THESIS

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MANAGEMENT AND LEADERSHIP MA

Gödöllő

2023

Hungarian University of Agriculture and Life Science

Szent István Campus

Management and Leadership Course

Economic and Management Aspects of Vertical Farming

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Management and Leadership

Gödöllő

2023

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1 INTRODUCTION

How to solve the problem of human food and clothing on limited land is what we have been thinking about all the time. According to the forecast of the United Nations, the global population will reach 9.6 billion by 2050, and 86% of them will live in cities away from traditional farms. To solve the food needs of these people, we need to find and innovate a new agricultural production model, in order to solve the sustainable development goals of the United Nations and the challenges caused by population growth, water shortage, arable land loss, excessive use of pesticides and supply chain. In view of the wider agricultural problems brought about, vertical farming may be an important direction in the future. Vertical farm is a new type of indoor planting method. It makes full use of the indoor vertical space and builds planting racks. The planting racks are as high as the roof, and workers need to take care of them on ladders. Its emergence lies in solving resource constraints and making full use of urban space, which can effectively expand crop production area and production output, and is known as the future of the food industry and agriculture.

The original reason I chose the topic was because the population problem is a very serious problem in my country and many people are still poor and do not get enough food. Secondly, in recent years, due to climate reasons, disasters including floods, droughts, cold damage, hail, sandstorms, etc. have caused huge losses to our country's agriculture. In addition, reducing greenhouse gases is also a major goal of our country at present. Finally, the large and unscientific use of pesticides and chemical fertilizers has caused food safety problems caused by pesticides, chemical fertilizers and other harmful substances in agricultural products.

The topic of vertical farming was first mentioned to me by my thesis advisor, and then I went to read related literature and popular introduction videos about vertical farming. At that time, I was very attracted by this idea and wanted to know more about vertical farming. Because my major is management and leadership, and I also studied related economics and marketing knowledge at the undergraduate level, I chose the economics and management aspects of vertical farming as my research topic.

1.1 Background of the Study

According to the statistics of the United Nations, the world population is expected to reach 8.5 billion by 2030, and then the population will continue to grow, reaching 9.7 billion in 2050 and 11.2 billion by 2100, with a population of 4.7 billion in Asia (*United Nations*, n.d.). It is predicted that in order to ensure production in the future, it must increase by about 25%–70% compared with the recent level to meet the annual needs of the global population in 2050 (Hunter et al., 2017a) . Climate change and associated extreme weather events on a global scale bring heightened risks and uncertainties to open-air agricultural production (Pinstrup-Andersen, 2017).

"Vertical farming" was first proposed by (D. Despommier, 2010) , a professor at Columbia University in the United States. (D. Despommier, 2010) hopes to grow the food people need in light-filled buildings made of glass and steel. For example: feeding tilapia on the 1st floor, planting tomatoes on the 12th floor... Inside the building, all water is recycled; plants do not use compost; gases such as methane produced are captured and turned into heat; livestock excrement becomes a source of energy, etc. "Vertical farming" is a new way to obtain food and dispose of waste.

Vertical farming has received a lot of attention from academia, investment, and industry because of its enormous potential benefits. (Shao et al., 2022) investigated the impact of UFVF on the self-sufficiency rate of farmers and the city's vegetables and fruits. The results show that UFVF helps to increase the self-sufficiency rate of vegetables and fruits by 20.68% and 2.54%, respectively, and the return on investment UFVF can reach about 30%. (Wong et al., 2020) studied the effect of LED spectrum or intensity on the growth and phytonutrient accumulation of green leafy vegetables, and the results proved that The quality and quantity of light can be controlled in vertical farms to increase the yield and phytonutrient content of green leafy vegetables. Since the response of leafy green vegetables to light depends on genotype and developmental stage, light recipes for different developmental stages should be formulated for different species to maximize yield. (Gentry, 2019) linked hydroponic agriculture to district heating, and it turns out that exploiting these varying degrees of

integration between urban agriculture and district heating can create a circular, mutually beneficial system in which agriculture and energy The close connection of production promotes each other and improves the efficiency of both.

1.2 Aim of the Study and Research Questions

When researching this topic, because the idea of vertical farming is so attractive, I often think of myself as a future investor in vertical farming. In short, I want to start a vertical factory by myself, so I need relevant expertise. Advice from researchers and the successes and failures of operators who have already experienced it. So I would ask what is the difference between vertical farming and conventional farming? Vertical farm mainly grows plants? How big a vertical farm would be better? How to choose a site for vertical farming? What kind of talents are needed to manage and how to manage a vertical farm?

To achieve this aim, the study focused on the following research questions **(Table 1).**

Table 1: Interview questions

Aspects	Questions
Economic Aspects of Vertical Farming	How does the cost input of vertical farms differ from traditional farms?
	What are the most profitable crops to grow on a vertical farm?
	If vertical farming is classified into large, medium and small scale, which scale of vertical farming will have higher economic benefits?
	What factors will affect the site selection of vertical farms?
Management Aspects of Vertical Farming	What are the current management forms of vertical farming?
	The production process of vertical farming and the production process of traditional agriculture, which one is better to manage?
	What kind of management talent does it take to run a vertical farm?
	How to effectively manage vertical farms?

Source: Author's own research

2 LITERATURE VIEW

2.1 Introduction

In this chapter, researcher first mainly introduce the problems that the current society is facing, such as the land problem caused by population growth, the contemporary climate change caused by the emission of greenhouse gases (such as CO^2), climate change, and food safety issues that the general society is concerned about. Secondly, the researcher introduced the related concepts of vertical farming, the types of vertical farming, the main technologies related to vertical farming, opportunities of vertical farming and the challenges faced by vertical farming. Finally, the researcher introduced the economic feasibility of vertical farming and the Vertical farms in Practice.

2.2 Population and land problem

The population issue has always been a hot topic in the United Nations. According to the statistics of the United Nations, the world population is expected to reach 8.5 billion by 2030 **(Figure 1).**

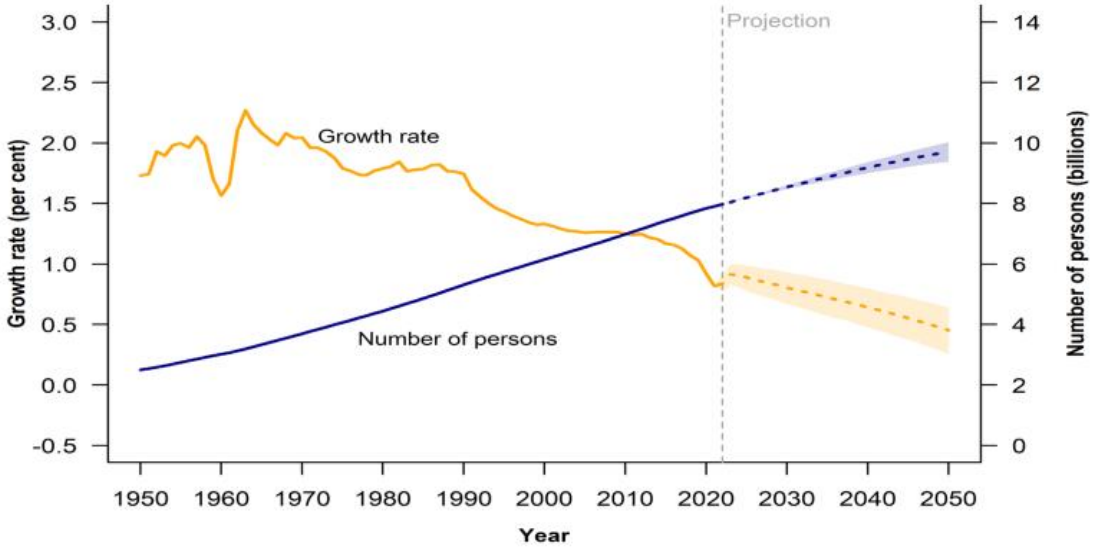

Figure 1: Global population size and annual growth rate: estimates, 1950-2022, and medium scenario with 95 percent prediction intervals, 2022-2050

Source:(World Population Prospects, 2022)

The population will continue to grow, reaching 9.7 billion in 2050 and 11.2 billion by 2100, with a population of 4.7 billion in Asia (*United Nations*) . The proportion of the world's population living in urban areas will increase from 55% to 68% by 2050, which would add another 2.5 billion to urban areas population, 90% of which will take place in Asia and Africa, A large number of people are moving to cities, making urban land, such as buildings and businesses Land use increased. Urban sprawl has led to a serious loss of cultivated land globally, with a total loss of 2.0% (1.8-2.4%) of the total global area - about 30 Mha (27-35 Mha), with countries such as China, Vietnam and Pakistan losing between 5 and 10 Between Mha. Much of this lost farmland is more than twice as productive as the national average. Asia will experience the highest absolute loss of arable land, while African countries will experience the highest percentage loss of arable land (D'Amour et al., 2017).

On the one hand, the development of urbanization has led to the reduction of agricultural land. On the other hand, the continuous growth of the population has continuously increased the requirements for food production and quality. Feeding a growing and increasingly affluent population with the planet's finite resources is one of the grand challenges of our time. It is predicted that in order to ensure production in the future, it must increase by about 25%–70% compared with the recent level to meet the annual needs of the global population in 2050 (Hunter et al., 2017b) , and to feed the growing world population on average may An additional 2.7–4.9 Mha of arable land is required.

2.3 Climate Change and Associated Issues

According to the Intergovernmental Panel on Climate Change (IPCC), global greenhouse gas (GHG) emissions must be reduced by 45% by 2030 to limit global warming to 1.5°C above pre-industrial levels (IPCC) . Agriculture, including food production and distribution, is a significant contributor to GHG emissions, accounting for approximately 25% of global emissions (FAO, 2018).

Climate change and associated extreme weather events on a global scale bring heightened risks and uncertainties to open-air agricultural production (Pinstrup-Andersen, 2017) . Extreme weather events such as drought, flooding from heavy rains, heat waves and frost

often lead to severe crop loss, affecting food security and farmers' incomes (Lesk et al., 2016). Damien Beillouin et al. conducted a machine learning model (random forest) on crop yield data (9 main annual crops such as barley and corn) from more than 1,400 local geographic units (called regions) in 17 countries. On the **(Figure 2)**, the experimental results proved that The above-normal crop yield losses experienced in Northern and Eastern Europe in 2018 are related to atypical climate conditions in Europe in recent years (Beillouin et al., 2020).

