# Urbanizing Agriculture;

## Vertical Farming as a Potential Solution to Food Security Issues

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# Contents

## Introduction

As countries around the world continue to deplete natural resources and as the world's population continues to grow, many industries, as well as people, have begun to suffer from the strain on dwindling natural resources. Agriculture and food distribution industries send goods from all around the world to stock grocery stores, restaurants, and other retail centers. The high costs of the distribution format causes people to be unable to afford food even though the amount of production is more than sufficient. "Enough food is produced worldwide to feed all the people in the world (Leathers and Foster, 2009). However, despite this alarming truth, nearly one billion people are suffering from chronic hunger today. There are a wide range of factors that contribute to this problem, however, the most significant is poor food distribution." (Mission: Feeding the World, 2014) In an attempt to diminish these issues, organizations such as the FAO (Food and Agriculture Organization of the United Nations) have focused their research on various ways to grow within smaller regions and lower transportation distances to limit costs. They focus on these attempts largely to reach their Urban Food and Supply goals of providing efficiency in distribution to stabilize supplies of low-cost food to provide for everyone rather than only those who can afford it. (FAO, 2000) Additionally, work has been done to decrease waste at points along the supply chain. The challenge and goal, however, should not be to limit the scope of travel by a small fraction, but completely eradicate it.

Focusing on agricultural techniques that occur within urban areas could allow the growth of most agricultural products within the confines of a city. Practicing locally grown agricultural techniques could diminish food distribution costs as the distance of travel would become within a quick drive or walk. The inhabitants of the city could purchase food out of their own neighborhoods at a much lower cost. Restaurants and grocery stores could limit their supplies so that very little went to waste. Additionally, farms would be close by, meaning there would be no issues getting food in enough time as well as allowing a greater awareness of the product's growing conditions. Residents would immediately have a much greater understanding of their food supply chain and could participate in the growing of those products.

Classical agricultural techniques do not work in this setting. In typical agriculture techniques, the growing population will outgrow the amount of land we have to grow crops. (Biello, 2009) Already today, over 80% of the land that is suitable for raising crops is in use (FAO and NASA). Historically, some 15% of that has been laid waste by poor management practices (Despommier, 2011). To simply account for the population growth predicted, food production will have to increase by 70% according to the UN's Food and Agriculture Organization (2011). As the same percentage of people move towards urban living, the question is, should the food production industries follow suit? Unfortunately, space is both limited and at a premium in an urban environment. Vertical farming could be a solution to agriculture needs with population growth. Vertical farming allows skyscrapers to be filled with floor upon floor of orchards and fields, producing crops all year round (Technology Quarterly, 2010). The benefits of successful vertical farming are exceptional as it could reduce transport costs and carbon emissions, free up land, reduce spoilage, and finally, limit the water usage as compared to classic agriculture techniques. Unfortunately, there are limited examples of vertical farming and it remains mostly untested; however, some examples have begun to show up around the world. In the US, no vertical farms have been constructed, although the materials and technology exists. In the 2015

World’s Fair in Milan, this technology was showcased by Biber Architects in their project “Farm Walls”, a hydroponic technology that allows the plants to grow without soil and vertically (ZipGrow, 2017).

Knowing the potential benefits of this type of system, the question remains of should agriculture transfer to this arrangement? What are the potential costs of these systems and technologies? Do the benefits outweigh the costs? Finally, what potential downfalls could result for farmers in non-urban environments? This capstone intends to analyze the costs and benefits of vertical farming technology as well as explore case studies of existing vertical farms to determine if it is an appropriate strategy for cities to adapt to address food insecurity.

# Literature Review

## Cost, Benefit Analysis Overview

As the population grows, creating food security is constantly a challenging aspect of agricultural technologies and an issue that requires immediate attention. The current classic agricultural techniques cause high food distribution costs and much of the products go to waste while people remain hungry all over the world (Cockrall-King, 2012). The distance required for food to travel from source to table as well as the abundance leftover in many supermarkets is the core of many of these concerns and how to mediate this issue is what agriculture development in the future must focus on. Examining various agricultural strategies in terms of their costs and benefits allows a comprehensive understanding of the best way to more forward to extinguish food insecurity and provide for the current and future population whether it be remaining with organic farming or moving towards urban solutions such as vertical farming. In the following portion of this analysis, organic and urban agriculture techniques will be studied alongside one another to view the potential benefits as well as costs of each strategy.

## Classical Agriculture Techniques

Organic agriculture is the cultivation of products to sustain and enhance human life. In terms of food production, the most common technique to achieve this goal is in the development of farmland. Farming began to create stable locations for settlements as the human population began to understand crop growing and cultivation. For many centuries farming finally allowed people to have stable food sources rather than simply following large herds of animals for hunting which unfortunately was less than stable food. At the time, the hunting option functioned as the best option for a food source while a lack of knowledge and technology required the need for hunters and gatherers. Finally, when classic agriculture systems began to be understood and developed this option became more consistent and has been used as the most common source of crop growth ever since. Even as technology as bettered and the systems have become more efficient, the design for agriculture has not changed. Now however, classic agriculture has shown its' downsides as needs for land usage in other growth departments and various distribution issues arise from these techniques. A need for a different type of development in agriculture has arisen and where to go next continues to be a question for developers as the population grows

The benefits of organic agriculture of farming has increased drastically as technology has improved. The use of synthetic fertilizers in the past were seen as a large misstep and an attempt to get back to nature allowed agriculture to grow in an organic manner. "Organic agriculture promotes free-roaming livestock, crop rotation and the use of biological insecticides and fertilizers. This practice, aside from improving the purity of water and preserving animal habitats, also purportedly reduces flooding, air pollution and global warming" (Dems, 2010). The importance of using natural processes in food production showcase the importance of classic agriculture and why it remains a primary source of food development. The ability of organic agriculture to consider not only short-term sustainable strategies but the long-term ecological needs of an area encourages a proactive approach. According to FAO or the Food and Agriculture Organizations of the United Nations, various areas benefit from organic agriculture such as soil, water, air and climate change, and finally biodiversity (2016).

