Opportunities and Challenges in Sustainability of Vertical Eco-Farming: A Review

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Abstract—**Population is growing exponentially and Global food demand is rising. Eco-friendly solutions to meeting food needs are seriously concern. Vertical Eco-Farms are a revolutionary approach to produce high quantities and quality fresh nutritious food year round and have numerous advantages. Essentially, locally need based crops are grown on every floor of a skyscrapers with highly mechanized and automated control system for irrigation and environment. A high degree of competence in plant science and engineering skills are required for successful operation. Economically and practically, there are many problems inherent with designing a vertical eco-farm. In this paper, the state of the art opportunities and challenges in sustainability of vertical eco-farming have been reviewed which will help eco-farming farmer and researcher for efficient design and monitoring parameters of vertical Eco-Farms. The challenges include eco-friendly efficient design of the structure with controlled environment, monitoring of nutrient solution, selection of ideal crop and watering system. The ph value of nutrient solution determines the nutrient availability for plants. The addition of plant nutrients to eco-farming systems are performed according to the plant nutrient requirement. Accordingly, ph adjustment must be done daily due to lower buffering capacity of nutrient solution. Knowing the kind and concentration of ions allows identifying on the one hand, those that are needed in the nutrient solution and therefore can be subtracted from the original formulation.**

Index Terms—**vertical eco-farming, controlled environment agriculture, plant nutrient solution, crop watering system**

I. Introduction

Ref. [1] with the advent of civilization, open field agriculture is facing some major challenges most importantly decrease in per capita land availability. Agricultural productivity is one of the key challenges for the future. Food production will need to double by 2050 to meet the UN's Millennium Development Goals on hung. This needs to be achieved in the world where suitable agricultural land is limited and climate change is predicted to have an adverse impact on food production. Ref. [2] vertical eco-farming method can be implemented in places where the soil type is not ideal for the desired crop. In addition, the technique can be used in roof top farming and therefore is very useful in areas with limited space such as urban areas. Ecological farming is recognized as the high-end objective among the proponents of sustainable agriculture. Ref. [3] vertical eco-farming is perhaps the most intensive method of crop production in today's agricultural industry.

1) Importance of vertical eco-farming farming

Ref. [4] vertical eco-farming is becoming increasingly popular, especially in the United States, Canada, Western Europe, and Japan. It is high technology and capital intensive. It is highly productive, conservative of water, land and protective of the environment. Ref. [5] growing food within cities at the doorstep of the consumers eliminates the need for transport, therefore reducing greenhouse gas emissions and food-waste. Ref. [6] growing crops in skyscrapers would not only mitigate the need for more land, it would also produce available growing space in the air. Also, farming in a controlled environment drastically increases yields and decrease water use, waste production, and disease transmission. Vertical farming allows local crops to be produced year round, discarding the need for transporting food and thus, decrease greenhouse gas emissions. The major agricultural problems such as pesticides, pests, deforestation, and soil erosion are nearly non-existent. A key aspect that makes vertical farms efficient is the usage of natural light. Ref. [7] most green leafy vegetables are growing well in the hydroponic subsystem, although most profitable are varieties of Chinese cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers. Other species of vegetables that grow well in an aquaponic system include beans, peas, kohlrabi, watercress, taro, radishes, strawberries, melons, onions, turnips, parsnips, sweet potato and herbs. The commercial Vertical eco-farming industry is probably the fastest growing in the developing countries.

A. Objectives of This Research

There are many literature where different literature have discussed different aspects of opportunities and challenges in sustainability of monitoring environmental, nutrient solution, watering system, selection of ideal crop and crop variety in vertical Eco-Farms. Therefore, in this paper an attempt has been made to review the state of the art opportunities and practical challenges in sustainability of operating Vertical Eco Farms. This paper is expected help vertical eco-farming grower for eco-friendly higher yield by efficient use of vertical space and sustainably monitoring the controlling growing parameters of vertical eco-farms thereby which increases its adoptability.

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II. OPPORTUNITIES OF VERTICAL ECO-FARMS

Vertical eco-farming is a revolutionary approach to produce high quantities of nutritious and quality fresh food all year round. According to the United Nations Population Division, the world population will increase from about 6.9 billion in 2010 to 9.2 billion in 2050. The percentage of urban population will likewise increase from 50.46% in 2010 to 68.70% in 2050. This is a major concern because the land area of the Earth is limited only to about 13 billion hectares. In 2008, the total agricultural area in the world was about 4.88 billion hectares. Ref. [8] production overheads in vertical eco-farm are commercially competitive and predictable. In some cases profitability of over 30% has been demonstrated even after deducting full amortization of capital equipment over a 10 year period.