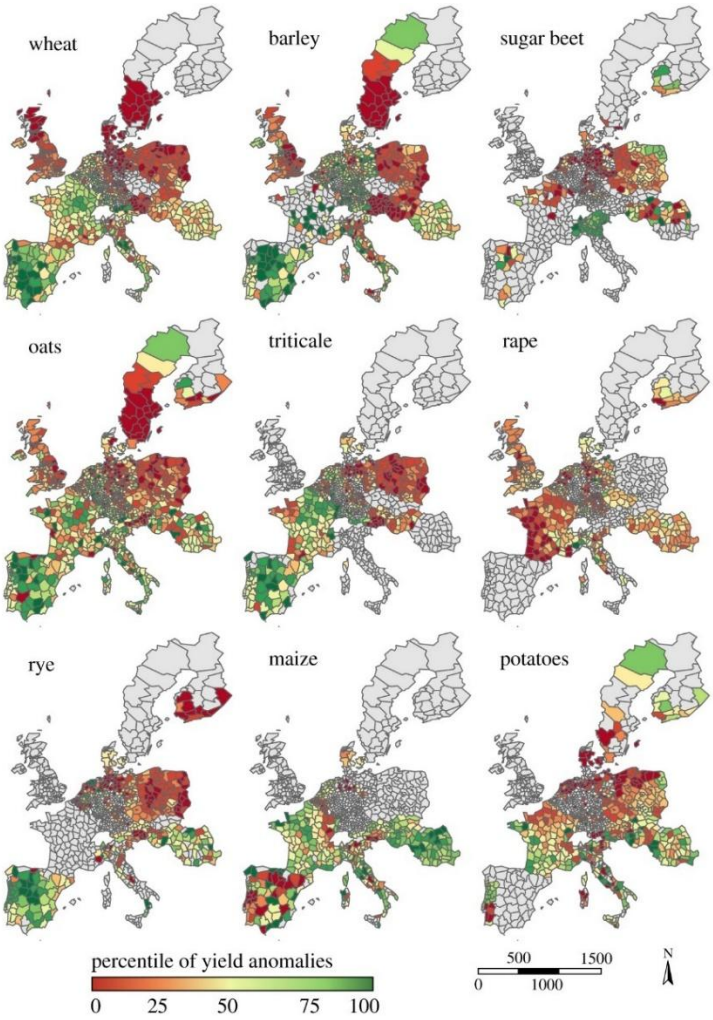

Figure 2: European yield anomalies in 2018 for the nine considered crops

Source: Impact of extreme weather conditions on European crop production in 2018(Beillouin et al., 2020).

Vertical farming, as a sustainable form of agriculture, can help address climate change by reducing GHG emissions. By producing food in urban areas, vertical farming can reduce transportation-related emissions and energy consumption (Godfray et al., 2010). Additionally, vertical farming can use renewable energy sources, such as solar and wind power, to further

reduce GHG emissions.

2.4 Food Security

Food security refers to the state in which all people have access to safe, nutritious, and sufficient food to meet their dietary needs for an active and healthy life. Economic and management aspects of vertical farming have the potential to contribute to food security by providing a sustainable and efficient way of producing food in urban areas, where land is scarce, and demand for fresh produce is high.

Outdoor farming and most greenhouses perform procedures on harvested plants that include pre-washing, salt-water washing, and finally disinfecting the greens with choline solution, which unfortunately reduces the quality of the greens (Avgoustaki & Xydis, 2020). Indoor vertical farming uses only nutrients in the irrigation system, completely avoids the use of any chemicals during the growing period, excludes pesticides, herbicides and chemical spraying fertilization, and in addition to the zero dependence of crops in vertical farming on weather conditions, seasonality and possible insect, pest and bacterial infections (Despommier, 2011). According to a study by (Despommier, 2010), vertical farming can produce up to 100 times more crops per square foot than traditional farming methods, which can help to increase food production and reduce food insecurity. Based on computer simulation, supported by public data, survey data and experimental verification, Shao et al. investigated the impact of UFVF on the self-sufficiency rate of farmers and the city's vegetables and fruits. The results show that UFVF helps to increase the self-sufficiency rate of vegetables and fruits by 20.68% and 2.54%, respectively, and the return on investment UFVF can reach about 30% (Shao et al., 2022). systems (VFS) with conventional horizontal hydroponic systems (HHS) and showed that indoor controlled environment crop productivity (defined as the ratio of yield to occupied area) was 13.8 times higher in VFS than in HHS (Touliatos et al., 2016)

2.5 The Vertical Farming Concept

For several years, there has been a need for novel agricultural techniques and improvements.

This is evident by the problems the agricultural industry keeps facing. One of the main problems is the scarcityof useable land for crop production, together with the estimated world population of 9.3 billion people in 2050, climate change, water shortage, and other factors (Kozai, 2015) . One of the innovators of this concept is Dickson Despommier, an American professor who came up with the term vertical agriculture (D. Despommier, 2010). The core idea of vertical farming is to grow crops in vertically stacked layers, we can see from **(Figure 3)**, using artificial lighting and controlled environments, while integrating them into buildings located in the heart of the world's cities.

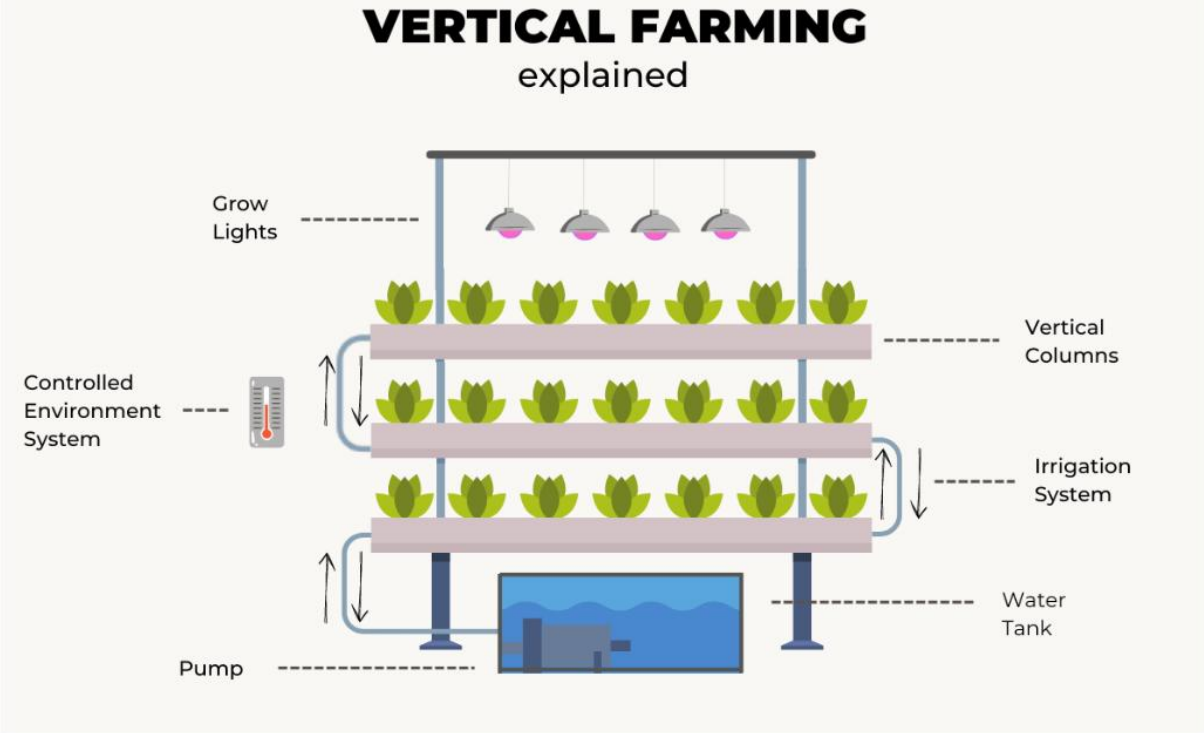

Figure 3: Vertical farming explanined

Source: (*Everything You Need to Know About Vertical Farming*)

2.5.1 Vertical Farming-Related Technologies

Controlled environment agriculture is fundamentally at the heart of vertical farming, as it integrates multiple technologies in order to provide the optimal environment and growing conditions for the plant during its growth period. By using controlled environment systems, vertical farming can grow fresh, pest-free crops year-round. In vertical farms, plants are isolated from the outside environment and workers take precautions against pest infestations

that can damage crops.

Controlled environments system

Vertical farms use smart sensors to monitor technical variables including temperature, carbon dioxide, oxygen, lighting, humidity, nutrient concentration, pH, pest control, irrigation and harvesting. Usually, controlled environments involve hydroponics, aeroponics, or aquatic culture. In addition, controlled environment agriculture can take advantage of advanced imaging and sensor technology, including cameras and thermal imaging to measure plant growth, temperature and other factors (Wong et al., 2020). Currently, controlled environment systems have proven to be very effective in growing leafy greens, herbs, micro vegetables, and vegetables such as tomatoes, peppers, melons, and sweet corn.

LED lighting

One of the most important technologies used in vertical farming is LED lighting. LED lights are energy-efficient and can be tuned to specific wavelengths of light, providing the optimal light spectrum for plant growth. According to a study by (Massa et al., 2008), LED lighting can significantly improve crop yields in vertical farming systems. When coupled with regulation of temperature and humidity, the effects of seasonality on production can be minimized or even be eliminated (Shao et al., 2022).

Artificial intelligence（AI）

Artificial intelligence (AI) is also being used in vertical farming to improve crop yields and reduce resource use. AI can be used to optimize growing conditions, predict crop yields, and detect diseases or nutrient deficiencies in plants. According to a study by (Siregar et al., 2022) , AI can significantly improve the efficiency and profitability of vertical farming systems.

Filtering systems

For plants to grow properly, a vertical farm must have constant airflow. The airflow in vertical systems movies the air through the filtering systems, reduces humidity, removes heat, and circulates CO^2. The build-up of heat and humidity in the growing area makes it a perfect

breeding ground for bacteria, fungi, and mold, thus increasing the risk of infection. According to (ZipGrow Inc, n.d.) , the layout of an indoor farm also plays a crucial role in the air movement within the facility. Vertical farming systems, for instance, use vertical planes that allow the air to move easier than in horizontal layouts.

The Internet of Things

The Internet of Things has been used in the agricultural sector to increase yields, monitor crops at all times and improve agricultural efficiency. The Internet of Things enables vertical agriculture to control the growing environment in which crops are planted, as the smart sensors used measure every detail from humidity to pH and transmit them in real time to the grower (online, n.d.).

