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Finding synergies between vertical farms of the future and traditional farming systems

Written by:

Will Brown NSch

January 2025

A NUFFIELD FARMING SCHOLARSHIPS REPORT

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A NUFFIELD FARMING SCHOLARSHIPS REPORT (UK)

Date of report: January 2025

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	Finding synergies between vertical farms of the future and traditional farming systems
Scholar	Will Brown
Sponsor	The Food Chain Scholarship Central Region Farmers Trust
Objectives of Study Tour	To summarise the points in favour of vertical farming To summarise the points against vertical farming To outline potential opportunities for vertical farms within British agriculture.
Countries Visited	UK, Germany, Holland, Singapore, Japan, United Arab Emirates, Canada
Messages	Limited opportunities for mainstream leaf and fruit crop production in vertical farms in the UK Vertical farming technology can be used to compliment existing glasshouse production practices Opportunities exist for the production of specialist crops inside vertical farms Vertical farms should be used to help reconnect society to food production and be used in education settings Through research and development, vertical farms must be used to aid the development of traditional crop production, particularly in the face of changing growing conditions

EXECUTIVE SUMMARY

Between 2016 and 2022, global annual growth in vertical farming was 25%. In early 2022 forecasters were projecting the market to grow from $5.8 billion, to $30 billion by 2030.

This project set out to assess the potential impact of a growing vertical farming sector on British Agriculture. 3 hypotheses were to be scrutinised:

1) Vertical farming is a viable means of food production

2) Vertical farming will present a diversification opportunity on existing farms

3) Synergies exist between vertical and traditional farming systems that could offer a competitive advantage to existing farm businesses

Simplistically, vertical farming is using technology to replicate the sun, wind and rain, creating an artificial growing environment. As electrical lighting is used, plants can be stacked in layers without shading, hence the term "vertical".

By its nature, vertical farming is energy intensive. Since beginning this project in 2022 the sector has been severely impacted by the global energy crisis. Early adopters exposed their fragility to energy market volatility, and many have ultimately succumbed to pressures. Further, uncertain energy markets have caused external investors to reconsider the risks associated with the emerging sector.

Therefore, much discussion around the impact of vertical farming on traditional farming methods focussed on hypothesis one – is the system a viable means of producing food?

Several countries were visited between 2023-24, where businesses of all shapes and sizes demonstrated their unique interpretations of vertical farming. It was evident that food could be grown extremely efficiently when compared to traditional outdoor systems, often with minimal human input. Most innovators were applying the kaizen approach to growth recipes, continuously tweaking formula and timings until conditions were infinitely optimised. Circularity with waste by way of nutrient cycling and resource use efficiency was also a common theme.

With the technology proven, the question turned to application. Four different applications for vertical farming were identified:

- Production of mainstream salad / herb crops
- Production of specialist crops
- Community engagement / education
- Research and development

Mainstream crop production is considered high risk and therefore unlikely suitable for farm diversification. The large capital requirement, existing competition (from outdoor and indoor growers, domestic and international), and price sensitivity of the fresh produce sector are issues experienced by vertical farmers in all countries visited.

Finding an outlet for specialist crops, that perform better when grown in a controlled environment, would be favourable to growing mainstream crops. Pre-determined distribution and restricted competition reduce the risk.

Farm businesses that are public facing could benefit from small scale, low cost, vertical farming. Multiple businesses visited were marketing the growing experience of the novel food system. Controlling the farm on an iPhone with bright LED lights makes for a very instagramable story.

When considering the synergies between vertical and traditional farming systems, perhaps the most impactful prospect is research and development within vertical farms, to enhance conventional agriculture. Critics argue that research is flawed because growing in a controlled environment does not represent true conditions. However, having total control of variables, speeding up processes, and simulating changing conditions, could bring considerable value to agricultural research. Particularly as change becomes urgent as we adapt to the climate crisis.

Using vertical farming for research and development purposes could also open the door to more farmer led research. An area that would need further exploration…

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DISCLAIMER

The opinions expressed in this report are those of the author alone and not necessarily those of the Nuffield Farming Scholarships Trust, of the author's sponsor, or of any other sponsoring body.

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CHAPTER 1: INTRODUCTION

"Technology made large populations possible; large populations now make technology indispensable." (Krutch, 1967)

I write on 23rd September 2024. In the time it has taken me to brainstorm this introduction, our arable farm in Oxford, UK, has been submerged under 150mm rainfall. Extreme weather again. Our ability to grow food compromised. Climate change a reality.

Across the world the conditions in which we farm are changing. To remain viable, growers must continue to evolve. Arguably, with the ongoing climate crisis and political uncertainties, the need for food systems to adapt has never been more urgent.

Looking back, so much has changed in farming throughout the last century. The global population has quadrupled to 8 billion (United Nations, 2024), yet global malnutrition levels have fallen from ~40% to ~10% (FAO, 2024). In the UK, century old yield data show increases in wheat productivity close to 300% (University of Oxford, 2022).

Among many, obvious catalysts for this progress are mechanisation, genetics and breeding, artificial fertilisers, pesticides, information technology, and global positioning systems (GPS). Such advancements have not been flawless, but must be celebrated!

Reflecting on these historic changes over the last century makes me curious about how farming will look 100 years into the future. Asking the question of change is what sparked my curiosity in vertical farming, and subsequently it is what motivated me to embark on this Nuffield Scholarship journey.

If the predictions about technological advancement are true – its increased adoption will accelerate the rate of change exponentially – then the farming landscape as we know it, could look entirely different. Vertical farming is one area of technology that has been capturing the imagination and gaining momentum.

I shall now offer a forewarning – the following pages shall depict vertical farming from the perspective of someone who's background is farming in the traditional sense. I have no formal training in the world of vertical farming. I don't think such training exists, perhaps there is a case for it?

Despite a lack of expertise, what qualifies me to write, is the fantastic Nuffield Farming opportunity presented to me. An opportunity to spend two years speaking at length to experts in the sector and all the affiliated fields. Each have shared with me unique insights. In this report, I shall attempt to convey their experiences, and summarise my thoughts on vertical farming and where it may, or may not, feature within a futuristic British farming landscape.

Before I begin, I must express my thanks to those who have made this opportunity possible. To all those involved in the Nuffield Farming Scholarship Trust, and my sponsors; the Food Chain Scholarship and the Central Region Farmers Trust – Thank You. Throughout this study, there have been countless hosts and contributors, all so generously sharing their time, thoughts and ideas. Some offered me a glimpse at the most advanced food production technologies on the planet. I will always be grateful to those whom I have met on this journey. Thank you also to my family who have supported me throughout and afforded me the time to travel.

Figure 1 - Will with his wife and son during a farm visit in Japan

CHAPTER 2: STUDY OBJECTIVES

Since starting to research vertical farming some 10 years ago, I have witnessed the transition from concept to reality. As the technology progressed, I began to consider… is this an opportunity to establish an additional on-farm revenue stream? And is vertical farming the tool to bridge the gap between rural farms and urban populations?

Subsequently, I experimented by setting up a vertical farm of my own – OX3 Greens – supplying local commercial kitchens with fresh herbs. Truthfully, my knowledge and confidence in the sector was lacking, and so I set about developing my understanding.

