Mirai & GE opened an indoor farm. Unlike outdoor farming, which is fraught with excessive sunlight risk that can damage the crop yield. On the other hand, in this farm, GE's special cost-effective LEDs have provided the right spectrum for photosynthesis instead of providing the full spectrum as provided by the normal LEDs. As a result, most of the produce come in acceptable ranges from quality and quantity perspective. GE and Phillips are continuously carrying out further research to bring light spectrum for different plants, which would eventually bring better efficiency in the vertical farm operations. GE and Mirai are further looking to expand operations in Russia and Hong Kong with a goal to build vegetable factories (Jung, 2012).

Several local governments in collaboration with companies have expressed serious interest in establishing vertical farms in cities such as New York, Portland, Los Angeles in the USA; Abu Dhabi and Dubai in United Arab Emirates; Dongtan, Shanghai and Beijing in China and Incheon in South Korea. The Illinois Institute of Technology created a detailed plan for implementing vertical farms in Chicago. Initial plans were to develop prototype versions of vertical farms first at large universities that are interested in researching in vertical farming practices and technology development (Cho, 2011; Ellingsen and Despommier, 2008). The hydroponic and aerophonic systems have shown increased yield potential by 23 times and at the same time reported a decreased water use of 30 times (Ellingsen & Despommier, 2008). Thus, these systems show promising scope for the expansion of vertical farming for personal and commercial purpose in urban regions.

## Challenges

There are several challenges in vertical farming, which are to be addressed so that the farming system can become a mainstream farming process capable of solving food scarcity across the globe. The biggest concern for now is the economies of scale. The vertical farming system is currently not equipped well to harness benefits of economies of scales as efficiently as horizontal farming does. Vertical farming requires huge investments for infrastructure set-up and scale up. Moreover, vertical farming may be suitable for growing green leafy vegetables like basil, cilantro or chives, fruits, herbs, pharmaceutical plants (Banerjee and Adenaeuer, 2014) considering cost of production and returns on investment. There is a constraint for growing several varieties of crops or different crops in a single vertical farming facility as every crop has different environmental requirements and it is very difficult to change the design of a vertical farming facility to suit needs of different crops. Even if this doable, the cost of doing so will be humungous. Other costs pertaining to vertical farming such as labor costs, energy costs and maintenance costs are also very high for vertical farms to function compared to those of horizontal farming for the same output of a crop in open field conditions (Cox and Tassel, 2010). Some of the natural processes such as cross pollination have to be manualized which require a lot of manpower and money (Cox and Tassel, 2010; Alter, 2010; Bax, 2015)

The farming system is energy intensive system. Per the researchers at University of Utah, even the most effective sources of energy (assuming that they function at the peak of their capacity) also incur huge costs due to high-energy requirements of the plants. These costs in turn increase the overall cost of cultivation. The maintenance cost of the structure and equipment to control plants microenvironment is another important deterrent factor for now.

## Technological interventions to make vertical farming attractive

Crop production produces huge amount of data and it always becomes important to analyze it and draw insights for effective crop growth. The success of day-to-day operations depends on effective data collection and analysis, which requires crop specific simulation models so that these structures can run with minimum human interventions taking care of all needs specific to a crop grown in the structure.

Though vertical farming appears promising alternative of horizontal farming, it can only be a viable option when all above-mentioned challenges are addressed (Cox and Tassel, 2010; Taylor, 2015).

Though the practice of vertical farming has been increasing rapidly, aided by the advanced use of technology, still there is a long way to make these structures more viable from ROI and complexity point of view. Information Technology (IT) has an important role to play to enable easy data collection and analysis to support decision-making processes. In fact, automation and IT have to go hand in hand so that agri domain principles can be effectively applied for crop production system.

