AfroBeyondistCivilization

BEYONDIST Hanging GARDENS

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ABSTRACT

Our BEYONDIST concept of “Hanging Gardens” gets it tap roots from the ideal of “Vertical Farming”, which is modelled on the science of “Hydroponics”. The word HYDROPONICS has its derivation from combining the two Greek words, *hydro*, meaning water, and *ponos*, meaning labor (i.e., working water). By 2050, the global population is expected to reach 9.8 billion people. Yet the amount of agricultural land has remained steady for the last 50 years (hovering around 37% of total available land) with no dramatic changes in that figure anticipated over the coming period. In 2013, when the 2050 population was projected to reach 9.6 billion, a UN report found that global food production would need to increase by approximately 70% just to keep pace with population growth. The farming community has risen to the challenge by increasing production per hectare by leveraging technology innovation and advanced agronomic practices to boost yields and fight off pests (“intensification”). Today’s consumers have also become more conscious of the impact of pesticide use on health, as well as the environmental toll of plastic packaging, food miles and over-exploitation of the Earth’s resources—including farmland. We are entering a new era of technology-enabled-growing, where indoor vertical HYROPONICS farming, or Controlled Environment Production (CEP), is considered one of the best opportunities to boost the production of a range of crops whilst maximizing quality, nutrition and visual appeal that will help maintain and, in many cases, improve living standards for global citizens. We also see huge, relatively untapped potential in the pharmaceutical industry, with vertical HYDROPONICS farms offering controlled, cleanroom conditions in which to grow powerful, natural pharmaceutical ingredients.

INTRODUCTION

Only one fourth (nearly 27%), is the total land mass on the planet earth, the rest being water (nearly 73%). Out of this land mass, only three fourth is productive, the rest being high mountains, cold and hot deserts, etc. Over the years, mankind has been able to convert nearly 57% of productive land for cultivation of various crops for food, often at the expense of forest and grasslands (43%).

With rising urbanization - a worldwide phenomenon - it has been estimated that most of the world’s population (>60%) by 2030 will shift to cities for urban dwelling. Interestingly in the same period (by 2030), the human population is expected to reach 8.6 billion from the current 7.6 billion, and expected to rise further exponentially to 9.8 billion by 2050 and explode to 11.2 billion by 2100.

The rapid urbanization on the other hand is putting pressure on the meagre available land resources that is witnessing gradual but continuous decline in the cultivated land worldwide. Urbanization has resulted in innumerable small and large concrete structures mostly to accommodate the ever rising population at the expense of farm land.

The population of cities would obviously keep on multiplying and put pressure on food production where in several crops it has already plateaued. In many regions, the cultivable land has almost exhausted and there is hardly any scope for further adding the area to the crop cultivation.

In Africa, the cultivable area is almost constant for last several years. Whatever land area is reclaimed, almost same productive area goes to construction and other infrastructure development. Cultivable land has become a limiting factor and land prices are skyrocketing in recent years.

The transportation of food to cities from rural production sites will add to the problem, compounded further in perishable and semi-perishable food especially from horticultural crops having shorter shelf life.

One innovation that has potential to partly manage the above problem is by production of food items in cities itself in residential buildings, roof tops, public spaces, etc. Whereas the present improved agriculture practices put immense pressure on finite resources with diminishing returns on land, water, energy, etc., the innovative technology of vertical HYDROPONIICS farming is expected to relieve this pressure to a large extent.

Considering the above, year round production of large quantities of nutritious food from vertical HYDROPONIICS farming within a limited space/area appears to be a revolutionary approach. Vertical HYDROPONIICS farming generally refers to the growing of crops mostly vegetables, ornamentals, and herbs on stacks of indoor shelves using artificial light and nutrient solutions, without much sunshine and soil. Such farms are not dependent on seasons/controlled environment and have ability to enhance production round the year with little risk of crop failure. Further they give fresh quality produce without depending on favorable climate, healthy soil, high water consumption and above all saves on labour, a scarce commodity today.