A. *SWOT Analysis of a Vertical Eco-Farm*

The vertical eco-farming crop farming industry remained resilient during the recession, due to consistently high demand for healthy and organic produce. Vertical eco-farming systems do not require pesticides; require less water and space than traditional agricultural systems. The largest reason to be unenthusiastic is the energy requirement to power the supplemental lighting and operating the environmental controls. There are many controversies in the literature regarding efficient design for optimal plant growth. Scientists are still unsure regarding the best design for a vertical eco-farm. The strength, weakness, opportunities and threats (SWOT) analysis are summarized in Fig. 1.

Strength	Weakness
a. Faster and high yields b. Grows healthier crops c. No pesticides needed d. Savings in water e. Reuse of nutrient solution f. Can grow round the year g. Requires less land surface b. No carbon footprint	a. High initial costs b. Requires precision monitoring c. Limited to low profile crop d. Requires higher energy
Opportunities	**Threats**
a. Highly controlled environment b. Artificial lights may be used c. No seasonal restrictions b. Crop need based nutrient	a. Failure to the any system components of the vertical irrigation system may leads to rapid plant death

Figure 1. SWOT Analysis of vertical eco-farming.

B. *Advantages of a Eco-friendly Vertical Farm*

Ref. [9] the goal of ecological farming is not only sustainable food production, but is to optimize the provision of ecosystem services, both in the design of the farm and by significant reduction of the ecological footprint. The vine crop productivity in vertical eco-farming is more than twice as high as traditional agriculture and crop cycles are also faster due to the controlled media and environmental parameters. The several benefits of vertical eco-farming over conventional farming are shown in Table I.

TABLE I: ECO-FRIENDLY ADVANTAGES OF VERTICAL ECO-FARMING.

Sr. No.	Features	Descriptions
1	Year round crop grown	Year-round crop production of wide range of vine crops in any regions.
2	Protection from extreme weather	Crops are grown under controlled environment; therefore, crops are protected from extreme weather occurrences such as droughts and floods.
3	Organic crops production	The controlled growing conditions allow a reduction or total abandonment of the use of chemical pesticides.
4	Water conservation and recycling	Around 70 % lesser water use in comparison to open field agriculture. Urban wastes water may be recycled and sewage sludge may be converted to topsoil and processed for agricultural use.
5	Environment friendly	Eliminates the use of mechanical plows and other equipment and reduces the burning of fossil fuel. As a result, a significant reduction in air pollution and CO2 emission which reduces climatic change and ultimately favors biodiversity.
6	Human health friendly	Reduces the occupational hazards associated with traditional horizontal farming.
7	Solar and wind energy conservation	Installation of solar panel and wind mills on the rooftop of the vertical eco-farm may generate electrical power to contribute in its own environmental controlling system.
8	Sustainable urban growth	The technology could upgrade employment and income generating opportunities for the urban poor.
9	Reliable harvests	Vertical Farm Systems growing cycles are consistent and reliable, allowing commercial growers to confidently commit to delivery schedules and supply contracts.
10	Minimum production overheads	Minimum overheads and grow costs are maintained through low labor costs, low water usage, reduced cost of crop washing and processing and reduced transport costs
11	Increased growing area	For the same floor area, vertical eco-farm systems multi-level design provides nearly 8 times more growing area than single level hydroponic or greenhouse systems or open field system.
12	Maximize crop yield	The land productivity of vertical farming is more than twice as high and faster as traditional agriculture.

The estimated yield of six important vine crops grown in vertical eco-farm compared to traditional agriculture are summarized Table II. Ref. [10] the benefits in terms of growing time, nutrient requirements, land requirements and water requirements of vertical eco-farming versus conventional farming are shown in Fig. 2.

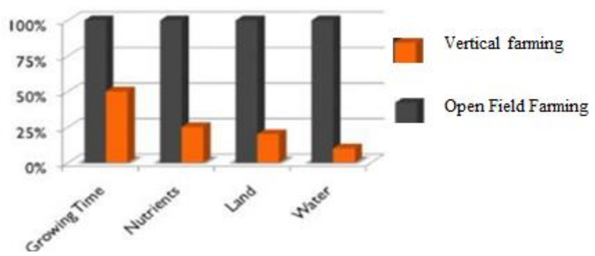

Figure 2. The benefits of vertical eco-farming versus conventional farming.

III. CHALLENGES IN SUSTAINABILITY OF VERTICAL ECO FARMS

Economically and practically, there are many problems inherent with creating a vertical eco-farm. A high degree of competence in plant science and engineering skills viz. agriculture, agronomy, civil planning, architecture, engineering, economics and public health would be engaged work together for successfully maintaining of vertical eco-farms. The essential factors of plants to grow are nutrients, water, light, and air.

Ref. [11] in hydroponics culture, water and nutrients are always available, the plant never gets stressed. Sunlight and air are readily available in an outdoor eco-farming system.

