VERTICAL FARMING: A REVOLUTION TO SUSTAINABLE AGRICULTURE

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Abstract – *With a growing human population, there is a growing need for sustainable practices, especially within agriculture. As the population increases, so does the amount of resources used to provide for it. Vertical farming technology has the potential to impact the world economically, environmentally, and socially.*

Evan Bromfield defines vertical farms in his paper, "Why Vertical Farms?", as "a type of indoor farming that seeks to maximize production and efficiency per square foot by growing crops in multiple levels on a vertical axis". The goal of this paper is to present the most efficient vertical farming technology using the best sustainable agriculture techniques to combat global issues caused by traditional farming practices and overpopulation. The use of specialized LED lights and aquaponics enables these crops to grow more efficiently than in a field, where they are prone to various dangers from their environment. A vertical farm, such as AeroFarms, might look like a normal office building or warehouse from the outside, but on the inside, are rows of crops being grown on each story. By farming inside of a building, one can decrease the amount of land, water, energy, chemicals, and transportation used to feed the world.

Key Words—Aquaculture, Aquaponics, Food Insecurity, Habitat Fragmentation, Hydroponics, Nitrification, Vertical Farming

EVOLVING AGRICULTURE INFRASTRUCTURE

Humans have made an impact in almost every area of the world throughout history. Industrial farming, for example, was an innovation that caused a great change for the world socioeconomically by creating high yielding farms for the rapidly increasing human population. These farming techniques, many of which are still used today, were created with little to no regard for the environment. Today however, society is beginning to face the repercussions of not making such practices more sustainable for future generations, and as the years pass, these repercussions will only become worse. Typical farms use great amounts of land, energy and water and have harmful effects on the environment due to chemical runoff and habitat destruction. According to the Vertical Farming Association, "It is estimated that by the year 2050, the world's population would increase to ten billion, and close to 80% of human settlements would be concentrated in and around urban locations" [1]. It will not be possible to sufficiently provide food and water for that many people with the continuation of traditional farming practices. To put into perspective just how unsustainable it is, "almost 70% of the world's fresh water reserves are used for agriculture and, nearly 40% of the Earth's total landmass is now being used to support soil-based agriculture, with over 80% of the world's land available for agriculture now in use," [2]. In the last 18 years, the percentage of arable land being used for crop production has more than doubled. These numbers grow as the population grows unless society changes the way things are done. As Albert Einstein once said, "we cannot solve our problems with the same thinking we used when we created them." Humans are reproducing faster than nature can create the resources we need to survive, which is why society needs to focus more on developing new forms of sustainable agriculture.

According to the Food and Agriculture Organization of the United Nations (FAO), "sustainable agriculture conserves land, water, and plant and animal genetic resources, and is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" [3]. Vertical farming has the potential to be the future of sustainable agriculture and replace traditional farming as society's main source of food. By replacing traditional farms with vertical farms, society would be protecting the environment while also benefitting socially and economically.

The main idea behind vertical farms is to reduce the overall amount of resources used and to decrease agriculture's carbon footprint. Vertical farming has been defined as "a type of indoor farming that seeks to maximize production and efficiency per square foot by growing crops in multiple levels on a vertical axis" [4]. The goal of vertical farming proponents is to replace traditional farms with vertical farms located directly in urban communities to reduce the amount of land, water, and energy used to create a more sustainable form of food production.

THE TECHNOLOGY INSIDE

Plants require specific environmental conditions for optimal growth. For a plant to function properly, it must be grown in the proper climate. Crop destruction is often caused by variations in temperature due to radical weather changes, climate change, and seasonal changes. By farming indoors however, one can create a controlled environment and eliminate such dangers, increasing crop production. Plants also require light to undergo photosynthesis and produce sugars for energy. Using light emitting diode (LED) lights, vertical farms provide plants with a light source more efficient for growth than natural sunlight. Plants are commonly grown in soil because it provides the nutrients they require to survive. There are a variety of ways however, to grow them in a soilless medium that provides them with sufficient nutrients. Although crops can naturally grow outdoors, there are many cases when conditions do not accommodate all of their needs. The technologies used within vertical farms create optimal conditions year-round in any location, creating faster and higher yielding crop production than traditional farming.