Vertical HYDROPONIICS farming has potential to sustain ever increasing world population especially in the urban areas with nutritional supplement thus providing food security. Vertical production of mushrooms, hydroponic green fodder, some vegetables and fruits and even poultry birds are either already in vogue or at advanced stage.

Vertical gardens in ornamental horticulture, a component of vertical farming are also known as green walls, living walls, bio walls or vertical garden (Jain and Janakiram, 2016). It is a free-standing space or part of a building that is partially or completely covered with attractive vegetation luxuriantly growing in an organic or inorganic medium and in some cases soil also.

Hydroponics and vertical farming address the need of safe and healthy, pesticide/ acaricides/ insecticide free, natural antioxidant rich produce with low carbon and water foot print (Pant et al., 2018).

HISTORY OF VERTICAL HYDROPONIICS FARMING

Vertical HYDROPONIICS farms have come to lime light on the agricultural front only in the last decade, however the concept behind this innovative farming technique is not new as is evident from the following:

Pre - 20th Century

Perhaps the earliest example of a "vertical farm" is the legendary ***Hanging Gardens of Babylon***, built by King Nebuchadnezzar II, more than 2,500 years ago (600 BC). The gardens consisted of a series of vaulted terraces, stacked one on top of the other planted with several different types of trees and flowers. Reaching a height of 20 meters, the gardens were irrigated probably by another early engineering innovation known as a chain pumps. These pumps may have used a system of buckets and pulleys to bring water from the Euphrates River flowing at the foot of the garden to a pool at the top.

Nearly a thousand years ago (1150 AD), Aztec people used a form of hydroponic farming known as ***"chinampas"*** to grow crops in marshy areas near lakes. The swampy soil in these areas was not suitable for agriculture; the Aztecs instead constructed rafts out of reeds, stalks, and roots and covered them with mud and soil from the lake bottom. These rafts were then drifted out into the lakes. The structural support provided by the rafts allowed crops to grow upwards letting the roots grow downwards into the water. Often, many of these rafts were attached together to form floating "fields."

The first published theory of hydroponic gardening and farming methods appeared in the book *Sylva Sylvarum* (1627), by the English scientist and statesman Sir Francis Bacon. In this book, Sir Bacon established and explored the possibility of growing terrestrial plants without soil.

In 1699, English scientist John Woodward using spearmint refined the idea of hydroponic gardening with a series of water culture experiments. Woodward found that the plants grew better in water having impurities than in distilled water. This led to his important finding that the plants derive important nutrients from soil and other additives mixed into water solutions.

Twentieth Century and Beyond

In 1909, *Life Magazine* published the earliest drawing of a "modern" vertical farm. The sketch shows open-air layers of vertically stacked homes set in a farming landscape, all cultivating food for consumption.

The term "vertical farming" is coined by American geologist ***Gilbert Ellis Bailey*** (1915) in his book of the same name. Interestingly, Bailey focused primarily on farming "down" rather than "up." That is, he explored a type of underground farming where farmers used explosives to reach deeper, increasing their total cultivable area and thus allowing for crops to be grown in larger area.

William F. Gericke, an agronomist at the University of California, Berkeley, is credited with developing modern hydroponics. In his article *"Aquaculture: A means of Crop production,"* published in December 1929, Gericke first outlined the process of growing plants without soil in sand, gravel, or liquid, using added nutrients.

The term "hydroponics" however has origin in an article published in ***Science magazine*** (1937), derived from the Greek words "hydro," or water, and "ponos," or labor. The term was suggested to Gericke as an alternative to "aquaculture" (which was already in use to describe fish-breeding techniques) by the botanist William Albert Setchell, his associate in the University of California.

The HYDROPONIICS system of growing crops on large scale was used for the first time in modern history during World War II (1940). More than 8,000 tons of fresh vegetables were produced hydroponically on South Pacific Islands to feed the allied forces stationed there (Kojai et al., 2015).

At the Vienna International Horticulture Exhibition (1964), a vertical farm in the form of a tall glass tower was displayed.