2.5.2 Vertical Farming Systems

2.5.2.1 Hydroponics

Hydroponics is a soilless method of growing plants in which nutrient-rich water is circulated through the roots of the plants. This method of growing has gained popularity in vertical farming because it enables crops to be grown in a compact space and with reduced water usage. Hydroponic systems in vertical farming provide precise control over nutrient delivery to plants and enable high crop yields with minimal use of resources.

One of the most common types of hydroponic systems used in vertical farming is the nutrient film technique (NFT) **(Figure 4)**. In this system, a thin film of nutrient-rich water is continuously circulated over the roots of the plants, which are held in a channel. The plants absorb the nutrients they need from the water, and excess water is collected and recirculated through the system. According to (Vidhya & Valarmathi, 2018), NFT is a popular method in vertical farming because it requires minimal water usage and can produce high yields of leafy greens.

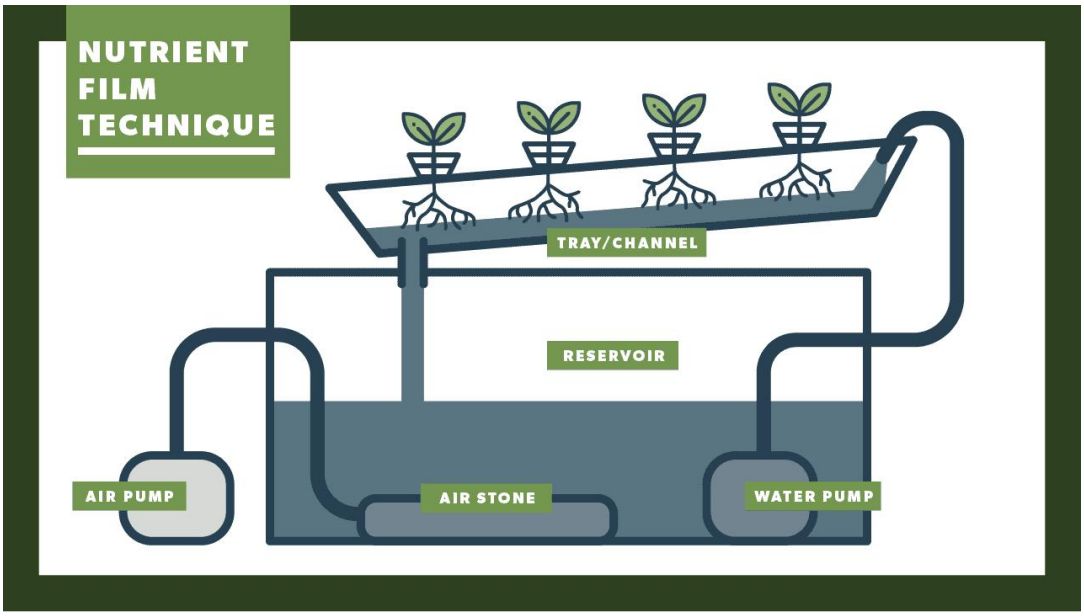

Figure 4: How Nutrient Film Technique (NFT) Hydroponic Systems Work

Source: (*Nutrient Film Technique NFT*)

Another type of hydroponic system used in vertical farming is the deep water culture (DWC) system **(Figure 5)**. In this system, the plants are suspended above a nutrient-rich water solution that is aerated to provide oxygen to the roots. The plants absorb the nutrients they need from the water and grow rapidly in the nutrient-rich environment. According to (Resh, 2018), DWC is a popular method for growing herbs and vegetables in vertical farms because it is easy to set up and maintain, and requires minimal use of resources

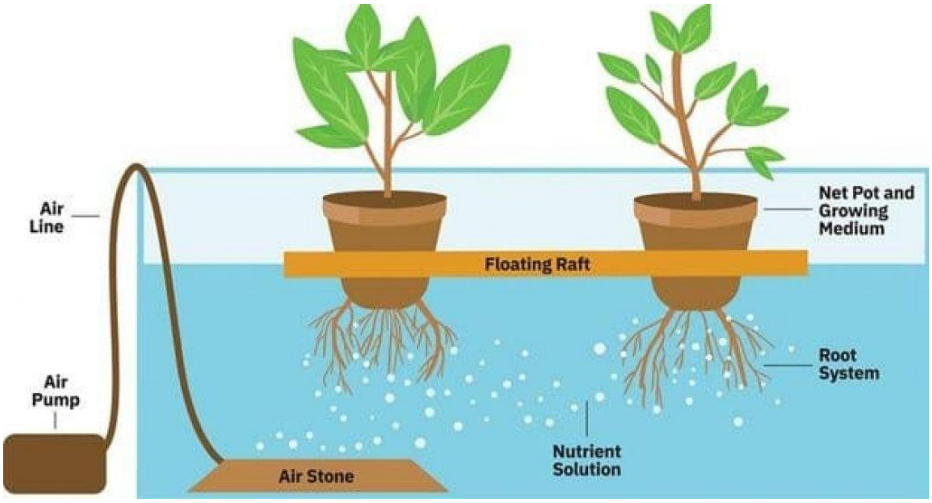

Figure 5: Deep water culture (dwc) hydroponic system

Source: (*The Ultimate Guide On Deep Water Culture Systems*)

One of the advantages of using hydroponics in vertical farming is that it allows for precise control over the growing environment, including the nutrients, pH levels, and temperature. This can result in faster growth rates, higher yields, and better quality produce. Additionally, hydroponic systems can be designed to recirculate water and nutrients, reducing water usage and waste. According to (Shrivastava et al., 2021) vertical hydroponic system is used to reduce water use by up to 70% as a sustainable energy source compared to traditional farming methods and will be used to minimize land without soil for crop production.

2.5.2.2 Aeroponics

Aeroponics is a new type of cultivation method. It is mainly to hang the crops in a closed cultivation device (trough or box) and the root system is exposed inside the cultivation device, and the nutrient solution is atomized into small droplets by a spray device **(Figure 6)**, which is directly sprayed on the root system of the plant to provide plant protection. A soilless cultivation technique for the water and nutrients required for growth.

Figure 6: An Aeroponic System

Source: (*Aeroponics - Understanding Hydroponics Systems*)

This technology doubles the crop yield. It is an agricultural high-tech that does not use soil or substrate to cultivate plants. Because it replaces the soil environment with artificially created crop root environment, it can effectively solve the problem of water that is difficult to solve in traditional soil cultivation. The contradiction between air, nutrient supply, and the root system of the crops are in the most suitable environmental conditions, so that the growth potential of the crops can be brought into play, and the growth and biomass of the plants can be greatly improved (Wong et al., 2020).

In addition to accelerating the growth rate of plants, aerosol cultivation accelerates the growth and development of fruits and vegetables cultivated in agricultural production (Barbosa et al., 2015) , in the vertical farming technology, aerosol cultivation is the most water-saving and fertilizer-saving cultivation technology, which can reduce or avoid the use of chemical pesticides, which is unmatched by any other technology, as long as there is electricity and water. Aerosol cultivation can be carried out in the place where there is light, so as to achieve the maximum implementation of three-dimensional planting, and there is no dirt caused by soil or other pollution, and it can completely achieve factory-style clean production.

2.5.2.3 Aquaponics

Aquaponics is a new type of compound farming system. The aquaponics system is similar to the hydroponic system **(Figure 7),** but more optimized (Yanes et al., 2020). It combines two completely different farming technologies, aquaculture and hydroponics, through ingenious ecological design, to achieve scientific synergy and symbiosis, so as to achieve fish farming without changing water without water quality concerns, and vegetable cultivation The ecological symbiosis effect of normal growth without fertilization (Yanes et al., 2020).

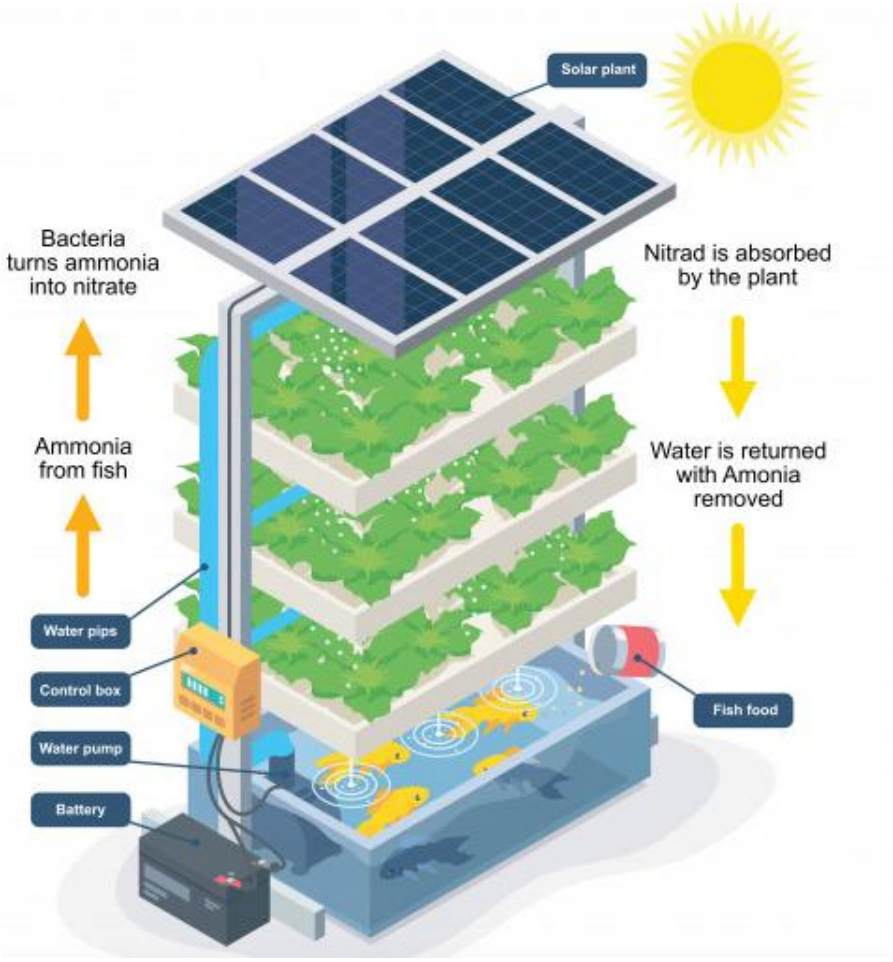

Figure 7: An aquaponics system

Source: (*Aquaponics – How This Is Useful for Off The Grid Living*, n.d.)