In terms of soil, the techniques used in organic agriculture allows increased development of flora and fauna. The development of these nutrients and organisms in the soil allows the depletion of soil erosion issues by adding to its stabilization. Transferring from classic fertilizers, which have harmful pesticides and cause water pollution, to organic fertilizers has drastically improved the water quality in farming also adding to the ability for the soil to stabilize (Dems,2010). Air and climate change is also mitigated by the techniques used in organic agriculture such as, crop rotation and returning residues to the soil allows carbon to be digested by the soil itself rather than being emitted into the atmosphere. The lack of chemicals used in organic agriculture aids in the development of biodiversity, according to FAO “At the species level, diverse combinations of plants and animals optimize nutrient and energy cycling for agricultural production. At the ecosystem level, the maintenance of natural areas within and around organic fields and absence of chemical inputs create suitable habitats for wildlife” (FAO, 2017). In all these areas, organic agriculture is an important part of food development for the benefits the land used receives, however, there is a downside when inorganic and harmful chemicals are used instead. In both techniques as well, food distribution and waste is still a key cost to classic farming technologies.

Due to the inefficiency of our current food distribution system, classic agricultural techniques makes food difficult to afford and receive for many areas around the world. In impoverished nations, transportation is not an easily accessible commodity and having to move food from farm land to inner city areas is a difficult and expensive issue. Looking to avoid many of these external costs from food distribution in classic agriculture is causing an “agriculture awakening” (O’Reilly, 2010). The new wave of agricultural awareness is causing a movement for farm to fork sourcing of produce which is moving restaurants and wholesalers to small scale farmers and localize their supply to meet the current demand for sourcing knowledge. The farm to fork movement towards local sources has begun to urbanize agriculture, however, the small size of the local farms sourcing individual restaurants and small grocers do not have the capacity to provide for corporate chains and large grocery stores which is why classic farming is still heavily relied on for food sourcing (O'Reilly, 2010). The reliance on these large farmers continues to increase the amount of people going without adequate food to survive. Many groups go hungry because of the current food distribution system in classic agriculture. The farm to fork movement is extremely effective because consumers are allowed to buy directly from the source, however in classic agriculture that does not provide local produce the costs of getting the food to the small amount of markets to sell from causes the food to be expensive and unattainable for lower income people and families.

The major issues with the current system is an inadequate amount of markets for consumers to attain produce from. "About 16% of the rural populations in developing countries lack convenient access to a market, which typically causes farmers not to sell their crops. In fact, it is estimated that at most 40% of the any crop is marketed and only one-third of farmers sell to markets" (Mission: Feeding the World, 2014). With high transportation costs and limited markets, the amount of waste in classic agriculture is also a major issue making it an inefficient future agricultural format. Due to the extreme perishability of most produce, the waste post-harvest and in transport is extremely high. The susceptibility of produce to bacteria, fungus, and insects causes the food to be inedible if infected with any of these contaminants. "It is estimated that 25%-50% of all food produced is wasted." (Mission: Feeding the World, 2014)

This extreme waste causes a food shortage and with the already high prices of transported produce, the shortage causes a rise in prices as well. These price increases cause even more of the population to be unable to purchase produce which adds to the ever-growing famine especially in developing countries. These issues are not a single country's issue but worldwide. Every country is stricken with issues of famine in at least one area and the current food distribution system is affectively causing much of the issues. The need to reorganize agriculture systems to better feed the world is a huge proponent to urbanizing agriculture and finding a system that can bring food to the consumer more quickly, with better knowledge of sourcing, as well as at cheaper prices.

## Urban Agriculture

As the population grows, and is expected to continue to grow, the world's development patterns have needed to change drastically. Housing development, for example, has changed as the population has. When more money was available, families wanted open spaces and backyards which caused a drastic move to suburban areas, however, as the population increases beyond the given land's potential housing has moved vertically (Vertical Farms, 2015). In food systems, the classic agricultural system poses the same problems. The costs of distribution as well as high amount of waste causes classic agriculture to be an ineffective future system, which is causing an urbanization of the agriculture system to small local farms in city limits or on rooftops. Bringing the producers and consumers into the same area will cut down on much of the costs of classic agriculture which is a huge benefit to urbanization, however, figuring out how to grow a large amount of produce within the city is still a limitation of the urbanization movement (Urban Agriculture, 2013).

Moving our current agricultural systems to an urban setting has already begun at the small scale as individuals have begun growing as small as personal gardens up to small greenhouses and rooftop gardens. In some major cities, such as New York and Chicago, urban farming groups bring together local farmers and sell to the public (including individuals and businesses) and due to the increased interest in locally grown produce, the groups have begun to sell 15 to 20% of the world's total produce (Royte, 2015). Though they're relatively small in scale, city farms have many beneficial conditions that cause issues in classic farming. First, the insect and animal infestation problems are much less likely which in turn allows for less produce to be eaten by scavenging animals or ruined by insects. Secondly, the small scale and typically vertical set up of urban farming allows the farmers to walk their plots in minutes rather than hours, giving them the ability to address and solve problems as they occur as well as harvesting at the opportune time in every plants growth cycle. The organization of urban farming also allows planting to be done at a higher density. The ability to micromanage every aspect of the produce growing cycle gives the city grower quite the advantage over a classic agricultural farmer. They do not have to rely on hiring a full time staff for their farm as well as have a high rent for the land they plot on, urban growers can usually get volunteers to help them with their work and tend to rely on land or space they already have access to. Growing in cities

Another major positive of urban growing is the ability to attain local produce for individuals as well as restaurants and marketplaces (Urban Agriculture, 2013). The high trend towards farm to fork works as a disadvantage to most large scale farmers that have to ship food to consumer locations, however, for the urban grower it's an extreme advantage. The higher percentage of people looking for locally grown and sourced produce will continue to turn their shopping habits towards small city markets already providing these growers with a consumer basis. This local focus also provides urban growers with a large restaurant consumer basis as chefs strive to make their menu locally sourced (O'Reilly, 2010).

Finally, another huge proponent for changing to urban growing habits is the need for food security. Especially in developing countries, the cost of food distribution itself causes extreme famine (Leathers & Foster, 2009). In areas where they have the land, people have turned towards growing for themselves not only to supplement their incomes but also to feed themselves. A change over to urban growing in the US could aid in many of these developing countries food shortages as well as take a huge slice out of current supply costs from classic farming (Dems, 2010). According to studies by Ensia writers collaborating with the Food and Environment Reporting Network, "In the U.S., urban farming is likely to have its biggest impact on food security in places that, in some ways, resemble the global south — that is, in cities or neighborhoods where land is cheap, median incomes are low and the need for fresh food is high" (Royte, 2015).  The advantages of growing produce within city limits as well as individually are positive for consumers as well as growers. The farmers can add to their income as well as provide food for themselves and the consumers receive locally sourced, extremely fresh, and wonderfully planted produce.

