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Are we making the right investments?

Written by:

Dr Edward Thomas Jones NSch

February 2025

A NUFFIELD FARMING SCHOLARSHIPS REPORT

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NUFFIELD Farming Scholarships

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

Title	Are we making the right investments?
Scholar	Dr Edward Thomas Jones
Sponsor	The Royal Welsh Agricultural Society
Objectives of Study Tour	For AgriTech to be successful in significantly and quickly increasing food production while reducing agriculture's impact on the planet, investors, entrepreneurs, farmers, and policymakers all need to have a similar and complementary vision for the industry. This study will explore and evaluate the AgriTech vision of investors (the providers of finance), entrepreneurs (those who seek-and-solve), farmers (food producers and users of technology), and policymakers (those who guide and regulate the industry). Are we all heading in the same direction?
Countries Visited	• France • Italy • The Netherlands • Republic of Ireland • Spain • USA
Messages	• The future of AgriTech is likely to be shaped by a wide range of factors, and it is difficult to predict exactly how the industry will evolve over time. • Technology will continue to play a critical role in the agriculture industry, and AgriTech will continue to be an important source of innovation and growth. • There are concerns that new technologies will create an unequal power dynamic between farmers and technology providers, with power increasingly consolidated in the hands of the latter. • Governments needs to ensure that all farmers have the capacity to benefit from AgriTech.

EXECUTIVE SUMMARY

With the global population set to rise from 8.2 billion in 2024 to 9.7 billion in 2050, world governments face an overwhelming dilemma: how to feed the future without putting an irreparable strain on our planet's already overburdened soils and oceans?

Our food system needs to be part of the solution to climate change while also meeting the challenge of feeding a growing population in a way that is sustainable for the planet. This can only be achieved through the adoption of new technologies and changes in business practices.

Global investment in AgriTech was $15.6 billion in 2023, accounting for 5.5% of all venture capital investment in that year (down from the height of $51.7 billion in 2021). Investors are continuing to invest in this sector because it represents a new approach to tackling climate change and the market potential is nearly limitless precisely because our appetites are, too. This allows entrepreneurs to have a profound impact on agriculture and the food system by ensuring they have the necessary finance to develop new business models and reshape production, consumption, transportation and delivery systems.

This project explores and evaluates the AgriTech vision of investors (the providers of finance), entrepreneurs (those who seek-and-solve), and policymakers (those who guide and regulate the industry) and considers: Are we all heading in the same direction?

Because of its expertise in a cross-section of technologies and disciplines, from sensors, AI and big data, to robotics, the USA has found itself to be at the forefront of AgriTech and the home to many start-ups in this field. Europe can also claim to have AgriTech champions. For example, Italy has successfully incorporated blockchain into its agricultural system. Because of this, the countries visited included USA, United Kingdom, Republic of Ireland, France, Italy, and Spain.

The investment argument for AgriTech is multifaceted. It is anticipated that second out of 10 people will live in cities by 2050, with an increased middle-class society. Middle-class people generally have healthier diets with more fresh fruits and vegetables.

The cost of traditional agriculture is becoming more expensive (when taking into account, for example, climate change, soil health, complex supply chains and water consumption). The $15.6bn of investment needs to have a direct impact on traditional farming methods to help tackle these costs.

Outputs of this study showed that alternative metrics are required, such as ‘return on energy’ or ‘environmental efficiency’, for technology investment decisions in traditional agriculture. Such measures will ensure the allocation of finance to support those technologies that will allow farmers to reduce their impact on the planet. The development of such technologies will need to be supported by the government which has the capacity to make investment decisions not based on financial returns alone. Further, traditional agriculture needs to learn and adopt the technologies from farming in controlled environment systems. While it is not possible to control all the elements of traditional agriculture, it is possible to measure each aspect and modify farming practices accordingly.

CONTENTS

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.

CONTACT DETAILS

Dr Edward Thomas Jones

Anglesey, Wales (UK)

edwardthjones@gmail.com

linkedin.com/in/edwardthomasjones

Nuffield Farming Scholars are available to speak to NFU Branches, agricultural discussion groups and similar organisations.

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Bullbrook, West Charlton, Charlton Mackrell, Somerset, TA11 7AL
email : office@nuffieldscholar.org
www.nuffieldscholar.org

CHAPTER 1. PERSONAL INTRODUCTION

"*What is not started will never get finished*"

Johann Wolfgang von Goethe

Figure 1 - Author: Dr Edward Thomas Jones
(Source: Author's own)

I come from a farming family and grew up on a beef and sheep farm on Anglesey, North Wales (UK). I am the son, grandson, and great grandson of farmers on both my father's and mother's side of the family; farming is in my blood! Not only was I fortunate to grow up on a farm but also lucky to feast on milk from cows in our field, fruit and vegetables from the garden, and eggs from free roaming chickens. I've always had a passion for farming but also a keen interest in banking and finance.

After completing my PhD in Economics at Bangor University I embarked upon a 10-year career in banking and specialised in the area of quantitative finance. I moved back to Anglesey in 2015 to become a Lecturer in Economics at Bangor Business School, Bangor University. This allowed me to build on my experience in the banking industry and continue developing cutting edge solutions to today's financial and economic problems. This appointment also gave me the opportunity to live and work (part-time) on the family beef and sheep farm and renovate my great-grandparents farmhouse, becoming the fourth-generation family member to live there.

Early in 2018, I decided to enrol on the Farming Connect (Welsh Government) AgriAcademy Rural Leadership Programme so that I could develop the skills and professional network needed to have a positive impact on the agricultural industry. This Programme included meeting with various industry leaders and policymakers in Brussels and in Cardiff which provided me with a unique insight

into the industry, and exposed me to a network of ambitious and dynamic individuals, all with a passion for farming. Nuffield Farming Scholarships were always a prominent feature of farming in Wales and something that I'd always hoped to apply for following the Rural Leadership Programme. I admired the philosophy of the Nuffield Foundation (and later the Nuffield Farming Scholarship Trust) of seeking new ideas and markets through travelling overseas, with the aim of developing farming and agricultural industries. In addition, the Scholarship provided me with a unique opportunity to combine my background in banking with my passion for agriculture.

CHAPTER 2. BACKGROUND TO MY STUDY TOPIC

While at university, I had the opportunity to study the dot.com bubble that occurred in the late-1990s. Share prices of internet companies increased much faster and higher than their peers due mostly to speculation caused by the excitement and euphoria of the new internet age. The frenzy of buying internet-based stocks was overwhelming, as many internet-based companies, so-called dot.coms, were starting up. Instead of focusing on the fundamental company analysis involving the study of company revenue generation potential and business plans, many investors focused on the wrong metrics such as web-traffic growth and the number of engineers employed. Investors' appetite for internet-based stock created a bubble that grew rapidly for several years before crashing in 2000.

As a banker, I witnessed first-hand the bursting of another bubble – the property market. This bubble had been growing since early 2000, driven partially by the low interest environment, and burst in 2008. Like the dot.com bubble, there had been a property buying frenzy with investors pouring money into the market with the belief that property prices never fall. During the growth of the bubble, newspapers were full of articles and supplements discussing the latest deals, price movements, and how property investors were making millions. Again, there was a failure by investors to conduct fundamental analysis when deciding on investment opportunities.

When I returned to live and work in Wales, I noticed that newspapers were beginning to be filled with articles about investments in AgriTech (i.e. the marriage of agriculture and new technology). These articles were not only appearing in the Farmers Weekly and Farmers Guardian, but in the Financial Times, Wall Street Journal, and Bloomberg, and they brought back memories of other bubbles that I had witnessed and experienced.

Figure 2 - An example of AgriTech newspaper articles

(Source: Financial Times, Wall Street Journal, Bloomberg.)

Booming investors' interest in AgriTech should hardly come as a surprise; the market potential is nearly limitless precisely because our appetites are, too. Investors allow entrepreneurs to have a profound impact on the industry by ensuring they have the necessary finance to develop new business models and reshape production, consumption, transportation and delivery systems. Farmers expect these new technologies will address the challenges and problems they face during the food production process. Policymakers hope that these entrepreneurs will help increase food production quickly to feed a much larger population in a way that is sustainable for the planet.

CHAPTER 3. AIM AND OBJECTIVES

"*Effort and courage are not enough without purpose and direction*"

John F. Kennedy

3.1 Aim

For AgriTech to be successful in significantly and quickly increasing food production while reducing agriculture's impact on the planet, investors, entrepreneurs, farmers, and policymakers all need to have a similar and complementary vision for the industry. This study explored and evaluated the AgriTech vision of investors (the providers of finance), entrepreneurs (those who seek-and-solve), farmers (food producers and users of technology), and policymakers (those who guide and regulate the industry). Are we all heading in the same direction?

3.2 Objectives

The objectives of the project were to:

1. Identify and understand key trends and technologies of the Fourth Industrial Revolution and their potential impact on agriculture and food production;
2. Determine investors' sentiment towards agriculture innovation and technology and the investment decision process;
3. Investigate where AgriTech entrepreneurs are focusing their efforts;
4. Evaluate farmers hopes and concerns towards the new technology being developed;
5. Understand policymakers' perception and understanding of AgriTech and the development of new technologies.

3.3 Case studies

Through desk-top study and discussion with practitioners and stakeholders, I have identified six current technologies that illustrate the potential of emerging opportunities in agriculture and food systems – including improving consumer nutrition, increasing supply chain efficiency and transparency and boosting farmer productivity and profitability. These six promising technologies are

presented as Case Studies in the Appendix. While some are in the early stages, these technologies could deliver significant positive impacts in food systems by 2050 (when the world population is expected to reach 9.7 billion).[1] At the same time, however, scaling these technologies poses challenges and risks that need to be addressed if they are to achieve their full impact.

This is not a definitive, static, or comprehensive list of technologies but, rather, it represents new and exciting market activity that reflects my discussions with investors, entrepreneurs, farmers and policymakers during this study.

[1] See www.un.org/en/global-issues/population#:~:text=The%20world%20in%202100,to%20improve%20in%20all%20countries.

CHAPTER 4. SEVERE ACUTE RESPIRATORY SYNDROME CORONAVIRUS 2 (COVID-19)

"Never let a good crisis go to waste"

Winston Churchill

4.1 The global pandemic

Figure 3 - Empty shelves during Covid-19
(Source: The Guardian)

On 31 December 2019, the World Health Organisation (WHO) received reports of an unknown virus in Wuhan, the capital of China's Hubei Province. This unknown virus caused the respiratory illness which later became known as severe acute respiratory syndrome coronavirus 2 (or Covid-19). It took just 12 weeks for the virus to bring the world to a halt, to put lives, societies, and economies in lockdown (i.e. government only permitted people to leave their homes for limited purposes, banned public gatherings, and closed non-essential shops). Other countries followed similar policies.

Chinese government records show that the first case of Covid-19 was discovered on 17 November 2019. By St David's Day (1 March 2020), Covid-19 cases had been detected in England, Northern Ireland, Scotland, and Wales.

4.2 Impact on agriculture and the food industry

The Covid-19 pandemic resulted in serious health risks and difficulties for food chains. For example, above normal demand and hoarding of some basic products affected the regular operation of the food supply chain during the early months, resulting in empty supermarket shelves and some retailers forced to limit quantities sold.

Food supply chains are, generally, quite agile and flexible and adaptable. What causes problems are very short, sharp shocks, and that's exactly what happened during the early months of the pandemic. Given the likelihood of more shocks in

the future, there is a need to make the food system more robust. Covid-19, therefore, provided a unique experiment to see which new AgriTech innovations provided support for the food production system during time of stress.

4.3 The food supply chain

Food supply chains have evolved over time and are designed for the pursuit of efficiency (i.e. providing the same or improved products at lower costs). Bas Groveneveld NSch (2019) found that trust between suppliers and buyers is critical for successful food supply chains. In a modern supply chain where tastes change rapidly, it is inefficient to have too much of a product in stock, and having minimal stocks also helps to identify quality problems with products. As a result, food retailers tend to adopt

- Just-In-Time (JIT), and
- Build-To-Order (BTO)

supply strategies. These strategies have been developed to provide a near-instant supply of the food products demanded by customers which is possible thanks to the transmission of information along the chain to reach a high level of market coordination.