LED Lights

Light energy is essential to the first phase of photosynthesis. In nature, light energy comes from the sun. Light is the reason organisms see colors because light itself comes in a range of different wavelengths across what is known as the electromagnetic spectrum, each wavelength a different color. Humans can only see a fraction of the light spectrum—the visible light spectrum—but what cannot be seen still exists and causes various reaction. When a sunburn occurs, it is due to a range of light at a wavelength invisible to the human eye. Sun burn can also happen to plants. In this paper, the idea of using LED—**Light Emitting Diodes—** systems like the one in Figure 1 to replace sunlight in vertical farms is examined in an economic and biological perspective. This is to determine whether LED lights provide the nutrients needed by crops and can the use of these systems be cost effective.

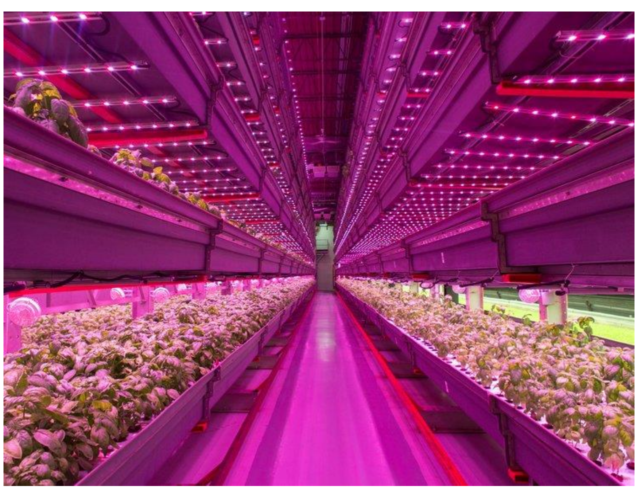

FIGURE 1 [5]
LED lights inside of a vertical farm

The process of photosynthesis requires the right conditions and components to occur. With respect to light in the photosynthetic process, the plant's chloroplast traps the energy. This light energy is converted into chemical energy in the form of ATP —Adenosine Tri-Phosphate– a compound that, when broken apart, releases its stored energy which is used in the second stage of photosynthesis. The energy that is provided by light and stored in ATP assists in the creation of oxygen and carbohydrates.

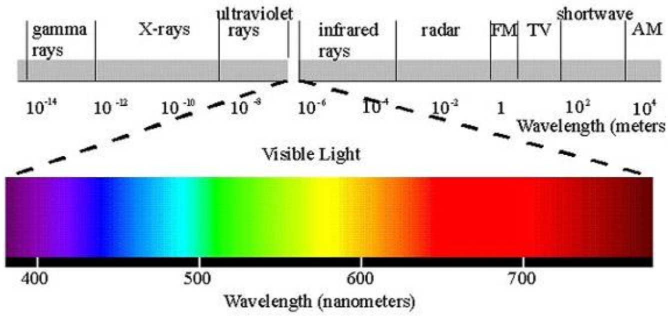

FIGURE 2 [6]
Light spectrum and wavelengths

Not all wavelengths of light are used by plants; wavelengths corresponding to the red and blue electromagnetic spectrums in Figure 2 are the most useful in the photosynthesis process [5]. The Green light spectrum is the only wavelengths that are not used in photosynthesis. The green wavelengths are reflected, and when the reflected green light meets the human eye, the plant looks to have a green color. With LED lighting, the wavelength of the light emitted can be controlled. Unlike other man made light sources, LED's are made from semiconductor compounds such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), Gallium Arsenide Phosphide (GaAsP), Silicon Carbide (SiC) or Gallium Indium Nitride (GaInN) mixed at different ratios to produce a distinct wavelength. Different LED compounds emit light in specific regions of the visible light spectrum and can be dialed in to the right spectrums to feed the crops the best combination of wavelength for their growth.

The different wavelengths and amount or duration of light given by an LED lighting system are useful for controlling how the crop grows. Plants use light to determine their growth pattern.

> "Phytochromes are special chemicals that are released in response to the amount and duration of light that is provided. Plants will bloom in response to the number of hours of light that they receive. Some plants will bloom only when there are less than 12 hours of light each day, while others require more light to flower" [5].

This knowledge and the ability to change the light cycle of an indoor lighting system allow a vertical farm to start a crops flower and seed production whenever. A vertical farm can have multiple harvests per season from a crop that, in a field under natural conditions, will only produce a harvest once.