In traditional aquaculture, with the accumulation of fish excrement, the ammonia nitrogen in the water body increases, and the toxicity gradually increases. In the fish and vegetable symbiosis system, the aquaculture water is transported to the hydroponic cultivation system, and the ammonia nitrogen in the water is decomposed into nitrite by bacteria and then decomposed into nitrate by nitrifying bacteria. Nitrate can be directly absorbed and utilized by plants as nutrients (Yep & Zheng, 2019).

Aquaponics allows animals, plants, and microorganisms to achieve a harmonious ecological balance relationship. It is a sustainable, circular, zero-emission, low-carbon production model and an effective method to effectively solve the agricultural ecological crisis. The aquaponics system simplifies Production efficiency can be maximized by understanding production and economic issues (Love et al., 2014).

2.6 Opportunities and advantages of Vertical Farming

1. The vigorous development of the economy has accelerated the development of human society and the process of modernization and urbanization. This situation also requires the food production system to feed more and more urban population with a small amount of labor, limited land resources and water resources. Low land use is a major advantage for agriculture to enter the city and be close to urban consumers. It is also a new link and bridge linking cities and agriculture, providing solutions to the problem of "no land to grow" in cities train of thought.

2. It can produce uninterrupted throughout the year, and can arrange the production plan as one likes throughout the year. All products are "seasonal" crops, and the unit yield is high. Vertical farming technology can reasonably achieve shorter growing cycles and faster harvests, which means that more food can be grown each year in a much smaller space than traditional farms. While vertical farming can reduce water use by 95%, it can reduce the need for chemical pesticides by being tightly controlled, weatherproof, and resistant to infection. Shorten the supply chain, which means that the crops produced in the city are sold directly, reducing a lot of transportation distance and time, which can not only ensure the freshness of food, but also reduce supply chain waste.

3. A vertical farm will integrate crop production, livestock raising, office and leisure. This new agricultural production model will become a part of urban culture, providing urban residents with a lot of leisure space and solving their leisure needs. In addition, vertical farms can provide a large number of employment opportunities for urban residents. Vertical farms are a self-sufficient ecosystem that includes not only agriculture, but also a series of projects such as electricity, machinery, and construction. Its construction requires a large number of high-tech talents with professional skills such as architects, engineers, urban planning designers, and agricultural machinery technical experts.

4. The vertical farm is an independent green ecological cycle system. In the farm, renewable energy such as solar energy and wind energy can be fully utilized, and some unusable crops can be made into fuel through environmental protection technology to provide some

renewable clean energy for the city energy. In addition, vertical farming can reduce the carbon dioxide content in the atmosphere, which has a positive effect on solving the problem of global warming.

5. The concept of consumers has changed, and more people have begun to pay attention to food safety and food quality, and pursue pollution-free, green and organic agricultural products. The demand for green agricultural products of middle and high-end consumer groups continues to increase, and at the same time, they also pay more attention to product quality, health, nutrition and other aspects. Consumer demand for green food will lay a good market foundation for the rapid development of vertical farms, and will also force more traditional farms to transform into vertical farms, bringing new growth to related companies.

6. At present, LED lighting, precision planting technology, cloud computing, etc. have been applied to the development of vertical farms, and artificial control is used to deal with the adverse effects of the natural environment, to achieve end-to-end refined operations, to reduce external environmental impacts and impact on Reliance on pesticides, improving the utilization rate of land, fertilizer and water. In order to further improve the efficiency of data planting and break through environmental constraints, related technologies represented by LED lighting technology will achieve continuous innovation, big data will focus on optimizing planting plans, and artificial intelligence will monitor plant growth cycles, adjust light, Temperature, water flow and other links play an important role.

7. In addition, vertical farms can completely get rid of the harsh environment and greatly reduce economic losses caused by natural disasters such as droughts and floods. The crops grown in vertical farms can avoid natural disasters to a high degree, get rid of the shackles of soil, geography and climate in the production process, and effectively improve the quality of agricultural products. Fresh food that is not easily accessible to the public can also be solved through vertical farms, and it can even be directly established in the kitchen or in your own backyard. This is also an important message conveyed by the development of vertical farms.

2.7 Challenges and disadvantages of Vertical Farming

1. Energy consumption. The biggest disadvantage of vertical farming is that it needs to use a lot of LED lights, so the electricity bill is a big expense. Among them, in order to ensure a mild and consistent environment and climate, the sunlight that must be used during plant growth is replaced by hundreds of thousands of LED fill lights, which means that from a commercial point of view, vertical farming is only suitable for planting Those high-value, perishable produce like raw leafy vegetables and herbs. Of course, this is a market that cannot be ignored. But for a wider range of produce, vertical farming may prove cost-prohibitive.

2. Product price. The high cost makes the price of vertical farming food one to several times higher than that of traditional agricultural products. Taking lettuce as an example, the price of lettuce produced by vertical farms is as high as 30~40 yuan/catties, which is 3 yuan/catties compared to ordinary lettuce. The price is indeed "daunting", and ordinary people are not willing to consume. At present, there is still a long way to go to attract consumers' attention by offering competitive prices. In addition, in terms of fruits and vegetables, there are still many deficiencies in the research, breeding and application of natural enemies and pollinating insects, resulting in great differences in the yield, fruit shape and taste of grass fruit planting and planning.

3. Technical reserves. Although the trend of vertical farming has risen, its difficult production operation and high equipment costs require corresponding technical reserves in advance, requiring practitioners to carry out refined operation and debugging, and put forward a severe test of extremely high professional technical support for practitioners, but The lack of technical personnel and management personnel makes the development of vertical farming seem to be more than enough. As a disruptive technology, avoiding the "technical gap" caused by technology cost is also a major issue worth thinking about at present.

4. Software and hardware problems. At present, the shortcomings of vertical farming technology in terms of software and hardware are mainly manifested in the single detection of intelligent control equipment sensing system, incomplete decision-making system, and the lack of nutrient liquid ion sensors required. Really solve common problems and key problems.

In terms of software, the plant production data package of vertical farming (substrate ratio, temperature, humidity, light, water and fertilizer, CO^2, ventilation, etc.) is not perfect and cannot be standardized, and off-site replication may become empty talk.

5. Each vertical farming company has its own patented technical standards, and the equipment standards are not uniform and not universal. Such as planting racks, planting trays, lamps, such as grafting, wound healing, transplanting and other proprietary equipment, each vertical farming company has considerable differences. The industrial chain is incomplete and partially closed, which seriously hinders the proliferation of the vertical farming market. And investor confidence, it will take a long period of promotion and market competition to form a convergent standard.

6. In the process of system startup and later maintenance, the financial support needed by vertical farms is also a huge account. As an emerging form of agriculture, the economic and social benefits brought by vertical farms have not yet been clarified. How much superiority vertical farms have over traditional farms is still a question mark. Offices in skyscrapers may be more beneficial than building farms, at least for now.

2.8 The Economic Viability of Vertical Farming

One of the biggest challenges in vertical farming is the high cost of energy, technical equipment, construction facilities and labor. To make vertical farming more economically viable, growers must find ways to reduce operating costs (Shao et al., 2022) . One way to achieve this is to optimize the use of resources such as electricity, water, energy and nutrients. For example, growers can invest in energy-efficient lighting and HVAC systems, install rainwater harvesting systems, and use hydroponic systems that recycle water and nutrients. Additionally, growers can reduce labor costs by investing in automation technologies such as robots, sensors and machine learning algorithms that optimize plant growth and reduce waste.

Another way to make vertical farming more economically viable is to diversify the types of crops grown. While leafy greens such as lettuce and herbs are a popular choice for vertical farming, there is growing demand for other crops such as strawberries, tomatoes and

cucumbers. By diversifying their product offerings, growers can reach new markets and generate more income. Furthermore, by using data analytics and market research, growers can identify emerging trends and adjust their production accordingly.

Finally, governments can play an important role in making vertical farming more economically viable. By offering tax breaks, grants and subsidies, governments can encourage growers to invest in vertical farming technology and infrastructure. In addition, governments can help reduce operating costs by providing affordable energy and water, as well as favorable zoning laws and building codes that encourage the development of vertical farms.

While vertical farming faces many challenges when it comes to financial viability, growers and governments can use a variety of strategies to make this farming method more sustainable and profitable. By optimizing resource utilization, diversifying product offerings, and providing financial incentives, vertical farming can become a more attractive and competitive option to meet the growing demand for fresh produce in urban areas.

2.9 Vertical Farming in Practice

Aero Farms USA. In 2016, ground was broken on Aero Farms in Newark, New Jersey, USA. The vertical farm covers an area of about 6400m^2, can produce 22 kinds of crops every year, and can produce up to 910,000 kg of vegetables. It is currently the largest vertical farm in the world. The farm utilizes the latest technologies such as LED lighting, aeroponics and environmental control, a scientific farming system that allows plants to grow and develop without soil, sunlight and pesticides. Aero Farms farm distance from New York. It's only about 15 miles away, and already has partnerships with several supermarket chains, including Whole Foods, an organic supermarket in nearby New York.

Crop One Farm, Dubai. In June 2018, Emirates Airline Catering Company (EKFC) and Crop One, a vertical farm start-up company in the United States, signed a joint investment agreement of US$40 million. The agreement stated that the two parties will establish a global vertical farm in Dubai in November 2018. This vertical farm is expected to cover an area of 12,000m^2, and can produce up to 2,700kg of green organic pollution-free vegetables per day,

and the vertical farm's water demand is 1% of that of outdoor cultivation. The farm is just 30 miles from downtown Boston, and Crop One claims that vegetables can be harvested and shipped to consumers within 24 hours. This farm is also expected to replace the Aero Farms farm in New Jersey, USA, as the world's largest vertical farm, the **(Figure 8)** shows the integrated architecture of Crop One Farm and **(Figure 9)** shows the Rootics™ uesd to check the data of the farming.