Although modern food supply chains are designed to cope with variable demand, JIT and BTO strategies are not able to significantly increase the quantity they supply in the short term if there is a large surge in demand within a very short time, such as during the pandemic. Despite its shortfall during the pandemic, the JIT and BTO strategies continue to appeal to food retailers because they are hugely cost-effective. That is, the risk of keeping products is held elsewhere – there isn't a need to invest heavily in large warehouses as there is no need for the products until they are absolutely needed. While this is efficient for the retailers, it does mean that the risk is held elsewhere in the system, and it became evident during the pandemic that it is suppliers, producers, and consumers who are managing that risk. Additional food supply chain issues were created by labour shortages caused by Covid-19 (either due to illness or self-isolation). This affected every stage of the chain and made it less flexible.

4.4 The rise of the robots

With livestock needing daily attention, farm workers (and others in the food supply chain) were not furloughed during the pandemic. But the risks to people keeping the country fed was high. Significant outbreaks of the virus were reported in food factories and processing plants where staff had long periods working close together indoors. In June 2020, the 2Sisters Food Group suspended production at its chicken plant in Llangefni, Anglesey after confirming multiple cases of Covid-19. The pandemic had hit meat processing plants hard but this wasn't the case for Danish Crown, the largest meat processing company in Europe.

The Danish Crown meat processing facility in Horsens, Denmark, continued with business as usual during the pandemic because robots do most of the work. Infrared laser-emitting robots measure, extracts internal organs, and cut each pig carcass to the required dimensions. These robots are an example of how AgriTech innovations supported food production during time of stress (i.e. Covid-19). The pandemic is likely to accelerate the acceptance of slaughterhouse robots, especially with growing concerns about labour shortages.

Figure 4 - Robots process pig carcasses
(Source: Danish Crown virtual tour)

4.5 Food on demand

In a strategic business move, Nestlé's US unit added the food delivery start-up Freshly to their portfolio in 2020. Undoubtedly, the Covid-19 pandemic played a crucial part in driving up the customer bases and order volumes of food-delivery

technology firms, encompassing online grocers, restaurant-ordering applications, and even companies like Freshly that offer consumers the convenience of personalised meal delivery. In the midst of the surge in demand for food delivery services, Daily Harvest, a start-up that entered the market in 2014, successfully attracted funding from established venture capital funds and garnered the endorsement of well-known personalities such as Bobby Flay, Shaun White, and Haylie Duff. The combination of a compelling narrative and a well-designed product allows frozen food to meet the needs of today's health-conscious consumers. Through flavourful recipes created by in-house chefs and nutritionists using ingredients that are picked at peak ripeness and frozen right at the farm to lock in nutrients, Daily Harvest has been successful in explaining its supply chain differences and how frozen food can be healthy. Similarly, Real Good Foods and Mosaic have managed to attract health-conscious consumers by providing the perfect product and telling a captivating story. Due to their innovative steam fresh packaging system, Parsley Box, an Edinburgh-based start-up, is able to prepare and deliver delicious and convenient meals that can be stored for up to six months in the cupboard.

4.6 Concluding remarks

The impact of Covid-19 on the food supply chain may be the trigger needed for society to start thinking very hard about what a resilient food system has to be, and the evidence I've seen during the pandemic suggests that it's back to the local, with a strong relationship between producers and consumers, utilising modern technology. It's a measure of the impact of the pandemic on the food system that people were worrying where their next meal is coming from. A positive outcome of concerns about food security is that it has and will continue to drive demand by consumers for locally produced foods which can be purchased from local businesses.

CHAPTER 5. MY STUDY TOUR

'Why do you go away? So that you can come back. So that you can see the place you came from with new eyes and extra colours'

Terry Pratchett

5.1 Where I went

My initial plan was to focus on a set of countries that are at the forefront of the technology revolution playing out across the agriculture and food industry. Consequently, I targeted the USA and countries across Europe for my study tour.

Since its detection on 31 December 2019, Covid-19 had a devastating impact on people lives, societies, sectors (in particular global travel), and economies. This global pandemic, and related travel restrictions, had an adverse and unexpected impact on my Nuffield studies. Global travel restrictions meant that the initial phase of my study had to be completed through virtual communications (e.g. Zoom or Microsoft Teams meetings) and networking was done through LinkedIn and Twitter social media platforms. While this approach was different to those taken by previous Scholars, modern technology allowed me to meet (virtually) people and businesses from a wide variety of countries that I did not initially target.

To compliment these virtual meetings, I carried out the following (physical) travel for my Nuffield study:

- France: 1 trip in September 2022
- Italy: 1 trip in October 2022
- Netherlands: 1 trip in September 2022
- Republic of Ireland: 1 trip between March 2022 and April 2022
- Spain: 1 trip in October 2022
- USA: 2 trips between August 2022 and October 2022

Due to time constraints (as a result of the disruptions caused by the pandemic) I was unable to physically visit Silicon Valley but did meet with various people from the city virtually.

Contributors to my study fell into the following categories: investors, entrepreneurs, business owners, farmers, policymakers, and academics. Participants contributed through formal interviews and planned in-depth conversations, as well as spontaneous, unplanned meetings and discussions. This reflected the ever-increasing network I developed during this study and the close relationships nurtured with those working in the industry.

5.2 Why I chose those countries

American cities such as Boston and Silicon Valley are at the forefront of the digital technology (Third Industrial) revolution that started in the 1970s. Today, these cities are global centres for high technology, innovation and are the home of giants such as Apple, Microsoft and thousands of start-up companies. Being home to expertise in a cross-section of technologies and disciplines – from sensors, AI and big data to robotics and drones – has meant it is these cities and not rural areas that have found themselves at the forefront of AgriTech and home to many start-ups in this field. The USA isn't the only country to have an innovative AgriTech eco-system. Europe also claims to have AgriTech champions. For example, the Netherlands has made food science one of its strategic priorities and boasts one of the world's most efficient agricultural system.

Because of this, I travelled to those American and European countries that are at the forefront of the AgriTech revolution to study the vision of investors, entrepreneurs, farmers, and policymakers.

Figure 5 – Countries visited.
(Source: Google Maps)

CHAPTER 6. THE FOURTH AGRICULTURE REVOLUTION

'*Food is the new internet*'

Kimball Musk

6.1 The Fourth Industrial Revolution

The Fourth Industrial Revolution is fundamentally changing the way we live, work, and relate to one another by blurring the boundaries between the physical, digital and biological worlds. In its scale, scope, and complexity, the Fourth Industrial Revolution is unlike anything humankind has experienced before. The First Industrial Revolution spanned from about 1760 to around 1840. Triggered by the construction of railroads and the invention of the steam engine, it ushered in mechanical production. The Second Industrial Revolution, which started in the late 19th century and into the early 20th century, made mass production possible, fostered by the advent of electricity and the assembly line. The Third Industrial Revolution began in the 1960s. It is usually called the computer or digital revolution because it was catalysed by the development of semiconductors, mainframe computing (1960s), personal computing (1970s and '80s) and the internet (1990s). The Fourth Industrial Revolution, which began during the 2010s, is characterised by much more ubiquitous and mobile internet, by smaller and more powerful sensors, and by AI.

It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions. At the same time, the Fourth Industrial Revolution is driving disruptive technology innovations across many sectors.

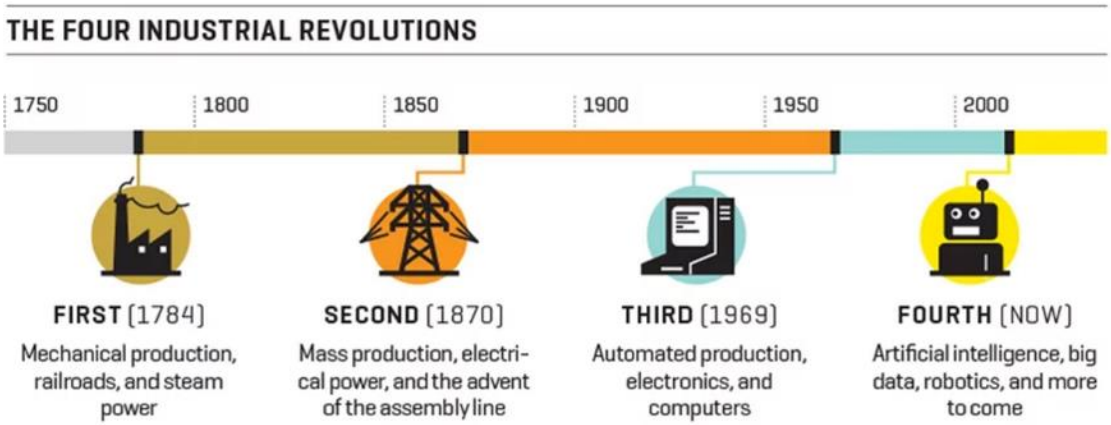


Figure 6 – Industrial Revolutions

(Source: Fourtune)

6.2 Defining AgriTech

During my study I have found that individuals had different definition and interpretation of AgriTech. The concept of AgriTech – the marriage of agriculture and new technology – isn't new. The tractor was first introduced on farms in the early 19th century and was considered a revolutionary new technology at the time as it allowed farmers to work more land in a shorter time. Cornell AgriTech celebrated its 140th anniversary in 2022 and provides a historical account of technology and innovation in the food and agriculture sectors across the years.

Most agreed that current AgriTech incorporates the technologies of the Fourth Industrial Revolution to improve efficiency, reduce labour requirements, increase yield, enhance food safety and traceability, as well as optimise the use of resources such as water, fertilizer and energy and reducing the impact of farming on environment. This can include a wide range of applications, such as precision agriculture, which uses sensors, drones, and other technologies to gather data about crop health, soil conditions, and weather patterns, and then uses this data to optimise planting, irrigation, and other agricultural activities.

6.3 Innovations in AgriTech

The recent advancements in Fourth Industrial Revolution technologies present a major opportunity to accelerate agriculture and food systems transformation.

AgriTech, also known as AgTech, comprises technological innovations and capabilities that change how food and other agricultural products are grown, harvested, packaged, stored, transported, processed and sold – making the farm-to-table process more efficient, sustainable and safe. These technologies could fundamentally shape the demand landscape, enhance value-chain linkages and increase the effectiveness of the production landscape. While many of these technological innovations are in the early stages of development, these technologies could deliver significant positive impacts in meeting the challenge of feeding a growing population in a way that is sustainable for the planet. However, both agriculture and food systems are behind many other sectors in adopting technology innovation; they lag significantly behind in harnessing the power of technology and making it widely accessible. As part of his 2019 study, Barry O'Boyle NSch found that farmers involvement in AgriTech start-ups remains low across the world and that there is concern regarding the practicality of new technology implemented on the farm.

The appendix provides six promising technologies that reflect the application of Fourth Industrial Revolution technologies in agriculture and food production.

6.4 Concluding remarks

Technologies of the Fourth Industrial Revolution are transforming the world around us. Improvements in the performance and cost of computing power, storage and bandwidth have led to the growth of new technologies. The spread of these technologies to agriculture have the potential to increase yields, lower costs, and reduced environmental impact. These are also empowering food producers to unlock new plant-based innovations and increasing their resilience to extreme weather events and climate change.

CHAPTER 7. THE INVESTOR

"Be fearful when others are greedy. Be greedy when others are fearful"

Warren Buffett

7.1 The AgriTech pitch

In 2018, the Intergovernmental Panel on Climate Change (IPCC) called for 'rapid, far-reaching and unprecedented changes in all aspects of society' to limit global warming to 1.5°C above pre-industrial levels so as to avoid the impact of climate change.[2] According to the IPCC report, warming of more than 2°C is likely to cause 'sustained food supply disruptions globally.' As one of the lead authors of the report put it: 'The potential risk of multi-breadbasket failure is increasing.' These pressures come at a time when there are growing demands on farmers to feed a growing population. The world's population is expected to increase to 9.7 billion by 2050. But this increase only tells half the story: the share of city-dwellers in the world's total population reached 50% in 2007 and is still rising. Despite this projected increase in world population, the number of people of working age is set to decline in the coming years. This means that there will be more mouths to feed at locations further away from rural areas (i.e., traditional areas for food production) with less young people available to join the workforce.