In 1989, architect and ecologist Kenneth Yeang created a vision of mixed-use of buildings that are seamlessly integrated with green spaces, allowing plant life to be cultivated in buildings in the open air. Yeang described this as "vegetated architecture." Unlike many other approaches to vertical farming, his vision was based on personal and community use rather than large-scale production and marketing.

The concept of the modern vertical farm was given shape and developed in a class led by ***Drs Despommier and Carter***, Professors of Environmental Health Sciences, Columbia University during 2011. Despommier and his students developed the idea of a multi-story building in which layers of crops could be grown on each floor to feed the population of New York using only urban rooftop agriculture - in other words, a contemporary vertical farming tower. (*Despommier has since become the world's foremost expert on and proponent of vertical farms*). In the year 2010, he published a book entitled *The Vertical Farm: Feeding the World in the 21st Century*, wherein he laid down the principles and practices of modern vertical farming around cities, and inside buildings, instead of horizontal expansion on the ground.

VALUE OF THE HYDROPONIC METHOD

In 1981, Jensen listed the advantages and disadvantages of the hydroponic technique for crop production, many of which are still applicable today.

Advantages:

- ✓ Crops can be grown where no suitable soil exists or where the soil is contaminated with disease.
- ✓ Labor for tilling, cultivating, fumigating, watering, and other traditional practices is largely eliminated.
- ✓ Maximum yields are possible, making the system economically feasible in high-density and expensive land areas.
- ✓ Conservation of water and nutrients is a feature of all systems. This can lead to a reduction in pollution of land and streams because valuable chemicals need not be lost.
- ✓ Soil-borne plant diseases are more readily eradicated in closed systems, which can be totally flooded with an eradicant.
- ✓ More complete control of the environment is generally a feature of the system (i.e., root environment, timely nutrient feeding, or irrigation), and in greenhouse-type operations, the light, temperature, humidity, and composition of the air can be manipulated.
- ✓ Water carrying high soluble salts may be used if done with extreme care. If the soluble salt concentrations in the water supply are over 500 ppm, an open system

of hydroponics may be used if care is given to frequent leaching of the growing medium to reduce the salt accumulations.

- ✓ The amateur horticulturist can adapt a hydroponic system to home and patio-type gardens, even in high-rise buildings. A hydroponic system can be clean, lightweight, and mechanized.

Disadvantages:

- ❖ The original construction cost per acre is great.
- ❖ Trained personnel must direct the growing operation. Knowledge of how plants grow and of the principles of nutrition is important.
- ❖ Introduced soil-borne diseases and nematodes may be spread quickly to all beds on the same nutrient tank of a closed system.
- ❖ Most available plant varieties adapted to controlled growing conditions will require research and development.
- ❖ The reaction of the plant to good or poor nutrition is unbelievably fast. The grower must observe the plants every day.

Wignarajah (1995) gave the following advantages of hydroponics over soil growing:

- ➢ All of the nutrients supplied are readily available to the plant.
- ➢ Lower concentrations of the nutrient can be used.
- ➢ The pH of the nutrient solution can be controlled to ensure optimal nutrient uptake.
- ➢ There are no losses of nutrients due to leaching.

Wignarajah (1995) gave only one disadvantage of hydroponic systems: “that any decline in the O_2 tension of the nutrient solution can create an anoxic condition which inhibits ion uptake.” His recommendation is that only aeroponics solves this problem since it provides a “ready supply of O_2 to the roots, hence never becomes anoxic.”

THE SCIENCE OF INDOOR GROWING

Every plant requires the same core essentials: light, CO_2, water and nutrients. That is the simple part. However, these core essentials combine with a multitude of additional factors depending not only on what crop you are looking to grow, but also what you want in terms of nutritional value, visual appearance and taste.

When out of balance, these factors can also have a catastrophic effect on the plant, potentially causing death at the extreme or a lower yield in a best-case scenario. Such factors include temperature and humidity, airflow, length of growing day and more.