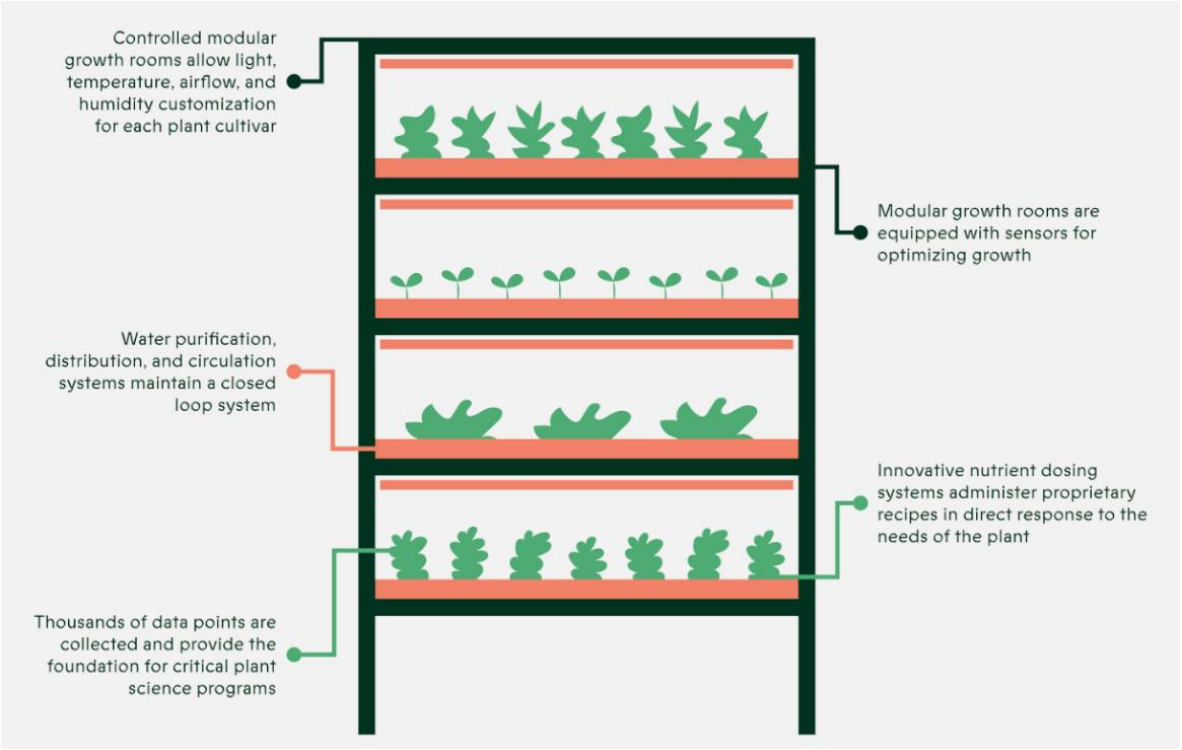

Figure 8: Integrated architecture of Crop One Farm

Source : (*Crop One*)

Figure 9: Rootics™

Rootics™ is an integrated hardware and software architecture designed to optimize crop health, quality, and yield in vertical farms. The system utilizes data analytics collected over years of operation to control, evaluate, and monitor the environment in Crop One's vertical farms. With a secure and efficient design, Rootics™ connects business systems and automation equipment to streamline workflow, ensure optimum plant growth, and promote operational efficiency.

Source (*Crop One*)

Singapore Sky Greens. Singapore has created a 6m high A-shaped tower with an 'A-Go-Gro' vertical planting system **(Figure 10)**. The tower covering an area of 6 m^2 includes 26 floors of planting tanks. Different types of vegetables will be planted in trays on each floor. Each floor rotates at a speed of 1mm per second. The stepped arrangement ensures that all plants can receive sufficient of light. The hydrogravity system automatically collects rainwater, which is then filtered to the irrigation system after powering the rotating system. If the energy consumption is compared, the energy consumption of the "A-Go-Gro" vertical planting system is only equivalent to a 60-watt light bulb, which realizes low-carbon and environmental protection. In addition, tourists can also participate in crop picking and

experience the fun of harvesting.

Figure 10:'A-Go-Gro' vertical planting system in Sky Greens

Source : (*Sky Greens*)

Vertical farm in Scunthorpe, UK. In November 2018, the UK's first vertical farm appeared in an industrial area in Scunthorpe, UK. Built by a food company, this vertical farm has a total planting area of about 220m^2, and is expected to produce 500 tons of plants per year, including vegetables such as leeks, coriander and basil, meeting the living needs of urban residents. At the same time, the farm adopts the hydroponic farming mode, and all the nutrients needed by the plants are provided by the aqueous solution. In addition, the farm regularly discharges the water solution to provide sufficient oxygen to the plants, and the

entire process is automated.

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter of the study describes the research methodology used - qualitative analysis. In the previous section, we have examined the available insights and literature on the relative economic benefits and management of vertical farming, and the information obtained will then be used to build this empirical study. Next, the researcher will introduce the research methods, research design, research objects, data collection methods, and data analysis methods. In the final section of the chapter, researcher discussed research validity, reliability, and ethics to ensure research quality.

3.2 Research Approach

3.2.1 Semi-structured interviews

Interviews are often used in qualitative research to collect raw data about people. Because the VF industry is relatively new and complex, the use of in-depth interviews is more applicable to these types of situations and the need for in-depth information. Semi-structured interviews are characterized by predetermined questions that are not always phrased in the same way. Each interview will be different depending on the process of the interview, the experience and knowledge of the interviewee. The problem is that sometimes they are asked in a different order and wording. However, all framework variables are discussed and questioned. Semi-structured interviews have the flexibility of unstructured interviews, but still have an outline to keep the interview between the lines (Kumar, 2018).

3.2.2 Open-ended questions

Open-ended questions are those in which the interviewer does not provide an answer option. Instead, they encouraged respondents to answer in their own words (Kumar, 2014). It is recommended that these types of questions be used for exploratory research, especially when

a suitable set of answers is not known. Open-ended questions often produce a wider range of answers. However, this requires more time and effort to answer, and the depth level of respondents varies (Kumar, R. (2014).

3.3 Research Design

Research design is the basis of this study. It sets out the methods by which research is used to analyze and investigate research questions. Research design is an important part of one of the studies, which requires scientific research and literature development on the basis of previous studies in order to achieve research goals and objectives, **(Figure 11)** shows the process of the research.

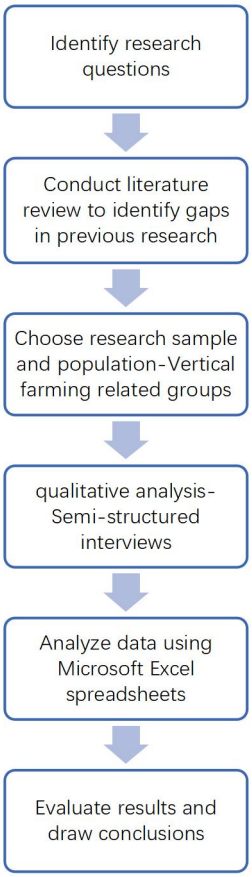

Figure 11: Research Design
Source: Author's own research

3.4 Target Population

3.4.1 Sampling

Non-probability sampling is a commonly used method for forming research teams in qualitative research (Kumar, 2018), Expert sampling is best suited for this study. The experts in this study are VF growers, VF industry players, VF industry researchers.

The researchers searched for key words through the Google engine: "vertical farming in USA", "vertical farming in EU", "vertical farming in Asia", most of the search results are vertical farming consulting companies, vertical farming research related persons, Existing commercial vertical farming, Suppliers and manufacturers of vertical farming equipment, etc. Most websites provide relevant contact channels, such as email, telephone, LinkedIn, and facebook, through which researchers randomly send emails or messages to these target groups to reach them.

3.4.2 Participants

In this study, the researchers initially contacted 30 vertical farming stakeholders, but only 18 vertical farming stakeholders were able to participate in the interview, including 6 participates from the USA, 7 participates from the EU and 5 participates from Asia **(Table 2)**. These agricultural stakeholders include employees working in vertical farming, managers of vertical farming companies, and vertical farming researchers who have deep insights into vertical farming **(Table 3)**. There are more men than women interviewed.

Table 2: Demographic Information: location

location	Contact	respondent
USA	10	6
EU	10	7
Asia	10	5

Source: Author's own research, 2023 n= 18

Table 3: Demographic Information: function and gender

ID	Function	Gender
USA-P1	Researcher	Female
USA-P2	Top manager	Male
USA-P3	Employee	Female
USA-P4	Researcher	Male
USA-P5	Top manager	Male
USA-P6	Researcher	Female
EU-P1	Top manager	Male
EU-P2	Employee	Male
EU-P3	Researcher	Female
EU-P4	Researcher	Male
EU-P5	Researcher	Female
EU-P6	Top manager	Male
EU-P7	Top manager	Male
Asia-P1	Researcher	Female
Asia-P2	Researcher	Male
Asia-P3	Researcher	Male
Asia-P4	Top manager	Male
Asia-P5	Researcher	Male

Source: Author's own research, 2023 n= 18

3.5 Data collection method

This section Outlines how interview data is collected. After the first contact with the participants, a date was arranged for the interview. Most interviews were conducted by phone, occasionally via Skype or Zoom. During the interview, the researcher presented the interview guide to question the interviewee. The interview was recorded and notes were taken during the interview. Transcribes are made after the call using notes and notes. Later, transcripts were sent to participants for permission and confirmation of the answers they gave.

3.6 Data analysis

Data analysis is the process of interpreting collected data to gain meaningful insights. Researchers must take appropriate steps to ensure that the information collected is valid and supports the research question and research objectives. The researcher collated the raw data obtained from the responses before conducting any further analysis. The researcher

categorized and grouped the collected information based on the respondents' responses before conducting additional analyses. Raw data collected through interviews are condensed and presented in a graphical format to provide clear and precise summaries and conclusions.

The researchers chose graphical representation methods because they provide a more vivid view of data representation, providing a valuable basis for future research. Primary and secondary data are systematically evaluated, categorized, structured, categorized, and entered into a computer for further analysis using Microsoft Excel spreadsheets. For a comprehensive analysis, the researchers assessed the relationships and interdependencies between the collected data and the research questions and research objectives.

3.7 Validity and Reliability

Validity and reliability are two important indexes to measure the quality of research results. Validity refers to the extent to which the results accurately reflect the purpose of the study, while reliability refers to the consistency and stability of the results at different times and under different conditions (R.Gibbs, 2007) . In this study, interview results were confidentially managed and analyzed through a rigorous interview-results transcription process. During the interview, the permission of the 18 interviewees was first obtained, and the interview process was voice-recorded, and relevant important information was continuously recorded. After the interview, the recorded voice will be compared and analyzed. If important findings are found during the analysis, the research memo will be continuously recorded and repeated confirmation with the interviewee to ensure the validity and reliability of the information.

3.8 Ethical Consideration

The study adhered to ethical guidelines for research involving human subjects, including obtaining informed consent from all participants, maintaining confidentiality of all data collected, and protecting the privacy and autonomy of participants. The integrity and quality of the information obtained was maintained throughout the study process.

4 RESULT AND DISCUSSIONS

4.1 Introduction

This part analyzes and summarizes the ideas and opinions of 18 interviewees. The interviewees come from different regions **(Figure 12)**. Through their practice and cognition of vertical farming, more comprehensive information about vertical farming can be obtained.