The aim of this project initially was to explore potential synergies between vertical farms of the future and traditional farming systems. Three hypotheses were to be scrutinised:

1) Vertical Farming is a viable means of food production

2) Vertical Farming will present a diversification opportunity on existing farms

3) Synergies exist between vertical and traditional farming systems that could offer exiting farm businesses a competitive advantage

However, as the project progressed, the conversation gravitated towards hypothesis one, and opinion was divided between the believers and the sceptics. This report shall summarise each position, and subsequently, outline potential opportunities for vertical farms within British agriculture.

CHAPTER 3: MY STUDY TOUR

To conduct the research, I am lucky to have travelled extensively. Destinations included:

- UK
- Germany
- Holland
- Singapore
- Japan
- United Arab Emirates
- Canada

I will refer to key points from visits throughout this report. A full list of visits and conversations can be found in Table 1.

Table 1 - List of contributors

Country	Organisation / Destination	Contact	Comment
UK	Intelligent Growth Solutions	Georgia Lea Tanvaer	UK & Dubai visits
UK	James Hutton Institute / Advanced Plant Growth Centre	Rob Hancock Andrew Christie	
UK	Angus Soft Fruits	John Gray	Nuffield Scholar
UK	T W Clark & Sons	Thomas Clark	Nuffield Scholar
UK	Syan Farms	Preyesh Patel	
UK	Dyson Farming, Carrington	James Thompson	
UK	NIAB	Benjamin Tea Lydia Smith	
UK	G's Fresh	Emma Garfield	Nuffield Scholar
UK	Vitacress	John Benfield	
UK	AHDB	Izak Van Heerden	Nuffield Scholar
UK	Innovation Agritech Group	Kate Brunswick	
UK	University of Essex		
UK	Growup Farms	Ben Logan Kate Hofman Gillon Dobie	
UK	Fischer Farms		
UK	DEFRA	Tim Mordan Russell Batten Thomas Powell	
UK	Oxford Farming Conference		
UK	Bright Biotech	Mohammad Elhajj	
UK	Author / Journalist	George Monbiot	
Switzerland	Vivent	Nigel Wallbridge Norm Janson	Remote meeting

Singapore	Urban rooftop garden architect	Chris Leow	
Singapore	Grograce	Grace Lim	
Singapore	City Sprouts	Simone Lim	
Singapore	Capita Springs / Arden Sky Garden	Brendt	
Singapore	Beco Ventures / Sustenir	Benjamin Swan	
Singapore	Archisen	Lim Hui	
Singapore	Singapore Food Agency	Ling Ling Bee	
Singapore	Hospitality & ESG Consultant	Yim Choong	
Singapore	Chan Family		
Japan	Japan Plant Factory Association	Eri Hayashi	
Japan	Asai Nursery	Yuichiro Asai	Nuffield Scholar
Japan	Tomatoh Farm		
Japan	Diamond Tokaehi		
Japan	Maeda Grain Farm	Shageo Maeda	Nuffield Scholar
United Arab Emirates	Conference of Parties 28		
United Arab Emirates	Pure Harvest		
United Arab Emirates	Bostanica		
United Arab Emirates	Alescalife		
United Arab Emirates	Re-Farm		
Germany	Fruit Logistica		
Germany	Lite and Fog	Peter Uwe	
Holland	Growy	Laura van de Kreeke	
Holland	Burgerboerderij Oosterwold	Diana Van Veelen	Nuffield Scholar
Holland	Pixel Farming Robotics	Cindy van Dommelen	
Holland	I 4 Nature	Xander Beks	Nuffield Scholar
Holland	Boerin Linda	Linda Kopczinski	Nuffield Scholar
Holland	Zonnespelt	Rogier Scherpbier	Nuffield Scholar
Canada	Ocean Spray		
Canada	Author	Adan Connolly	The Future of Agriculture
Canada	NASA		Vertical Farm in Antarctica
Australia	Stacked Farm	Rob Coe	Remote meeting

CHAPTER 4: PROJECT HIGHLIGHTS

Table 2 - Project highlights

Favourite destination:	Singapore – I can't wait to return with the family
Most inspiring contributor:	Shigeo Maedo NSch, Japan – Amazing farm diversification into popcorn and an inspiring attitude towards staff and community
Pick a farm:	I'd narrow it down to three, all in the UK! Dyson Farms, Carrington – dream setup for any arable farmer GrowUp Farms, Kent – exactly how you'd imagine a plant factory to be Syan Farms, Northants – A team of dentists with a very different perspective on food production
Wow moment:	A glimpse at early designs of farms on Mars. Will this concept turn to reality within my lifetime?
Moment of reflection:	COP28 – A totally new experience for me. A tough awakening to the realities of climate change from people already experiencing the consequences. Eye-opening to see the challenges of global politics in action. Refreshing to see community groups making a real difference. Thank you NFU for facilitating.

Figure 2 – Shigeo Maedo with his popcorn product

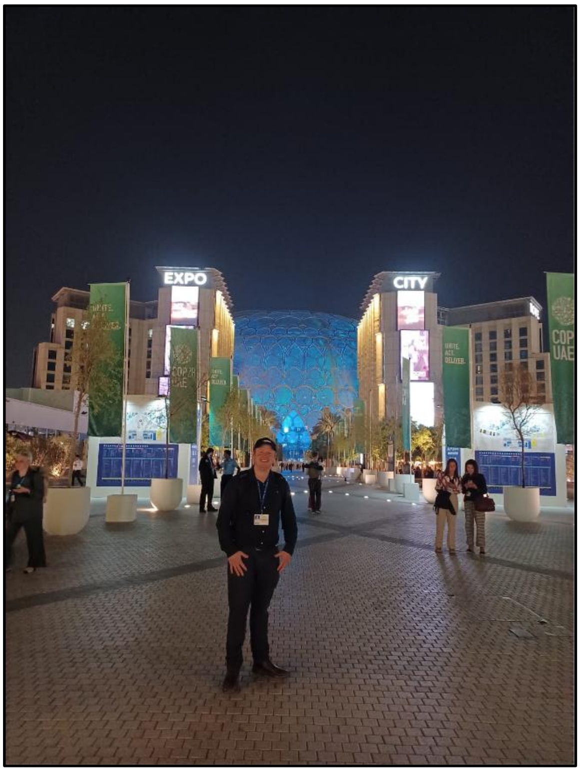

Figure 3 – Will at COP28, Dubai

CHAPTER 5: BACKGROUND TO STUDY TOPIC

Between 2016 and 2022, global annual growth in vertical farming was 25% (Statistica, 2023). In 2022 forecasters were projecting the sector to grow from USD 5.8 billion, to exceeding USD 30 billion by 2030 (Statistica, 2023). Several factors caused this growth, the most notable being:

- Advancement and availability of technology
- Investor interest in "Green Tech"
- Governments incentivising sustainable supply chain innovations
- Demand for a "cleaner" food source

The concept of vertical farming is not new, but the term remains unfamiliar to many. Simplistically, vertical farming is using technology to replicate the sun, wind and rain, creating an artificial growing environment. As electrical lighting is used, plants can be stacked in layers without shading, hence the term "vertical". Typically, systems are indoors where air temperature and humidity can be closely regulated, and conditions can be tweaked to minuscule degrees of accuracy. Plants can be grown in soil, but artificial substrates are commonly used in conjunction with precise irrigation and nutrient delivery systems. Controlled Environment Farming (C.E.F) or Controlled Environment Agriculture (C.E.A) are similar expressions but can refer to growing systems beyond plant production.