Light from the sun comes in the whole range of wavelengths, some that are damaging to organisms. Crops in a field can get a form of sunburn from light in the infrared spectrum just like humans. This is becoming more and more of a problem for farms in areas that are most effected by global warming. As more dangerous light energy is hitting the fields, crop production goes down. When farming is moved indoors, the light source, LED, can be tuned to not emit the infrared light spectrum, thus protecting the crops and increasing crop productivity relative to outdoor sunburned fields.

One of the downsides to the use of artificial lighting, rather than the natural light of the sun, is that the sun's light is free. Vertical farms must pay for the electricity to power the LED lighting systems and the computers that control them. The cost of installing LED lighting systems in vertical farms is also not favorable. However, the overall benefits of using LEDs in vertical farms instead of sunlight in a field are crop production year-round, healthier plants, and increased harvest yields. These will increase income by a greater amount than the cost of running LED lighting systems. The existence of fully operational and profitable vertical farms, using LED lighting systems, is proof that this technology works and is economically viable.

Aquaponics

The three most common soilless agricultural systems used in vertical farms are hydroponics, aquaponics, and aeroponics. Hydroponics is the production of plants in a nutrient-enriched solution, with or without the mechanical support of a growing medium [7]. Hydroponic systems grow plants in water that is supplied with the nutrients the plants need. While this system reduces the amount of overall labor, water, and soil resources used, it still requires the input of expensive chemicals to create a solution that must be regularly drained. Aeroponics is a sub-category of hydroponics that suspends the roots in the air instead of in water. A mist of nutrient solutions is sprayed onto the roots to utilize up to 95% less water than traditional farming methods in a minimal amount of space [7]. While aeroponics is an upgrade from hydroponics, aquaponics is a more sustainable solution. Al-Kodmay defines aquaponics as, "a bio-system that integrates recirculated aquaculture (fish farming) with hydroponic… production to create symbiotic relationships between the plants and the fish" [7]. The symbiotic relationships counteract the weaknesses of both hydroponics and aquaculture. They allow the system to become a closed loop, reducing waste and water usage while growing both fish and plants. In Susan Patterson's comparison of aquaponics and hydroponics, she explains that hydroponic solutions result in large amounts of waste water due to periodic replacement. The disposal of such fertilizer-rich solutions into natural water bodies is an environmental risk. The only waste in aquaponics is leftover solid fish waste that wasn't broken down by bacteria. Since it is organic in nature, it can be disposed of into the common drain or used for composting [8]. While hydroponics is more sustainable than traditional farming practices, it still has the potential to harm the environment. Patterson concludes, "being the more sustainable and profitable system of food generation, aquaponics is the future of alternative agriculture" [8].

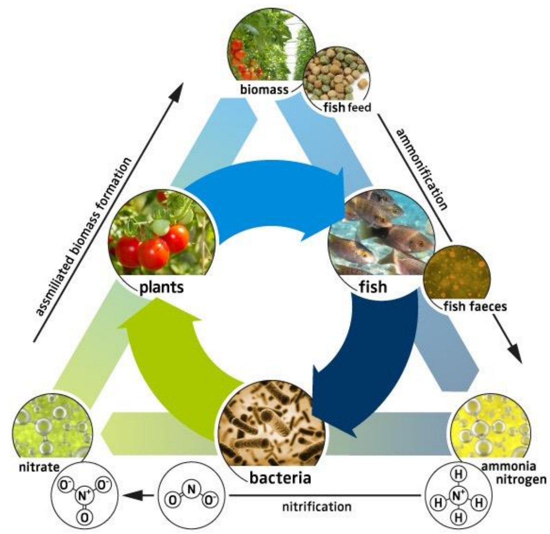

FIGURE 3 [9]
Aquaponic system components

FIGURE 4 [9]
Aquaponic fish tanks and plant beds within a vertical farm

All aquaponic systems are made of three biological components: fish, plants, and bacteria. As shown in Figure 3, these components work synergistically to create an environment safe for each to live and grow. In The Aquaponic Farmer by Adrian Southern and Whelm King, aquaponics solves the primary problems of both aquaculture and hydroponics by combining them together. Fish waste provides both plant food and fertilizer while plants clean the water for the fish when utilizing minerals from their waste. The goal of aquaponics is to eco-mimic complex natural systems to simultaneously grow fish and plants [9].