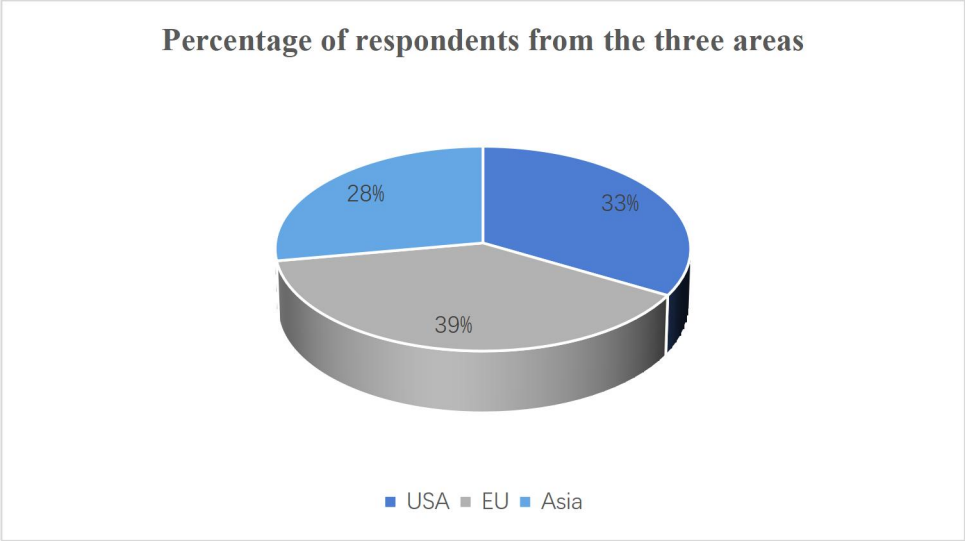

Figure 12: Percentage of respondents from the three sectors

Source: Author's own research, 2023 n= 18

4.2 Economic Aspects of Vertical Farming

4.2.1 How does the cost input of vertical farms differ from traditional farms?

- Most of the interviewed participants (10 out of 18) mentioned that the start-up cost of vertical farms is higher than that of traditional farms, and the energy cost of vertical farms is much higher than that of traditional industries **(Table 4)**. Because the light and most of the heat needed for plant growth basically come from the sun, and the vertical farms are in the greenhouse, the sources of light and heat are LED lights or other electrical support, which brings huge power consumption costs.

"I have studied this kind of facility before, and later found that the cost of electricity and labor is still huge, and it has little advantage over traditional agriculture."

"It is only after the cost of LEDs is extremely low and the cost of electricity is extremely low that there is potential for development."

"From the perspective of the Japanese market, 20%-25% of the production cost of vegetables per US dollar is electricity costs, including lighting, air conditioning, ventilation, water pumps and other costs."

Table 4: Cost input of vertical farms differ from traditional farms

Cost	Occurrence
Energy cost	10
Initial construction cost	7
Technology cost	7

Source: Author's own research

- A number of participants (7 out of 18) mentioned The initial construction cost of vertical farms is very high, which mainly includes land costs, because most vertical farms will be built in big cities. When building a vertical farm, building materials such as glass, steel, and concrete are required, and operators also need to invest a lot of upfront costs.

"Many vertical farms in China are built in the city center or in prosperous areas. The rent and land costs here are higher than those of agriculture."

"It looks beautiful, but when it is actually implemented, you will find that the construction cost and the labor cost of operation are very high."

"Not including labor, an investment of about $4 million is required to set up a vertical farm of about 2,800 square meters in a city like New York."

"The cost of vertical farming is as high as 5,000 to 10,000 yuan per square meter. A high-quality vertical farm may cost billions of dollars. This is obviously far more than traditional agriculture."

- There are also those who mentioned (7 out of 18) that technology is costly because

vertical farming relies heavily on technology (controlling temperature, light, humidity and other parameters) Precise control of production links such as light, temperature, water and nutrient delivery. If you want to use data to build a standardized growth environment that breaks through geographical restrictions, you must use a variety of software and hardware devices. Such as temperature control involves a variety of systems, including fans, heaters, air conditioning systems, etc. These devices and related technical personnel are huge expenses in the operation of vertical farms. In addition, these devices must also be maintained through daily maintenance to ensure their normal operation and data maintenance, which is also an expense.

"Vertical farms rely heavily on technology, which can be expensive, especially with constant lighting and environmental controls to run."

"The cost of energy consumption is a small matter, and the production capacity can be fully covered. The most important thing is labor cost and planting cost"

"The daily maintenance cost is also very high. Compared with the two, large-scale commercialization is nowhere in sight."

- Two of the researchers believe that vertical farms have a good future, because with the improvement of the whole system technology and the improvement of the luminous efficiency of LED technology, the cost of labor, land, transportation and environment in traditional agriculture are all low. Gradually climbing, this will make the overall cost of vertical farms close to the state of bridging the cost of traditional agricultural production.

"Have a good idea, and then continue to reduce costs."

"As the technology continues to develop, the efficiency and productivity of vertical farms will continue to increase and costs will gradually decrease."

4.2.2 What are the most profitable crops to grow on a vertical farm?

- A large number of participants (15 out of 18) mentioned that the best choice for vertical farms is to grow green leafy vegetables, because they have a short growth cycle and can be harvested many times a year **(Table 5)**. Compared with plants, the overall plant is short and the planting capacity per unit area is large. In addition, the daily demand for these green leafy vegetables is very large, which is a good profit choice for enterprises.

"Vertical farming can only be used in leafy vegetables, which is very limited."

"At present, only green vegetables can be grown, and the main food production is still not enough."

"Vertical farming is still suitable for fresh plant products with a higher value per unit of planting."

"Most vertical farming companies focus on growing leafy greens (like basil, lettuce, and kale) because they're in high demand and it doesn't take long to grow them."

"Our lettuce and other leafy greens grow quickly and can be harvested 15 times a year."

"Swedish company Plantagon produces a range of leafy greens including salad leaves, spinach and mustard greens."

"Crops produced by vertical farms in Europe are: tomato, bell pepper, hot pepper, lettuce, herbs, leafy vegetables (excluding lettuce), strawberries, etc."

Table 5: The most profitable crops to grow on a vertical farm

crops	Occurrence
Green leafy vegetables	15
Strawberry	8
Staple food	4
Marijuana	2

Breeding	1

Source: Author's own research

- Some participants (8 out of 18) mentioned that strawberry is the first choice of many companies at present. This is because strawberry has well-developed fibrous roots, and the distribution is shallow, the plants are short, and the tolerance to shade is relatively strong. It can be intercropped with other crops. Interplanting can greatly increase the income per unit area, so that double harvests can be obtained, and the economic benefits are also very high. Secondly, the strawberry growth cycle is short, and through protected areas to promote cultivation and plant refrigeration delay and early-maturing cultivation in different places, it can basically achieve annual production and annual supply to the market. Finally, the difference in strawberry varieties is essentially a difference in taste for consumers. , On the demand side, as a high-end fruit, consumers have a higher acceptance of premium prices due to different tastes, safety, and seasons.

"I had looked into Plenty's previous operation, which was mainly growing leafy greens, and started growing strawberry products because of its high bargaining power."

"Planting high-value crops will be a more profitable option at this stage to gain bargaining power."

"Strawberries have more likely profit margins and commercialization prospects."

"Some companies choose to grow strawberries locally in Singapore."

- Four of the participants mentioned that staple food is not an option for vertical farming because staple crops such as rice and wheat take up more space and are more expensive. If commercial value is taken into consideration, the market value of staple food crops is far less than that of commercial crops, vegetables and fruits, etc. It is difficult to be accepted by the market at this stage to produce relatively unsalable staple food at a higher cost.

"The main food cannot be produced, wheat, corn, rice, sweet potatoes and potatoes."

"Not every conventionally grown crop can be successfully grown on a vertical farm. Major crops such as wheat and potatoes are difficult to grow indoors, as are some fruits and

vegetables."

"Vertical farms are not suitable for all current crops, such as corn, wheat, etc."

- A researcher and a manager mentioned that medical raw materials such as marijuana can be grown, and these products have high profits.

"It is also good to plant some high-value edible, medicinal and medical plants that are difficult to survive."

"Seed selection, crop selection (traditional Chinese medicine, industrial hemp) will greatly affect profit margins"

- One of the researchers mentioned that vertical farms can be used to breed staple foods such as potatoes. This is because the breeding cycle of staple foods such as potatoes is short and does not occupy too much growth space. Large-scale breeding is possible, but the entire life cycle is vertical. It is very uneconomical on the farm.

"Although staple food cannot be grown, breeding is a good choice."

4.2.3 If vertical farming is classified into large, medium and small scale, which scale of vertical farming will have higher economic benefits?

- Most participants (12 out of 18) mentioned that the economic benefits of small farms are higher, mainly because the input costs of small farms are lower than those of large farms, and one of the advantages of small farms is convenience. In addition, the equipment of small farms is also easy to manage. If there is a problem in any link, it can be found in time and will not have a big impact on the whole.

"Small vertical farms such as containers have a single production, are easy to manage, and have low labor, equipment, and energy costs, which are more advantageous."

"A vertical farm of a few square meters does not require much labor costs. The main costs are equipment, seeds, and nutrient solutions."

"Currently, there are more than 2,000 vertical farms in the United States, of which more

than 60 percent are owned by small growers."

"To engage in vertical farming, you need to combine planting and breeding. You can start from a small and medium scale and develop in a rolling manner."

"Our farm is not big, only 40m^2, but the profitability is also very good"

- Another group of participants mentioned that large farms (6 out of 18) have higher economic benefits, mainly because large farms are large enough to grow a variety of crops, and the output is large, even if it has a large initial investment, but in a few years Afterwards, its income is more objective. Secondly, large farms often have very mature business models from product planning, to market analysis, to supply chain organization, to production, to packaging marketing, to post-sales, and their target customers are clear. , has obvious market advantages. Finally, large-scale farms can also carry out leisure, catering, entertainment, vacation and other projects, so that the farm is not only a production place, but also a place for consumption and leisure. Chic feel, so larger farms are more economically advantageous.

"Large farms are mainly operated by some big companies, because their initial investment is very high, such as equipment, land, etc., but they can produce a wider variety of crops. They will cooperate with supermarket farms as suppliers and regularly provide them with In total order, I think large vertical farms are more economical in the long run."

"Large vertical farms usually have fixed target customers, which is also their market advantage."

"Our large farm is open for visitors every week"

"The cost of large farms is really high"

- As for the scale of vertical farms, most people have mentioned that there are many vertical farms of different sizes on the market, ranging from small family vertical farms of a few square meters to large vertical farms of hundreds of feet, depending on the company's site selection and goals.