Vertically farmed produce can be distinguished into three categories:

a) Leaf crops

b) Fruit crops

c) Grain crops

In Britain, there are a handful of large vertical farms leading the sector having generated significant external investment. All of them currently specialise in the production of mainstream leaf crops. Other vertical farms exist on a small scale, mostly focussing on niche crops or markets. Some early adopters have since pivoted to become farm technology providers, exporting their leading-edge systems around the world. More recently, there are growing numbers of institutions using vertical farms for plant research.

Intelligent Growth Solutions (IGS), UK / Re-Farm, UAE

From Dundee, IGS is a global provider of vertical farming technology. The focus is currently on their flagship growth towers, which provide 320 sqm grow space on just a 40 sqm footprint. The towers are fully automated and benefit from machine learning and artificial intelligence to create optimal grow conditions. Each tower is controlled by the IGS in house growth management software that is used to control all aspects of the growing environment and automation.

IGS is focused on developing sustainable solutions to global challenges impacting food production, from climate change to staff shortages. Their technology can adapt to an array of requirements. During the visit, I witnessed a range of crops grown from basil to oak trees, all within the same grow tower.

IGS has partnered with Re-Farm to install 200 grow towers in Dubai's Food Tech Valley. Re-Farm is a project, bringing together 6 companies, each focussing on circularity and clean technologies. The ambition is to recycle 50,000 tonnes of food waste annually, extracting the water and nutrients to grow two billion plants vertically. The project is expected to replace 1% of the region's fresh produce imports, and prevent any food waste going to landfill.

Case Study 1 - Intelligent Growth Solutions, UK

Figure 4 - Will visiting an IGS growth tower at the launch of Re-Farm, Dubai

CHAPTER 6: THE BELIEVERS

Vertical farming enables plants to be grown under absolute control. This means conditions can be optimised indefinitely. Effectively, any plant can be grown anywhere at any time. This is exciting.

Furthermore, optimal conditions enable maximum productivity and consistency, as well as full utilisation of inputs. Such growth systems promote circularity, eradicating any environmental impact of waste and runoff. In addition, controlled growth rooms create a barrier against any pest or disease invasion. By adjusting certain growing conditions, plant behaviour can be manipulated such to tailor specific outcomes, for instance, appearance, flavour, and nutritional content.

The benefits of vertical farming are numerous and the extent of each benefit is dependent on specific applications. A summary of the key benefits could be listed as:

1) Maximum output
2) No seasonality
3) Consistency
4) Crop enhancement (appearance, taste, nutritional content)
5) Food safety
6) No pesticides
7) Water efficiency
8) Reduced food miles
9) Accessibility (No requirement for fertile land or climatic conditions)
10) Climate change resilient

Each of these benefits can be better understood by explaining the levers of control within vertical farms, with examples observed throughout the project:

Lighting

Lighting is probably the most widely discussed and researched aspect of vertical farming. Due to their output stability, longevity, size, controllability, energy efficiency, and more recently, affordability, Light-Emitting Diodes (LEDs) are now the preferred light source among vertical farms. Except for one commercial operator and one research site, all facilities visited during this project were using LED lighting.

Outdoor and glasshouse production are dependent on natural sunlight. This presents huge variation diurnally and seasonably in intensity, duration, and spectral composition. Inside vertical farms, operators have total control of light conditions – duration, intensity, and spectrum. Lighting can be adjusted to the extent that day/night patterns become unrecognisable and of no correlation to the familiarity of the 24/7/52/365 routine. Although, in most instances commercial growers are sticking to 24-hour cycles for operational ease, most opting for 16 – 18 hours of light per day.

Precise controls enable operators to determine lighting based on economic and agronomic reasoning. Large vertical farms are adjusting lighting patterns according to output and energy costs. Often the yield response to extending the photoperiod does not offset the additional energy cost. However, tweaking the photoperiod can provide flexibility in meeting demand criteria or maximising space utilisation.

The Japanese Plant Factory Association (JPFA) provided some excellent examples of plant responses to light manipulation, particularly between different plant species. For example, a trial showed basil yield increased by up to 78% when light intensity increased, but yield remained unchanged when only the photoperiod was extended. In contrast, spinach and kale yield recorded a positive corelation with the photoperiod, however the nutritional content reduced, probably the consequence of a dilution effect.

Another interesting concept discussed at the JPFA was that pulsing lights could have a positive yield response despite a lower energy input.

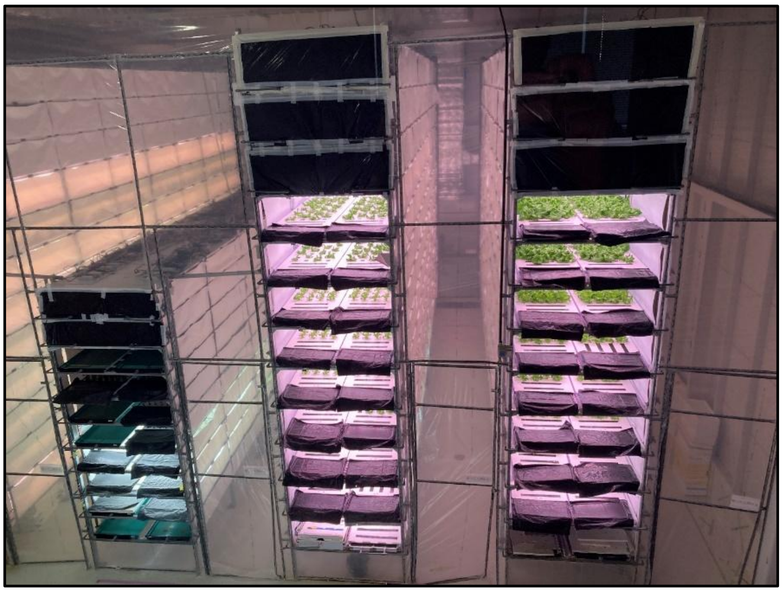

Figure 5 - One of the grow chambers at the JPFA

Growy, Amsterdam, have completed trials where light spectrum was adjusted throughout the growth cycle. Preliminary findings were that increasing blue rays by 20% four days before harvest, caused a 30% increase in Vitamin C content. Other results showed that increasing red rays prior to harvest was extending shelf life by up to 2 days.

Growy, Holland
Growy are a vertical farm that grow microgreens, herbs, and leafy greens. They emphasise the benefits of vertically farmed produce, focussing on superior taste and health traits of their produce, supported by an on-site R&D facility. Affordability is also key to their business model, achieved through automation but also low-cost production systems.
The business model has been to use existing climate-controlled facilities, enabling the business to avoid excessive capital expense. To date, the company has farms in Amsterdam, Kuwait, and soon to be Singapore.

Case Study 2 - Growy, Holland

The impact of manipulating plant growth stages by adjusting light duration, intensity, spectrum, or a combination of all three, is widely reported throughout the industry. This could be critical when considering production of crops with a longer lifespan. Findings by Fischer Farms, UK, show that five wheat crop cycles per year could be possible inside their vertical farms.