Leading climate scientists have concluded that how we farm and use our land is responsible for about 25% of global greenhouse gas emissions. If we include emissions caused by the processing, transport, storage, cooling and disposal of the food that we consume, then that figure rises to more than 40%; an unthinkable price for how we farm and eat.

[2] See IPCC 2018 report Global Warming of 1.5 °C. Intergovernmental Panel on Climate Change (available at: www.ipcc.ch/sr15/) and IPCC 2019 report Climate Change and Land. Intergovernmental Panel on Climate Change (available at: www.ipcc.ch/srccl/).

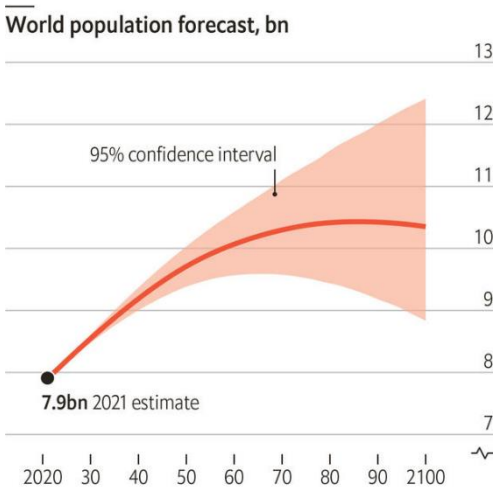


Figure 7 – Population forecasts

(Source: The Economist)

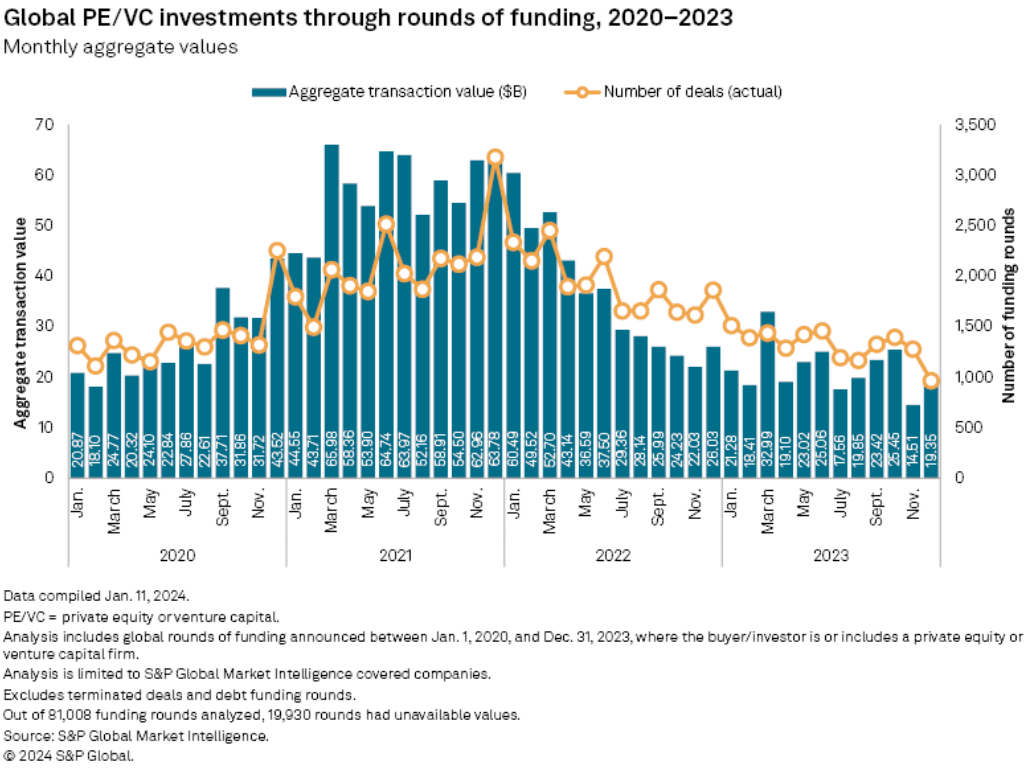
With global population set to rise from eight to nine billion between now and 2037, world governments are faced with an overwhelming dilemma: how to feed the future without putting irreparable strain on our planet's already overburdened soils and oceans? The AgriTech pitch to investors is that technology and innovation of the Fourth Industrial Revolution can help address these issues.

Our food system needs to be part of the solution to climate change while also meeting the challenge of feeding a growing population in a way that is sustainable for the planet. This can only be achieved through the adoption of new technology and changes in business practices.

7.2 Investors' appetite

There has been a steady increase in institutional investors exposure to agriculture since early-2000. Gus Selby NSch (2018) outlines the reasons for this increased interest, including strong underlying soft commodities fundamentals, good diversification, large market opportunities, and natural inflation hedge. His study did focus on farmland investment and farming businesses. New AgriTech technologies of the Fourth Industrial Revolution offer investors an alternative way to gain exposure to agriculture and food systems.

According to AgFunder, only $15.6 billion was invested in AgriTech during 2023. This was a 50% decline on the previous year, when $30.5 billion was invested.[3] Despite a record amount being invested in 2021 ($51.7 billion), it was only a fraction of the $643bn global venture investments made in that year (see Figure 6.2 for further information). 31% of the investments made in 2023 was in downstream technologies, which improves consumer conveniency but does little to help tackle climate change. $9.7 billion was invested in upstream technologies: those technologies that have a direct impact on agriculture and food production.



Data compiled Jan. 11, 2024.
PE/VC = private equity orventure capital.
Analysis includes global rounds of funding announced between Jan. 1, 2020, and Dec. 31, 2023, where the buyer/investor is or includes a private equity or venture capital firm.
Analysis is limited to S&P Global Market Intelligence covered companies.
Excludes terminated deals and debt funding rounds.
Out of 81,008 funding rounds analyzed, 19,930 rounds had unavailable values.
Source: S&P Global Market Intelligence.

Figure 8 – Global private equity/venture capital investments

(Source: S&P Global)

While opportunities for sizeable returns exist, many investors seeking to invest in technology innovations appear to have a more definite (and higher) expectation of financial returns than AgriTech-focused investments may offer. In addition, many AgriTech enterprises are still small. Their needs for capital can range from equity to debt, to working capital or even grants, depending on the task required

[3] See www.agfunder.com. AgFunder is a venture capital firm and one of the world's most active FoodTech and AgriTech investors.

to scale up or reach commercial viability. And the amounts required are likely to be substantially lower than the floor of most institutional investors.

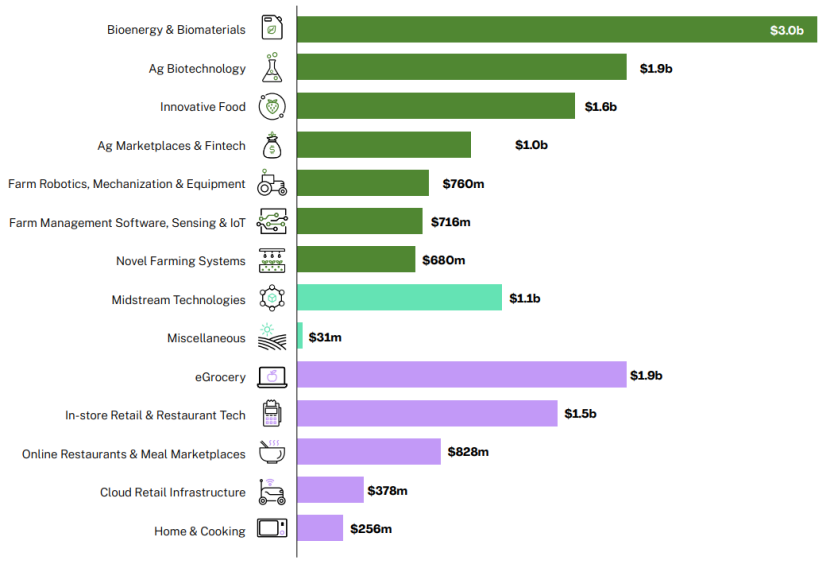


Figure 9 – Breakdown of investment in AgriTech (2023)

(Source: AgFunder)

7.3 The Venture Capital (VC) model

AgriTech innovations and early-stage companies are typically financed by Venture Capital (VC) firms. In this model, the VC firm provides capital to a start-up in exchange for equity ownership in the company. The VC model is typically used for companies that are too small or too risky for traditional bank lending but have the potential for significant growth and profitability.

In the VC model, the firm typically takes an active role in the company, providing not only financial resources but also strategic guidance and mentorship to help the company grow and succeed. In return, the VC firm expects a high rate of return on their investment when the company eventually goes public or is acquired by another company. However, it is difficult to accurately predict which start-ups will be successful, and many venture-backed companies do not achieve the expected level of success.

Studies have shown that the success rate of venture-backed companies is relatively low compared to other types of investments. For example, a study by the National Bureau of Economic Research found that around 75% of venture-

backed companies do not provide a positive return on investment.[4] However, it is worth noting that the remaining 25% of companies that do achieve success can often generate very high returns, which can make up for the losses from the unsuccessful investments.

7.4 Picking winners

The VC model is commonly employed in the technology and innovation sectors, as well as in the AgriTech industry, where start-ups may be focused on pioneering technologies or business models that could potentially revolutionise established markets. In recent years, the AgriTech industry has garnered growing attention from VC firms due to technological advancements that have the potential to transform agricultural practices, enhancing sustainability and efficiency. VC firms and individual investors strive to identify winning companies, those with a high probability of achieving substantial growth and profitability. There are many models to help comprehend an AgriTech investment opportunity. Four popular models are nice-to-haves, substitutes, solutions, and gospel (although VC firms tend not to invest in 'nice-to-haves').

7.4.1 Nice-to-haves

Despite their initial appeal, 'nice-to-haves' technologies rarely gain popularity due to the financial implications. These technologies offer users an ambiguous and incalculable advantage down the line, with an upfront cost. Since these technologies that fall under the category of 'nice-to-haves' don't bring about an immediate qualitative transformation for the user, there isn't a persistent drive to make use of the product. When the user's investment to use the product involves time and/or money, it creates an additional barrier to repurchasing. As a result, the overall performance of these technologies often suffers due to frequent turnover.

An AgriTech innovation that can be categorised as a 'nice-to-have' is an Enterprise Resource Planning (ERP) platform that enables farmers to automate and effectively manage core business processes for maximum efficiency. This technology is frequently presented as an upgraded alternative to a farmer's reliance on Excel spreadsheets, necessitating extensive integration and data

[4] See John Cochrane (2001) The risk and return of venture capital. National Bureau of Economic Research, 8066. Available at: https://www.nber.org/papers/w8066.

input, or interactive dashboards for informed decision-making. In most cases, customers do not see the value in the product and are reluctant to commit their time and finances to it.

7.4.2 Substitutes

A business's success heavily relies on its capability to understand and effectively manage CapEx and OpEx. CapEx is an abbreviation for capital expenditure. When it comes to AgriTech, CapEx denotes the financial resources invested by farmers in the procurement or enhancement of physical assets such as machinery, equipment, or facilities. OpEx is an abbreviation for operating expense. In other words, the expenditure that farmers face as part of their typical business operations. Unlike 'nice-to-haves', technologies that impact CapEx and OpEx appeal to farmers' functional needs.

The continuous increase in labour costs compared to gross farm income has been straining farmers' narrow profit margins. Labour expenses have become a major concern for farmers, and it's not solely the cost that poses challenges. In addition, farmers face challenges in terms of finding workers, retaining workers, and dealing with the extra burden of personnel management. Given these challenges, it comes as no surprise that the most prosperous AgriTech breakthroughs are centred around replacing manpower with investments in alternative technologies.

In order to alleviate the labour burden that farmers are grappling with, it is sensible for VC firms to allocate significant funds towards on-farm robotics, such as Root AI (which has been brought by AppHarvest).

Figure 10 – Root AI *(Source: TechCrunch)*

Given that labour costs are already a significant expense for farmers, investors can accurately assess the market demand and quantify the potential. In comparison to technologies that are seen as extras, 'substitutes' technologies have a minimal rate of change as farmers cannot function without them.

7.4.3 Solutions

'Solutions' are a type of technology that tends to be extremely addictive, and people often become more dependent on them as time goes on. Moreover, once a farmer has embraced these technologies, they become indispensable. The technology's role transitions from being a mere 'substitute' to becoming an essential 'solution' as more features are introduced, and the farmer discovers it resolves problems they weren't even aware of.