"There are many vertical farms of different sizes, from small vertical farms that may be

only a few square meters to large vertical farms such as inform, which can reach 500 square feet."

"Like some small family farms, they can even be grown at home, requiring only a few square meters."

4.2.4 What factors will affect the site selection of vertical farms?

- Most of the participants mentioned that urban centers (15 out of 18) are the best choice for vertical farms, mainly because big cities are close to customers, have abundant labor force, convenient transportation, and can provide greater added value **(Table 6)**.

"The main purpose of vertical farming is land intensive use. From this perspective, it must be suitable in big cities."

"Vertical farms need relevant technical personnel, and it will be better in cities"

"We choose the city center."

"The metropolitan center area brings us closer to our customers"

- Thirteen participants mentioned (13 out of 18) that transportation is also an important factor affecting vertical farms, because vertical farms aim to provide fresh and healthy products, and areas with developed transportation reduce the time consumed by transportation and also reduce transportation costs , making the product more advantageous and more economically beneficial.

"Where the traffic is developed, because we have to take transportation costs into account"

"But the traffic is not developed"

Ten participants mentioned that population density also affects farm site selection, because places with high population density may have higher consumption power and a larger market.

"Our products sell better in areas with high population density"

Table 6: Factors affect the site selection of vertical farms

Factors	Occurrence
Urban centers	15
Transportation	13
Population	10
Land price	7
Environment	5

Source: Author's own research

- A small number of participants (7 out of 18) mentioned that land price is one of the factors affecting the site selection of vertical farming, because land price is one of the main initial cost inputs of vertical farming.

"Many companies in Japan are now researching vertical farms in abandoned factories."

"Land costs are lower outside the peri-urban areas."

Five participants also mentioned that the environment is also one of the site selection factors for vertical farms. This is because the farm will generate a lot of waste water and garbage during operation, which requires a local waste treatment system.

"Based on factors that are also important for the local climate."

"Wastewater and litter from farms also needs to be taken into consideration."

4.3 Management Aspects of Vertical Farming

4.3.1 What are the current management forms of vertical farming?

• Most participants mentioned (12 out of 18) fully mechanized management, and two managers mentioned that they have researched and used fully mechanized on the farm **(Figure 13)**, mainly because fully mechanized can fully protect the farm's sunlight, Temperature, humidity, and air quality data are monitored, self-collected, and self-analyzed through an autonomous system. The efficiency will be higher than that of manual labor, and timely responses to problems arise; on the other hand, the use of intelligent systems such as robots can help optimize the growth of plants The whole process, such as automatic seeding, automatic irrigation and fertilization, automatic picking, etc., not only greatly improves the efficiency, but also greatly reduces labor costs.

"Our vertical farm sunlight, temperature, nutrition and air quality will all be monitored through an autonomous system, just set a program for the robot"

"If an intelligent system is used, the intelligent digital management of the whole process of crop growth can be realized."

"Fully automated irrigation system."

"Data analytics tools and robotic automation are more efficient."

"The investment in automation, and the installation of robots, has helped us consolidate labor costs."

"Strawberry picking robots can make the whole harvesting process more convenient."

"Full automation can greatly reduce costs."

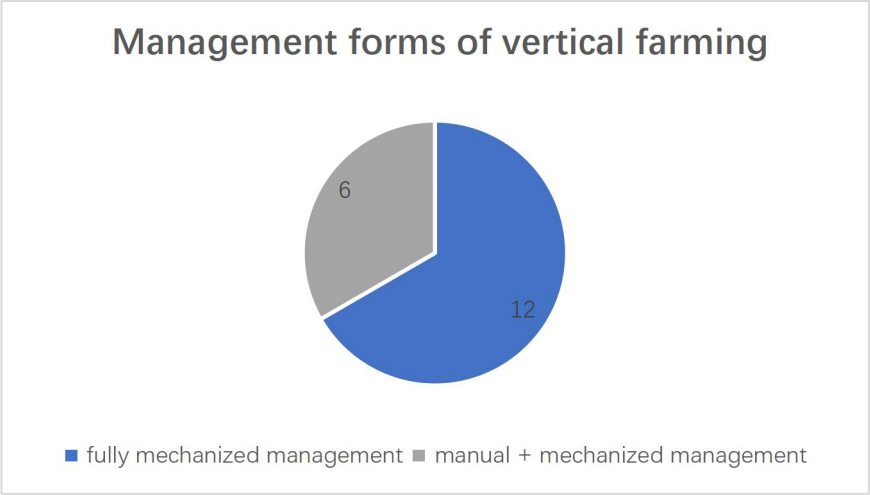

Figure 13: Management forms of vertical farming

Source: Author's own research

• A small number of participants mentioned (6 out of 18) manual + mechanized management, mainly because the cost of automation and intelligence is too high, some companies do not have much funding in the early stage, and the current level of automation is not yet reached The needs of their crop cultivation process, the operation of the machine also requires manual intervention management.

"Our vertical farm employs some employees to control the seeding equipment."

"I'm currently testing the growing environment of plants in a farm, such as temperature, humidity, etc."

"The growing process of crops still requires manual inspection."

"Some links are not yet fully automated."

"Full automation requires a lot of upfront investment, and most farms don't have enough money"

4.3.2 The production process of vertical farming and the production process of traditional agriculture, which one is better to manage?

• Most people (13 out of 18) mentioned that the production process of vertical farms is better managed. Vertical farming can achieve a high degree of mechanization and automation.

It can sow seeds, control the environment, and harvest through mechanical equipment, which is convenient and efficient. On the one hand, vertical farming crops grow in a closed environment, which can limit the entry of outdoor insects, crops are free from pests and diseases, no pesticide residues, no heavy metal pollution, stable yield and quality, avoiding the problem of evaporation of traditional irrigation water, resource recycling The use efficiency is improved, and the annual planning and stability of crops can also be realized.

"Vertical farming can be managed systematically in a closed environment."

"Vertical farming enables a fairly high degree of mechanization and automation"

"Can restrict outdoor insects from entering the production site"

"Vertical farms avoid the evaporation of traditional irrigation water and improve recycling efficiency"

"Crops can be exposed to light for a long time"

"The growth and development of plants in the facility is not or rarely restricted by natural conditions"

"Crops are protected from pests and diseases, no pesticide residues, no heavy metal pollution, stable yield and quality"

"Plant production is not affected by the external climate environment, and can achieve crop annual planning and stability"

"The production process can be managed mechanically"

- A small number of people (5 out of 18) mentioned that traditional agriculture isbetter managed, mainly because traditional farms do not have too many complicated equipment and do not require too many technical personnel compared with vertical farms.

"Vertical farming systems are too complex"

"It involves too many people in related fields, it is not easy to manage"

4.3.3 What kind of management talent does it take to run a vertical farm?

- All participants mentioned the technical managers who need to closely monitor the growth and development of crops using advanced technology such as sensors, machine learning algorithms and remote monitoring systems. Developers and software engineers are responsible for the proper working of technology and systems, so everything is controlled and automated. This requires highly skilled specialists, as wrong timing, wrong amount of water or wrong nutrient mixture can damage the plants and cause losses.

"Smart computer technologists are definitely needed."

"Technical personnel required for data analysis and processing."

"I am now in charge of analyzing data related to crops on the farm"

- Twelve participants mentioned botanists, This is because plant science is the study of plant processes such as photosynthesis, plant nutrition, etc. Plant scientists also help develop new ways to more efficiently produce food without damaging the environment. In greenhouses or vertical farms, they are crucial for providing optimal crop growing conditions for plants used in food production.

"One of the benefits of hiring plant scientists is helping companies save money by finding new ways to use less water, energy and other resources."

"It's a complex job that requires knowledge in many different fields, from business management to plant science"

"Senior Growers Will Get Professional Salaries"

"They can help you find solutions to issues like pest control, climate control and water efficiency"

- Ten participants mentioned plantation technical managers because plantation technicians play an important role in the growth process of crops, including sowing, germination, planting, transplanting seedlings, farm cleaning and maintenance, and harvesting crops. In addition, planting technicians can also beautify the farm to attract consumers to visit.

"Sowing seeds, germinating, planting, transplanting seedlings, farm cleaning and maintenance, harvesting crops"

"Vertical farms require planning and scheduling of crops"

"Farmers are an essential part of vertical farms"

"Planting Technician"

"Includes preparing planting containers, planting seeds, cleaning farm facilities"

"We choose more professional senior growers to oversee all tasks"

"Employees with horticultural background and technical expertise"

- Seven participants mentioned marketing managers because, as a for-profit organization, they have marketing, corporate management or sales personnel who can sell high-quality products to local consumers in a timely manner.

"The salesperson can sell the product to a fine dining restaurant or a local artisanal grocer."

"Our farm is looking for sales jobs from a steady stream of quality product buyers"

"Packaging the final product"

4.3.4 How to effectively manage vertical farms?

- All the participants mentioned that the management of people is the most important part of effectively managing a vertical farming, because the whole process of vertical farming is still indispensable to the participation of people, and people are also the main body of operating artificial machines. If there is a problem with one main body, the rest of the links will also have problems. In addition, in the process of vertical farm operation, it is necessary to hire relevant professionals to guide and train the workers to make the workers' operability more standardized.

to be effective

"You need to train workers regularly and have relevant training courses."

"Although we grow crops, the management of people is more important."

"At the beginning, we must ask relevant professionals to guide us."

"Including machine equipment management, production process management, and worker management."

- Another participant (17 out of 18) mentioned that the management of technical equipment is also the focus of the entire vertical farm operation. Technical equipment mainly monitors data on crops and crop environments, which can manage crops more efficiently and give timely feedback. Through these data, farm personnel will take corresponding measures. These data are the key to the healthy growth of crops, so the equipment should be monitored and managed regularly.

"Equipment management is very important. If there is a problem with one point, then your crop growth will be affected."

"If you use manual equipment to monitor crops, you need to monitor the equipment regularly."

"You need real-time monitoring and management of closed structures through artificial intelligence equipment, and real-time recording of data."

"Robots and artificial intelligence can manage vertical farms more effectively than humans because they can plant crops more accurately."

- Some participants (7 out of 18) mentioned the production and operation of crops. This is because most vertical farm companies are still profitable companies with clear markets and target customers. They choose crops based on these factors. For crops, the customer will come to the factory to receive the goods at the specified time, so the cultivation process and growth process of the crops must be managed to ensure that the crops can be delivered to the customer on time, so as not to affect the next order, and the crop growth process must be managed , Consumers will favor products that are able to receive high-quality and

high-volume products, which can also increase consumer loyalty and help companies make profits.