Irrigation

The benefits of irrigation within vertical farms can be viewed through two lenses, both of which complement one another:

- Resource use efficiency
- Optimal delivery

Forecasters project that around half of the world's population are to live in water-stressed regions by 2050. Hence, there is expectation on food producers to act in a way that is "water responsible". Farmers invited to speak at COP28 were already experiencing water stresses. Out of necessity, they were moving faster than government policy to find solutions for their local environments.

Many in the industry believe vertical farming to be part of the water solution, particularly in dry regions, such as the United Arab Emirates. Water use efficiency in vertical farms should exceed 95%. Theoretically, the only water required should be that to replace water removed in harvested crops and water lost as vapour through air gaps. Most water lost through evapotranspiration is recycled through the cooling panels of air conditioning units.

Of the farms visited throughout this project, most were irrigating with ebb and flood hydroponics, a technique familiar to glasshouse operations. Periodically, water, with a nutrient solution, floods the grow trays to a level so that roots are submerged, and the growing media remains moist. Key to success is the perfect relationship between aeration and irrigation.

Figure 6 - Lettuce grown using hydroponics at GroGrace, Singapore

A similar technique witnessed is the nutrient film technique, where there is a continuous flow of water and nutrients through the plant root network. In both scenarios, unused water is sanitised and returned to the irrigation tank. There is no wastewater run-off.

A different approach to irrigation is aeroponics. In aeroponics plants are suspended above a water / nutrient mist, as opposed to being submerged. The theory is that roots have greater access to oxygen, promoting healthier, higher yielding plants. Despite the science, this method was seen less frequently due to its higher cost and added layer of complexity.

A newer approach to irrigation is “fogponics”, explained by Peter Uwe from German company Lite&Fog as a step on from aeroponics in terms of plant health. It works by suspending a water / nutrient solution, quite literally creating a fog effect. The “Fog” is uniformly distributed through a root layer. Irrigating through fog could enable us to rethink the configuration of vertical farms (away from warehouse racking format) to better utilise factors such as light and space. Lite&Fog promote cylindrical farms to maximise growing surface area, essentially growing plants in circular columns instead of flat grow benches.

Each of the irrigation techniques described promote the same benefit, crops can receive optimal levels of water throughout their lifecycle, without the issue of contaminated and wasted water. Some farmers were also tweaking irrigation cycles prior to harvest, monitoring the impact on shelf life and plant weight. Too much water compromises quality, too little water reduces plant mass and harvestable yield.

Nutrient Delivery

In vertical farms plants access nutrition through the irrigation methods outlined previously. The benefits are similar too, minimal waste and contamination, and optimal delivery. Theoretically, plants can receive a bespoke recipe of nutrients dependent on their requirements at any point in time. This is regulated by a suite of sensors throughout the grow chamber and a pre-determined "diet", calculated to optimise crop performance. In many ways, this is similar to a nutrient management plan in broadacre farming, just with considerably more precision detail.

Despite the potential to control nutrients to ensure optimal resource use efficiency, commercial vertical growers tend to be using a standardised A/B solution with a pH regulator, much the same as glasshouse hydroponic systems. The reasons being are typically due to standardisation and ease of management. Plus, the marginal gains from bespoke formulations are not cost effective.

Environment Control

In this instance, environment control refers to temperature, humidity, and air flow. Regulating these factors within an enclosed environment is one of the greatest operational challenges of vertical farms. If a grow chamber is too densely populated, inadequate air flow can cause an entire farm to fail.

In outdoor growing systems airflow, humidity, and temperature are self-regulating natural processes. A good analogy to illustrate the conditions inside a vertical farm is to consider the inside of a car during a rain shower. How quickly does the windshield become "misty", and what dials need tweaking to clear the mist? The same principals are true inside a vertical farm to maintain a regulated growing environment.

To get the full benefit of vertical farming, environmental controls should be altered throughout the crop cycle. This is challenging if multiple crop types at different growth stages are within the same growth chamber. One extreme example explained was that shock conditions such as sub-zero temperatures can be enforced on a crop at specific growth stages to instigate a chemical response altering flavours. In this example carrots were to taste sweeter if exposed to a period of <0°C.

Location

The location of vertical farms is not determined by access to fertile soils or plant friendly weather. Hence, the positioning of a vertical farm, is to be considered a lever of control. Subject to local planning laws, vertical farms can be situated anywhere. For instance, in a more extreme example, NASA have positioned a vertical farm in Antarctica to imitate the harsh growing conditions on the moon.

One of the world's largest vertical farms, Bustanica, demonstrated the ability to grow in the Dubai desert, producing 3 tonnes leafy greens per day, despite outdoor temperatures averaging 40°C during summer months.

Bustanica, UAE

Bustanica is one of the world's largest vertical farms and was established in association with The Emirates Group. The vision is to align itself with the countries ambition for water and food security. The vertical farm enables food production close to Dubai where the desert climate is otherwise unsuitable. Bustanica can offer premium fresh produce and continuity of supply, where previously only imports from North Africa or Europe were available. Uniquely, Bustanica offers two weeks shelf life on all its fresh produce.

The facility has 27 grow chambers which have the potential to grow 50 times greater yields (lettuce) compared to outdoor production on the same footprint. Crop output is three times more productive and there are 18 tiers of plant racks. Currently leafy greens are the focus of production, although the site has the potential to harvest 20t tomatoes.

Case Study 3 - Bustanica, UAE

Figure 7 - Bustanica vertical farm, Dubai (inside & out)

Figure 8 - View from the Burj Khalifa, Dubai - the worlds tallest building

GroGrace are growing lettuce surrounded by skyscrapers in Singapore, the epitome of an urban farm. Singapore demonstrate the ability for vertical farms to grow food at the place of consumption, often referred to as hyper local. One benefit of this is increased consumer choice. Through vertical farms, consumers can access fresh produce that would otherwise not have been grown in the region. Another example of this would be Oishii, an American vertical farm, which introduced Japanese fruit culture to New York.

GroGrace, Singapore

GroGrace is a vertical farming business founded on the principal that growing food indoors is more environmentally friendly than outdoor production and must therefore be a consideration for future food production. Grace Lim also explained the health benefits associated with not using pesticides.

Grograce have partnered with the Urban Farm Partners and also benefited from grant funding from the Singapore Government, who recognise the future potential of vertical farming. Unlike other vertical farms visited, this farm uses a dry hydroponic system, where plants float on deep water, but are positioned above an air pocket so the plant remains oxygenated.

Production costs are the company's biggest challenge, citing the cost disparity between Singapore, Malaysia, and Indonesia. At the time of visiting, energy

Case Study 4 - GroGrace, Singapore

A benefit of hyperlocal, more important than consumer choice, is minimising food waste and food miles. Transporting food is expensive, environmentally and economically. One example presented was that to transport 1kg coriander, 1000km would take two days, and produce 0.5kg carbon dioxide. The financial cost was not disclosed.