The major issue with urbanization of agriculture is the ability to feed the large numbers of the city without taking up much of the city's land use. Currently, urban farming is typically in small scale lots, rooftops gardens, and small scale greenhouses. As stated above, urban farms do produce a large supply of produce, however, for large grocers and corporate chains a larger food supply is necessary to keep their stock constantly fresh. Another issue with urban growing are potential soil contaminants, especially lead (FOA, 2017). Plants are known to only take on a limited amount of lead from their water source which makes eating plants ingesting lead water is still healthier than ingesting the water directly, however, lead is still an unhealthy contaminant in growing. The bigger issue pertaining lead in the soil is the direct ingestion of the soil by wandering and playing children as well as if consumers do not properly wash the produce they purchase (Leathers & Foster, 2009).

Finding a reliable source of water is also an important disadvantage to urban growing, though the technologies involved are more precise, finding a dependable water source is a major issue with most industries with the world's growing population. According to the American Society of Agronomy, "Technologies such as drip irrigation that precisely deliver water where and when it's needed can help conserve water. Reusing rainwater and wastewater can provide additional water, but those sources must be monitored for contaminants, and perhaps treated" (Science News, 2013). Finally, the more drastic climate changes within an urban environment in comparison to rural areas can create obstacles when it comes to urban growing.

High temperatures both during the day and overnight can constrain photosynthesis in plants causing growing issues which will limit the yields of these urban farms, however, even these issues are being researched. Scientists such as Wortman and his colleagues are continuing with an ongoing research project to "isolate the effects of the atmosphere. We are monitoring concentrations of carbon dioxide, ozone, temperature, humidity, wind, and other factors across all of the sites" (Wortman, 2013). The results of these studies are already useful, showing which crops grow better in the urban environment and which grow better in rural plots as well as how to create the right environment for the growth of crops outside of their typical.

Urban agriculture has many benefits as well as a few downfalls. Growing within city limits allows for fresh produce for the city consumers aiding in the desire for farm to fork food in current trends. The proximity to the produce as well as the farmers and plots allows for a more knowledgeable public about the food they are consuming (O'Reilly, 2010). The high density, high yield urban plots create an easily accessible produce community and though there are some challenges facing urban growing, the benefits are worth considering a change to more urban agricultural development.

There are many options for agricultural development in an urban setting such as the rooftop gardens as stated above as well as infill projects on lots that have been abandoned or not used, however, urban agriculture can also be worked into urban design. Similar to how housing has moved vertical in urban settings, agriculture can be designed in a similar fashion with the use of vertical farms. The following examines the benefits and disadvantages of vertical farm design and technology and then moves into case studies of the technology already in use.

## Vertical Farming

Vertical farming is the production of food in a stacked position. The system utilizes CEA or controlled-environment agriculture which is a technology that allows ever part of the growing process to be controlled. Being organized in this manner allows for the food to be in buildings such as skyscrapers or warehouses as well as shipping containers. In some cases, vertical farming design mimics greenhouses where natural sunlight is used directly and in other cases the sunlight is augmented with artificial lighting and reflectors. There are three types of vertical farms; the mixed-use skyscraper, the Despommier's skyscraper, and stackable shipping containers. The mixed-use skyscraper utilizes an open air design for climate control and consumption that cultivates a community use that gathers consumers and producers together. Despommier's Skyscraper design plan is isolated from the surrounding world. The plants are produced at mass scale in airtight artificial environments. This design has barely been usable as the maintenance and construction costs are high, however, with the new wave of renewable energy this could become a more applicable style of growing. The idea is to be sustainable and community driven by allowing local inhabitants to work on the farm (Despommier,2013). Finally, the stackable shipping containers is a similar idea to the skyscraper in producing vertically, however, within a different material context. The artificial environments are set up in stacked shipping containers and produce is grown inside these spaces, aiding in the farm to fork movement (Sivamani, 2013). All of these vertical farming strategies are applicable in future development, and can be adjusted to fit budget.

The benefits of urban agriculture are among the benefits of vertical farming as vertical farming takes urban agricultural concepts and applies them to the built environment, using building technology to house the produce and control the growth environment. Bringing the farm to the city reduces transportation costs associated with typical agricultural practices as well as provides a reliable local source of produce products, however, if a vertical farm system the arrangement, capacity, and environment can be very different as well as beneficial. The environment of the vertical farm system being fully enclosed and climate controlled allows no external factors to affect the harvests, making them more reliable than the classic farm. This also allows the farm to function in any climactic region and time of year since the environment remains the same inside the farm.

Another benefit of using a vertical farm system is that the production overheads are predictable and competitive production overheads. According to Vertical Farm Systems, “In some cases profitability of over 30% has been demonstrated even after deducting full amortization of capital equipment over a 10 year period.” (Vertical Farm Systems, 2015) These costs are maintained through various elements such as low energy usage, low labor costs, low water usage, reduced washing and processing, and finally, reduced transport costs. High efficiency LED lighting is implemented to guarantee maximum power usage which allows for strong plant growth. Lacking the need for sunlight greatly reduces the energy usage of the building, especially since the design does not have to be like a greenhouse but can build high thermal efficiency structures. In addition, the elimination of the need for tractors and other fossil fuel emitting technology allows vertical farms to not only be carbon emissions competitive but also use green power systems. Labor costs also tend to be low in vertical farming systems as most of the systems are mechanized and workers are only required for planting, harvesting, and packaging which does not require high skill sets and can even be done by volunteers in the community (Royte, 2013).

Water usage is much lower in vertical systems and according to Vertical Farm Systems, “Vertical Farm Systems use only around 10% of the water required for traditional open field farming and around 20% less than conventional hydroponics.” (Vertical Farm Systems, 2015)

The implementation of vertical drip systems, the reuse of water and controlled transpiration loss allows for this lesser use of water. The enclosed space also eliminates the need for washing and processing because no pesticides and herbicides are used. Finally, the urban setting that is allowed in a vertical farming system allows for decreased transport costs, especially in a skyscraper system where the bottom floors are a marketplace to sell the produce (Gruner, Orazi, & Power, 2013). Simply by being in the city setting allows for quick and easy transport to local restaurants and grocers, cutting down on much of the transportation costs required in classic farming styles.