The ability of growers to control just about every element of the recipe for growth means that we can truly ensure that every plant reaches its maximum potential. However, each element must be carefully monitored in order to optimize its impact on plant morphology.

Can LEDs Replace the Sun?

Light is one of the most crucial elements for plant growth. Outside, the sun's light spans a broad spectrum from UV through to infrared wavelengths. The green wavelengths are reflected and transmitted more strongly by the plant's leaves than the red and blue wavelengths, which are absorbed more effectively within leaves for photosynthesis.

The available light spectrum and intensity will be affected by geography, weather and seasons. In addition to the core function of photosynthesis and growth, light can also act as a signal to the plant, encouraging it to develop in a certain way, such as to promote greater leaf mass, produce taller stems or encourage flowering.

However, different plants have different light needs, and they respond differently to the light wavelengths used, the length of the growing day and the night period. Take flowering for example: you have short day and long day plants, with both requiring different photoperiods to induce optimal growth.

In the natural world, plants may also have to compete with their neighbors for light, nutrients and water. All this uncertainty and guesswork can be removed through vertical farming.

Understanding the Light Spectrum

In recent years, lighting experts have discovered how to effectively isolate and combine different light wavelengths. By varying the light spectrum "recipe", you have far greater control over how plants will grow. The three major categories of Growth Spectrum look like this:

- **Reproductive**: - To promote leaf coverage and fruit generation.
- **Vegetative**: - To promote plant structure and leaf mass.
- **Balanced**: - To promote overall growth performance

Fluorescent lights were previously used for indoor farming, but advances in LED technology, including their processing ability when it comes to light generation, light extraction and reabsorbance, have made LED grow lights the most efficient product available on the market. As well as having the potential to run 24/7, LEDs offer a greater level of control as specific light recipes can be designed within the three main growth spectrum categories to maximize the results for individual crops. LEDs also offer a much longer lifespan than previous lighting technologies and can be manufactured in a way that makes them easy to clean and cheap to maintain.

Different light recipes can also be employed at the end stage of growth to increase **anthocyanin** synthesis and **pigmentation** in produce like red lettuce, where a green plant would be less appealing to the end customer. However, light is not just critical to maximizing growth, manipulating colour and shortening the cycle from sowing to harvest. Light also governs the **circadian** rhythms of pests, bacterial and fungal pathogens, which may be found in growing rooms. Light can therefore be used to design traps to limit the movement of stray insects or to prevent fungal spores from spreading through the crop.

Heat and Humidity Control

Temperature and humidity both have the potential to accelerate growth or ruin a crop and are possibly the two most challenging elements of managing your vertical HYDROPONIICS farm. Temperature has a significant impact on the speed of growth, alongside the physiology of plants. The ideal temperature for a plant depends on a number of factors, and the correct balance between air temperature, relative humidity and light must be achieved. The growth habit of the plant also impacts this process.

Additionally, as you increase temperature within a defined range, you get an increase in gas and water exchange between the plant and the environment. When the temperature rises, you increase the loss of water, which is why you need to worry about the humidity of the environment even though warmer air can hold more water.

Humidity impacts photosynthesis. This is due to the need for water from plants, which is used to keep them cool and retain their cell flexibility. The ability to retain water is determined, in part, by the humidity of the air which can increase levels of evapotranspiration.

Humidity also impacts the ability of the stomata to draw in carbon dioxide and release oxygen and water. Too much humidity can effectively stop the plant from functioning on a basic level. As the racks of lights filling the growing floor are the major source of heat in the facility, airflow and HVAC systems are crucial to reducing cases of tip burn and wilt.

Plant Nutrition

Plants require a range of nutrients to grow properly, but you will need to tailor your nutrient mix specifically to the crop, as well as your planned growth cycle, root mass and other variables. The three main types of nutrients are Nitrogen, Phosphorous and Potassium, but Calcium, Sulphur and Magnesium are also important. A deficiency in key nutrients can result in everything from death of the tissue and discolouration to abnormal growth so it is crucial that you deliver the right nutrients at the right level of concentration to the roots at the right moment of the growth cycle.