In the UK around 40% of purchased salad is wasted (Horticultural Sector Committee, 2023). Much of this is the result of short shelf life on perishable goods. Saving two days in transit would help to overcome this. Also, this figure only considers purchased goods, much produce is wasted prior to retail, either because of harvest losses or grade specifications. Vertical farming can address each of these challenges considering:

- Fixed growth schedules and yields, help determine production quantities that correspond to market demand
- Harvest losses are minimal, as produce is always harvested within a controlled environment
- Produce is uniform and consistent

Singapore has a population of 5.8 million, yet only 600 ha "agricultural land". That amounts to 1m² food production per capita, compared to 6,200m² in the UK. The

Singapore Government has recognised food sovereignty as a key component of food security, and has therefore established the "30 by 30" framework – producing 30% of the nutritional requirement by 2030. The policy places significant emphasis on ag-tech to achieve this, with the inclusion of vertical farms due to their ability to grow large food quantities with minimal land footprint. Hence, vertical farms can be integrated into the urban landscape.

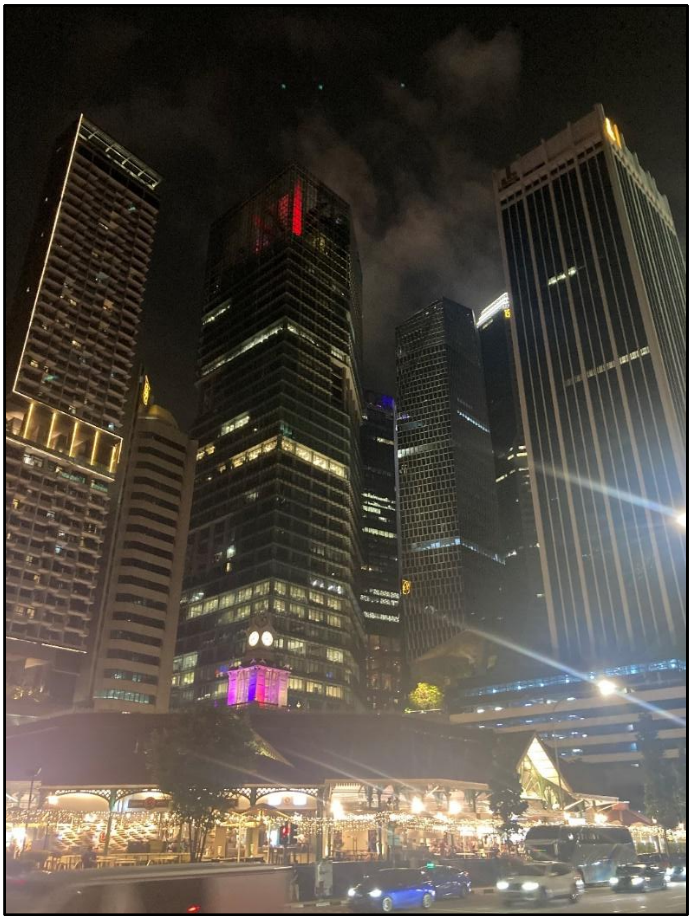

Figure 9 - Spectacular urban landscape in Singapore (Lau Pa Sat)

Hopefully this analysis of some of the levers of controls within vertical farms illustrates the potential of the technology and the compelling case put forward by the "believers" throughout the project. Any plant, anywhere, anytime, maximum output, with minimal input. Now let us consider the sceptics of vertical farming.

CHAPTER 7: THE SCEPTICS

Despite the benefits described in the previous chapter, there is a powerful argument to be made against vertical farming. These claims shall be distinguished as economic, environmental, and social, although the three are interlinked.

Economic

Author Aidan Connolly states in his book, "The Future of Agriculture", that until 2023 just 27% of vertical farms have been profitable (Connolly, 2023). This report agrees with Mr Connolly's reasoning; high operating costs and high initial capital expenditure.

Vertical farms are characterised by their high energy requirement, particularly when compared to outdoor or glasshouse production. Reducing energy consumption was a top priority for all vertical farms visited. It is also the reason why all commercial vertical farms were focussing on leaf crops which are much faster to yield, hence requiring less light energy. Bustanica was trialling strawberry production and supplying in-flight catering from the Middle East to the UK during the Wimbledon tennis tournament. They were only catering for Business Class, which gives an indication of production costs.

Obtaining energy use data from vertical farms is challenging, as was evident throughout this project. Many hosts were not able to share data, or where possible, information was dependant on factors such as: farm size, farm layout, crops grown, outside temperature, farm capacity. The range of energy usage varied greatly across the farms visited. Table 3 provides an illustration of typical energy requirements for production.

Table 3 - Example energy requirement of vertical farms*

Energy Requirement per M² / Day	2.63	kWh
Energy Requirement of 10,000 M² Farm / Day	26.3	MWh
Energy Requirement per Year	9599.5	MWh
Typical Lettuce Yield / M²/ Year	50	kg
Lettuce Yield from 10,000 M² / Year	500	tonne
kWh / kg Lettuce	19.20	kWh

* Data taken from three businesses and standardised to calculate an approximate energy requirement per kilogram of lettuce

Assuming 1kg lettuce requires 19.2kWh to grow inside a vertical farm, that equates to 0.21kg CO_2, and £5.76 (30p / kWh). Of this cost, light energy makes up >50%. Many vertical farms are countering energy costs by utilising renewable energy. For instance, GrowUp Farms in Kent, UK, are using local forestry as a biofuel. Several other farms were using solar energy, either on site or outsourced.

If renewable energy is internally sourced, it is important to calculate the opportunity cost of this energy – the revenue lost from not selling it to the grid. There is no such thing as free energy. For example, if photovoltaic solar panes are installed installed to power a vertical farm, the alternative potential income must factor to show the true cost to the vertical farm. It could be the case that selling energy to the grid is more profitable and lower risk, than using the solar to power the vertical farm.

Dyson Farming - Carrington, UK

Dyson Farming at Carrington is part of a wider arable farming operation but of particular interest was the relationship between the anaerobic digestion plant and the glasshouse production facility. Interestingly the company opted for glasshouse production despite considering a vertical farm whilst planning the enterprise. Using artificial lighting was viewed unfavourably compared to natural sunlight.

The anaerobic digestion plant supplies energy to the grid, whilst the additional heat energy is transferred to heating the glasshouse facility. The feedstock requirement of 150t per day is incorporated into the arable cropping rotation (28% of cropping area), growing crops including oats, vetch, and rye, in addition to maize. These crops also contribute towards countryside stewardship options, adding to the overall financial performance. The digestate was then fed back into the arable enterprise.

Case Study 5 - Dyson Farming, UK

Figure 10 - Dyson Farming, Carrington (view from AD plant, looking over feedstock and glasshouses)

To install a vertical farm is expensive. Depending on location, research shows that £1,000 / m² is the approximate cost of growing equipment. This excludes the cost of assembling the controlled grow room, and the cost of any technical equipment such as robotics and sensors. To construct 10,000 m² would cost £10m. In Japan the cost of installing a vertical farm is reportedly fifteen times greater than a glasshouse.

As with all sectors, vertical farming has been impacted by the rise in interest rates and raw material costs since 2022. This has further exacerbated the financial challenges facing vertical farms and the associated risk.

Risk perception is also heightened due to the scale at which vertical farms must operate to compete with traditional leaf crop production. To compete on price, vertical farms must access economies of scale enjoyed by conventional growers. And to remain competitive, they must also offer a broad product range and continuity of supply, which requires scale.