Innovative 'solutions' technologies are difficult to come across. The scarcity of 'solutions' technologies can be attributed to their exceptional growth rates, low churn rates, and high frequency of use, which are all components of product-market-fit.

Solintec is a good example of a 'solution'. Solintec's AI technology solution effectively manages the activities of equipment operators, guiding them to the required locations at specific times. Solintec has become the dominant platform in Brazil, utilised by nearly all major sugarcane producers, effectively overseeing almost 80% of all sugarcane acreage. Involving thousands of machines, it is crucial for everything to run smoothly and precisely. Today, running these operations smoothly would be unattainable without a solution such as Solintec.

7.4.4 Gospel

These technologies are highly sought-after investments for VC firms due to their ability to satisfy the functional and emotional needs of farmers. These technologies personify the farmer's desired image and aspirations and they show their dedication to these principles by actively adopting and promoting these technologies.

It is rare for 'gospel' technology developments to be achieved overnight. Such ventures, when they come into existence, stem from the founder's visionary beliefs and are highly resistant to competition. Their vulnerability lies in the perpetual necessity to uphold an elevated level of performance.

‘Gospel’ technologies are few and far between. But some exciting start-ups that show early signs as ‘gospel’ technologies are Simulate and Atomo Coffee. The former makes plant-based meat and aims to make the ‘Tesla of Chicken’, while the latter is making sustainable ‘molecular coffee’ without the coffee bean.

7.5 Concluding remarks

There is continued interest in investing in agriculture and associated technologies. Investments in AgriTech can be categorised as nice-to-haves, substitutes, solutions, and gospel, with the latter being rare. Those who closely examine innovation systems recognise that the VC model might not be the most suitable framework for all of them. The private sector, with its focus on fast profits and familiar patterns, now dominates innovation spending. As a result, major innovations often struggle to gain widespread adoption. Breakthrough innovation has been replaced with incremental innovation. So how can that change? A potential solution lies in the government's ability to unleash a deluge of investment.

CHAPTER 8. THE ENTREPRENEUR

'As a start-up CEO, I slept like a baby... I woke up every 2 hours and cried'

Ben Horowitz

8.1 The innovation process

Innovation involves bringing new approaches and technologies to fruitful application and the process can happen in one of two pathways:

- Seed-driven innovation, and
- Needs-driven innovation.

Throughout the 20th century, there was a more technology-driven innovation approach where a company worked to find matching applications for advancements in technology. The entrepreneur would begin with the seed and search for applications, following the so-called seed-driven (or supply-driven innovation) approach. The process of seed-driven innovation involves leveraging the capabilities of a technology to discover new applications. It encompasses the initial stages of creating and bringing to market innovative ideas, technologies, or products.

However, during the past two decades, a different strategy known as needs-driven innovation has emerged, placing significant importance on understanding users' needs through extensive market research. In this scenario, the entrepreneur begins by addressing the identified need. The entrepreneur in this scenario prioritises understanding the concerns and 'pain points' of users, such as farmers, by spending ample time with them. They subsequently strive to explore novel technological approaches to tackle these issues. Their innovation is motivated by the need to address specific challenges or meet specific needs, rather than solely focusing on creating new products or technologies.

In contrast to seed-driven innovation, needs-driven innovation is centred around addressing specific challenges or meeting specific requirements, rather than focusing on the creation of new technologies for the sake of innovation itself. Although both types of innovation have their merits, needs-driven innovation is often considered more valuable as it directly tackles specific challenges or problems.

8.2 Data is the new oil

Data is often referred to as the 'new oil' of AgriTech because of its potential value in improving agricultural operations and increasing yields. The agriculture industry's vast amount of data makes it a prime candidate for entrepreneurial innovation. Similar to oil, data possesses immense value and can be harnessed to fuel various applications and processes and it can be used to inform decisions about planting, irrigation, fertilization, and pest control, among other things.

Figure 11 – Maximising pid data

(*Source: AHDB*)

By combining traditional (e.g. seen through the eye and recorded through pencil and paper) and cutting-edge approaches (e.g. measured through sensors and recorded on a blockchain), farmers amass and record a diverse set of data points.

Examples seen during this study of data being used in AgriTech includes:

1. By gathering data on various factors like soil moisture, temperature, and nutrient levels, farmers can implement precision farming methods to maximise crop growth, resulting in higher yields and lower expenses.
2. Through data analysis, farmers can keep a close eye on the well-being of their crops, promptly spotting any signs of pests, diseases, or water stress, enabling them to intervene before these problems escalate.

3. Through the analysis of extensive data, farmers employ predictive modelling to forecast weather patterns and crop yields, enabling them to effectively plan and strategize.
4. The ability to gather information from sensors and various sources enables farmers to utilise automation technologies in order to streamline activities like planting, harvesting, and irrigation, resulting in improved efficiency and reduced labour expenses.
5. Utilising data for livestock monitoring empowers farmers to proactively address any arising health issues, ensuring the welfare of their animals.

The exponential rise in data produced by interconnected devices and the continuous progress in Artificial Intelligence (AI) are propelling the expansion of AgriTech, revolutionising the precision and automation of the agricultural ecosystem. To safeguard farmers and their businesses, data must be managed responsibly, with privacy and security in mind. It is crucial for farmers to understand the importance of their data and take appropriate measures to manage it. The value may not always be measured by the data's monetary worth or potential sale price. Rather, it should symbolise the significance of data to the farmer's economic well-being.

8.3 Farming in controlled environments

Farming in controlled environments, such as vertical farming, fully harnesses data for production optimisation. Sarah Hughes NSch (2017) examined the primary expenses associated with these systems, advancements in relevant technology, and the impact of automation and robotics. Sarah Hughes NSch concluded that businesses recognised the worth of data collection, plant-growing algorithms, and light manipulation techniques as valuable intellectual property. Following her study, there have been notable progressions in the realm of controlled environment farming, accompanied by substantial investments in this domain (such as AeroFarms' successful $100 million funding round in 2019).

AeroFarms raises $100m as investors rush to indoor farms

Vertical farms seek to grow new crops and reduce costs through technology and scale

Figure 12 – Investors rush to indoor farming (*Source: Financial Times*)

Figure 13 – AeroFarms

(*Source: AeroFarms*)

Many investors have been drawn to farming in controlled environments due to several compelling reasons. The ability to create a more predictable and consistent environment in controlled environments makes it easier to optimise growing conditions for specific crops and achieve higher yields, which is one of the reasons why investors are flocking to invest in this type of farming. By carefully managing the light, temperature, humidity, and nutrients, farming in controlled environments allows for decreased reliance on water, fertilisers, and pesticides. Through precise pest and disease control, it can decrease the reliance on chemicals that may pose risks to the environment and human health. This becomes particularly significant in areas where climatic or other environmental factors are not conducive for conventional outdoor agriculture. Furthermore, the utilisation of controlled environments enables crops to be grown continuously, regardless of the weather or seasons, thereby enhancing productivity and ensuring a consistent crop yield.

The advent of technologies like AI, artificial lighting, and robotics has revolutionised the feasibility and efficiency of farming in controlled environments. In response to the growing global population and the urgency of ensuring food security, controlled environment farming emerges as an efficient and sustainable means to feed local communities.

The visionaries behind 80 Acres Farm are spearheading a movement to overhaul the controlled environment food system. They envision a network of indoor farms in urban areas that sustainably grow pesticide-free crops year-round, fuelled by renewable energy. The driving force behind this vision is the recognition of numerous flaws within the current farming systems, especially in regard to the supply chain's inefficiencies in delivering food from farm to people. The founders are convinced that the supply chain's excessive length, complexity, and involvement of multiple stakeholders pose significant challenges, including food safety risks, potential damages, and a considerable loss of product value.

80 Acres Farm's presence inside a warehouse gives it an appearance more akin to a NASA setup rather than a conventional or contemporary agricultural operation. The farm's multistorey buildings are equipped with cutting-edge climate control systems and bathed in the soft glow of LED lights, creating the ideal environment for plants, all guided by data analysis. While Sarah Hughes NSch delved into the world of vertical farms in 2017, they now seem to have reached full maturity. The evolution of vertical farms has seen them progress from merely producing lettuce to effectively cultivating tomatoes, other vine crops, and soft fruits. Moreover, vertical farms, located within communities, offer a solution to the fragmented food supply chain by hiring individuals from the local community, thus reestablishing a direct link between people and their food supply.

The workers at 80 Acres Farms possess a unique set of skills, that differs from traditional farmers; they are more comfortable working with robots and computers, that reflect the technologies and growing methods employed by the company. The incorporation of sensors and cameras allows for the collection of data pertaining to room temperature, light, water, air flow, and other factors that have an impact on plant growth. Using advanced AI algorithms, the data is processed to identify the precise environmental conditions necessary for plants to flourish. These conditions are then replicated using cutting-edge technologies

such as robots, artificial lighting, and other state-of-the-art tools. This innovative approach transforms vertical farming into a profitable business venture that ensures the delivery of superior quality and highly nutritious food to consumers precisely when and where it is needed.

Figure 14 – 80 Acres Farms

(*Source: Urban Vine*)

80 Acres Farms is not the only player in this movement towards vertical farming. Like 80 acres, Aerofarms has made waves in the vertical farming industry, earning recognition and accolades for its groundbreaking approach to growing the highest quality plants to benefit humanity. Operating in multiple countries, the business specialises in cutting-edge vertical farming technology, with a notable demo farm in Abu Dhabi. Utilising former warehouses, nightclubs, paintball centres, and steel mills, Aerofarms boasts the largest vertical farm worldwide in terms of annual growing capacity.

The company ensures that its main products, such as rocket, watercress, and baby kale, are available at multiple retailers located within a 50-mile radius of its farms. By inventing its own lighting system, the company has transformed indoor vertical farming into an exceptionally precise and sustainable practice, enabling the growth of nutrient-rich crops without the need for sunlight, soil, or pesticides. Employees of the company, hailing from various sectors such as agriculture, biology, and data science, are strategically positioned across the globe.

A wave of advanced vertical farms is emerging worldwide, securing substantial investments. For instance, Ocado invested in Jones Food, a vertical farm in Scunthorpe, UK, renowned as Europe's largest vertical farm. With only two acres of vertical farming, Plenty is able to generate enough produce to match the output of a sprawling 720-acre agricultural plot. This impressive feat is accomplished by utilising robots and AI to carefully monitor and manage water usage, light, and temperature in the growing environment. With each passing day, the AI improves its ability to cultivate crops more efficiently and with enhanced quality by evaluating the effects of these variables.

8.4 The rise of the city farm

The traditional regions known for food production are not the primary locations for controlled environment farms; instead, they are predominantly found in urban cities. Growing food in different locations and using various methods aids in reducing the vulnerability of food supplies to disruptions and shocks. The presence of urban farms within communities could have alleviated the adverse effects of harvest labour shortages witnessed during the pandemic. Due to the substantial initial investment and ongoing energy expenses, urban farming currently focuses on cultivating a limited selection of premium crops, like leafy greens and herbs. As the technology advances, the range of crops cultivated indoors will broaden. It is important to highlight that growing food in urban areas is not a recent phenomenon, and there exists a lengthy tradition, even in the UK, of producing food within city limits.

Contrary to popular belief that urbanisation poses a major threat to biodiversity, cultivating food in urban areas holds the potential to enhance the population and variety of wildlife, while safeguarding their natural habitats. A case in point is the presence of community gardens and allotments, which attract and support pollinating insects by offering a wide array of fruiting and indigenous plants. With careful design and implementation, allotments and community gardens can offer tangible advantages to the preservation of biodiversity. By converting barren areas into thriving and productive gardens, and establishing connections between them, an environment can be created that promotes wildlife movement and enhances biodiversity. These important connections can be established

through the creation of canals and cycle paths. As progression into creating a variety of spaces for food production continues, particularly on rooftops and underground, an exciting puzzle to solve will involve discovering unique methods of connecting them in order to facilitate wildlife movement. Connecting rooftop gardens through innovative crossings, like green bridges, could provide wildlife with safe passage across bustling urban areas.