TABLE II: COMPARATIVE YIELD OF SIX IMPORTANT VINE CROPS GROWN IN A VERTICAL ECO-FARM AND OPEN FIELD FARM.

Sr. No.	Crops	Yield in Vertical Farms (tons/ha)	Open Field Yield (tons/ha)	Reference
1	Tomato	155	45	Ref. [12]
2	Capsicum	133	30	
3	Lettuce	37	25	
4	Strawberry	69	30	
5	Spinach	22	12	
6	Cucumbers	300	30	Ref. [13]

For indoor farming, adequate light and good air circulation must be provided. The monitoring of important growing parameters of vine fruits and vegetable crops are discussed in this section. The optimum value of important four controlling parameters of six important vine crops are summarized in Table III.

A. *Monitoring of Optimum Air Quality, Temperature and Relative Humidity*

Air quality, temperature and humidity levels are closely monitored and maintained in an optimum range for each crop being grown. In warehouse installations the addition of CO^2 is an optional addition that further increases crop growth and yield. Warm-season plants perform best when the temperature is between 70 and 80 ℉ during the day and 60 to 70 °F at night. Cool-season plants generally require temperatures approximately 10 °F lower than those suitable for warm-season plants. Above or below this range, plant growth will slow dramatically. Therefore, it is important that the temperatures be maintained in an optimum range.

B. *Monitoring of Optimum Water Quality*

Water containing particulate, fluoride and heavy metal contaminants should be removed and sterilized before entering the vertical eco-farm system. Water would be carefully distributed through irrigation while any excess water would be collected and recycled. Black water can be cleaned by algae and made potable for irrigation in vertical eco-farming. Ref. [14] scientific American supports vertical eco-farming as a solution to the problem of a growing population and a dwindling world food supply.

C. *Monitoring of Optimum Light Quality*

High-intensity low-energy LED lighting has been widely used for maximizing crop growth, high reliability and cost-effective operation. The duration and intensity of the specific parts of the light spectrum that plants use during different stages of their growth rate should be carefully programmed into the computer management system.

The amount of light intensity required varies from plant to plant. Most fruiting plants such as corn, tomatoes, and peppers need 8 to 10 hours of sunlight a day. If these plants are grown indoors, an artificial light must be used to provide high light intensity without causing the temperature to rise above acceptable levels. On the other hand, many ornamental and foliage plants require less sunlight than fruiting plants do and therefore perform very well in indoors. Halide and sodium metal type light used by commercial growers to 'supplement' natural light and to extend the day length. Metal halide lamps give off a 'blue' light which is more suitable for young plants and vegetative growth. Perhaps one could design a vertical farm building that it takes advantage of the available sunlight, such as the Pyramid Farm designed by Eric Ellingsen and Dickson Despommier. Lighting the interior of the vertical farm with artificial light is very expensive. Ref. [15] generally plants are intolerant of continuous light for 24 hours. Therefore, 12 to 14 hours of light per day are given to plants.

TABLE III: OPTIMUM VALUE OF FOUR CONTROLLING PARAMETERS OF SIX IMPORTANT VINE HYDROPONIC CROPS

Sr. No.	Crops	Controlling Parameters							
		Temperature		Relative humidity		Light Intensity		Ph	
		Value (℃)	Ref.	Value (%)	Ref.	Value (Wm^{-2})	Ref.	Value	Ref.
1	Tomato	20 to 22	Ref. [16]	65 to 70	Ref. [22]	127	Ref. [28]	5.8	Ref. [34]
2	Capsicum	20 to 24	Ref. [17]	70	Ref. [23]	300	Ref. [29]	6.0 to 6.2	Ref. [35]
3	Lettuce	24	Ref. [18]	72±7	Ref. [24]	150	Ref. [30]	7.4 to 8.2	Ref. [36]
4	Straw berry	28	Ref. [19]	60	Ref. [25]	100	Ref. [31]	5.0 to 5.5	Ref. [37]
5	Cucumbers	27 to 29	Ref. [20]	70 to 85	Ref. [26]	100	Ref. [32]	5.0 to 6.0	Ref. [38]
6	Spinach	24	Ref. [21]	60	Ref. [27]	100	Ref. [33]	7.5	Ref. [39]

D. Substrate of Vertical Eco-Farming

Ref. [40] in order to serve as a suitable replacement for soil, the substrate must be capable of supporting the root system and holding moisture and nutrients. It should be inert, free of insects and diseases, and not easily broken down. Also, the substrate should allow adequate aeration of the roots and have good drainage qualities. Plants need sufficient access to oxygen in the air in order to grow and take up water and nutrients. Poor drainage can lead to decreased growth, stunting, wilting, and discoloration of the leaves and, in the worst cases, drowning. Commonly used substrates are coarse sand, gravel, perlite, coarse vermiculite, and rock wool. An inadequate water supply is the most limiting factor to plant growth. It is important that the substrate media should be flooded, and subsequently drained, one to three times daily or as often as necessary to keep the roots moist. Optimum nutrient and mineral quality are very important for maximum plant growth and the nutritional wellbeing of consumers. Vertical eco-farm systems specially use formulated biologically active nutrients in all the crop cycles.