The vertical layout of these systems are also beneficial as they provide more space in less ground area. In some cases, "For the same floor area, Vertical Farm Systems multi-level design provides nearly 8 times more growing area than single level hydroponic or greenhouse systems. This compact design enables cost-effective farming installations in industrial estates, urban warehouses and other low cost and typically under-utilized environments not previously associated with high-quality high-margin agricultural activities" (Vertical Farm Systems, 2015). The controlled environment combined with this vertical layout allows for vertical farming to provide a maximum crop yield not only by avoiding harmful environmental factors but by controlling the crops' growth to increase the speed of the growth cycle. These factors also aid in allowing the vertical systems to grow a wide range of crops such as baby spinach, loose leaf lettuce, and basil, among others.

Vertical farming does have its disadvantages as well. Though the production costs once constructed are minimal the initial costs are high. Urban land is more expensive than farmland and building a skyscraper with the proper technology to house the farm is a more expensive construction process than planting and managing land. Finally, the need for pollination with an insect free environment poses the challenge of pollinating by hand which can be cost intensive due to material and labor costs. Many of the benefits of vertical farming outweighs the possible disadvantages but the more evolved the technology becomes the more efficient it will be. As some of the kinks get figured out vertical farming could be the best and only solution to agriculture that will provide for more land for other uses as well as provide a cheaper and reliable source of produce.

## Cost, Benefit Analysis Conclusion

Every strategy of agriculture has its advantages and disadvantages; classic agriculture though effective thus far is aiding in famine throughout the world there are a lot of reasons to stick to the classic platform. As the population grows however, a need for sources of produce within the community is necessary for a sustainable urbanized future. Urban agriculture is already an efficient and effective way of growing that also provides the consumers with locally sourced ingredients. Vertical farming is an intelligent solution to these issues. It allows produce to move to local sources that produce a large amount of produce in limited time spans as well as using sustainable technology to use less energy and resources. The small current issues, if fixed, could provide a future solution to agriculture needs by providing a less expensive, more accessible market for consumers to access.

## Case Studies

In the following segments, a selection of pre-existing vertical farm structures will be reviewed to show the systems current standing. Since the technology is already in practice, the following vertical farm examples will allow an analysis of successfully implemented urban agriculture practices in the built environment.

## Chicago, Illinois

In Chicago, Illinois farming and food production are not among the top industries in the city, however, the potential is there as technology companies such as Green Sense Farms continue to develop and create the country's largest vertical farm. The company, Green Sense Farms, unveiled their warehouse vertical farms in 2014. Next generation LED grow lights as well as vertical hydroponic systems aid in allowing the farm to produce masses of food in any climactic condition. Due to the technology used in these systems, the produce is harvested 26 times a year while consuming less energy and water than classic agriculture. Being isolated from the outdoor environment allows for no use of harmful pesticides or herbicides. The benefits of growing indoors are all present in the Chicago system and are spoken about by Robert Colangelo, founding farmer/president of Green Sense Farms said in a press statement. "We produce little waste, no agricultural runoff and minimal greenhouse gasses because the food is grown where it is consumed" (Tarantola, 2014). The ability of this vertical farm to produce year round makes it an integral part of the food production and distribution system in the city, especially in the potentially harsh climate of the winter months in Chicago. Moving the system to a vertical farm allowed Chicago to become a major player in food production, showing that urbanization of agriculture as well as integration into the built environment is an advantageous strategy to provide cities with locally sourced produce and feed cities on an individual basis.

## Singapore

Sky Green Farm in Singapore is the first of its magnitude, capable of producing 1 ton of food every other day (Beach, 2015). The steel structure in vertical layout, allows the dense urban fabric of Singapore to produce more food locally and add to its currently low production rate as most of the produce in Singapore is imported from other countries which adds to the expense of the food itself. According to Farming 4 Change, “the farm itself is made up of 120 aluminum towers that stretch thirty feet tall.” (Farming 4 Change, 2013) Though the system grows a massive amount of food, the farm originally only grew three types of produce, however, as the system expands there will continue to be added produce which will allow the area to potentially become agriculturally independent. Achieving independence will allow the area to stop relying on other countries for aid in food production and distribution; helping avoid the major issues with classic agriculture that causes famine.

Already, those purchasing from the vertical farm in Singapore enjoy the local produce “although the produce costs 10 to 20 cents more than other veggies at the supermarket, consumers seemed eager to buy the freshest food possible – often buying out the market’s stock of vertical farm foods.” (Farming 4 Change, 2013) Although this system does not reduce all costs associated with farming, it reduces many of the harmful chemical uses in classic agriculture, avoids the distribution costs and CO2 emissions associated with them, and provides local produce for those who prefer farm to fork type systems which most seem to prefer.

## Japan

The Pasona HQ office building in Tokyo, Japan is a 215,000 square foot corporate building incorporating a vertical farm system growing food for the employees of the building (Kono Designs, 2013). The system is the first farm to desk system of its kind. The growing area takes over 43,000 square feet and houses over 200 species (Kono Designs, 2013). The building grows most of its own food such as rice, broccoli, squash, tomatoes, etc.

The building was rehabilitated to include green infrastructure including the living walls which allows reduction of the building energy needs. The plants use both hydroponic and soil based growing that is integrated into the building's interior environment. The technology used is LED lighting and monitoring systems to control humidity, water use, and temperature. This system is also supporting Japan's education of urban farmers through various internship systems. The workers as well as volunteers participate in harvesting of the plants which adds to their understanding and appreciation for growing.

The air quality is also improved by the oxygen given off by the plants. In this system, the utilization of vertical farming technology as well as the farm to fork system proves how resourceful vertical farming can become (Farm Exchange, 2014). If built in an urban setting, any typology of vertical farming is executed correctly can provide cleaner and more efficient local growing systems in cities throughout the world. Cutting down on food distribution costs as well as harmful classic agriculture techniques, vertical farming could be the growing habit of the future and could provide the world with a future path to agriculture allowing land use development to focus on other areas of expansion and bring food to the consumer in a well-organized and integrated fashion.

## Methodology

According to Guba and Lincoln, qualitative research “can redress the imbalance by providing contextual information” (Guba and Lincoln, 1994) by asking questions that allow for greater depth of understanding more so than quantitative studies. The allowance of contextual information in to research provides a well-rounded conclusion that includes personal experience in the subject matter, an important piece to the research of agriculture as well as vertical farms. To compare and contrast various agricultural forms including traditional farming methods, urban agriculture, as well as cases where vertical farms are already being implemented are all important pieces to studying the best solution for food distribution issues.