Figure 15 – Agritechture

(*Source: Agritechture*)

Sky Vegetables is known for their development and maintenance of rooftop greenhouses. Alongside the creation of an efficient rooftop hydroponic greenhouse system that guarantees a bountiful harvest, Sky Vegetables has also established an innovative approach to conducting business. As part of their distinctive business model, Sky Vegetables constructs their hydroponic greenhouse system on the premises of a partnering company, securing a long-term commitment from them to purchase the resulting produce and granting them a consistent supply of fresh, organic food throughout the year. The rooftop greenhouses are strategically designed to maximise profits by taking advantage of reduced delivery costs and the growing demand for locally sourced produce.

Figure 16 – Gotham Greens

(*Source: Gotham Greens*)

Gotham Greens chose the Greenpoint neighbourhood of Brooklyn as the site for its initial greenhouse facility. The construction of the state-of-the-art hydroponic greenhouse facility marked a significant departure from traditional approaches to urban farming. The rooftop greenhouse was constructed above the Whole Foods Market flagship Brooklyn store, ensuring a constant supply of fresh produce to the store and nearby restaurants throughout the year.

8.4 Local food

The term 'local' food can have different meanings depending on the person. Local food can be interpreted as food that is either grown or sold in close proximity to the consumer, such as at a farmers' market or within a certain distance from their residence. Local food is often perceived by consumers as being fresher, and they find comfort in knowing its origin and production methods. Moreover, consumers are attracted to the idea of bolstering their local economy by buying local, which can lead to the generation of new employment and higher incomes within the community.

Nevertheless, it is unrealistic and not always advantageous to exclusively procure food from local sources within a specific distance. Places with dense populations, extreme cold climates, or arid conditions, for instance, may have to obtain food from more distant locations. If relying on local sources is too restrictive, what

distance should be deemed acceptable for food transportation? When considering a regional approach to food production, the focus is on determining the optimal distance required to meet the demand for a wide range of food options while prioritising sustainability. Due to the variations in distances across different locations, the definition of a regional food system lacks universal boundaries, although it typically encompasses a significantly larger geographical area than the concept of 'local'.

8.5 Concluding remarks

Both the needs-driven and seeds-driven approaches have their merits and challenges, and relying on just one is insufficient. Instead, integrating them in a closed loop leads to accelerated innovation, which is crucial for transforming global food systems to feed nearly 10 billion people by 2050 while meeting UN Sustainable Development Goals. These food systems must be inclusive, sustainable, efficient, and nutritious. Achieving this transformation demands a comprehensive consideration of the environmental, economic, and health-related aspects of food systems. It also calls for sustained investment in technologies, management practices, policy innovation, and significant changes from current practices to enhance the food systems' resilience and productivity.

CHAPTER 9. THE FARMER

'Agriculture is our wisest pursuit, because it will in the end contribute most to real wealth, good morals and happiness'

Thomas Jefferson

9.1 Have we been here before?

The use of agricultural technology began some 10,000 years ago. The first tool was likely a simple tree branch used to mix and loosen the earth. This primitive hand tool, used to scratch the earth's surface and improve its fertility, also allowed for better moisture penetration. The resulting soil would be suitable for growing seeds. Simple hand tools eventually developed into the advanced farm machinery we see today.

With the help of animals, farmers could cultivate land faster and easier, resulting in higher yields. In time, the horse, ox, and human were successfully replaced by the tractor for on- and off-field work requiring mobility and muscle power.

Figure 17 – Early example of a tractor working on a farm

(*Source: Farmers Weekly*)

Early tractors, while cleverly engineered with ingenious parts, only handled relatively simple tasks and lacked adaptability to varied objects and work environments. The tractor didn't know which operation to perform, where, or how (the farmer was still required to make these decisions). Many different tools have been attached to tractors over time to help produce food.

Agriculture has been constantly innovating and using new technology to produce food. Farming began around 10,000 years ago, initiating the First Agriculture Revolution. Following Europe's end of feudalism, farmland was reorganised starting in the 17th century, this being the Second Agriculture Revolution. This revolution is perhaps best known as the British Agricultural Revolution, characterised by innovative crop rotation, selective livestock breeding, and new technology, which resulted in a substantial rise in agricultural yields. The Green Revolution (the Third Agricultural Revolution) involved the introduction of chemical fertilisers, pesticides, high-yield crops, and heavy machinery during the 1950s and 1960s.

Similar to the Fourth Industrial Revolution, the Fourth Agricultural Revolution is anticipated to change to the industry given new technologies, particularly the use of AI to make smarter planning decisions and power autonomous robots. New farm technologies are often discussed optimistically, seen as crucial for overcoming farming problems.

Figure 18 – Driverless tractor
(*Source: Farmers Weekly*)

However, many past agricultural innovations initially sparked similar excitement, only to become controversial later, like the first genetically modified crops. With the controversies surrounding emerging technologies like nanotechnology and driverless cars, unchecked enthusiasm for new agricultural technologies is unwise.

9.2 Farmers' CapEx and OpEx

The high cost of technology and equipment needed for agricultural production leads to substantial CapEx and OpEx in the sector. CapEx and OpEx decisions have substantial lasting effects on a farmer's capacity to produce and sell food. Therefore, farmers must make thoughtful investment choices and to ensure that they are making sound financial decisions. In addition, reduced farmer income hinders investment in technology upgrades, regardless of their advantages.

9.3 Adopting new technologies

The stage of farming operations dictates farmers' AgriTech investment choices, aligned with individual needs and goals. Some farmers adopt AgriTech early to boost productivity and operations, while others integrate it later for expansion or optimisation. Farmers' technology adoption is considerably impacted by peer-to-peer farm networking. Michael Ratcliffe NSch (2019) discovered that networking and awareness of other farms' technology adoption are key indicators of a farm's technological adaptation success. This idea is further explored by Ben Mclauchlan NSch (2020) in his study of New Zealand's food and fibre producers. A trust-based model, proposed by him, reduces obstacles to change, improving innovation centred around the consumer.

Many reasons explain why farmers invest in technological advancements. They expect these investments to boost efficiency, save time, and free them up for other tasks or expansion. Farmers believe that AgriTech can boost crop yields and quality, leading to higher profits through precision agriculture and other technologies. AgriTech should lower farmers' expenses on labour, water, and fertilizer, resulting in more sustainable farming. This technology should help farmers adjust to climate change, lessen its effects through precise irrigation, environmental control, and drought-resistant crops, and lessen farming's environmental effect by using fewer resources and chemicals.

The key factors that may influence a farmer's decision to invest in new technologies include:

1. Access to capital,
2. Return on investment, and

3. Goals and priorities.

Farmer investment in new technology hinges on anticipated returns, shaped by the technology itself and market factors. While this is understandable, financial objectives aren't sufficient to address climate change. Farmers committed to sustainability invest in eco-friendly technologies regardless of whether there's a financial benefit.

Farmers, especially smallholders, often face capital constraints, hindering their ability to obtain necessary financing (e.g. limited borrowing facilities due to insufficient security). Farmers may struggle to adopt new AgriTech technologies for other reasons. For example, despite the advantages of farming in controlled environments, the majority of farmers won't be able to replicate this type of system because of the number of uncontrolled factors (e.g. weather) faced in traditional agriculture. However, there is an opportunity for farmers to use some of the technologies used in farming in controlled environments (e.g. AI, cameras) to improve production and reduce their impact on the environment.

9.4 Issues with new technology adoption

History indicates that the agricultural industry's adoption of new technologies often leads to uneven distribution of benefits, leaving some farmers disadvantaged. The advantages of this type of change are frequently captured by technology companies and large farms, with smaller farms rarely benefiting. The Fourth Agricultural Revolution might leave farmers without ownership or full access to their farm's data from new technologies, or force reliance on third party companies for maintaining crucial, complex machinery: The new revolution could create unequal power dynamics. I found that some farmers were optimistic about a high-tech future. But others wondered whether those with less capital, poor broadband availability and IT skills, and access to advice on how to use the technology would be able to benefit. A dairy farmer told me that using robots had improved his work-life balance and allowed a farm worker to avoid dextrous tasks on the farm. But they had also created a different kind of stress due to the resulting information overload and the perception that the farmer needed to be monitoring data 24/7. There are also the potential risks or unintended consequences of certain technologies. For example, they may be concerned

about the environmental impacts of certain AgriTech practices, or about the potential for AgriTech to disrupt traditional farming practices or to disadvantage small farmers.

On the whole, farmers view new technologies as a way to improve the efficiency and productivity of their operations, and to address challenges such as food security and sustainability. Some farmers see AgriTech as a way to increase their profitability and competitiveness, by using technology to optimise their farming practices and reduce their costs. Others view AgriTech as a way to address specific challenges or needs, such as the need for more sustainable farming practices or the need to adapt to changing weather patterns.

9.5 Concluding remarks

To encourage adoption, farmers need to be involved in AgriTech innovation from the start: Their unique knowledge, usually handed down from generation to generation, ensures the technology developed is suitable and adaptable. A farmer's decision to use AgriTech hinges on their goals and priorities, with sustainability-minded farmers favouring eco-friendly technologies. Overall, many farmers are interested in using new technologies to improve their operations and increase yields, but they want to make sure they are making informed decisions that will benefit their farm and community in the long term.

CHAPTER 10. THE POLICYMAKER

'*Honesty is the best policy*'

Benjamin Franklin

10.1 The cost of traditional farming

UK agriculture has been successful. One of the greatest unsung triumphs of human progress is that most people are no longer working on the land. That is not to demean farming. Rather, it is to praise the monumental productivity growth in the industry, achieved almost entirely by the application of technology in the form of farm machinery, fertilisers and other agrochemicals, along with improvements in crops and livestock. Total Factor Productivity growth – the efficiency with which producers combine inputs to make outputs – has driven most of the growth in UK agricultural production.[5] In the early 1990s, over 2% of the UK labour force worked on a farm; now that proportion is below 1%.

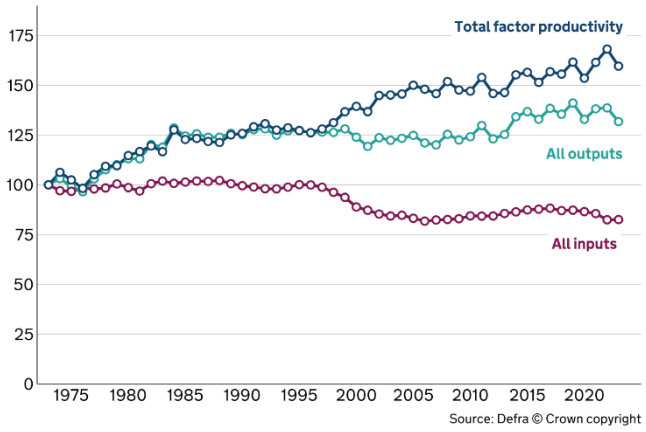


Figure 19 – Long term trends in total factor productivity

(*Source: Department for Environment, Food & Rural Affairs*)

But traditional farming methods are getting more expensive. When considering total cost, there is an increasing impact on the climate, water consumption, deterioration in soil health, and complex supply chains. The adverse impact of agriculture on the environment should not be a surprise as the interaction

[5] See Total Factor Productivity of the United Kingdom agricultural industry in 2023. Available at: www.gov.uk/government/statistics/total-factor-productivity-of-the-agricultural-industry/total-factor-productivity-of-the-united-kingdom-agricultural-industry-in-2023

between environmental policy and agriculture policy is poor according to Emily Norton NSch (2018).

10.2 Agriculture policies

Agricultural policies in Wales are shaped by its status as a devolved nation within the UK, with its unique rural landscape and economy. They are also influenced by broader UK policies and the legacy of EU Common Agricultural Policy (CAP) programs, as well as future trade and environmental considerations. Wales, like the rest of the UK, exited the EU and its Common Agricultural Policy in 2020. In response, the UK government introduced the Agriculture Act 2020, allowing devolved nations to set their own agricultural policies. The Welsh Government is gradually replacing CAP funding with devolved schemes to support farmers in transitioning to sustainable practices; it is developing the Sustainable Farming Scheme (SFS), which focuses on replacing direct payments with a system emphasising environmental outcomes. Farmers will be rewarded for sustainable land management practices such as improving biodiversity, carbon sequestration, and water quality. A key challenge for Wales is balancing environmental goals with economic viability for farmers while adapting to changing trade dynamics and ensuring competitive markets.