TABLE IV: SUMMARIES OF THE NUTRIENT CONCENTRATION AND THEIR ROLES IN GROWING VINE CROPS

Elements	Ionic Forms	Concentration (ppm)	Major role in plant growth
Carbon (C)	CO_2	396.10	Formation cell wall, sugar, and chlorophyll
Hydrogen (H)	H_2	0.55	Nutrient uptake from roots, formation sugar and starches
Oxygen (O)	O_2	209,480	Respiration and formation sugar and starches, cellulose
Major Nutrient			
Nitrogen (N)	NO_3, NH_4	100 to 200	Formation of amino-acids, co-enzymes and chlorophyll for plant growth and new leaves and stems
Phosphorous (P)	HPO_4 , $H2PO_4$	15 to 30	Root growth, photosynthesis and in the production of flowers and seeds
Potassium (K)	K^+	100 to 200	Formation of sugar and starches. Chlorophyll growth in all stages particularly during fruit development
Calcium (Ca)	Ca^{2+}	200 to 300	Formation and growth of cell walls and cells
Magnesium (Mg)	Mg^{2+}	30 to 80	Chlorophyll and enzyme production
Sulfur (S)	So_4^{2-}	70 to 170	Protein synthesis, water uptake, fruiting and seeding
Micro-Nutrient			
Iron (Fe)	Fe^{2+}, Fe^{3+}	2 to 12	Chlorophyll formation and respiration
Manganese (Mn)	Mn^{2+}	0.5 to 2.0	Works as catalyst in formation of oxygen during photosynthesis
Boron (B)	Bo_3^{3-}	0.21 to 0.3	Cell wall formation
Molybdenum (Mo)	MoO^{4-}	0.01 to 0.05	Nitrogen metabolism and fixation
Zinc (Zn)	Zn^{2+}	0.05 to 0.5	Chlorophyll formation, respiration and Nitrogen metabolism
Copper (Cu)	Cu^{2+}	0.01 to 0.10	Activates enzymes, photosynthesis and respiration
Chlorine (Cl)	Cl^-	Cl<4	Photosynthesis

E. Monitoring of Optimum Nutrients Concentration

Levels of nutrition available to the plants should be constantly managed and adjusted to optimum levels relative to the growth stage of each crop. The key ingredient in the recipe for successful eco-farming is the nutrient solution. Ref. [41] vertical eco-farming systems provide readily available, water-soluble minerals directly to the roots in a complete and balanced solution, thus eliminating the need for soil. The nutrient concentration and their roles in the most vine crops are summarized in Table IV. Ref. [42] there is sixteen elements needed for proper plant growth. Plants extract oxygen, carbon, and hydrogen, from water and air. The rest of the elements are supplied through the nutrient solution. The nutrient elements needed for vertical eco-farming crop growth are widely available in premixed that can be purchased form from fertilizer companies, and hydroponic material supply companies, greenhouse material supply companies, and chemical companies. Most hydroponics amateurs are rely on these commercially available mixes rather than preparing their own solutions at home.

However, for those enthusiasts who are willing to mix their own, the extra time and effort may offer more precise nutrient combinations for specific plants, as well as provide an opportunity for experimentation. Many nutrient solution recipes have been developed, some for general use and others for specific plants, and no one recipe is better for all plants than another.

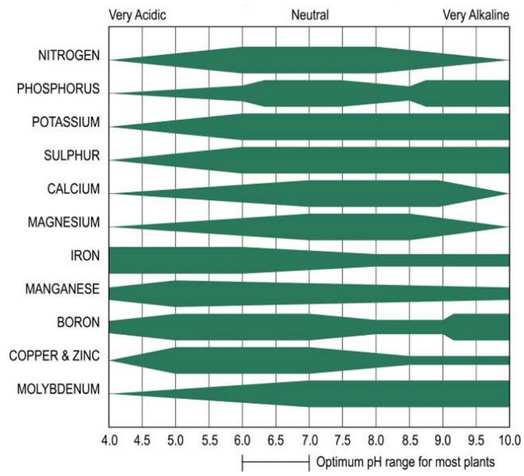

Figure 3. Scale of pH and subsequent relation with nutrient availability for plant growth