The purpose of the fish within the system, besides aquaculture, is to provide nutrients for plants growth. Plants require both macronutrients and micronutrients. The most important elements for plant growth are the macronutrients nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg), and the micronutrient iron (Fe). Gill excretion, urine, and feces from the fish provide minerals that dissolve into the water and ionize into nutrients that plants can assimilate [8].

Ammonia (NH_4^+) buildup from the fish urine and gill excretions can be toxic for the fish themselves at levels higher than 3 ppm. Due to this, microorganisms must exist in the system for nitrification purposes [9]. Nitrifying autotrophic bacteria are a key microbial component composed of nitroso-bacteria and nitro-bacteria. The ammonia must be broken down in steps from a process called nitrification. The nitroso-bacteria first convert ammonia into nitrite (NO_2^-), and the nitro-bacteria convert nitrite into nitrate (NO_3^-). By converting the ammonia into nitrate, the bacteria work as a biofiltration unit, making the water less toxic for the fish. This nitrification process also means the plants now have a main source of nitrogen to help them grow [10].

The process of the plants absorbing the nitrate is basic due to a release of bicarbonate ions, however the acidic nitrification process has a higher percent of ionization which therefore causes a constant slight decrease in pH. Due to this issue, the authors of "Challenges of Sustainable and Commercial Aquaponics" explain two approaches that have been developed to maintain pH levels. The first and most common process is manually supplementing nutrients such as carbonate, bicarbonate, or hydroxide to increase the pH levels. This process also increases the alkalinity parameter by making a buffer solution that is more resistant to fluctuations in pH [01]. To maximize the efficiency of the process, the nutrients should be based on calcium, potassium, and magnesium compounds so that when they dissociate, the cations can become nutrients for the plants in areas where they may face nutritional deficiency [9,10]. The second approach to maintaining pH levels is the implementation of the fluidized lime-bed reactor concept. The concept uses the controlled addition of limestone ($CaCO_3$) to an acidic solution to neutralize it during a dissolution process [10].

Maintaining the proper pH is crucial to a successful aquaponic system. While each organism may require a slightly different pH to thrive, a compromising point must be met. Most plant species require a pH of 6 to 6.5 for optimal nutrient assimilation. Fish vary far more from species to species so tilapia is used as an example. Tilapia are widely used in the aquaponic farming business due to their reputation for being disease resistant and can exist in a wide pH range of 3.7 to 11 [9]. The optimal pH to grow them in is between 7.0 and 9.0. The optimal pH for bacteria to produce ammonium oxidizers is 8.2, however they are still highly effective within a pH range of 5.0 to 9.0. The optimal pH conditions may still vary slightly from one bacteria to another. For example, nitrosomonas' optimal pH range is 7.0 to 7.5 and nitrospira's is 8.0 to 8.3. The average range for water pH is 6.5 to 7.5, however studies have determined that the ideal pH value for a system is typically between 6.8 and 7.0 [8,9]. The highest possible pH must maintain a high enough nitrification efficiency to prevent the accumulation of ammonia in the system.

For plants to assimilate other nutrients from the fish waste, the waste must be broken down by mineralizing bacteria. The mineralizing bacteria decompose suspended solids and decrease the amount of potential discharge by the system. Chemical testing and monitoring must be done regularly to ensure the aquaponic system is producing enough of each material for optimal plant growth [10]. Manual supplements of nutrients must be added to counteract deficiencies, varying between. Adding bases such as $Ca(OH)_2$ and KOH has dual functionality in supplementing minerals as well as controlling pH levels. When the bases dissociate, the anions mineralize into nutrients for the plants and the hydroxide ions (OH^-) increase the pH of the system, counteracting the constant increase in pH from ammonia.

Another important factor that must be monitored is nutrient input and waste solubility. To make the system as sustainable as possible, with a minimal carbon footprint, one must aim to create a zero-discharge recirculating system by minimizing the amount of solid waste [9]. Uneaten feed and fish excretions have varying percent ionizations and solubility rates, so an absolute zero output of waste without some amount of manual labor is currently not feasible. The waste that is not solubized is filtered out through the mechanical filter and can either be discarded or manually mineralized and added back into the hydroponic system. These varying mineralization abilities can create inconsistencies in nutrient concentrations, which must be monitored and accounted for to maximize crop output and minimize discharge. Using proper fish feed composition, relative to the amount of nutrient excretion by the fish, allows for the attainability of a water composition that is close to hydroponic requirements. Obtaining nutrient concentrations produced by the feed is required to predict the amount of mineral input that will be manually added to the hydroponic system to meet plant nutrient requirements.