10.3 Innovation policies

Wales leverages its devolved powers to promote innovation within its economic and social framework. The Welsh Government Economic Action Plan encourages innovation as a driver for sustainable economic growth and resilience, with a focus on priority sectors like advanced manufacturing, energy, and health. The Welsh Government's innovation policies for AgriTech are centred on driving sustainability, enhancing productivity, and supporting rural economies. Through initiatives like the SFS, the government promotes the adoption of precision agriculture, renewable energy technologies, and smart farming practices to meet environmental and economic goals. Collaboration is encouraged via programs like Farming Connect, which connects farmers with research institutions such as Aberystwyth University's Institute of Biological, Environmental & Rural Sciences (IBERS), fostering the development and deployment of cutting-edge

technologies like AI, IoT, and drone systems. Funding support is provided through schemes like SMART Cymru, ensuring that start-ups, businesses and farmers can access the resources needed to innovate. These efforts align with broader policies to modernise agriculture, reduce carbon emissions, and strengthen Wales' position as a leader in sustainable AgriTech innovation.

10.4 Efficient and effective policies for AgriTech

It is difficult to assess the views of policymakers on AgriTech, as different policymakers have different perspectives on the industry. In general, policymakers view AgriTech as a way to improve the efficiency and productivity of the agriculture industry, and to address challenges such as food security and sustainability. Also, policymakers see AgriTech as a way to drive economic development and innovation, by fostering the growth of new industries and supporting the development of new technologies.

But policymakers are also concerned about the potential risks and unintended consequences of AgriTech, such as the impact on small farmers or the potential for negative environmental impacts. As such, they seek to regulate or guide the development and use of AgriTech in order to mitigate these risks and ensure that the benefits of the industry are shared fairly (these are also concerns shared by farmers).

Given the potentially transformative effects of upcoming technology on farming – positive and negative – it's vital that all stakeholders pause and reflect before the revolution takes hold. It must work for everyone, whether it be farmers (regardless of their size or enterprise), landowners, farm workers, rural communities or the wider public. However, most policymakers (and the media) are framing the Fourth Agricultural Revolution as overwhelmingly positive, without giving much focus to the potential negative consequences.

10.5 Four main concerns

While policymakers are generally positive about the potential benefits of AgriTech, they have concerns which can be grouped in four main areas: environmental, displacement, employment, and consumers.

- Environmental impacts: There is a risk that certain AgriTech practices could have a negative impact on the environment, such as through the inappropriate use of biotechnology and genomics. Policymakers are concerned about the potential for these technologies to cause harm to ecosystems or to undermine the sustainability activities of the agriculture industry.
- Displacement: AgriTech may also pose a threat to small farmers, as it can lead to the concentration of production in the hands of a few large companies. Policymakers are concerned about the impact of this trend on rural communities and on the diversity of the agriculture industry.
- Employment: The adoption of AgriTech could have an impact on employment in the agriculture industry, as new technology usually leads to the automation of certain tasks. Policymakers are concerned about the impact of this trend on workers and are seeking to mitigate any negative effects through regulatory or policy measures.
- Consumers: There are also consumer concerns about the safety and quality of foods produced using AgriTech, as well as about the potential for these technologies to be used in ways that are not transparent or accountable. Policymakers are concerned about the potential for these issues to undermine consumer trust in the agriculture industry and food production.

10.6 Reasons to be optimistic

There are several reasons why policymakers are overwhelming positive about AgriTech, as it has the potential to revolutionise the agriculture industry in several ways. It is anticipated that new technology will increase the efficiency and productivity of farming optimising processes such as planting, watering, and harvesting. This can help to boost food production and reduce waste, which is crucial as the global population continues to grow. AgriTech can improve food security by increasing the availability of food and reducing reliance on traditional agriculture practices that can be vulnerable to weather-related disruptions. In addition, new technology will contribute to sustainability by reducing the environmental impact of farming practices through the use of precision agriculture technologies that can help to minimise the use of water, pesticides, and other inputs. AgriTech can drive economic development by fostering the growth of new industries and creating jobs, as well as stimulating innovation and

encouraging the development of new technologies with wider benefits for society. It should be noted that these specific economic benefits are most likely to be felt in cities where most AgriTech start-ups are based.

10.7 Concluding remarks

British farming has enjoyed success, yet traditional practices are facing rising costs. The total cost increasingly includes farming's effects on climate, water, soil, and supply chains. Policymakers are largely enthusiastic about AgriTech due to its transformative potential for the agriculture industry. The expectation is that new technologies will increase the efficiency and productivity of farming while reducing the environmental impact of the industry. The challenge for policymakers is to amalgamate agriculture and innovation policies to foster an environment where AgriTech thrives and has a positive impact on producers and consumers.

CHAPTER 11. DISCUSSION

'The Nation that destroys its soil destroys itself'

Franklin D. Roosevelt

11.1 Farming in a concrete jungle

The industrial park between Manhattan and Brooklyn did not look like a promising place to grow food but something innovative and exciting was happening inside the warehouses amidst the concrete jungle. Located in the middle of the Big Apple, and many other cities, were start-ups using modern technology to revolutionise the world's food supply.

These businesses were growing fruit and vegetables in tightly controlled, indoor environments that used automation, cutting-edge plant science and vast amounts of data processing. Much of the underlying research for these types of farms comes from NASA which for decades competed with the USSR on how to grow food in the confined quarters of a spacecraft. After years of laboratory testing, the start-ups that I visited were now racing to scale-up commercial production and gain a dominant share of what they are convinced will be a vast market.

Without having to worry about outdoor scourges such as bad weather, pests, flooding or drought, the start-ups can choose from a wider and tastier variety of crops that might never otherwise make it to a shop. The controlled environment allows them to grow crops without pesticides or herbicides, with 90% less water than is used in traditional farming methods, and the moisture that growing plants emit is sucked up by dehumidifiers and recycled for irrigation.

With rows of crops piled one on top of another, several storeys high, farming in a controlled environment can produce many times more per acre than a traditional field. And because these 'farms' can, in theory, be located anywhere, produce can be grown in an industrial park beside the East River of Manhattan rather than having to truck it across the country. That means food can be transported from where it is grown to a shop shelf in hours – not days.

Figure 20 – Farming beside the East River (Manhattan)

(*Source: Author's own*)

11.2 The ace up farmers' sleeve

The Fourth Industrial Revolution is transforming all aspects of our economy and society, including the way we produce food. A lot of AgriTech is being developed not for farmers (e.g. farming in a controlled environment); however, these new technologies will have a considerable impact on the agriculture industry, even if farmers don't use them.

What impact will these urban-based start-ups have on Welsh farmers? Is the very term 'farmer', along with the practice and socio-cultural history with which they are associated, soon to be revolutionised?

It is not only Welsh farmers that are experiencing a period of transition to a new way of working. The AgriTech of the Fourth Industrial Revolution is not a unique challenge to Welsh agriculture. In his 2020 report, Phil Weir NSch outlined how New Zealand agriculture faced the challenge of rapidly moving towards a low carbon emissions society, restoring the health of water, reversing the decline in biodiversity and at the same time feeding a population of a country. Welsh farmers face similar challenges of feeding an increasing population while reducing the impact of the industry on the environment.

Food production is an important industry in Wales and one worth supporting and I believe that Welsh farmers have an ace up their sleeve.

It is something that has, until very recently, been overlooked and it is something that those start-ups that I visited will never have. It is the soil, or more specifically, its health and fertility, which offers solutions to several urgent problems from food production to wildlife conservation and carbon sequestration. Healthy and fertile soil will allow farmers to blend the roles of food producers, conservationists, carbon sequesters, leisure providers and linchpins of the rural economy and community. Those in the cities believe the future of food is in the latest technology and innovation; for farmers across Wales, the future lies underground.

Figure 21 – The ace up Welsh farmers' sleeve

(*Source: Author's own*)

11.3 A new love for food producers

One positive outcome from the pandemic is the newly discovered love for primary food producers as consumers become more worried about their food. Where does it come from? Will it be available? Who produced it and how? If Covid-19 has taught us anything, it is the value of foundational services such as health, social care, and food security. Lockdown measures may have caused lasting behaviour to change in relation to food consumption, marked by substantial shifts in shopping patterns, meal preparation and eating habits. The agriculture industry has a real opportunity to innovate to meet consumer needs, for instance through new experiences for consumers to enjoy food at home or tailoring their online experience to new ways of shopping.

People are appreciating the importance of food in their lives much more. They are enjoying eating as a family, enjoying taking time over food, discovering new flavours for the first time, and they are unlikely to give that up. And the supply chain is evolving in recognition of this new consumer attitudes and the operational challenges that occurred during the pandemic. New technology is revolutionising supply chains and shortening the distance between producers and consumers. For example, online platforms are changing the traditional food supply chain and building a stronger relationship between producers and consumers.

As Winston Churchill said: “Never let a good crisis go to waste”, and that should be the case with Covid-19. The food supply chain's pandemic-induced fragility may compel a critical societal reassessment of food system resilience. Food producers (especially small farmers) should capitalise on this and provide locally produced foods which can be purchased from local businesses.

CHAPTER 12. CONCLUSION AND RECOMMENDATIONS

'*Any sufficiently advanced technology is equivalent to magic*'

Arthur C. Clarke

12.1 Are we making the right investments?

AgriTech's future remains unpredictable, dependent on different factors such as technological innovation, economic patterns, and government policies. Nevertheless, the AgriTech growth is likely to continue, fuelled by rising food demand and the need to tackle food security and sustainability issues.

Some of the trends that may shape the future of AgriTech include:

1. Greater adoption of precision agriculture: Precision agriculture technologies such as GPS-based equipment and sensors are likely to become more widely adopted, allowing for more precise and efficient management of farming practices.
2. Increased use of AI and machine learning: Artificial intelligence (AI) and machine learning technologies are likely to play an increasingly important role in AgriTech, helping to optimise production and decision-making processes.
3. Growth of the plant-based protein market: The market for plant-based protein is expected to continue to grow, leading to increased investment in technologies related to plant-based protein production.
4. Increased focus on sustainability: Sustainability is likely to become an increasingly important focus in the AgriTech industry, as consumers and policymakers become more concerned about the environmental impacts of agriculture.

Overall, the future of AgriTech is likely to be shaped by a wide range of factors, and it is difficult to predict exactly how the industry will evolve over time. However, it is clear that technology will continue to play a critical role in the agriculture industry, and that AgriTech will continue to be an important source of innovation and growth in the coming years.

It is critical that home grown Welsh AgriTech capabilities are nurtured through business support, cluster development, knowledge transfer and inward investment and funding to enable proof of concept and scale up to commercial size.

12.2 Main conclusions of my study

Covid-19's effect on the food supply chain might force society to rethink what makes a resilient food system; the pandemic showed that local production, strong producer-consumer ties, and modern technology are key. Our world is being transformed by technologies of the Fourth Industrial Revolution. Using these technologies in food production may increase output, decrease expenses, and reduce the environmental footprint.

Despite a decline in the amount invested by VCs, there is continued interest in investing in agriculture and associated technologies. The VC model might not be suitable for AgriTech given its focus on fast profits and that government intervention and financial support may be better to encourage innovation in food systems. These food systems need to be inclusive, sustainable, efficient, and provide nutritious food. The transformation of the food system needs careful thought given its environmental, economic, and health effects. The success of AgriTech will depend on farmers participation in the innovation process. Farmers' generational knowledge can ensure the technology developed is suitability and adaptability.

British farming has been successful, but its costs (effects on climate, water, soil, and supply chains) are increasing. Because of this, farmers and policymakers are eager to adopt new technologies that will improve the efficiency and reduce the industry's impact on the environment. Despite this optimism, there are concerns that new technologies will create an unequal power dynamic, where farmers don't have full access to the data that their farm produces or forced reliance on companies to maintain crucial, complex machinery. The government needs to ensure that all farmers have the capacity to benefit from AgriTech by supporting those who are unable to access the finance necessary to invest in new technologies, poor broadband availability and IT skills, and access to advice on how to use the technology.