F. Monitoring of Optimal pH in Nutrient Solution

Ref. [43] the pH value determines the nutrient availability for plants. The addition of plant nutrients to vertical eco-farming systems may be performed according to the plant nutrient requirement. The pH balance between acidity and alkalinity in nutrient solutions is an important aspect of monitoring. Plants have pH ranges within which they grow best and each mineral is absorbed by plants within a certain pH range. It is necessary to carry out a chemical analysis of water to be used in the nutrient solution for growing vine crops in vertical eco-farms. Knowing the kind and concentration of ions allows identifying on the one hand, those that are needed in the nutrient solution and therefore can be subtracted from the original formulation; and on the other hand, to take decisions about ions not needed in the nutrient. Ref. [44], the pH adjustment must be done daily due to the lower buffering capacity of soilless systems. The most vine crops prefer the pH between 5.5 and 7.5 beyond this range some nutrient elements will be unavailable to the plants. Most tap waters are between pH 7 and 8. The chemical adjustment in nutrient solution is normally done by addition of acids to reduce the pH value. Regulation of pH is normally carried out by adding nitric, sulphuric or phosphoric acid, and such acids can be used either individually or combined. Ref. [45] the scale of pH and subsequent relation with nutrient availability for plant growth are shown in Fig. 3.

It is seen from this Fig. 3 that the movement away from this pH in either direction results in greatly reduced availability of many nutrients, which results in sub-optimal plant growth.

G. Design of Watering Systems

There are several types of watering system for vertical eco-farming. Ref. [46] the common watering systems are wick system, water culture, flood and drain culture, drip systems, nutrient film technique and aeroponic culture. The features of the six important watering methods of vertical eco-farming are summarized in Table V. Ref. [47] the crop and variety selection is the first consideration in starting or developing the farm. There are many factors to consider in crop selection, a requisite that must be undertaken before starting a vertical eco-farming venture. Even without a predetermined location and site of a farm, the crops to be grown are decided mainly based on its marketability and profitability. However, there are many cases especially in countries having agriculture-based economy in which farmlot is used which acquired through inheritance or by purchase.

TABLE V: SUMMARY OF FEATURES OF SIX IMPORTANT WATERING METHODS OF VERTICAL ECO- FARMING

Sr. No.	Watering methods	Features	Growing medium	Suitable crops
1	Wick System	It has no moving parts. The nutrient solution is drawn into the growing medium from a nutrient reservoir with a wick.	Perlite, Vermiculite, Coconut Fiber	Vine crops
2	Water Culture	It has a platform that holds the plants are usually made of styrofoam that floats directly on the nutrient solution.	Water, styrofoam platform	Leafy crops like lettuce
3	Flood and Drain Culture (Ebb and Flow)	The ebb and flow system works by temporarily flooding the grow tray with nutrient solution and then draining the solution back into the reservoir by a timer operated pump.	Rocks, gravel or granular rockwool.	Vine crops
4	Drip Systems	Drip systems are probably the most widely used type of eco-farming system in the world. Nutrient solution is dripping onto the base of each plant by a small drip line.	Drip line	Vine crops
5	Nutrient Film Technique (NFT)	The nutrient solution is pumped into the growing tray (usually a tube) and flows over the roots of the plants and then drains back into the reservoir.	Plastic tubes	Vine crops
6	Aeroponic	The aeroponic system is probably the most high-tech type of eco-farming system. The roots are hanging in the air and then misted with nutrient solution.	Air	Leafy crops like lettuce, spinach

H. Selection of Ideal Crop for Vertical Eco-Farming

Right decision in the selection of crops to be grown ultimately converts into a successful farming venture. The major factors to be considered in crop selection include are prevailing farm conditions, crop or varietal adaptability, marketability and profitability, resistance to pests and diseases, available technology and farming system.

I. Vulnerability of Vertical Eco-farming

The largest reason to be unenthusiastic is the sheer volume of energy that required powering the supplemental lighting and operating the other environmental controls. There are many controversies in the literature regarding efficient design for optimal plant growth. Ref. [48] any failure to the vertical eco-farming system leads to rapid plant death. Other disadvantages include pathogen attacks such as damp-off due to verticillium wilt caused by the high moisture levels associated with hydroponics and over watering of soil based plants.

IV. CONCLUSIONS

Eco-friendly solutions to meeting food needs are today's seriously concern. The vertical eco-farming is the fastest growing in the developing countries. It is a capital intensive technology which drastically increases yields and quality of fresh nutritious food year round and has numerous advantages. It is protective of the environment. Growing crops in skyscrapers would not only mitigate the need for more land, it produces growing space vertically. Growing food within cities at the doorstep of the consumers eliminates the need for transport, therefore reducing greenhouse gas emissions. Mostly, leafy vegetables are growing well in the vertical eco-farming sub-system. The most common and profitable crop varieties grown in vertical eco-farms are cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers. The two chief merits of the soil-less cultivation of plants are potentially produce much higher crop yields and also can grows in places where in-ground agriculture is not possible. The crop productivity in vertical eco-farming is more than twice as high as traditional agriculture and crop cycles are also faster due to the controlled media and environmental parameters.