According to Dr. Dickson Despommier of University of Columbia, technology is advanced enough to make vertical farming a reality, only different types of technologies have to be brought together and integrated so that crops can be grown indoors in a simulated environment (Mellino, 2015). Firms such as Bimantis, based at Bangalore, has developed an IoT based solution. TheGreenSAGE™ that provides optimal conditions for efficiently growing culinary herbs & greens so that it is not required of users to have prior knowledge of growing. TheGreenSAGE™ solution provides automatic monitoring and control of nutrients, irrigation, light and other important parameters required during different stages of plant growth. The GreenSAGE™ solution is powered by Bitmantis Connected Technologies™ and other indoor/precision agriculture technologies so that growth functions like nutrient management, irrigation management, light management and growth zone management can be automated.

With the help of big data analytics, internet of things and simulation modelling, the growing environment in vertical farms can be constantly monitored, tested, reviewed and improved using predictive analysis. Internet of things (IoT) has the potential to become the backbone of vertical farming, using the sensor and actuator technology. Technology companies can deploy wireless sensors to collect data of interest such as change in natural light and growing environment information such as temperature, pH etc. and wireless actuators can be used to automate those actions. Coupled with such sensors, intelligent systems can be developed which can assess the needs of the plant and calculate if those needs can be met with the available environment or not. If not, the balance growth conditions and artificial light can be provided/created for meeting the optimum growth conditions (Fajar et al, 2010). In addition, if the ultra violet levels from the natural light are too intense for plants, provisions can be made to reduce the intensity of light with use of technologies like switchable glass. Infrastructure health sensors can be used to monitor the condition of machinery and the building used for vertical farms. Such sensors can relay regular information on health of the building and machinery to the maintenance crew (both humans and robots) so that proactive actions could be taken for maintaining the conditions (Fajar et al, 2010).

The level of $CO_2$, moisture content and nutrition status within the structures are monitored, and controlled for maintaining optimal growing conditions with the help of a fully integrated computer management system. IT companies can play a significant role in building such integrated systems, which farmers can use remotely to completely control the relevant parameters. IoT framework can play a major role by encompassing and integrating three functional layers namely; sensing layer, delivery layer and control layer. The sensing layer consists of environmental sensors can sense change in environmental conditions such as PAR, pH, temperature, soil moisture etc. For example, light sensor can show distribution of intensity of light in real time. Video sensors are useful to monitor the size of the plant to decide various required interventions. Moreover, spectral analysis can indicate bio-stress for further analysis and cure on real time basis.

The delivery layer delivers the information collected from the sensing layer to the control layer using different protocols such as ZigBee, 6LoWPAN, Wi-Fi, Zwave, near field communication (NFC), Bluetooth low energy, wireless HART, mobile-phone technologies (2G/3G/4G), Ethernet, etc. The third layer is the intelligent control layer, which consists of cloud computing facilities, personal digital assistant (PDA), controller, regulation equipment and operating terminal. This layer comprises of intelligent systems having simulation modeling to conclude relevant decisions in favour of better crop growth. Such simulation modeling may use variety of observations and reference data for complete analysis considering multiple constraints such as soil moisture, bio-stress, weather forecast, evapotranspiration, crop management practices etc. Fig. 4 depicts few examples of such analysis. LEDs can be tailored to specific spectrums and intensities, the ventilation, amount of water sprayed and even the root temperature can be adjusted to the exact required amount (Tongke, 2013; Sharma et al, 2016; Garfield, 2016).