To penetrate the mainstream leaf crop market vertical farms must either start with a large facility or grow rapidly. As the sector remains in its infancy, this is considered very high risk, with unknown rewards. In all countries visited, vertical farms intending to disrupt the leafy crop market have benefitted from large external investments, either public or private. Reporting on capital investment is commercially sensitive and findings from the project will not be published. An observation in Singapore, was that public funding was too focussed on capital expenditure and not operational expenditure. Essenitally funding business models that could not sustain themselves.

Also observed in Singapore, was the degree of progressive technology used inside vertical farms to create the optimal and automated environments described in chapter 4. Many critics of vertical farming argue that technology is used excessively and is adding unnecessary cost to production, in relation to the marginal gains in crop performance. It could be argued that this is endemic of the wider agriculture sector. Is food production becoming too technologically focussed, where returns are not being realised in input savings or outputs gains?

Vertical farming is regarded as a young sector. Therefore, associated companies are to be considered early adopters. By their nature, they will have greater research and development requirements than conventional growers. This is another factor adding to production costs.

Due to the high costs outlined above, vertical farms inevitably charge a price premium to return a positive gross margin. Often this is justified through the benefits outlined in chapter 4, such as the exclusion of pesticides, minimal food miles, and water use efficiency. Typically, vertical farmed produce is priced in the same market segment as organic certified goods.

However, in the UK the House of Lords Horticulture Sector Committee reported in 2023 that the horticulture industry was locked in retailer price wars, and that loss leader price strategies had created a race to the bottom (Horticultural Sector Committee, 2023). The same report records that food inflation peaked in March 23' at 19.2% (Horticultural Sector Committee, 2023). These market conditions do not favour the pricing strategies frequently deployed by vertical farms. New entrants should consider two observations:

- How price elastic is the target market segment?
- How close to saturation is the market?

Figure 11 - Example of pricing in Singapore - $7.98 / 130g

For example, in Singapore the price elasticity of lettuce was very high, so the market size for premium priced lettuce was small. Government policy has incentivised several new vertical farming entrants, who are all competing for the same small consumer base and the market appeared saturated.

Table 4 illustrates some pricing differentials between vertical farmed produce and conventionally grown.

Table 4 - Vertical farm vs conventional price comparison

Country	Product	Weight	VF Price £ Equivalent	Conventional Price	Percentage Difference
UK	Baby Salad	100g	£1.67	£1.38	21%
Dubai	Spinach	150g	£2.87	£2.23	29%
Singapore	Lettuce	200g	£7.17	£2.28	214%
US	Kale	225g	£5.40	£1.90	184%

Environmental

Vertical farms boast the environmental benefits highlighted in chapter 4. – no pesticides, no soil degradation, less waste, drastically less water usage. However author and journalist George Monbiot provided a different perspective on the environmental impact of vertical farming. Mr Monbiot explained that the negative environmental impact of the additional energy requirement of vertical farms must be factored in. Particularly when comparing vertical farming to conventional systems that regulate their own natural environment and rely on natural sunlight.

The interview with George Monbiot was intended to evaluate vertical farming against other controlled environment agriculture (CEA) practices, such as precision fermentation. In his book *Regenesis*, Mr Monbiot advocates for precision fermentation, yet when asked in the interview about vertical farming, he is sceptical. His logic was to reflect on the processes each technology was replacing. Vertical farming is replacing natural sunlight, whereas precision fermentation is replacing livestock production. The use of natural sunlight requires no energy inputs, unlike livestock farming which is energy intensive. Following this logic, precision fermentation is justifiable, in contrast to vertical farming, which is not.

In addition, Mr Monbiot recognised that for any new technology to be acceptable, intelligent energy procurement was vital. For example, intensive energy users should work with energy suppliers to analyse the peaks and troughs of supply and demand. Scheduling production cycles around peak energy usage was a practice observed in Singapore, the UK, and Holland.

The economic opportunity cost of powering vertical farms with renewable energy has been discussed. Similarly, the environmental opportunity cost must be factored. For every kilowatt of renewable energy used by a vertical farm, is a kilowatt not available for other uses. UK energy infrastructure is under pressure to fuel other emerging sectors, such as electric vehicles, with green energy. Is there the capacity to supply vertical farms with green energy, without detracting resources from initiatives promising greater environmental benefits?

Regardless of energy source, if the vertical farming sector emerges as a disruptor to the food industry, then the impact on the energy sector must be considered. To provide context, to grow 100g salad vertically requires the same energy as that required to power a dishwasher cycle (19.2 kWh). Assuming every household consumes 100g salad each day, relying on procurement from vertical farms would be the same as each household running an additional dishwasher cycle every day.

Throughout this project, discussions on energy usage focussed on the production of leafy greens. This crop group requires the least energy to grow, compared to fruit and grain crops. Regardless of economic and agronomic justifications, the environmental cost of energy to grow slower energy converting crops, could be the determining factor in the argument against vertically farming fruit and grain crops.

One other factor to consider is the environmental cost of constructing artificial growing spaces, and the rate at which they degrade over time. This has been discussed at multiple meetings throughout the project, but not investigated further.

Social

The perceived social benefits of vertical farming have been described in the previous chapters; food resilience, food safety, consumer choice, improved quality. Yet in the UK, where food inflation, energy costs, and energy security are high on the public agenda, there is a social argument to be made against vertical farming.

Philosopher Emanual Kant depicts the idea of "Categorical Imperative", whereby society should universalise a principle, only when rules can hold true for everyone, without contradiction. In the case of vertical farming in the UK, widespread adoption would be problematic due to the associated economic and energy costs of production. To replace existing food systems with vertical farming technology, would make access to healthy produce more restrictive, and would therefore not be in the best interest of society more broadly.

A similar argument can be made in the context of Net Zero – a target of completely negating the amount of greenhouse gases produced by human activity. In the UK, there is the target to achieve Net Zero by 2050, with much progress having been made in the decarbonisation of our electricity system. Due the electrical demand of vertical farming, widespread adoption could slow, or even reverse this progress.

One contributor noted an example of the additional grid requirement needed for the transfer to electric vehicles. They remarked that the use of large vertical farms would compound this challenge.

An interesting conversation was had discussing the hypothetical installation of a 20 ha solar park, capable of generating 10,000 MWh electricity per annum. In the pursuit of Net Zero, it is debateable whether such facility would be best used to power the equivalent of 3,000 homes, or to grow 500t lettuce inside a vertical farm. Where vertically farmed produce commands a price premium and is unaffordable to most consumer groups, there is the social argument that renewable energy projects should focus on supplying energy accessible to all segments of society.

Figure 12 - Al Maktoum Solar Park (7,700ha), UAE, as presented at COP28

CHAPTER 8: VERTICAL FARMING AND THE OPPORTUNITIES FOR BRITSH FARMERS

This section shall outline four possible applications for vertical farming in Britain, and detail the perceived merits and pitfalls.

Mainstream Crop Production

You may sense a degree of bias in this statement, but the large vertical farms observed in the UK are among the most advanced in the world. Businesses such as GrowUp Farms, present an eco-friendly, inspiring, futuristic alternative to crop production. The highly automated facilities address so many of the challenges faced by more conventional farming systems.