The major challenges of vertical eco-farming are eco-friendly design of the farm structure, controlling indoor environment, monitoring of nutrient solution and watering system and selection of ideal crop. The ph value of nutrient solution determines the nutrient availability for plants. All vine crops have pH ranges within which they grow best. Therefore, the pH adjustment in the nutrient solution must be done daily due to lower the buffering capacity of soilless systems. Regulation of pH is normally carried out by adding nitric, sulphuric or phosphoric acid either individually or combined. The scale of pH and subsequent relation with nutrient availability for plant growth are widely used for regulating pH and nutrient check.

The essential growing factors of plants are nutrients, water, light, and air. Sunlight and air are readily available in an outdoor eco-farming system. Adequate light and good air circulation is necessary. Cool-season plants generally require lower than those suitable for warm-season plants. Therefore, the temperatures in an optimum range are maintained for successfully growing crops. Water containing particulate, fluoride and heavy metal contaminants are removed and sterilized before entering the vertical eco-farm system. Any excess water are recycled, black water are cleaned by algae and made potable for irrigation. Generally, halide and sodium metal type light are used to supplement natural light and to extend the day length. The vertical eco-farms must be design in such a way that it takes advantage of the available sunlight. Generally 12 to 14 hours of light per day are most suitable plants growth.

In order to serve as a suitable replacement for soil, the substrate growing media must be capable of supporting the root system and holding moisture and nutrients. It should be inert, free of insects and diseases. Also, the substrate should allow adequate aeration of the roots and have good drainage system. Commonly used substrates are coarse sand, gravel, perlite, coarse vermiculite, and rock wool. The most common watering systems are wick system, water culture, flood and drain culture, drip systems, nutrient film technique and aeroponic culture.

The major factors to be considered in crop selection includes are prevailing farm conditions, crop or varietal adaptability, marketability and profitability, resistance to pests and diseases, available technology and farming system. The largest reason to be unenthusiastic is the sheer volume of energy that required powering the supplemental lighting and operating the other environmental controls. There are still many controversies in the literature regarding efficient design of vertical eco-farm for optimal plant growth. Any failure to the vertical eco-farming system leads to rapid plant death. Other disadvantages include pathogen attacks such as damp-off due to verticillium wilt caused by the high moisture levels associated with hydroponics and over watering of soil based plants.

This review of the eco-vertical farming is expected to help eco-farming grower to know how the state of the art technology and its efficient and eco-friendly design, monitoring of environment and nutrient solution and watering system, crop selection of vertical eco-farming. The adaptability of the vertical eco-farms is also expected to increase among the unemployed youth and farmers, entrepreneurs and will generate more employment. This study will also help new researcher for carry out further development of vertical eco-farms for more efficient, eco-friendly design and precise monitoring of controlling factors for growing need based higher and nutritious crop year round.

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REFERENCES

[1] GEO. (2007). Global environment outlook (GEO), Part 4, United Nations Environment Programme. [Online]. Available: http://news.bbc.co.uk/2/shared/bsp/hi/pdfs/15_10_2007_un.pdf

[2] MIT. (2014). Urban Agriculture Mission 2014, Feeding the World. MIT, USA. [Online]. Available: http://12.000.scripts.mit.edu/mission2014/solutions/urban-agriculture

[3] J. H. Merle, "Hydroponic culture for the tropics: Opportunities and alternatives. Department of plant sciences," University of Arizona, Tucson, Arizona, USA, 1991.

[4] M. H. Jensen, "Hydroponics worldwide," in *Proc. International Symposium on Growing Media and Hydroponics*, 1997, vol. 481, pp. 719-730.

[5] AVF. (2013). The Association for Vertical Farming AVF), Munich, Germany, 23rd of June 2013. [Online]. Available: http://vertical-farming.net/en/vf/why/

[6] D. Despommier, "The rise of vertical farms," *Scientific American*, vol. 301, no. 5, pp. 80-87, 2009.

[7] RIRDC, Hydroponics as an Agricultural Production System, Publication No 01/141, Project No HAS-9A, Rural Industries Research and Development Corporation (RIRDC), Australian Government, Kingston, PO Box 4776, ACT 2604, 2001.

[8] VFS. (2012). Vertical farm Systems (VFS), Advantages of Vertical Farming, Minimum Input – Maximum Output. [Online]. Available: http://www.verticalfarms.com.au/advantages-vertical-farming

[9] B. Rosalyn. (2012). Plant Nutrients. All about Hydroponic Organic Gardening. [Online]. Available: http://www.plantnutrients.co/gardening/all-about-hydroponic-organic-gardening/

[10] C. Banerjee and L. Adenaeuer, "Up, Up and Away! The economics of vertical farming," *Journal of Agricultural Studies*, vol. 2, no. 1, pp. 40-60, 2014.