ENVIRONMENTAL IMPACTS OF AGRICULTURE

Water Use: Problem

At over 71%, agriculture is the largest user of water worldwide [10]. Irrigation is the process of diverting water from its natural path to water crops in areas where not enough rain falls to naturally hydrate the fields. These areas are known as arid or semi-arid lands, based on their annual rain fall. The trend of population growth in arid and semiarid regions has sparked agricultural development in areas that had not needed to be developed. As a human settlement grows, the need for food production to be closer to the settlement grows as well. The increased demand for food prompts farmers to cultivate land that naturally would not support crop growth. Irrigation increases the agricultural productivity of arid and semiarid lands. From the data collected by the authors of *Environment*, they concluded that "since 1955 the amount of irrigated land has more than tripled" and that "water use for irrigation will probably continue to increase in the 21st century" [11]. The sourcing and amount of water used for crop production is where a devastating environmental issue arises.

In a global regard, when water is overdrawn from a watershed, wetlands dry up, isolated bodies of water dry up, salinity levels rise in estuaries, and many other ecological issues occur. Natural wetlands play important ecological roles, such as serving as a breeding ground for a large variety of species. Estuaries, the areas where rivers empty into seawater, become saltier due to a smaller ratio of freshwater to seawater. This change in salinity reduces species richness, the diversity of animals and plants in an ecosystem, which hurts not only the ecosystem itself but commercial fishing in those areas as well. An issue with current farming practices is evaporation of irrigation water before the crops have a chance to soak it up. With commonly used open-air sprinkler system, that sprays water over the entire area of crops, about 5% of the water evaporates or blows away before it touches the ground. On the large scale, 5% is hundreds of thousands of gallons of water. When water makes it to the roots, "plants retain less than 5% of the water absorbed by roots for cell expansion and plant growth," the rest is transpired into the atmosphere [12].

Water Use: Solution

The solution to the problem of evaporation and reducing overall water consumption of crop irrigation using vertical farming comes with the use of a closed build as the location for the farming. When irrigating crops in the closed/controlled system inside a building used for vertical farming, evaporation of irrigation water can be either controlled by keeping watering system contained from contact with the surrounding air with water systems that only encompass the roots of the plants, such as aquaponics, or by containing and reusing the evaporated and transpired water that does end up in the air of the building by condensing the humid air that accumulates in a vertical farming building and then putting it back through the irrigation system.

It takes up to 97% less water over a year in a vertical farming building than in the open-air conditions of a current outdoor farm, [12]. The use of more efficient water delivery systems, and having a building that is a more controlled environment than a field, allows for water use for crop production to dramatically reduce.

Land Use: Problem

Many regions inhabited by humans have improper conditions for growing crops. The land that is considered right for crop growth, is known as arable land. Currently, about 40% of the Earth's surface is arable [3], some that is better than others. Data collected by Dr. Navin Ramankutty in 1999, suggested that about 30% of the world's total arable land was already in use. Recent data suggests that percentage is as high as 80%. To put that in perspective, in all human existence, up to 1999, agriculture had managed to cover about 11% of the world's surface, but in the last 20 years, it has managed to now cover more than double the percentage of the Earth's total land surface. As the rate of land conversion continues, humans will run out of room to grow the crops necessary to feed an ever-growing population.

Not only is the threat of running out of arable land a threat to humans, but it is also an issue for the animals that live in those regions and for the world's ecosystem. The regions of the world considered right for crop production are some of the richest areas on the planet in terms of number and variety of plants and animals; this is known as species richness. When species rich jungle is converted to soy bean groves, it removes plant variety. Many of the animals, previously happy in their jungle home, cannot live in the new conditions created by the soy bean groves. This negative effect, caused by development of dense forested areas to open expanses of low lying crops, is especially easy to see with regards to large predatory cat species in forested areas. To sustain a big cat population, large expanses of undisturbed forests are needed. One reason for this is the need for large populations of the big cat's prey, which are decreased by habitat loss. Another being,

> "For a species to survive, its members must be present within a range in large enough numbers for males and females to mate. The minimum population density and size that ensure reproductive success vary from one type of organism to another. For all organisms, if the population density and size fall below a critical minimum level, the population declines, becoming susceptible to extinction" [12].