This is not to say that quantitative and qualitative are incompatible. Mixed methods can provide an in depth analysis by using the strengths of both methods (Creswell, 2015). A cost/benefit analysis and a collection of case studies will provide the most complete research and conclusion about food distribution processes as well as solutions to such issues. A cost benefit analysis, according to Layard and Glaister (1994), seems like a simple solution to deciding between two courses of action. Weighing the benefits of action A versus the benefits of action B seem simply enough; however, comparing the costs of both actions can become very difficult. Measuring what potential cost outweighs the other is often the most difficult portion of this type of analysis as it causes a choice to be made that will still cause some sort of negative outcome. That is why in this research analysis the cost/benefit analysis will be but a singular area of inquiry. The case studies will aid in determining the real costs as seen already occurring as well as the benefits in the same light. Combining a cost benefit analysis and three separate case study analyses will provide the public with a descriptive analysis of the various potentials and downfalls of particular agricultural approaches and possible solutions moving forward to aid in limiting food waste as well as food distribution costs.

## Data and Results

As recognized from the literature review analysis of various types of agriculture, there are benefits to remaining in a horizontal platform of the current agriculture techniques as well as moving to a vertical urbanized platform. Multiple urban farming techniques are possible and understanding the costs and benefits of each is an important part of analyzing the most effective choice. Green roofs as well as small local farms in an urban setting are useful for small neighborhood markets and in the farm to fork movement discussed in the literature review section of this paper, however, as previously stated to feed the entirety of a city as well as fully stock large scale markets and grocery stores, this solution is too small scale which is when vertical farming began being explored. Vertical farms allow for large scale production with limited climate or insect effect on the plants allowing for no use of pesticides as well as controlled growth all year long. Being able to grow year-round in any type of climate condition is already an extreme benefit to growing indoors in a vertical layout, however, the startup construction costs and technological costs keeps many from moving to vertical farming as the future of agriculture. In the following sections the true costs in dollars of vertical farming in comparison to horizontal farming are shown. Land use and transportation costs however, are important additions to the benefits of the vertical farming within urban landscapes, therefore, these will also be examined in understanding the true benefits to farming in the two different layouts.

When first examining various types of agricultural systems, an assessment of the success of the farming systems in relation to each other is important to gather an accurate picture of which of the methods is most effective. As stated above investigating all of the various costs and benefits in classic, urban, and vertical farming demonstrates how these methods need to be considered based on price (in various areas), climate, and resource uses to select the best possible future method. The following tables begin to display how the costs and benefits of the various systems compare.

The first set of tables of data collected and created are to show the variation in construction costs between the three farming systems being studied.

**Classic Agriculture Construction Costs**

Construction Cost of Irrigation System

The first table lists cost of construction for the irrigation system in square feet:

| **Table 1** | Gravity | Pump | Classical Canal | Flume | Pipe |
|---|---|---|---|---|---|
| Average ($ per sq. ft.) | 5252 | 7234 | 5465 | 5173 | 8293 |

The above table shows the cost in United Sates dollars per square foot of creating an irrigation system in a classical horizontal agricultural system. Beyond leveling the land for a farm, if not already done, the irrigation system is the next major component to the cost of constructing agricultural land ignoring the cost of the needed buildings and structures beyond the land itself. In most cases, farms are set in a rural setting and the need for farm buildings and residences for the workers is an additional cost not included in urban farming where the farm is developed within the limits of the city environment. The need for an irrigation system is important in any large scale farming system, vertical or horizontal as well as urban or rural which in classic agriculture requires land renovation as well as land alterations which is not included in Table 1. Typically to hire a small scale machine that can be towed ranges from 50 to 70 dollars a day and a slightly larger machine such as a backhoe can cost from 100-200$ per half day or day, depending on the size and scale of the machine (Cost Helper, 2017). If looking for complete land renovation by an operator and bulldozer however, the cost increases to a range of about 50-150$ per hour because of the need for more intensive machinery as well as the labor to operate such machinery. Land for farming should be chosen carefully to require less need for land alteration or leveling, instead looking for a flat and easily manipulated land (Cost Helper, 2017). In addition to all of the construction costs of the three farming systems they also all involve crop costs and the tools necessary for the growth and maintenance of them which will be listed in table 4, however, the following table shows the costs of constructing classic farming structures.

**Construction Costs of Needed Farming Structures**

The following table shows per square foot the construction costs of the needed buildings in classical agriculture and farming:

| **Table 2** | |
|---|---|
| Type of Farm Building | Average Construction Costs |
| General Purpose Barn | $38.00 per sq. ft. |
| Hay storage Barn | $23.00 per sq. ft. |
| Walk-through Dairy Barn | $63.00 per sq. ft. |
| Machine Shed | $30.00 per sq. ft. |

| | |
|---|---|
| Poultry House | $52.00 per sq. ft. |
| Greenhouse | $25.00 per sq. ft. |

The above table, Table 2, shows the average costs of construction for the various farming structures of a classical agricultural system per square foot. Due to the rural location of classic agricultural systems, the maintainer of the facilities usually lives on site and the production occurs in these various structures which are required pieces of construction for this system and important to calculating the accurate cost of a classical agricultural system. The building and the technology involved of vertical farming tends to be a large cost that holds up the construction of more vertical farming throughout the country, however, the startup costs of a new farm would also be expensive however, many farms are already built and functioning which eliminates new costs unlike urban agriculture.

**Costs of Crop Production**

The final table shown below before moving towards urban agriculture will apply to all forms of agricultural techniques discussed here. Table 3 shows the costs of crop production in dollars per square acre. The table includes a variety of common crops grown across multiple farms in America and shows not only how much they cost initially but also the operating costs, fixed costs, and labor costs. Knowing not only the costs of each type of crop in total but also broken down into various categories shows not only the costs that will be necessary across the multiple methods of farming but also which costs can be avoided with some methods. Table 3 includes all of the costs required in classic agriculture, which will also be true in most open aired urban farms as well, however, since vertical farming is indoors and protected from outer environments, the costs of pesticides and insect repelling agents will not be necessary.