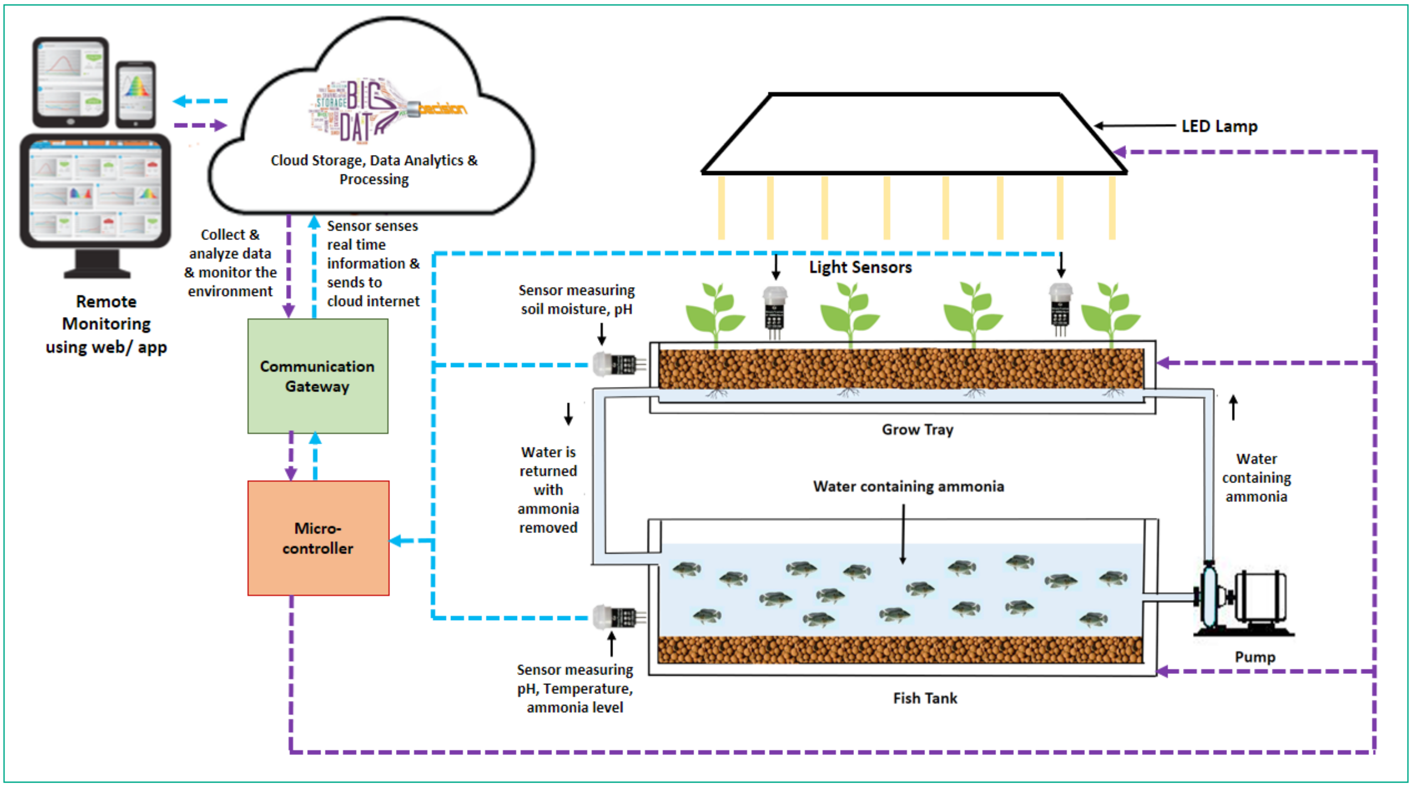


***Figure 4*** *Schematic Diagram of Implementation of IoT in Vertical Farming*

These huge amounts of data are mined by the researchers to predict the future growth of crops. Thus, there is a huge scope for IT companies to store and process these data for analysis (Baranuik, 2017; Garfield, 2016). In this way, use of technology can make vertical farming the major practice for growing food in the future.