12.3 Recommendations

The new technologies of the Fourth Industrial Revolution offer promising opportunities to transform agriculture and food systems. While instances of sizeable returns from greater opportunities exist, many commercial investors seeking to invest in technology innovations appear to have a more definite and higher expectation of financial returns than what innovations may offer. In addition, many innovative enterprises are still small. Their needs for capital can range from equity to debt, to working capital or even grants, depending on the task required to scale up or reach commercial viability. The required amounts are expected to be significantly lower than the minimum threshold set by most commercial investors. Investors will need generous amounts of patience, a willingness to tolerate some unpredictability in returns and, perhaps, some new vehicles for both finding and making relatively small commitments efficiently.

Alternative metrics are required, such as 'return on energy' or 'environmental efficiency', for technology investment decisions in agriculture. Such measures will ensure the allocation of finance to support those technologies that will allow farmers to reduce their impact on the planet while increasing food production. The development of such technologies will need to be supported by the government which alone has the capacity to make investment decisions not based on financial returns. Also, instead of blind optimism, we need to identify where benefits and disadvantages of new agricultural technology will occur and for whom. This process must include a wide range of people to help create society-wide responsible visions for the future of farming.

12.4 Final thoughts

If we do not collaborate on the issues highlighted in this report, we will not create the change to the food system needed to adapt to climate change and other social problems. These are no longer tomorrow's problems.

Technology's disruptive power is clear, and some incredible start-ups are poised to significantly reshape their part of the industry. But that's the problem; despite their ambitions and potential, they're still just one piece of the broader industry and a wider global system. Food production is a worldwide industry intricately

tied to weather, climate, and other natural elements. Therefore, true transformation requires a multifaceted strategy.

Increased engagement and collaboration within the AgriTech sector facilitates quicker determination of successful and unsuccessful changes to the food system. Most AgriTech start-ups aim to improve the food system, fight climate change, or positively impact people's lives. Different approaches don't automatically mean other approaches are wrong or that there isn’t space for it alongside what someone else is doing.

If this report is anything, it is a plea for open-mindedness, compromise, civility, and to stop any childish food fights!

CHAPTER 13. AFTER MY STUDY TOUR

'*The best way to predict the future is to create it*'

Peter Drucker

13.1 What next?

To butcher the quote by Terry Pratchett, I went away so that I could come back and see Welsh agriculture with new eyes and extra colours. I have been fortunate that my Nuffield journey gave me a unique opportunity to combine my background in banking with my passion for agriculture and meet with investors, entrepreneurs, farmers, and policymakers from all across the world.

Travelling provided me with different perspectives on agriculture and helped me understand the role of Welsh farming in the global food production system. I saw firsthand the application of the latest technologies that are being developed which will allow us to increase food production while also minimising our impact on the planet. I also got to meet the decision-makers that are allowing these technologies to flourish and have a real impact.

The Nuffield Farming Scholarship has enhanced my knowledge of AgriTech and other areas of agriculture, horticulture, and aquaculture, in addition to my leadership skills; I have learned to listen and ask insightful questions that focuses on understanding and not judgement. It has ignited a fire within me to make a difference to Welsh farming, UK agriculture, and the global food production system. This report is part of that journey to have an impact. It brings relevant knowledge on the AgriTech investment process, as well as identifying key technologies that are being developed, and farmers' and policymakers' views of these. I continue to disseminate the results at a number of conferences, speaking events, articles, and blogs and I am determined to give back to the next generation, ensuring that Welsh farming thrives, becomes a hotbed of innovation, while also being a role model of how to care for the environment.

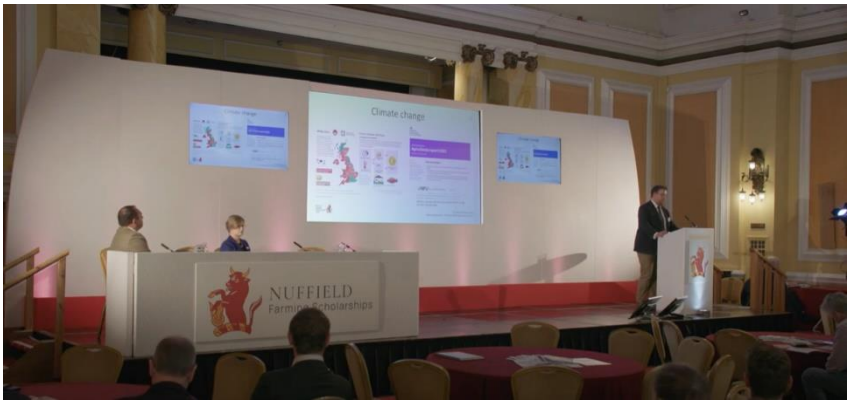


Figure 22 – 2022 Nuffield Farming Conference

(*Source: Nuffield Farming Trust*)

13.2 A priceless network

Being a Nuffield Scholar has given me an invaluable network of thinkers and doers, who have supported me during my study and will, I'm sure, be an invaluable source of knowledge and advice as I continue to seek new ways of impacting the food production system. I relished the opportunity I've had to speak with other Scholars and those within the industry, all of whom have been generous with their time. This network opened doors during my Nuffield journey and continues to offer access to industry leaders, experts and resources, which has supported my professional growth and gave me a unique insight into AgriTech and food production. It offered guidance and perspectives that helped me navigate complex situations and allowed me to make informed decisions and achieve my goals. I am proud to be a member of this network and will maintain strong links with as many as possible and continue to give back.

13.3 A Scholar for life

My journey as a Nuffield Scholar began in Warwickshire, England at the 2019 Nuffield Conference when I was presented with my award by His Royal Highness The Duke of Gloucester. By the time I had arrived at Queensland, Australia for the Contemporary Scholars Conference (CSC) in March 2020, Covid-19 had become widespread in most countries. The global pandemic meant my Nuffield journey did not have a conventional start. While the start of this study began with virtual meetings, it reverted to national and international travel in 2022.

During the difficult years of the pandemic, I was reminded that I am a Scholar for life and not just the duration of my study. This means I have committed to the pursuit of knowledge and learning throughout my entire life and using it for the benefit of others. This study is only the start of my journey. It has given me the foundational knowledge to understand the real issues, challenges and opportunities, and a unique network to help me grow and learn of new innovations, ideas, and solutions. I will continue to have the mindset of continuous learning and intellectual curiosity and being open to learning from others.

Figure 23 – 2019 Nuffield farming Conference

(*Source: Nuffield Farming Trust*)

DIOLCH – THANKS

'Thank you, and may your God go with you'

Dave Allen

Hoffwn ddiolch i bawb a alluogodd i mi gwblhau'r Ysgoloriaeth hon; mae yna lawer gormod o bobl i'w rhestru yma. Roedd pobl, a oedd gynt yn ddieithriaid llwyr i mi, yn hael â'u hamser a'u hamynedd, ac wedi fy helpu i ddeall y gwir faterion, heriau a chyfleoedd. Byddaf yn ddiolchgar i chi i gyd am byth.

Rhaid diolch yn arbennig i Ymddiriedolaeth Ysgoloriaethau Ffermio Nuffield am roi'r cyfle hwn i mi, ac i gefnogaeth ac amynedd cyson Mike Vacher a'i dîm gwych. Hoffwn ddiolch yn ddiffuant a chydnabod y cymorth ariannol a gefais gan Gymdeithas Amaethyddol Frenhinol Cymru, a'm galluogodd i gychwyn ar y daith gofiadwy hon. Yn ogystal, hoffwn ddiolch hefyd i Mr Wyn Owen NSch a wnaeth fy atgoffa fy mod yn 'Ysgolor am oes' ac nid am gyfnod yr astudiaeth hon.

Ni fyddai'r astudiaeth hon wedi bod yn bosibl heb gefnogaeth barhaus fy ngwraig Brioni, fy nheulu a'm ffrindiau. Diolch.

I would like to thank everyone who enabled me to complete this Scholarship; there are far too many people to list here. People, who were previously complete strangers to me, were generous with their time and patience, and helped me understand the real issues, challenges, and opportunities. I will forever be grateful to you all.

A special thank you must go to the Nuffield Farming Scholarships Trust for providing me with this opportunity, and to the constant support and patience of Mike Vacher and his fantastic team. I would sincerely like to thank and acknowledge the financial support I received from the Royal Welsh Agricultural Society, which enabled me to embark on this memorable journey. In addition, I would also like to thank Mr Wyn Owen NSch who reminded me that I am 'a Scholar for life' and not for the duration of this study.

This study would not have been possible without the continued unfaltering support of my wife Brioni, my family and friends. Thank you.

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APPENDIX

This Appendix provides information on six technologies, identified during this study, that illustrate the potential impact of innovations from the Fourth Industrial Revolution on the agriculture and food systems. This is not a definitive, static, or comprehensive list of technologies but represents new and exciting market activity that reflects desk-top study and discussions with investors, entrepreneurs, farmers and policymakers. These six promising technologies have the potential to transform our food system, allowing us to increase food production while also reducing our impact on the climate.

Each Case Study analyses the market position of the technology and evaluates the strategic options, development, and anticipated future difficulties. They consider their strength and weaknesses and gives a deeper understanding of the external environment and help to assess potential risks and threats to the success and survival of the technologies.

These Case Studies were disseminated via my blog, which aimed to promote discussion surrounding these technologies and share initial findings from my study. This blog is available at: https://medium.com/investments-in-agritech.

CASE STUDY 1 - ARTIFICIAL INTELLIGENCE (AI)

In the first half of the 20th century, science fiction familiarised the world with the concept of artificially intelligent robots. It began with the 'heartless' Tin man from the Wizard of Oz and continued with the humanoid robot that impersonated Maria in Metropolis. By the 1950s, there was a generation of scientists, mathematicians, and philosophers with the concept of Artificial Intelligence (AI) culturally assimilated in their minds. One such person was Alan Turing, a young British polymath who explored the mathematical possibility of AI. Turing suggested that humans use available information as well as reason in order to solve problems and make decisions, so why can't machines do the same thing? This was the logical framework of his 1950 paper in which he discussed how to build intelligent machines and how to test their intelligence.

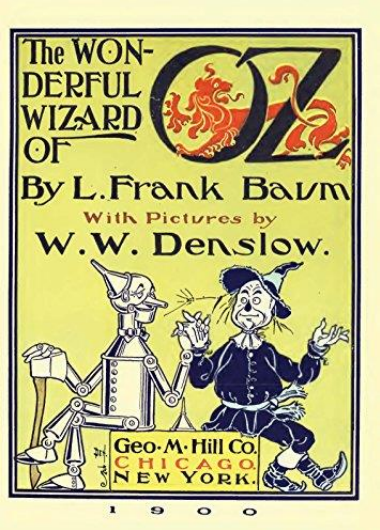

Figure A.1 – The Wonderful Wizard of Oz by L. Frank Baum

(*Source: Wikipedia*)

AI algorithms are designed to make decisions, often using real-time data. They are unlike passive machines that are capable only of mechanical or predetermined responses. Using sensors, digital data, or remote inputs, they combine information from a variety of different sources, analyse the material instantly, and act on the insights derived from those data. As such, they are

designed by humans with intentionality and reach conclusions based on their instant analysis.

The public became interested in the application of AI when, in 1997, the reigning world chess champion and grandmaster Gary Kasparov was defeated by IBM's Deep Blue, a chess-playing computer program. But AI has achieved more than just winning chess games. Its effect can be seen in homes, businesses and even public spaces. In its embodied form of robots, it will soon be driving cars, stocking warehouses and caring for the young and elderly. Silicon Valley, in San Francisco, is home to a number of established companies and start-ups in the area of AI, which benefit from a dense concentration of high-tech companies and leading universities.

Figure A.2 – How does AI work

(*Source: YouTube*)

AI is transforming the world at a rapid and accelerating pace, offering huge potential, but also posing social and economic challenges. Humans are naturally fearful of machines — this is a constant. Technological advancements tend to outpace cultural shifts. Unsurprisingly, much of the public discussion on AI has focused on recent controversies around facial recognition, automated decision-making and exam algorithms. Job losses due to automation have further underscored the need for AI systems to become better regulated and more ethical.