**Table 3**

| Crop Production Costs 2016 Guidelines (Dollars Per Acre) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canola | Wheat | Winter Wheat | Soybeans | Barley | Oats | Corn | Navy Beans |
| **Profitability Ranking** | *6* | *8* | *2* | *9* | *12* | *13* | *3* | *1* |
| **A. Operating Costs** | | | | | | | | |
| Seed & Treatment | $52.25 | $22.00 | $20.00 | $94.38 | $15.00 | $18.13 | $78.30 | $52.50 |
| Fertilizer | $78.99 | $61.23 | $66.14 | $11.35 | $53.48 | $48.57 | $94.42 | $56.32 |
| Herbicide | $13.13 | $26.21 | $13.83 | $14.67 | $24.88 | $9.50 | $18.17 | $66.21 |
| Fungicide | $36.25 | $21.31 | $21.31 | $0.00 | $17.25 | $10.13 | $0.00 | $39.50 |
| Insecticide | $4.73 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| Fuel | $16.43 | $20.05 | $21.71 | $15.34 | $21.67 | $23.33 | $23.65 | $18.87 |
| Machinery Operating | $10.00 | $10.00 | $10.00 | $10.00 | $10.00 | $10.00 | $10.00 | $10.00 |
| Machinery Lease | $3.60 | $3.60 | $3.60 | $3.60 | $3.60 | $3.60 | $3.60 | $3.60 |
| Rental and Custom | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| Crop Insurance | $14.96 | $11.82 | $10.24 | $22.31 | $12.34 | $14.21 | $24.53 | $28.78 |
| Other Costs | $7.75 | $7.75 | $7.75 | $7.75 | $7.75 | $7.75 | $7.75 | $7.75 |
| Land Taxes | $12.00 | $12.00 | $12.00 | $12.00 | $12.00 | $12.00 | $12.00 | $12.00 |
| Drying Costs | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $35.00 | $0.00 |
| Interest on Operating | $6.88 | $5.39 | $5.13 | $5.26 | $4.89 | $4.32 | $8.45 | $8.13 |
| **Total Operating** | **$256.98** | **$201.36** | **$191.71** | **$196.66** | **$182.85** | **$161.53** | **$315.88** | **$303.66** |
| **B. Fixed Costs** | | | | | | | | |
| Land Investment Costs | $53.75 | $53.75 | $53.75 | $53.75 | $53.75 | $53.75 | $53.75 | $53.75 |
| Machinery Depreciation | $45.91 | $45.91 | $45.91 | $45.91 | $45.91 | $45.91 | $45.91 | $45.91 |
| Machinery Investment | $11.48 | $11.48 | $11.48 | $11.48 | $11.48 | $11.48 | $11.48 | $11.48 |
| Storage Costs | $5.23 | $7.19 | $9.80 | $4.58 | $10.46 | $13.07 | $15.03 | $4.03 |
| **Total Fixed** | **$116.36** | **$118.32** | **$120.94** | **$115.71** | **$121.59** | **$124.20** | **$126.17** | **$115.16** |
| **Total Operating & Fixed** | **$373.34** | **$319.68** | **$312.65** | **$312.37** | **$304.45** | **$285.74** | **$442.04** | **$418.82** |
| **C. Labour** | $30.00 | $30.00 | $30.00 | $30.00 | $30.00 | $30.00 | $30.00 | $30.00 |
| **Total Costs** | **$403.34** | **$349.68** | **$342.65** | **$342.37** | **$334.45** | **$315.74** | **$472.04** | **$448.82** |

(Growing Productions, Arnott, 2017)

## Urban Agriculture Costs

The following table begins the analysis of urban agriculture in terms of cost beginning with green roof systems. As stated above, to create a large enough roof garden to supply markets or grocery stores would be extremely difficult and potentially not possible, however, they are already an important form of urban farming and necessary to analyze in comparison to other methods of farming in an urban setting.

**Table 4**

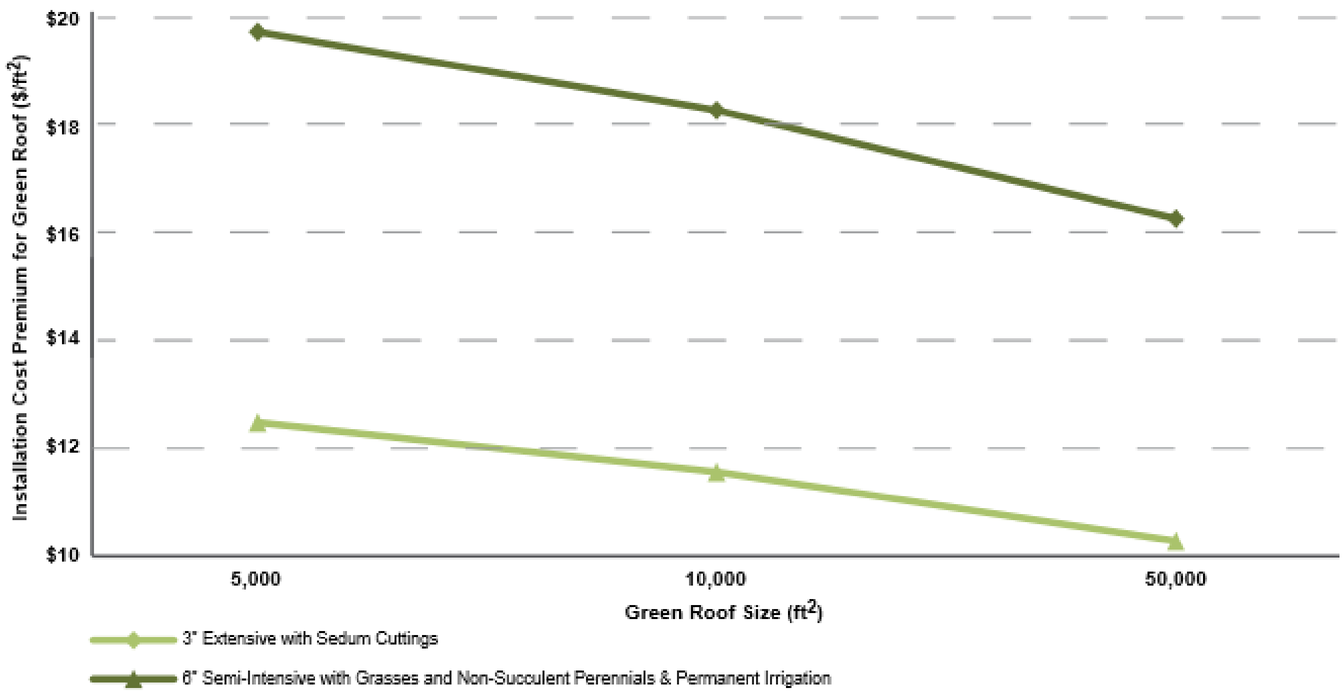
Table 8: Cost-benefit analysis results of green roof vs black roofs