"Crop Production Process Planning."

"It's important to know the type of crops you're planting, the best time to plant them, and the timetable for harvesting."

"Operation of the farm."

"You need to find customers to address these harvested crops."

5 KEY FINDINGS AND RECOMMENDATIONS

5.1 Introduction

This chapter includes the main findings of the study, recommendations and suggestions for further research. The researchers also highlight significant limitations of the study and concludes with suggestions for further research areas.

5.2 Key Findings

5.2.1 Economic Aspects of Vertical Farming

1. How does the cost input of vertical farms differ from traditional farms?

The initial investment includes the cost of machinery and equipment, factory and site use costs. Operating expenses include electricity costs, labor costs, consumable costs, operation and maintenance costs, etc. The two main costs of vertical farming today are energy and labor. The cost of energy is the biggest source of cost pressure for vertical farming. If cheap and stable power can be obtained, the cost problem of vertical farming will be alleviated. In addition, the maturity of production process standards and large-scale production technology (production automation) for specific plant varieties can also bring about a reduction in unit costs.

2. What are the most profitable crops to grow on a vertical farm?

Compared with traditional field agriculture, the types of vertical farming crops are relatively limited. Under the current model, in most cases, it is only suitable for planting dwarf, short-period leafy vegetables, medicinal plants and other high value-added economic crops. Value vegetables etc. There are also some vertical agricultural enterprises actively making breakthroughs in crop categories, from leafy vegetables to berries (such as strawberries, etc.) and more categories. However, staple crops such as rice, wheat, millet, and soybeans are difficult to grow in large quantities in vertical farms.

3. If vertical farming is classified into large, medium and small scale, which scale of vertical farming will have higher economic benefits？

At present, there are many vertical farms of different sizes on the market, ranging from small family vertical farms of a few square meters to large vertical farms of hundreds of feet, depending on the company's site selection and goals.

4. What factors will affect the site selection of vertical farms ？

The choice of vertical farm location needs to be based on a specific analysis of local traffic, population, environment and various other factors. Due to its comprehensiveness, it can be arranged in the central area of the city while considering the distance factor to reduce transportation costs. The connection between vertical farms and urban underground pipelines is an issue that must be considered to realize its function of treating urban sewage.

5.2.2 Management Aspects of Vertical Farming

1. What are the current management forms of vertical farming?

There are manual + mechanized management and full mechanization. The cost of automation and intelligence is too high. Some enterprises do not have much funds in the early stage. In addition, the current level of automation cannot meet the needs of their crop cultivation process, and the operation of machines also requires manual labor. Intervention management. Full mechanization can monitor the sunshine, temperature, humidity and air quality data of the farm through the independent system, self-service collection and self-analysis, the efficiency will be higher than that of manual labor, and timely response to problems that arise, all Automatic seeding, automatic irrigation and fertilization, automatic picking, etc., not only greatly improve efficiency, but also greatly reduce labor costs.

2. The production process of vertical farming and the production process of traditional agriculture, which one is better to manage?

The production process of vertical farms is better managed, and mechanical equipment can be used to sow seeds, control the environment, and harvest, which is convenient and efficient. On the other hand, vertical farming crops are grown in a closed environment, which can limit

the entry of outdoor insects and protect crops from pests and diseases. Infringement, no pesticide residues, no heavy metal pollution, stable yield and quality, avoiding the problem of evaporation of traditional irrigation water, improving resource recycling efficiency, and achieving annual crop planning stability. Compared with vertical farms, traditional farms do not have too many complicated equipment and do not require too many technical personnel. It is better for equipment and manpower management.

3. What kind of management talent does it take to run a vertical farm?

Vertical farming is where computing, bioscience, and business collide. Planting technicians are needed to sow, germinate, plant, transplant, farm clean and maintain, and harvest crops; and technical managers are needed to use advanced technologies such as sensors, machine learning algorithms, and remote monitoring systems , closely monitor the growth and development of crops; need plant scientists to come up with new plant varieties that can grow and thrive in controlled environment greenhouses for you, and find solutions to problems such as pest control, climate control and water efficiency to help companies save money ; It also requires marketing managers to package the final product and find buyers for high-quality products.

4. How to effectively manage vertical farms?

The management of people is the most important part of effectively managing a vertical farming, because the whole process of vertical farming is still indispensable to the participation of people, and people are also the main body of operating artificial machines. If there is a problem with the main body of people, the remaining There will also be problems in the link. In addition, in the process of vertical farm operation, it is necessary to hire relevant professionals to guide and train the workers to make the workers' operability more standardized. Manage the cultivation process and growth process of crops to help enterprises make profits.

5.3 Recommendation

Stakeholders should consider whether they aim to sell crops or provide leisure viewing

services, and choose suitable crops based on cost-effectiveness, such as green vegetables or strawberries. Site selection should factor in the city's geographic location, urban facilities, and access to low-cost urban transportation and sewage systems.

Costs of facilities and labor must also be considered when building vertical farms. Mechanized management can be adopted to improve accuracy in data management, and regular worker training is crucial. People are a key element in vertical farming, making the production process more specialized and standardized.

5.4 Limitations

This paper mainly studies the economic and management aspects of vertical farming, mainly using qualitative analysis, but the economic aspects of vertical farming will be more valuable through quantitative analysis. In addition, the research targets of this paper are vertical farming researchers, who only answer questions through theoretical knowledge or their own views and opinions, but the real vertical farming participants, such as managers and operators, are better at their views after practice. valuable.

5.5 Further Research Suggestions

This paper mainly studies the managers and researchers of vertical farming, and the recognition and perception of consumers in the future are also the main topics of vertical farming research. Secondly, the social value of vertical farming needs to be studied in detail, and the opinions of the government are also the answers that vertical participants urgently need. Financial analysis of vertical farming is also very important, especially in terms of investment and operations. The costs and benefits of different types of vertical farming systems, as well as comparisons to conventional farming, can be studied to determine their economic viability. Finally, how to position, promote and sell products produced by vertical farming, as well as the comparison of pricing and market competitiveness with traditional agricultural products are topics worthy of research. In addition, it should also study how to establish sustainable channels and partnerships to ensure stable sales of products.

6 SUMMARY

Vertical farming has become an agricultural production method that people pay more and more attention to. It solves the contradiction between limited urban space and high demand for agricultural products, and at the same time improves the production efficiency and quality of agricultural products, reduces the dependence on water and land resources, and becomes an important component of the sustainable development of urban agriculture part. However, compared with traditional agriculture, the management and economics of vertical farming are still the focus of research.

Through semi-structured interviews with relevant persons involved in vertical farming activities, this study concludes that vertical farming stakeholders should first determine the goals of farm management when participating in agricultural activities. One is to sell crops, but to provide leisure viewing services. The positioning of target customers is also very important; the second is to choose suitable crops, such as green vegetables or strawberries and other cost-effective fruits; in addition, according to the above factors, the site selection of vertical farms should also consider the geographical location of the city, urban facilities, and low prices in the city. , urban transportation, urban sewage system, etc. When building a vertical farm, the cost of facilities and labor must also be considered. For the management of vertical farms, mechanized management can be adopted, and the management of farm data is more accurate. In addition, workers must undergo regular training. People are a key element of vertical farms, making the production process more specialized and standardized.

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8 ACKNOWLEDGEMENT

Here I would like to thank my advisor Dr. Miklós Daróczi. During the writing of my thesis, from the initial topic selection to the completion of this project, he has been patiently guiding me, Encouraging me, providing me with helpful advice, with his help, I finished my thesis. I would also like to thank all the teachers who imparted my knowledge, which gave me the basis of related majors to do this research. And my school, which provided me with a good environment during my completion of this project.

9 APPENDIX

9.1 Attachment of introduction email

Dear participant,

I’m currently studying at Hungarian University of Agriculture and Life Science and Research in the Hungary, completing my Master of Management and Leadership Course,Presently, I'm conducting my MSc Thesis on Economic and Management Aspects of Vertical Farming.

Vertical farm is a new type of indoor planting method, which has attracted extensive attention from academia, investment circles and industry circles, and is known as the future of food industry and agriculture. I understand that you have a deep research experience in this area. As participant in the VF industry, you contain knowledge and experience that can contribute to the progression of the VF sector by conducting a short interview with me. Your answers can aid in validating the new VF Business Framework so that further research may be pursued, whilst increasing the recognition of the VF Industry.

We can assure you that your answers will be treated in the strictest confidence. The data obtained are for exploratory purposes and are not case-specific. After participation, the data will be processed in the paper. Once completed, an executive summary of the report can be sent to you if desired.

Finally, I want to commend you for being part of an industry dedicated to a better future. I do hope this research will help successfully build a better future for VF now and beyond.

Best ragards,

Qin Pengkun, +36 705878680 qinpengkun3@gmail.com

9.2 List of Questions

Aspects	Questions
Economic Aspects of Vertical Farming	How does the cost input of vertical farms differ from traditional farms?
	What are the most profitable crops to grow on a vertical farm?
	If vertical farming is classified into large, medium and small scale, which scale of vertical farming will have higher economic benefits?
	What factors will affect the site selection of vertical farms?
Management Aspects of Vertical Farming	What are the current management forms of vertical farming?
	The production process of vertical farming and the production process of traditional agriculture, which one is better to manage?
	What kind of management talent does it take to run a vertical farm?
	How to effectively manage vertical farms?

9.3 Schedule for research presented using Gantt chart

Tasks \ Week	1	2	3	4	5	6	7	8	9	10
Establish the purpose and objectives of the study										
Conduct a review of relevant literature										
Design the research methodology										
Organize and present the thesis structure										
Gather data through appropriate means										
Analyse the data collected										
Formulate recommendations and present concluding thoughts										
Review and revise the final draft of the project										

9.4 Declaration

MATE
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Appendix 4 – Declaration

STUDENT DECLARATION

Signed below, Quy Pengkun, student of the Szent István Campus of the Hungarian University of Agriculture and Life Science, at the BSc/MSc Course of management and Leadership declare that the present Thesis is my own work and I have used the cited and quoted literature in accordance with the relevant legal and ethical rules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course and my Thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no*

Date: Gödöllő 2023 month 5 day 8

Quy Pengkun
Student

SUPERVISOR'S DECLARATION

As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn on the importance of using literature data in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no *

Approval of thesis for oral defense on Final Examination: approved not approved *

Date: Gödöllő 2023 month 5 day 8

signature

9.5 List of Figures

9.6 List of Tables