The advantage of a recirculating HYDROPONIICS system is that we can potentially cut the use of water by 90% versus traditional farming methods if you re-condense and re-use the humidity from the growing environment. This makes vertical HYDROPONIICS farming an ideal option for regions where water is scarce or expensive and helps vertical farms to do their bit for environmental sustainability by reducing waste of inputs without compromising on output.

HOW CAN YOU ENSURE SUCCESS?

Any business can fail for any number of reasons, but a vertical HYDROPONIICS farm is an incredibly delicate organism that depends on many disparate factors being perfectly aligned and in balance. This increases the risk of failure for those unaware of the "number of plates that need to be kept spinning in perfect time". This list is not definitive but gives you a good idea of the most common mistakes to avoid.

1. Avoid a Trial and Error Approach to Design

There are multitudes of factors that are naturally managed and balanced when farming outdoors. The sun cannot be changed, irrigation to every plant is different as weather patterns can change from moment to moment and even the nutrition in the soil can vary across the area of the field. Planning your farm therefore gives you the ultimate control but also dramatically increases the variables that you can and must consider.

These variables start with the facility's very layout, such as the size of growing space, plant distribution, airflow and more. Additionally, without having the right models in place to determine the exact light recipe and combination of CO_2, nutrients and water required to grow a successful crop, growers can find themselves wasting time and money on testing phases to try to maximize yield and revenue.

Once you have developed a model for your vertical HYDROPONIICS farm, you should then put it through a testing phase on a smaller scale to ensure it is viable.

2. Pick the Right Crop

It is far easier to develop a profitable and scalable facility if you know the needs of your crop inside and out.

That ideally means specializing in one type of crop that you can design your facility around, selecting the right growth spectrum and studying that particular plant's biology to better understand how to optimize irrigation, nutrition, air flow, CO_2 concentration and propagation in order to maximize elements such as taste, nutritional content, visual appeal, potency or shelf life.

Too many growers have tried to hedge against perceived risk by trying to grow multiple crops. By default, it is extremely difficult to have one installation that is optimized for a wide variety of plants, and therefore the returns from each crop are lower than they could have been.

The facility then may have to suffer through downtime as the technology is tweaked and optimized for the next crop—eating into profitability and adding unnecessary costs.

3. Location, Location, Location

The old adage that "location is half the battle" has never been more relevant than in vertical HYDROPONIICS farming today. Vertical farms have a key advantage in their ability to be located close to their customer, whether they are selling to food processors, supermarkets or local shops. Removing the vast transport logistics associated with today's food supply chain slashes costs and helps appeal to an increasingly conscientious customer. The lack of transport costs also helps counter the higher production costs resulting from higher energy and labour inputs.

At city planning level, there are also many advantages of co-locating a vertical farm with other facilities such as office buildings, shops or residences—which could draw the vertical farm's excess heat to reduce demands on other sources of energy.

4. Simplify Your Business Model

Proximity to customers and the ability to produce crops year-round at a sustainable rate is a strong advantage in the market, whether you are growing for the food or pharmaceutical sectors. Therefore, consider the opportunities available through establishing exclusive contracts with customers at a fixed rate that will offer more financial security as you build your business.

5. Be Realistic About Operational

Cost Setup and fit-out costs represent a high initial outlay for any vertical HYDROPONIICS farming entrepreneur, but the ongoing operational costs (energy, labour, inputs, maintenance, etc.) are also significant. Businesses not only need to find creative ways to mitigate these risks (e.g. growing through the night when energy tariffs are lower and the outdoor climate is cooler to assist HVAC systems' efficiency), but also consider the cost benefits of different configurations and process flow.

6. Set Prices Based on What Consumers Will Pay

At the 2017 inaugural AgLanta Conference, PodPonics' CEO admitted that the company missed out on higher potential margins as it priced its crops to compete with conventional growers, ignoring the price premium that food traceability, pesticide-free growing and local production can increasingly attract from consumers in some markets.