GrowUp Farms

If one could imagine a state-of-the-art plant factory consistently growing high quality salad crops, 12 months of the year, the epitome of a vertical farm in 2024, this is exactly what was experienced at GrowUp Farms, Kent.

Most commercial farms visited throughout the project restrict public access, so for GrowUp Farms to open their doors was unique and a huge privilege. The specific processes and growth details are sensitive to disclosure. With only human intervention at checkpoints and to transfer crops between stations, the process from seeding to harvest was close to entirely automated. The growing crops observed were lettuce and rocket, and each process was designed to provide optimal growing conditions, for instance, sowing density, germination time, light spectrum, and harvest technique.

The farm is powered from renewable energy sourced from a local biofuel factory and all produce is sold through major British supermarkets under different retail brands.

Case Study 6 - GrowUp Farms, UK

However, establishing these businesses is capital intensive, often reliant on the support of external investors, and the market conditions in which they operate are unforgiving; competition from cheap imports and domestic growers, price elastic supply chains, race-to-the-bottom marketing strategies, volatile energy markets.

On balance, this report does not recommend growers adopt vertical farming practices for mainstream leaf crop production in the UK.

Geopolitical uncertainties and weather events have disrupted fresh produce supply lines into the UK in recent years. Many commentators cite this as one of the main advantages of operating a vertical farm in the UK. Plus, consumers are looking favourably at local provenance and pesticide free. However, these factors combined do not outweigh the risk of operating in the sector to grow mainstream leaf crops.

In the US enthusiasm for vertical farming has slowed, and so has investor interest. This trend may, or may not, transpire across Europe.

Specialist Crop Production

A less risky proposition is to determine a specialist market on which to focus vertical farming production. By finding a niche, typically there will be less competition from other traditional or vertical growers, and economies of scale will be less critical. Hence, a smaller facility may be adequate, requiring considerably lower capital investment.

Vertical farming lends itself to niche crop production as was explained by Prayesh Patel at Syan Farms. Crops can be grown where historically it has not been possible. Or specific traits are achievable through simulating specific growing conditions. At Syan Farms, crops were being grown for specific ingredients and they were conducting research on niche protein crops such as amaranth.

Syan Farms, UK

Not only was Syan Farms one of the most innovative vertical farms visited, they also provided the tastiest food samples, developed under the plant based food brand Eat Curious.

Syan Farms is located on a redundant dairy farm, and has been founded by a team of dental professionals. They have a unique prospective on food production and are focused on health and the nutritional content of food. Hence the produce grown inside the vertical farm is targeted at providing nutritional benefits and niche ingredients, they are not seeking to compete with growers in the mass production of leafy greens.

The farm recognises costs as one of their toughest challenges and is focussing on automation and innovation to enable them to grow food competitively.

Case Study 7 - Syan Farms, UK

In developed economies there are emerging markets in "personalised food" and "bio-hack" industries. Such consumer trends could present opportunities to vertical farms able to safely grow pesticide free crops, with targeted nutritional or aesthetic characteristics.

Furthermore, vertical farming is generating considerable interest from science, pharmaceutical and cosmetic sectors, among others. Operators in these industries have identified the benefits of vertical farming, but don't have the means, skills, or inclination to run them. For example, a conversation with a biotech start-up highlighted a clear opportunity in the procurement of consistent, fresh, tobacco plants to be used for chloroplast extraction.

Also to be included in the category of specialist crop production are nursery crops. John Gray of Angus Soft Fruits explained that importing propagules can be problematic due to disease pressure, timing, or reliability. Growing young plants inside vertical farms close to glasshouse operators would overcome these challenges and be economical as growing plants to a young stage is not as energy intensive. There are instances of vertical farms growing tree saplings in the UK where landowners are encouraged to create woodland and existing sapling supply is inadequate.

Community Engagement / Education:

Success of a vertical farm does not necessarily depend on selling produce. Growbix in Singapore are taking a different approach, they are selling the growing experience. A novel and very successful idea. Consumers can subscribe and lease one or more grow racks, which is periodically replenished with living plants. The technology is low-cost and the concept is simple, but unlike many vertical farming companies it is profitable. Typically, customers are office buildings, apartments blocks, or food outlets in urban areas, where people seek reconnection with food and attribute value to the growing experience.

Figure 13 - Growbix display at a premium food outlet, Singapore

Also identifying the psychological impact of growing food, Hyundai Motor Group have installed one of the most advanced vertical farms in Singapore, within their innovation centre. Lim Hui, Archisen, who specialise in controlled environment farming, explained that the purpose is not to grow food, but to:

- Show off the capability of robotics
- Appear green and environmentally sensitive
- Emotionally connect to customers through food

600 plants per day are harvested for the visitor centre and staff, with any surplus donated to charity.

Here are two very different vertical farming examples, with a common theme – engagement and education. Big or small, trailblazing or minimalistic, vertical farming can be used to reconnect food with people. Particularly with young or urban audiences as was seen throughout the project. At COP28, crowds of school children were fixating on LED lights illuminating a rack of basil plants, under the control of an iPad.

In the UK, farmers are seeking to reconnect with consumers either by directly marketing produce or through diversification. Using a simple vertical farming set-up could be a novel and engaging method of attracting attention. Also, conversations had with schools and universities indicate substantial interest in utilising vertical farms for educational purposes.

In Japan, where the average age of a farmer is 69, it is hoped that vertical farming will connect with younger generations and inspire young people to work in food production.

Research & Development

Despite concluding that vertical farming will not disrupt mainstream leaf crop production in UK, there are considerable prospects for vertical farms to impact conventional food systems through research and development. The capability of vertical farms to establish absolute control and grow food under an array of conditions creates new opportunities for their application as leading research facilities. This was demonstrated at The University of Essex where they have installed the Smart Technology Experimental Plant Suite (STEPS), which uses vertical farming to create an indoor field that replicates real environments anywhere on the planet.

Establishing facilities such as this provides researchers the ability to experiment on a range of challenges within one facility. Projects can range in scope, from large government funded projects such as the Andvanced Plant Growth Centre, Dundee, to far more modest investments that support existing on farm trails, focussing on farm specific issues.

Critics argue that data collected from indoor farming is often not applicable to outdoor production. The argument is that the outdoor conditions cannot be replicated exactly and therefore results cannot be relied upon.

If this project was extended beyond the two-year timeframe, the relationship between vertical farms, research and development, and conventional farming systems would be reviewed further. Below are some examples of how vertical farms should be used to enhance the productivity of conventional farming systems. The list is not exhaustive but an illustration of meaningful synergy between vertical farms of the future and traditional farming methods.

Climate Change Preparedness

The 1.5°C target established in the 2015 Paris Agreement (warming of the earth surface by no more than 1.5°C by 2100) is unlikely to be met. Some experts are warning a 3°C increase could be more realistic. Vertical farms must be used extensively to assess plant behaviour according to climate change predictions in different regions. Temperature change will impact rainfall, CO_2 levels and light intensity. Each of these factors can be modelled in isolation or in conjunction with one another within vertical farms. Such testing should not only focus on crops of today, but also be used to identify crops of the future. The effect on wider ecosystem services such as soil biology should also be replicated within controlled environments.