| NATIONAL LEVEL RESULTS | ROOF SIZE ($ft^2$) | | |
|---|---|---|---|
| | 5,000 | 10,000 | 50,000 |
| **Impact on Owners/Occupants/Investors** | | | |
| **Initial Premium,** \$/$ft^2$ of roof (extra cost of installing a green roof instead of a black roof) | -\$12.6 | -\$11.4 | -\$9.7 |
| **NPV of Installation, Replacement, & Maintenance**, \$/$ft^2$ of roof | -\$18.2 | -\$17.7 | -\$17.0 |
| **NPV of Stormwater,** \$/$ft^2$ of roof (savings from reduced infrastructure improvements and/or stormwater fees) | \$14.1 | \$13.6 | \$13.2 |
| **NPV of Energy**, \$/$ft^2$ of roof (energy savings from cooling and heating) | \$6.6 | \$6.8 | \$8.2 |
| **Net Present Value** (installation, replacement & maintenance + stormwater + energy NPV) | \$2.5 | \$2.7 | \$4.5 |
| ***Internal Rate of Return (IRR)*** | *5.0%* | *5.2%* | *5.9%* |
| ***Payback**, years* | *6.4* | *6.2* | *5.6* |
| ***Return on Investment (ROI)*** | *220%* | *224%* | *247%* |
| **Other Financial Impacts (less realizable)** | | | |
| **NPV of $CO_2$e,** \$/$ft^2$ of roof (emissions, sequestration & absorption) | \$2.1 | \$2.1 | \$2.1 |
| **NPV of Real Estate Effect,** \$/$ft^2$ of roof (value, rent, absorption & vacancy) | \$120.1 | \$111.3 | \$99.1 |
| **NPV of Community Benefits**, \$/$ft^2$ of roof (biodiversity, air quality, heat island, etc.) | \$30.4 | \$30.4 | \$30.4 |

(GSA, 2008)

The above table 4, is a cost benefit analysis of a green roof vs a normal black roof showing not only the startup costs but the maintenance and earnings and similar financial impacts of each option to illustrate a clear analysis of the similarities and differences of the two methods. Knowing the payback of investing in a particular option versus the other can give a more clear understanding of how to pick between the two. Though a green roof demonstrates a variation in construction and the requirement for more material and in many cases more expensive material, the pay off in potential crop selling as well as energy savings for some is enough of a payback that makes the slightly higher construction cost worth it. Green roofs are becoming increasingly popular in sustainable design because it protects the roof from heat infiltration while also adding an extra programmatic element to any building choosing to use this strategy. The crop costs and irrigation costs are still present, however, the aid the building is given by this strategy oftentimes makes green roofs a wonderful option especially in an urban setting. The following figure also shows a comparison of different types of green roofs and their installation prices based on the size, depending on the goal of the green roof being installed, a variation in construction cost is present.

**Figure 1**




(GSA, 2008)

Figure 1 above is important to understanding the development of green roofs because it shows that the larger the plot of green roofing the more price efficient the development is. The price per square foot decreases as the size increases which is important to the development of larger scale urban farming techniques. No matter what form of green roof the developer chooses to implement, the larger the size the more price efficient, which can determine a layout of the building depending on how important the green roof is to the development of the overall structure.

**Vertical Farming Construction Costs**

**Table 6**

| | |
|---|---|
| Sub-structure and electro-chromic glass shell | $25,000,000 |

| | |
|---|---|
| 1000 ton Geothermal HVAC | $2,500,000 |
| 400 ton chiller + cooling tower | $500,000 |
| Biogas to fuel cell cogeneration facility | $11,000,000 |
| 800 kWh/day tracking photovoltaic array | $500,000 |
| 4,500 kW water-cooled lighting system | $2,000,000 |
| Energy infrastructure and automation systems | $35,000,000 |
| Living machine-based water recycling system | $500,000 |
| Floating garden hydroponic system | $1,700,000 |
| Office and laboratory facilities | $5,000,000 |
| Total Building Cost for vertical farming | $84.7 million |

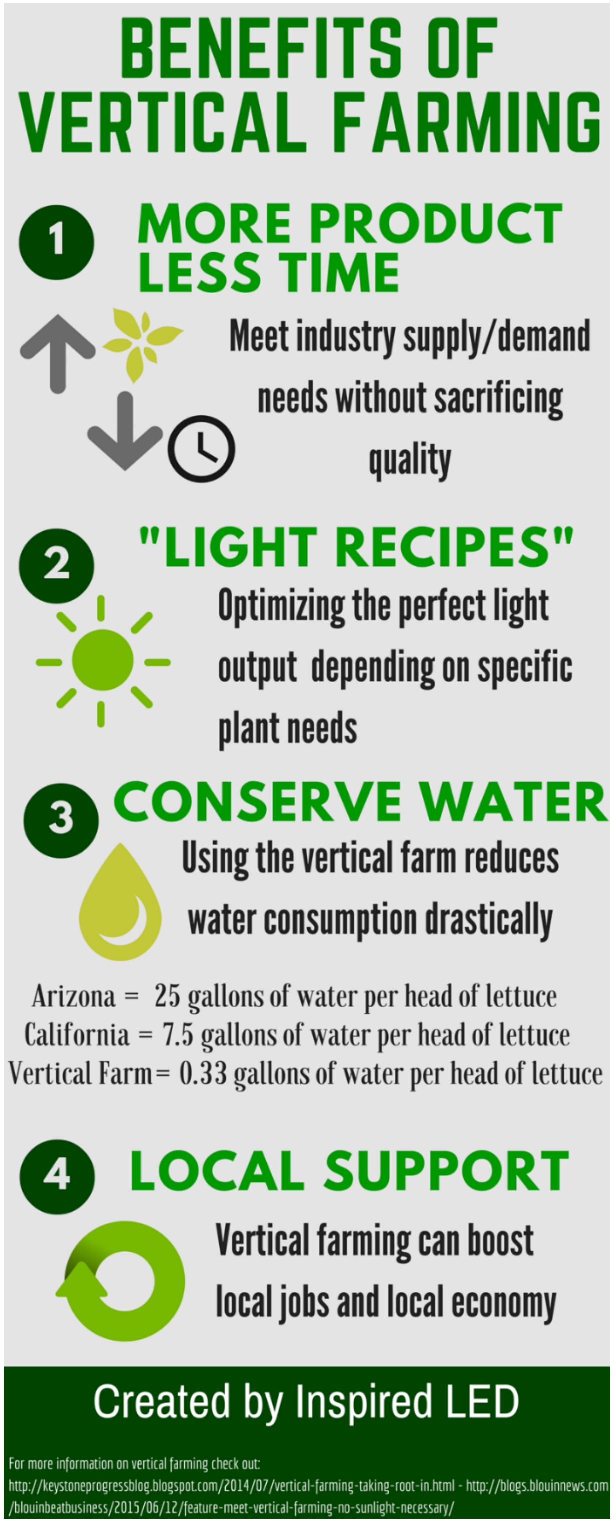
Table 5 is a complete list of the construction costs of a vertical farming system which includes the building including the various systems such as hydroponic systems. From all of various construction costs of the three farming system the vertical farm has the largest startup costs because it involves a large scale building cost as well as high tech system set up. Though the vertical farming has high costs necessary to build and set up correctly, the vertical farming method also allows for benefits that classic agriculture cannot allow. The following table, table 7 compares the costs of vertical farming to classic agriculture farming and then following various figures showing differences in farming techniques in terms of more than just dollars.