7. The Skills Gap

In many cases, those who have embraced the promise of vertical HYDROPONIICS farming have not been traditional growers but rather tech entrepreneurs, engineers or hobbyists. Vertical HYDROPONIICS farming requires a unique mix of skills to be successful: big data scientists, systems integrators, project managers, engineers, growers and plant scientists all have a role to play in addition to the core functions that any business needs to be successful (financial strategists, marketing and business development, etc.). From the leadership perspective, experience at replicating and scaling a business is critical. Ignoring any one of these functions leaves a serious gap in business capability that could undermine the overall success of the operation.

8. Remember What You Are Selling

In a bid to capitalize on the new technology and growth models offered by vertical HYDROPONIICS farming, some growers have forgotten that their primary focus should be on growing and selling the highest quality food. Instead, they have tried to recoup their investment by trying to commercialize their vertical farm's technology, process and methodology. Unfortunately, as we have seen, every vertical farm is different with potentially very different needs. The trick is to not to try and do many different things at once, but instead keep a clear focus on doing one thing as well as possible.

WHAT TO DO? PLAN, PLAN, THEN PLAN SOME MORE

As vertical HYDROPONIICS farming is still at the earliest stages of development, many of the early movers in this space have used an "informed trial-and-error" approach, investing huge sums of money into building and outfitting vertical farm facilities only to find that they do not have the right lighting, inputs, growing area or plant distribution to produce the yield needed to start recouping their capital expenditure and making a profit.

A lack of data in this regard has been a major barrier to the vertical HYDROPONIICS farming industry making the leap from "interesting concept" to scalable, commercial viability.

One important point to remember is that running a successful vertical farm at commercial scale requires it to be run more like a factory, rather than a conventional farm.

Planning your Vertical Farm

If **BEYONDISM** has convinced you of anything, it should be that there is no "one-size-fits-all" when it comes to vertical HYDROPONIICS farming. Everything from the type of crop to the growing area, levels of automation and location can have a significant impact on the setup of the facility, as well as its commercial opportunity. This is why it is so crucial to remove as much of the guesswork from the equation as possible with accurate modelling to find the optimal balance of inputs that will maximize the potential yield and earnings per harvest.

Such modelling should also include operational costs such as estimated energy usage, labour, input costs and the logistics required to bring the harvest to market, whether direct to consumers or to food processing customers nearby.

Minimizing Costs and Looking to the Future

The two highest costs in vertical farming are energy, which can typically vary between 20 - 50% of the total cost, and labour, which can account for 10 - 40% per kilogram of plants grown. Therefore, getting the right balance between initial investment in equipment and reduction in input costs per unit output is of prime importance.

To minimize costs, growers need to look to current and emerging technology and systems planning to improve operational efficiency. Compared with older sodium bulbs, LED lights offer a high level of control over energy usage, as they use comparatively less power. However, they will still draw significant power and generate heat that must be managed, potentially creating new opportunities to reduce the overall energy burden through co-location and heat reclamation for other purposes.

In the future, growing indoors with LEDs combined with solar panels could use solar energy more effectively than outdoor growing, as photovoltaic solar panels can capture and convert more of the sun's energy to electricity and the LED luminaires convert this to the most efficient wavelengths to spur plant development.

Some futurists, like Swedish company Plantagon, are designing vertical farms in office buildings, using the heat generated in the farm to heat the workspace and CO_2 generated by the workforce to feed the growing spaces in return. The goal is to create a sustainable facility with a lower carbon footprint that can fit into modern city planning.

Additional ways to maximize your energy efficiency include:

- Strategies for optimal cooling (e.g. growing at night when the surrounding air is cooler) and dehumidification.
- CO_2 supplementation and recycling from other sources.
- Water recycling and drawing excess nutrients from the mist in the air.

By planning carefully and being exact in your modelling, you will have a much better idea of day-to-day operational costs. Intelligent management systems can then help you monitor and adapt your settings to maintain the delicate balance of maximum yield set against minimal costs and track your performance against benchmark estimates.