[11] S. Ruth. (2009). Home Hydroponics. Extension Technician, Diane Relf, Extension Specialist, Horticulture, Virginia Tech. Virginia Cooperative Extension, Publication 426-084, Virginia State University. [Online]. Available: http://pubs.ext.vt.edu/426/426-084/426-084_pdf.pdf

[12] K. Mattas, M. Bentes, G. Paroussi, and I. Tzouramani, "Assessing the economic efficiency of a soilless culture system for off-season

strawberry production," *Hort Science*, vol. 32, no. 6, pp. 1126-1129, 1997.

[13] Haifa Chemicals. (2014). Nutritional recommendations for CUCUMBER in open field's tunnels and greenhouses. Haifa Chemicals ltd. [Online]. Available: http://www.haifa-group.com/files/Guides/Cucumber.pdf

[14] W. Claussen, "Growth, water use efficiency, and proline content of hydroponically grown tomato plants as affected by nitrogen source and nutrient concentration," *Plant and Soil*, vol. 247, no. 2, pp. 199-209, 2002.

[15] A. C. Schuerger and W. Hammer, "Effects of temperature on disease development of tomato mosaic virus in Capsicum annuum in hydroponic systems," *Plant Disease*, vol. 79, no. 9, pp. 880-885, 1995.

[16] H. C. Thompson, R. W. Langhans, A. J. Both, and L. D. Albright, "Shoot and root temperature effects on lettuce growth in a floating hydroponic system," *Journal of the American Society for Horticultural Science*, vol. 123, no. 3, pp. 361-364, 1998.

[17] S. J. Tabatabaei, M. Yusefi, and J. Hajiloo, "Effects of shading and NO_3: NH_4 ratio on the yield, quality and N metabolism in strawberry," *Scientia Horticulturae*, vol. 116, no. 3, pp. 264-272, 2008.

[18] D. B. James, A. D. Gandhi, N. Palaniswamy, and J. X. Rodrigo, "Hatchery techniques and culture of the sea-cucumber Holothuria scabra," *CMFRI Special Publication*, vol. 57, pp. 1-40, 1994.

[19] H. H. Kim, C. Chun, T. Kozai, and J. Fuse, "The potential use of photoperiod during transplant production under artificial lighting conditions on floral development and bolting, using spinach as a model," *Hort Science*, vol. 35, no. 1, pp. 43-45, 2000.

[20] C. Kaya, D. Higgs, and A. Burton, "Plant growth, phosphorus nutrition, and acid phosphatase enzyme activity in three tomato cultivars grown hydroponically at different zinc concentrations," *Journal of Plant Nutrition*, vol. 23, no. 5, pp. 569-579, 2000.

[21] P. Zornoza, J. Caselles, and O. Carpena, "Response of pepper plants to NO3: NH4 ratio and light intensity," *Journal of Plant Nutrition*, vol. 10, no. 7, pp. 773-782, 1987.

[22] J. Mathieu, R. Linker, L. Levine, L. Albright, *et al.*, "Evaluation of the NiCoLet model for simulation of short-term hydroponic lettuce growth and nitrate uptake," *Biosystems Engineering*, vol. 95, no. 3, pp. 323-337, 2006.

[23] CSUE. (2011). Plant Growth Factors: Light, Colorado State University Extension (CSUE). CMG GardenNotes #142. [Online]. Available: http://www.ext.colostate.edu/mg/gardennotes/142.pdf

[24] J. Jayaraman, J. Norrie, and Z. K. Punja, "Commercial extract from the brown seaweed Ascophyllum nodosum reduces fungal diseases in greenhouse cucumber," *Journal of Applied Phycology*, vol. 23, no. 3, pp. 353-361, 2011.

[25] I. M. Prosser, J. V. Purves, L. R. Saker, and D. T. Clarkson, "Rapid disruption of nitrogen metabolism and nitrate transport in spinach plants deprived of sulphate," *Journal of Experimental Botany*, vol. 52, no. 354, pp. 113-121, 2001.

[26] I. Seginer, G. Shina, L. D. Albright, and L. S. Marsh, "Optimal temperature setpoints for greenhouse lettuce," *Journal of Agricultural Engineering Research*, vol. 49, pp. 209-226, 1991.

[27] S. Hikosaka, K. Sasaki, E. Goto, and T. Aoki, "Effects of in vitro culture methods during the rooting stage and light quality during the seedling stage on the growth of hydroponic everbearing strawberry," in *Proc. International Strawberry Symposium*, March 2008, vol. 842, pp. 1011-1014.