When major animal and plant species go extinct, a serious ripple effect goes through an ecosystem, causing a collapse of that ecosystem.

The term habitat fragmentation, meaning "the division of habitats that formerly occupied large, unbroken areas into smaller areas by roads, fields, cities, and other land-transforming activities" [12], is the problem depicted by the big cat example, but is also a factor when it comes to the location of the farms relative to the communities they supply their crop to. Traditional farms, needing large areas of mostly flat land, are often miles from the cities and towns that they feed. Thus, requiring roads to be built between them and exasperating the habitat disruption even more. Another example caused by fragmentation is explained by the UK wild life organization, Trees for Life.

> "Imagine that you are a rare lichen, or a bird which prefers the dark interior of the woods, such as a Treecreeper. Half of your woodland home is destroyed to make way for a car park (in our case farm), and the remainder is bisected by a road (connecting farm to city). What happens to your cool, dark patch of the forest? It becomes flooded with light, the humidity and temperature are altered, and it may no longer suit your specific needs. Thus, fragmentation increases what is known as the 'edge effect', whereby the interior area of habitat is affected by the different conditions of the other habitats on its edges. The smaller a particular habitat is, the greater is the proportion of its area which experiences the edge effect, and this can lead to dramatic changes in plant and animal communities" [13].

Land Use: Solution

The name 'vertical farming' nearly says it all; instead of clearing new land for more traditional horizontal farms, stack new farms on top of each other. The main goal of vertical farming is to be able to produce crops in the same quantity as a horizontal farm, but using a tiny fraction of the land area as the horizontal farm. Another land use saver is the construction of a vertical farm inside already constructed buildings around or inside a city or community rather than having to develop new tracks of land from previously undisturbed ecosystems.

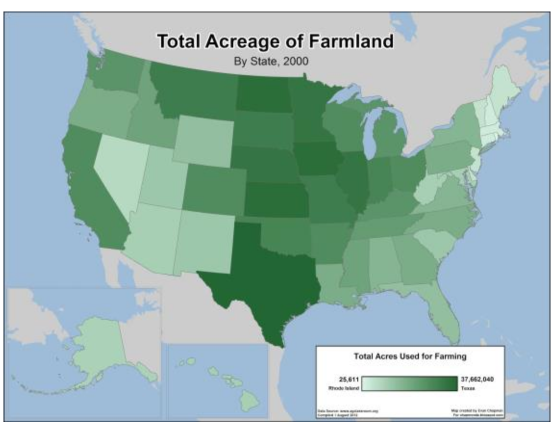

FIGURE 5 [12]
Map of land usage for farms in the United States

Whenever humans can redevelop already developed land, it is better for the environment rather than damaging intact natural lands. To a greater aid to the protection and recovery of the world's ecosystems, the possibility that if vertical farms can produce enough crops that traditional horizontal farms already in use are no longer needed, they can be converted back into the natural forests, grasslands, and wetlands that they once were. This is a very real possibility since vertical farms are so efficient in producing more crops, in less space and time than traditional farms [12].

Chemical Use: Problem

Humans use fertilizers and pesticides to make their crops more productive in areas where natural conditions and animals do not promote good harvests. These chemical pesticides and nutrient rich fertilizers runoff or leach into many ecosystems where they either don't belong or where in the quantity add they become detrimental to the health of those ecosystems and the humans who rely on them. Along with the nutrients and chemicals washed into ecosystems by agricultural runoff, sediment is picked up in large quantities and dispersed unnaturally. In this section, an examination of how the runoff from crop fields tips the balance of ecosystems, sometimes to the point of collapse.

The main chemicals used in farming that are an issue for the environment, are pesticides. Pesticides are chemicals used by farmers to kill or deter "pest" from eating and disturbing the crops in the fields. The concept of "pests" is perceived by preservationists as a negative human-environment interaction; a "pest" is any animal or insect that may interfere with human activities. When preservationists look at the situation, the humans are the actual pests to the sustainability of the environment. Farmers blame a rabbit for eating their crop, when it is the rabbit's natural right to do so and it is the farmers that moved into the rabbit's natural home and put the crops there. Pesticides are toxic to most animals that encounter them, including humans, and often effect animals either not considered pest or animals that are hurt inadvertently from their use. One of the main ways pesticides can hurt a whole ecosystem, is when they are swept by rain water in the form of agricultural runoff, into water supplies ranging from small streams to ground water. Chemical pesticides from agriculture find their way into water ecosystems and supplies in many ways. The National Water Quality Assessment Program has an ongoing study on pesticides and their degradation products, that has found that

> "more than 95% of river and stream samples and almost 50% of groundwater samples they examined contained at least one pesticide. More than 50% of all stream samples contained five or more pesticides, and about 10% of all streams contained 10 or more pesticides" [11].