## SWOT Analysis

| STRENGTHS | WEAKNESSES |
|---|---|
| • Food companies as well as venture and growth equity firms are investing in vertical farming.<br>• Farms such as AeroFarm, Ecopia Farms, Nuvege, Plant Lab etc. are economically viable, on an unsubsidized basis (Cho, 2011).<br>• Uses old buildings by creating suitable warehouses equipped with the right infrastructure for vertical farming, negating the need to destroy old buildings (Despommier, 2017).<br>• As crops are grown closer to the market, reduction in transportation cost of produce from rural farmlands to cities is evident (Lawson, 2015). | • Highly capital intensive to set up a vertical farm.<br>• Energy cost, labour cost and maintenance cost are very high.<br>• Space constraint limits what can be grown (Brennan and Gralnick, 2015).<br>• Difficult and high cost is involved to grow several varieties of crops in the same vertical farming facility.<br>• Approach best works only for salad greens and herbs which have higher margins and can be grown in large quantities. Staple crops such as wheat, soybean, corn etc are not cost-effective options.<br>• Due to lack of soil, the produce does not get an organic label even though it costs as much (Brennan and Gralnick, 2015).<br>• Scalability is the biggest challenge, needs to produce enough crops to sell at a profit at large grocery chains (Lawson, 2015). |
| **OPPORTUNITIES** | **THREATS** |
| • Vertical farm market is expected to grow at a CAGR of 24.8% from 2016 and reach USD 5.8 billion by 2022 (Markets and markets, 2017).<br>• Vertical farms can be used to produce biologically active molecules for novel medical applications.<br>• Demand for skilled workers in vertical farms will create future opportunities for education and training in this industry (Cho, 2011). | • The policy leaders do not have a clear knowledge of what a vertical farm actually is (Hepler, 2016).<br>• Being a completely new industry there is a lot of uncertainity about the return on investment (ROI).<br>• Proper management and investment in technology are highly crucial. Several start ups have struggled or failed in the past decade for these reasons (Lawson, 2015). |

***Table 1:*** *SWOT analysis from business perspective*

| STRENGTHS | WEAKNESSES |
|---|---|
| • Area with a massive potential for growth from a technology perspective.<br>• Technologies like remote sensing, electronic communication system integrated into a single data management system and a growing knowledge of applied hydroponics are strengthening the growth of this field (Thingworks, 2017).<br>• Companies like GE, Philips, Panasonic are investing heavily in technology used in vertical farms.<br>• Seed producing giants are working on producing genetically better seeds specifically designed for vertical farming.<br>• The best brains in several technologies are involved in this field such as Dutch bioengineers, scientists from NASA, staffers in Antarctica Research Centers etc. (Lawson, 2015).<br>• Using IOT, the right amount of fertlizer and water can be added to the plants, eliminating wastage of resources (Farm management, 2017). | • High energy requirement for artificial lighting within the vertical farms. Heating and air conditioning will add considerably to power demands (Brennan and Gralnick, 2015).<br>• Standards for sensor networks and data communication still under development.<br>• The speciality agri softwares for Vertical Farming are are not matured.<br>• Requires high precision monitoring (Beecham research Ltd, 2014). |
| **OPPORTUNITIES** | **THREATS** |
| • New technologies such as cost-effective monitors and controllers used are driving down costs of operation (Farm management, 2017).<br>• More efficient and lower cost LED lights are bringing down high costs of artificial lighting (Lawson, 2015).<br>• Machines used for harvesting crops and packaging them are cutting down labor costs (Brennan and Gralnick, 2015).<br>• Opportunity for new skill development with the increasing need of master growers, plant scientists, engineers trained to design high tech grow systems (Hepler, 2016).<br>• Alternative solutions are being used to generate energy within the farms. Natural energy sources like geothermal energy and solar energy are being harnessed to reduce huge energy costs (Despommier, 2017). | • Risk of information theft.<br>• Failure of even a single component of the IoT system may cause rapid plant death leading to massive losses |

***Table 2:*** *SWOT Analysis from technology perspective*

## Conclusion

Crops in traditional farming systems are vulnerable when it comes to global warming, natural calamities, and weather changes. There is also immense pressure on natural resources to feed the ever-growing population considering shrinking cultivable land, fresh water, and lower yields. Though vertical farming systems do not support all sorts of crops production considering return on investment, it appears to be one of the most preferred alternative for sustainable crop production. The advances in information and communication technology can make vertical farming a reality. All it requires is to integrate technology from various disciplines together so that crops can thrive indoors in a simulated environment. IT and other technology companies can play a significant role by integrating big data analytics, robotics, internet of things and agri domain simulation/modelling tools to make vertical farms cost effective.

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