[28] Off-Grid-World. (2012). Vertical Farm. [Online]. Available: http://www.offgridworld.com/vertical-farm/

[29] How Stuff Works, Inc. (2014). Vertical Farm Designs and Challenges. Environmental Science, Conservation Issues. [Online]. Available: http://science.howstuffworks.com/environmental/conservation/issues/vertical-farming1.htm

[30] E. Simeonova, M. Garstka, J. Kozioł-Lipińska, and A. Mostowska, "Monitoring the mitochondrial transmembrane potential with the JC-1 fluorochrome in programmed cell death during mesophyll leaf senescence," *Protoplasma*, vol. 223, no. 2-4, pp. 143-153, 2004.

[31] A. Chueca, J. J. Lázaro, and J. L. Gorgé, "Light-induced nuclear synthesis of spinach chloroplast fructose-1, 6-bisphosphatase," *Plant Physiology*, vol. 75, no. 3, pp. 539-541, 1984.

[32] M. Y. Siddiqi, B. Malhotra, X. Min, and A. D. Glass, "Effects of ammonium and inorganic carbon enrichment on growth and yield of a hydroponic tomato crop," *Journal of Plant Nutrition and Soil Science*, vol. 165, no. 2, pp. 191, 2002.

[33] T. J. Nowak, "Effect of foliar fertilization of Capsicum annuum L. together with optimal root fertilization in hydroponic culture on fruit yield and its capsaicin content," *Acta Agrobotanica*, vol. 33, no. 1, pp. 59-71, 1980.

[34] F. Benoit and N. Ceustermans, "Growing lamb's lettuce (Valerianella olitoria L.) on recycled polyurethane (PUR) hydroponic mats," in *Proc. International Symposium on Diversification of Vegetable Crops*, September 1988, vol. 242, pp. 297-304.

[35] F. Lieten, "Methods and strategies of strawberry forcing in central Europe: Historical perspectives and recent developments," in *Proc. International Strawberry Symposium*, September 1992, vol. 348, pp. 161-170.

[36] C. Sonneveld and W. Voogt, "Chemical analysis in substrate systems and hydroponics-use and interpretation," in *Proc. International Symposium on Growing Media and Hydroponics*, August 1999, vol. 548, pp. 247-260.

[37] P. Jauert, T. E. Schumacher, A. Boe, and R. N. Reese, "Rhizosphere acidification and cadmium uptake by strawberry clover," *Journal of Environmental Quality*, vol. 31, no. 2, pp. 627-633, 2002.

[38] M. Waisberg, W. D. Black, C. M. Waisberg, and B. Hale, "The effect of pH, time and dietary source of cadmium on the bioaccessibility and adsorption of cadmium to/from lettuce (Lactuca sativa L. Ostinata)," *Food and Chemical Toxicology*, vol. 42, no. 5, pp. 835-842, 2004.

[39] M. Gibbs and N. Calo, "Factors affecting light induced fixation of carbon dioxide by isolated spinach chloroplasts," *Plant Physiology*, vol. 34, no. 3, pp. 318, 1959.

[40] [40] K. J. Raymondr, W. J. David, and H. Robyn. (2006). Hydroponics for Home Gardeners, ANR-1151. Horticulture, Auburn University. [Online]. Available: http://www.aces.edu/pubs/docs/A/ANR-1151/ANR-1151.pdf

[41] Flair Form. (2012). The role of Essential Nutrients in Plant Growth, Flair Form. Australia. [Online]. Available: http://www.flairform.com/hints/nutrient_species.htm

[42] S. Arjina and D. Bruce. (2014). Hydroponics, HLA-6442 Oklahoma Cooperative Extension Service Oklahoma State University. [Online]. Available: http://osufacts.okstate.edu/docushare/dsweb/Get/Document-6839/HLA-6442web.pdf

[43] L. I. Trejo-Téllez and F. C. Gómez-Merino, "Nutrient solutions for hydroponic systems," *Hydroponics–A Standard Methodology for Plant Biological Researches*, 2012.

[44] Hydroponics Habitat. (2014). Hydroponic Nutrients. Learn to grow your own hydroponic plants. [Online]. Available: HydroponicsHabitat.com. http://hydroponicshabitat.com/hydroponic-nutrients

[45] Simply Hydro. (2008). Hydroponics University, Florida. [Online]. Available: http://www.simplyhydro.com/system.htm

[46] B. G. Bareja. (2011). Crop Agriculture Review: Towards an Informed Application in agriculture and Related Science. [Online]. Available: http://www.cropsreview.com/crop-selection.html

[47] Hydro Evolution. (2013). Hydroponics, Hydro Evolution Ltd., Hockley Hill, Birmingham, West Midlands, UK. [Online]. Available: http://www.hydroevolution.co.uk/Hydroponics.asp

[48] Hydrogarden. (2013). Guide to Hydroponic System Types. HydroGarden Ltd. [Online]. Available: https://www.hydrogarden.com/what-is-hydro.asp

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