The next form of pollution from agricultural runoff comes from the use of fertilizers in crop fields. Fertilizers are nutrients farmers add to the soil to grow their crops. Plants need several types of nutrients to grow properly and produce. Normally a plant would only grow naturally where they would get all their nutrients from the soil, but when farmers plant crops where the soil is either low on nutrients or where, from years of soil erosion and failure to replenish natural nutrient supplies in the soil, they need to add those nutrients themselves. This does not seem to be a bad thing, until rain fall causes excess fertilizer to be washed away—runoff—and into streams, lakes and other bodies of water. When excess nutrients get into a body of water, enrichment occurs. Enrichment is when the influx of nutrients in a body of water causes an algal bloom. An algal bloom is made up of millions of tiny plants known as algae, that explode in growth and replication at once, it can take over a body of water, starving other plants of the nutrients they need. As well as choking the animals that live under the water and even completely blocking out the sunlight from reaching plants and animals that need it to survive in the water. Some algae are toxic to the inhabitants of the water. The toxins from the algae can work their way up the food chain and threaten important species in the environment—keystone species—or even humans when contaminated fish are eaten.

Sediment from soil erosion in agricultural runoff cause problems for the environment, like the algal blooms. With lots of soil particles suspended in a body of water, that normally would not have been there, it can cause fish to be choked by the sediment getting caught in their gills. The suspended sediment also causes the issue of the sun being blocked from reaching organisms at the bottom of normally clear waters. When a heavy rain occurs, sediment naturally washes into streams and lakes, but this effect is amplified when much of a land's natural ground cover—vegetation growth—is removed to create a farm. Not only does this loosen the soil, making more sediment able to be washed away by rains, but by a process of years of soil degradation from crops being planted and harvested repeatedly, the soil can become more easily eroded, with less natural moisture content and less ability to withstand erosion, often due to less clay content.

Agriculture not only adds harmful chemicals and excess nutrients to the environment, it also alters the composition of the soil, causing more soil erosion and the need for more fertilizers. This cycle needs to end to protect the environment from multiple human caused hazards and prevent loss of naturally rich soils that is important to many ecosystems.

Chemical Use: Solution

Vertical farming uses a nearly closed system irrigation—aquaponics—and more direct fertilizing techniques thus preventing runoff. This eliminates the progression of environmental issues related to agricultural runoff. Since vertical farms are indoors, farmers can almost completely control the conditions inside the farm and thus contain any harmful byproducts of the farming process. Pests and subsequently pesticides are not found inside vertical farming facilities, because pests cannot gain access to the crops in a quantity prolific enough to be an issue.

When growing indoors, soil is not needed to grow the crops. Normally, plants get their nutrients from the soil they are grown in, but with the innovation of aquaponics, all the nutrients are delivered directly to the roots by closed system plumbing. With the nutrients contained by the closed system and direct application the roots of the crop, excess fertilizer and fertilizer runoff is absent from the vertical farming process. Fertilizers and pesticides are often an expensive part of traditional farming and since they are not any issue in vertical farming, the money can be applied to the lighting or aquaponics systems in the vertical farming industry.

SOCIAL IMPACTS OF AGRICULTURE

Social Issues

Harvest loss has a great impact on the lives of farmers and the communities they supply. When crops are destroyed by environmental factors such as droughts and pests, farmers can lose a season's worth of produce, causing financial setbacks and often impoverishment. Poverty is one of the driving causes of hunger, but hunger is also a cause of poverty. There is a cycle where those who are poor become malnourished and those who are malnourished become poor. When one is malnourished, it negatively affects cognitive development and child growth, leading to reduced levels of productivity and economic development and therefore causes an inability to work efficiently and drives them deeper into poverty. Food insecurity is an issue that affects one in nine people across the globe. About 800 million people suffer from malnutrition every day [3]. The FAO defines food security as, "A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life… [Four] food security dimensions can be identified: food availability, economic and physical access to food, food utilization and stability over time," [3].