**Cost Comparison Table**

**Table 7**

| | Vert. farm (40,000 sq. ft.) | Horizontal Farm (30 Acres) |
|---|---|---|
| Land ($) | Depends on City | 90,600 |
| Buildings | 83 Million | 250,000 |
| Irrigation | 1.7 Million | 157 Million |
| | | |
| Crops | See Table 3 | See Table 3 |
| Wheat | Do not include pesticides | Includes all costs |
| Corn | | |
| … | | |
| Total (excluding crops) | $84.7 Million + Land | $158 Million |

**Figure 2**




(Roselli, 2015)

Figure 2 begins to explain the benefits of vertical farming that are not included in a simple analysis of the prices and numbers. Many of the benefits attributed to vertical farming comes from the less amount of waste, more growing time per year due to indoor solutions to climate effects, as well as water conservation. Vertical farming does not only allow for proximity growing which limits fuel usage and transportation costs but stimulates the urban economy adding jobs and creating community involved growing. Another important component to vertical farming comes from the land use savings moving towards urbanized agriculture can create. As the population grows the world has limited space for classic horizontal growing as well as the new people being added to the population daily. The need for a programmatic change in land use creates the need for new solutions such as vertical farming.

**Figure 3**


(Spore, 2015)

Figure 3 explains more specifically the benefits of vertical farming, showing in statistics the important savings and improvements urbanized vertical farming has on the agricultural industry and potential for betterment moving into the future of crop growing. Every element illustrated in figure 3 is important to the future development of agriculture as well as the usable land left for the growing population. The first statistic showing how much less land vertical farming requires because you can develop the technology in old warehouses and no longer used industrial sites. New development can also take place but within the urban fabric already developed allowing for lesser space being taken by these structures as like apartment buildings helped reduce the spread of housing over usable land, vertical structured farming can do the same for agriculture. Eighty percent of the usable land for agriculture is already in place, meaning that as the world population grows further, more and more people will go without food due to transportation costs and limited land for use. Vertical farming can also limit water use significantly due to the technology that allows the need for less water unlike classic horizontal farming. Lastly one of the largest proponents for moving to a vertical and urbanized method of farming is the fossil fuel use and high transportation costs of classic farming. Due to classic horizontal farming needing open rural land, the food grown and sourced from these lands are traveling great distances to reach the grocery stores and markets that every day people shop in, increasing the use a nonrenewable resource necessary for other programs as well as increasing costs due to long lengths of transportation. If the world can take the transportation requirements of current farming and limit it almost completely by placing the farms within the cities, food prices would drop dramatically, waste would be much less, and people would more often be able to feed themselves and their families.

## Conclusion

The collected data and literature of various agricultural systems, as well as the growing population, shows that a move towards urbanization is necessary not only for living situations but for industries to sustain the human population without destroying all wildlife habitats. As the world urbanizes, proximity and efficiency of amenities and industries becomes vital to the affordability of common necessities. The amount of waste that occurs while many go without food is unnecessary and inhumane. If agriculture products are within the proximity of the majority of the human population, the affordability of food items will increase as transportation costs will decrease.

Moving towards an urbanized agriculture system will produce multiple challenges. The start-up costs of vertical farms, as well as the job changes for those in the current agriculture system, will have a wide effect on the urban environment as well as the rural environment. Those in the current agriculture industry will be forced out of current employment and potentially moved to urban environments in order to stay in their career. However, as we grow in population size, urbanized movement is a necessity to sustain us. The less land use from classic agriculture will open up opportunities for new programs within that land use, potential needs for expansion for urban environments, and finally allowing wildlife habitats to flourish alongside human environments.

Another important benefit from vertical farming is the ability to use old warehouse and industrial buildings for the farm itself as we see in Chicago's vertical farm development. To avoid initial costs of constructing a new building as well as the hydroponic structure and vertical structures for the plants, using existing buildings can limit those initial costs, making vertical farming more affordable than building an entirely new structure for the crops. The technology required for vertical farming is costly but reducing the building costs allows it to begin to be a good solution and cost efficient possibility for agriculture moving into the future.

As shown in the figures in the above data and results section, vertical farming is also beneficial because it reduces fossil fuel use in machinery as well as in transportation. Most crop and food supplies travel around 2000 miles to arrive at the grocery store of market destination where they are needed. The costs, both monetarily and in energy that this long distance transportation requires increases the prices of food at the everyday market as well as increases the use of fossil fuels that are not necessary when in a vertical farm and urbanized farming system. If this transportation cost could be taken off crop and produce prices, more of the population will be able to access produce products and afford to feed their families healthier food. Currently packaged, high sugar, low value foods are the most accessible due to their low prices and easily packaged items. If more valuable and healthier food was cheaper and fed more individuals then people tend to choose the healthier item, however, a packaged item that can feed many is still under the price of much of the healthier produce items that can potentially provide only one meal for a family of four. The need for cheaper, healthier food should push the development for urbanized agriculture systems to aid in feeding the world's population. Decreasing the already excessive fossil fuel emissions in current agriculture techniques will also aid the world in maintaining a healthier climate as well as saving more of a nonrenewable resource.

As the population of the world grows, the population is being forced into smaller and smaller spaces because the land available cannot grow as we do. The need for more efficient selection of land use begins to beg the question; what can be altered to fit into a smaller space? Vertical farming and urban agriculture techniques illustrates the ability to limit not only space taken by our food system but also the travel expenses that causes famine worldwide. Moving into urbanized areas, agriculture can become a more efficient and cost effective strategy to our food supply issues. This transition will not be simple or easy, the upfront costs of this system are high due to the necessary technology to grow for a large scale city; these costs, however, are worth the benefits. The world needs urbanization to accommodate the growth to 10 billion we expect to see by 2050. If we can alter our classic views and practices of agriculture, the world's habits, and habitats, can begin to change for the better.

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