Research enhancement – speed and accuracy

Agricultural research is frequently flawed by weather events, causing delays or anomalies in data collection. With growing conditions changing rapidly, there is an argument that research must be accelerated. Vertical farming provides an opportunity to speed up data collection and improve accuracy. Inside vertical farms abnormal weather events are avoided, influences from external variables are eliminated, and tests can be conducted all year round, without the research being determined by growing seasons.

Breeding

The role of plant breeding inside vertical farms warrants its own Nuffield report. Vertical farms are more frequently being used for speed breeding. Vertical farms also create a suitable environment for research in Gene Editing and Genetic Modification. The closed nature of grow spaces make for easier legislative compliance and reduces the risk of contamination.

Artificial Intelligence

A Nuffield report about agricultural technology wouldn't be complete without mentioning AI. AI is reliant on accurate data capture for machine learning. Relying on natural environments for data capture can be unreliable. Creating a controlled environment inside vertical farms for data capture to aid machine learning will increase the accuracy of AI and improve its future application within agriculture. It is suggested that capturing data inside could be a preliminary phase before models are tested in outdoor conditions.

Crop enhancement

A considerable issue on many British farms is the lack of crop diversity. In the introduction, this report alluded to progress in wheat yields. Similar progress is needed in the development of other crop types to improve the sustainability of farming systems. For instance, research is needed to improve the agronomic performance of leguminous crops. Research and breeding inside vertical farms could speed up and enhance this development.

Blackgrass control

Vertical farms should be another weapon used in the battle against blackgrass. Vertical farms could be set up with a sole purpose of monitoring blackgrass traits. Who knows, gene editing could be used to transfer the tillering potential of blackgrass into winter wheat?

On farm trials

Farms are science-based businesses, yet very few have an expenditure budget for research and development. Frequently, on farm "tramline trials" are conducted but data is likely unreliable because of too many variables, or trials are neglected because of adverse weather conditions or other business pressures. Small scale vertical farms may present an opportunity for farms or groups of farms to conduct their own independent research. The controlled environment means growers can complete trials with more accuracy and in their own time, without having to wait for annual cropping cycles. Different soil types can be placed into the same growth chamber to inspect the impact on different areas of the farm simultaneously.

CHAPTER 9: CONCLUSION AND RECOMMENDATIONS

As I close this report, Oxfordshire has just recorded its wettest month (September 2024) since records began. Another planting season to forget.

This reinforces my belief that farming systems must continue to evolve. This begins with a recognition that growing conditions are changing, but so too is the technology and science at our disposal.

Before this project, I believed that the power of vertical farms to overcome adverse weather conditions would be revolutionary. I still believe that the ability to grow any plant, anywhere, at any time, at maximum output from minimal inputs has enormous potential. But sadly, in my opinion, the likelihood of widespread application of vertical farms to grow mainstream crops is more pessimistic.

In the UK, we find ourselves dependant on cheap food whilst in the noose of an energy crisis. I therefore conclude that there is little requirement for a food system that will only intensify the energy burden, only to produce food unaffordable to so many. So I see no opportunity for existing farms businesses to diversify into vertical farming for mainstream crop production.

In the UK, the case for vertically farmed mainstream crops would be strengthened if one of two scenarios occurred:

- Diminished access to cheap food imports
- Plentiful access to cheap, "green" energy

In regions of the world that do not enjoy the same access to fertile soils, natural sunlight, and water as the UK does, the case for vertical farming to grow mainstream crops is stronger.

In context of leaf and fruit crop production, the progress in vertical farming technology shows most promise when used in conjunction with existing glasshouse systems. Combining open access to sunlight, with the increased ability to exert greater control over the growing environment has enormous potential.

Not only does society demand cheap food, but we have become accustomed to choice. This presents an opportunity for vertical farms to grow niche crops. This approach is achievable with lower capital expenditure and less exposure to risk. Vertical farms can grow unusual crops, manipulate bespoke plant characteristics, and offer unrivalled crop consistency. These benefits present opportunities for food, pharmaceuticals, science, and cosmetic outlets.

Communities are seeking to reconnect with food and its associated origins. The instagramable nature of vertical farms, with bright lights and high tech is an attractive story, particularly among young demographics. Therefore, vertical farms could become a useful tool for traditional farms to engage with their consumers. There is also growing interest amongst educational institutions seeing vertical farms as an opportune learning environment.

Arguably the most important application for vertical farming discussed is Research and Development. The conditions in which conventional farming systems operate are changing at an alarming rate. Vertical farms must be used to help farmers keep pace with the changing environment. Example applications could include; climate modelling, research repetition, speed breeding, gene editing, genetic modification, AI. By facilitating progression in each of these scenarios, vertical farming will certainly help shape the future of crop production.

“Technology made large populations possible; large populations now make technology indispensable…” (Krutch, 1967)

…but also indispensable are the natural resources that have afforded mankind the ability to grow healthy nutritious food for millennia. This must be front of mind when considering the application of any new technology. In the case of vertical farming, it must be used to supplement and support natural systems, it will not replace them.

Recommendations

- Limited opportunities for mainstream leaf and fruit crop production in vertical farms in the UK
- Vertical farming technology can be used to compliment existing glasshouse production practices
- Opportunities exist for the production of specialist crops inside vertical farms
- Vertical farms should be used to help reconnect society to food production and be used in education settings
- Through research and development, vertical farms must be used to aid the development of traditional crop production, particularly in the face of changing growing conditions

Looking Forwards

The Nuffield journey has been one of the most inspiring, thought provoking, and enjoyable experiences. The many conversations have opened my mind and enriched my perspectives. I am even hopeful that some have left the door of opportunity ajar. I look forward to exploring these further. Meantime, the arrival of our second child is imminent and my focus must turn to the greatest adventure of all… LIFE.

CHAPTER 10: ACKNOWLEDGEMENTS

I close by thanking all those who have made my Nuffield journey possible. Again, I refer to all those organisations and individuals listed in table 1, without them my exploration into vertical farming would not have been possible.

I was in awe at so many of the technologies I saw on my journey. Although I conclude by not recommending vertical farming be used for mainstream crop production in the UK, this is by no means a smear against any organisations who were kind enough to open their doors. This conclusion is a personal judgement, heavily influenced by my own perception of risk.

Again I thank all those involved in the Nuffield Farming Trust, in the UK and abroad. And importantly my sponsors, the Food Chain Scholarship and the Central Region Farmers Trust. Without their generosity this journey would not have been possible.

And finally, thank you to my family for their ongoing support and patience throughout the project.

<u>END</u>

REFERENCES

Connolly, A., 2023. *The Future of Agriculture.* s.l.:Irish Food Publisher Ltd.

FAO, 2024. *The State of Food Security and Nutrition in the World 2024,* Rome : Food and Agriculture Organisation .

H. S. C., 2023. *Sowing the seeds: A Blooming Emglish horticulture sector,* London: Authority of the House of Lords.

Krutch, J., 1967. *And Even If You Do: Essays on Man, Manners and Machines.* s.l.:s.n.

Statistica, 2023. *Projected vertical farming market worldwide from 2022 to 2032,* s.l.: s.n.

United Nations, 2024. *Population,* s.l.: s.n.

University of Oxford, 2022 . *Our World in Data,* s.l.: s.n.

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