Social Solutions

Vertical farms can break the poverty cycle and make a huge impact on both food insecurity and poverty. Due to indoor farming in a controlled environment, crop production can take place year-round. Environmental dangers to crops are no longer an issue and damage due to disease can easily be isolated. By implementing vertical farms in communities suffering from poverty, the cost of food would decrease and the economy could thrive. By placing the farms directly in the communities, transportation costs are cut dramatically, and therefore so are food prices. Food prices are also cut down due to higher yielding crop production. The farms themselves would create more jobs and increase educational opportunities. With a reliable way to produce crops year-round, people would be able to become economically and nutritionally stable, breaking the cycle of malnutrition and poverty.

CONCLUSION

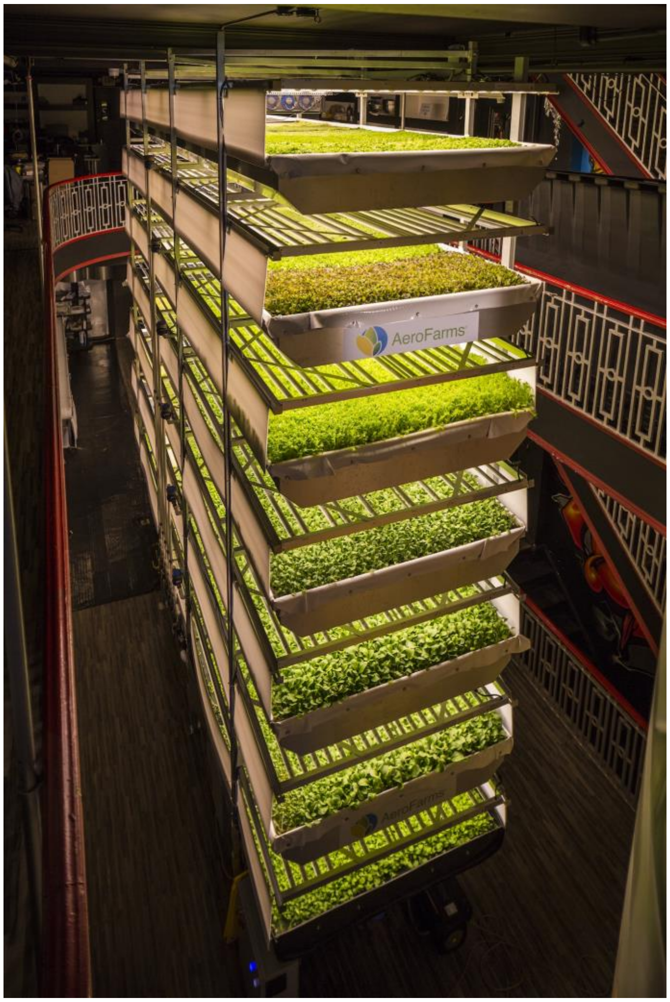

FIGURE 6 [10]
Plant beds inside of AeroFarms

All research leads to the conclusion that vertical farms are a strong candidate for solving issues due to the unsustainability of agriculture. Many companies, such as AeroFarms, PlantLab, and FarmedHere, have proved that vertical farms have the potential to make an impact. Joshua Burd's article, "Future Farm" goes into depth on how AeroFarms, the world's largest vertical farm, has become so successful. Marc Oshima, the co-founder of AeroFarms, claims that they have "75 times greater productivity per square foot annually than we would out in the field, and 10 times more than a greenhouse," [10]. In a report on the 2015 International Conference on Vertical Farming, it was found that the company PlantLab has, "developed a revolutionary high-tech growing concept for cultivation of plants in conditioned production units in the absence of sunlight. Besides saving 90% of the water used in normal horticulture, PlantLab has improved the photosynthetic efficiency to the tune of 15–18% as against 9% which is normally achieved under outdoor conditions," [14]. FarmedHere has three locations in Illinois and is expected to supply at least 6% of the Chicago area's premium green and culinary herb demand. Their facilities utilize aquaponics, creating 13,935 m^2 of growing space in their largest location, which only takes up about 8361 m^2 of land as opposed to 14,000 m^2. Their aquaponics systems reduce water use as well by 97% [14]. These facilities, amongst others, are making big impacts on the environment and the communities they dwell in. By spreading the use of this technology across the globe, engineers and farmers alike have the potential so save the environment from the detrimental effects of climate change and overpopulation.

SOURCES

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