But while the risks posed by AI have dominated the headlines, behind the scenes there is a quiet revolution underway as a new crop of start-ups are developing AI systems to tackle the greatest challenges facing humanity. This revolution also includes transforming the agriculture industry in supporting its efforts to increase food production and tackle climate change. While agriculture is one of the oldest and most important professions in the world, the industry is ripe for transformation by AI because of the hundreds of thousands of data points it produces on a daily basis. Recent advances in AI have depended upon building up systems from the bottom by training them on mountains of data. The future of AI is likely to rely less on bottom-up big data and more on top-down reasoning that more closely resembles the way humans approach problems and tasks. Machines will become less artificial and more intelligent. However, data will still play a role in AI. Weather conditions, temperature, water usage, soil conditions, crop yields, and livestock weight are only a few examples of the type of data points collected on a farm, all of which can feed into AI and help optimise production and minimise devastating consequences for biodiversity, freshwater supplies, and natural ecosystems.

As the world population continues to grow and land becomes scarcer, ways in which AI is helping to feed the hungry while saving the planet are:

1. In recent years, many farmers have begun to consult data about essential variables like soil, crops, livestock, and weather. Yet few if any have had access to advanced digital tools that would help to turn these data into valuable, actionable insights. There are now AI start-ups that focus on training powerful algorithms on this data to improve the efficiency and performance of traditional farms For example, Israel's Prospera collects 50 million data points every day across 4,700 fields and analyses them with AI to identify pest and disease outbreaks and uncover new opportunities to increase yields, reduce pollution and eliminate waste. Welsh-based Agxio received £750,000 investment in June 2020 to support the development of advanced data science and AI solutions in agriculture.
2. Other AI-based enterprises are focused on developing entirely new approaches to farming. Plenty and Aerofarms are pioneering vertical indoor farming, using computer vision and AI algorithms to optimise nutrient inputs and increase yields in real-time. Root AI is also using

computer vision but combining it with advanced robots to detect when the fruit is ripe and harvest it at its prime. While AI-driven indoor farming (or vertical farming) is unlikely to feed the whole planet by 2050, the more of it that can be done, the better.

3. AI is not only being used to improve agricultural productivity but to take on one of the most environmentally damaging parts of the food sector: industrial meat production. Chile-based NotCo and Brazil-based Fazenda Futuro have both developed AI tools that analyse vast amounts of plant data to identify the best approaches to replicating the taste and texture of meat using only plant-based materials. The market is clearly paying attention: Fazenda Futuro raised US$21.5 million in September 2020 from investors. While the growing shift to AI-powered plant-based meat alternatives is poised to yield enormous environmental benefits, it is also expected to bring financial benefits too.

Governments too are realising the value of AI in feeding their citizens and improving their agricultural productivity. For example, the new European Commission budget proposal looks to support farmers to deliver the green and digital transition. The Government of India and the State of Telangana identify high-value use cases for AI in agriculture, develop innovative AI solutions, and drive their widespread adoption. Governments across the world are recognising that improving the food system is critically important to achieving several of the Sustainable Development Goals (SDG) proposed by the United Nations. No one technology is going to address the challenges. But AI can work with other technologies and business practices to allow farmers to run more efficiently to produce the fundamental staples of our dietary lifestyles.

CASE STUDY 2 – AUGMENTED REALITY (AR)

Augmented reality, or AR, has been called the next big paradigm shift in computing, tantamount to the kind of transformational changes that the internet and the smartphone made in the field. AR is the interaction of superimposed data, graphics, audio and other sensory enhancements over a real-world environment that is displayed in real-time — the world we actually see, the world within which we actually work, the world our citizens navigate every day. AR should not be confused with virtual reality, which places the user in a created, virtual, world. The experience of AR is simple but powerful — it is contextual, visual and even visceral. Global technology leaders, including Google, Microsoft, Facebook, Snapchat and Apple, have all staked significant claims in the AR 'digital' land rush.

Figure A.3 – Pokémon Go
(*Source: The New York Times*)

The AR game Pokémon Go has been downloaded more than 800m times, making it one of the most successful examples of location-based media to date. However, AR is useful for far more than just mobile games.

All over the world, restaurants are using virtual presentations of their dishes to attract new customers, promote their menu, and upsell other items. Food tech company QReal (formerly Kabaq) has developed an AR platform that is

expanding in the restaurant and foodservice space given how the technology enables food makers to present products in 3D and provide visualisation of dishes using advanced scanning technology. The start-up has already provided AR experience with Dunkin' Donuts, Dominos, Subway, Panera, and KitchenAid. The company created 3D models of food items for use in AR technology applications using photogrammetry. Photogrammetry is the science of using photographs to take measurements that are used to construct 3D models.

Figure A.4 – Dominos use of AR technology developed by QReal

(*Source: Dominos*)

Fast-casual burger chain Bareburger is another example. They partnered with QReal to revamp their menu and create an experience unlike any other. QReal revamped Bareburger's menu by creating a Snapchat filter that showed customers an immersive virtual experience of their dishes. Diners only have to scan a QR code using Snapchat to see the virtual menu. From there, guests can rotate the augmented menu item and have a good understanding of what the dish looks like. Having lifelike 3D images of food on the menu will certainly enhance guests' experience and improve dine-in traffic. However, that's not the only part of the restaurant business that may benefit from using augmented reality capabilities. Takeout ordering is another. For some people, ordering takeout involves a bit of guesswork. But with AR technologies, consumers might start making better purchase decisions.

Restaurants are using AR to take customer experience to a whole new level. AR helps them elevate the brand experience and educate their consumers about what they stand for. Restaurants around the world have installed Skullmapping's project Le Petit Chef, an AR dining experience that displays 3D projections onto customers' dining tables. A tiny chef entertains the guest by hauling ingredients around the table and demonstrating how their meals are prepared. This brief, immersive experience happens while their actual meals are being cooked in the kitchen. After the presentation, the meals are served. California-based Pinot Noir specialist, Siduri, is taking a different approach with their AR experience. The new AR experience by Siduri puts the company founder (Adam Lee) on the table or other flat surfaces. In one experience, Lee is accompanied by three giant wine bottles; in an approachable, dating game style experience, Lee introduces the wines in terms of their flavour profiles. In another experience, the users participate in a competition to open a virtual bottle of wine with a virtual waiter's knife. Meanwhile, Lee explains the benefit of using corks. The third experience shows comparisons between the numbers of critical rewards won by Siduri compared to other Pinot Noirs.

At a time when travel is restricted due to Covid-19, Nestlé is expanding the use of augmented reality technology to provide remote support to its production and R&D sites and to connect with suppliers. Experts across the company and external providers are using remote assistance tools to connect with people at factories and other facilities around the globe, which raises efficiency across operations and allowed experts to support multiple projects at the same time. Using tools such as remote desktop, smart glasses, 360-degree cameras and 3D software, specialists can advise on complex tasks without needing to travel to the site. The technology has been used in projects such as the set-up or redesign of factory lines, vital maintenance work and checking equipment with suppliers.

Truly speaking AR technology is quite new to the agriculture field and has not yet been utilised to the best of its abilities. However, there are immense possibilities if it is applied in the said field in more varied and purposeful ways. As simple as it may seem, farming is one of the most laborious trades on the planet. Both crop farming and livestock farming are highly time-and resource-intensive, need special skills, and require physical labour. In this regard, AR can do a lot to assist farmers in streamlining their operations:

1. Facilitating decision-making — AR plays a significant role in precision farming. By offering farmers instant access to valuable data, AR can assist them in making accurate and timely decisions. Surely, collecting and analysing this data will demand using AR technology in parallel with AI analytics and the IoT, but the outcomes may give farmers an unprecedented competitive edge.
2. Accelerating training — Today's farmers have a lot to learn if they want to stay updated on the latest trends in the industry. AR minimises training time and enables farm personnel to learn on the go by delivering micro-learning content in real-time.
3. Reducing staffing expenses — Coupled with monitoring technology and AI for precision farming, AR can reduce the need to hire farm workers to regularly check on the state of the crops or livestock. On top of that, farmers can now hire personnel with only basic skills and knowledge and train them using real-time AR training.
4. Preventing disruptions and downtime — AR can facilitate the preventive maintenance of farm machinery. With AR content offering timely and informative updates, farmers can detect the breakages, defects or malfunctions, and schedule timely repairs.

AR is a great way to visualise complex ideas, like what all that code does, or how to cultivate plants in restricted conditions. One company with a view of a technological future is Plant Vision, which are aiming to create a decentralised collaborative AI ledger for plant breeding and optimisation. Using AR, each grower receives equity in the footage they annotate. Recorded in the Red Green Blue (RGB) colour spectrum, infrared for early disease detection and ultraviolet for flowering and pollination, the growers then add this data to a digital ledger to collaboratively train the AI system, and they receive value over time as their data is put into commercial use. Cainthus uses machine vision technology to monitor the health and well-being of crops and livestock. Using computer vision and artificial intelligence, Cainthus smart cameras observe nutritional, behavioural, health and environmental activities that can impact production. It then translates this visual information into actionable insights that enable the farmer to make data-driven decisions to improve farm operations and animal health.

CASE STUDY 3 – BIOTECHNOLOGY AND GENOMICS

For about 10,000 years, farmers have been improving wild plants and animals through the selection and breeding of desirable characteristics. Initially, this process was done unwittingly but ultimately with the intention of developing improved food crops and livestock. Advancements in technology have allowed farmers to use biotechnology to focus on addressing problems in all areas of agricultural production and processing. This includes plant breeding to raise and stabilise yields, to improve resistance to pests, diseases and abiotic stresses such as drought and cold, and to enhance the nutritional content of foods. The main areas of biotechnology (and genomics) in agriculture are:

- Gene editing for multi-trait seed improvements
- Microbiome technologies to enhance crop resilience
- Biological-based crop protection and micronutrients for soil management

Historically, there have been three ways to improve seeds: open pollination, hybridity and genetic modification. Thanks to advancements in technologies, there is now a fourth: genome editing (or gene editing). Like open-pollinated and hybrid breeding, gene editing manipulates genes, though more efficiently and precisely. It typically exploits the vast diversity of genes that exist within a plant species. In this sense, it differs from gene modification that can introduce traits from other species. Gene editing can help solve a range of food-related concerns for both consumers and growers: e.g. reduced-gluten wheat that could be tolerated by those with sensitivities, a mushroom that doesn't brown when bruised or cut, soybeans lower in unhealthy fats, and even protecting the global chocolate supply.

There are still scientific hurdles to achieve the anticipated benefits at low costs and development time, in addition to regulatory barriers. There are associated risks with gene editing in agriculture. First, given the transaction costs of serving small-scale farms, seed innovation is likely to be geared first towards developed countries and small farms run the risk of being left out. Second, the concentration of intellectual property in relatively few hands could create economic oligopolies

or monopolies that would limit the technology's use to only a few types of seeds. This could result in less biodiversity. Third, if used irresponsibly, gene editing could present risks to human health and environmental biodiversity.

In the same way that the human microbiome is revolutionising human medicine, the plant microbiome (the environment of microorganisms in and around the roots, in the soil, on the leaves and within the plant itself) has the potential to transform agriculture. When applied directly to the surface of seeds and to plants themselves, microbiome technologies can complement or replace chemical agriculture products.

The potential impacts are abundant; healthier crops that are more resistant to droughts, low nitrogen, high temperatures, salty soils and harmful insects. To realise this potential, continued advancement is needed in the methods for analysing agro-ecological conditions and in creating products for specific contexts. To better support proactive regulation, more research is needed to better understand the effects of microbiomes on the environment as well as on nutrition and health (however microbes are already present everywhere in the environment and in the food supply).

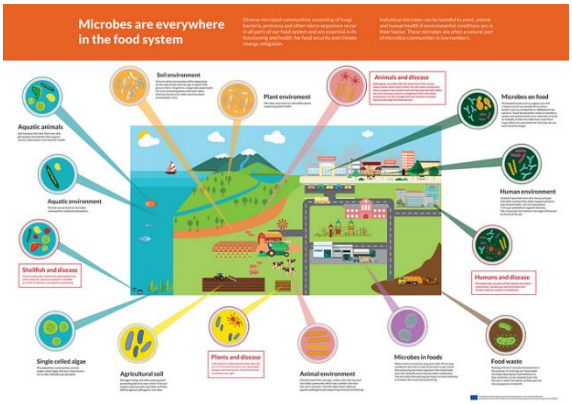

Figure A.5 – Microbes in the food system

(*Source: Microbiome Support*)

The environmental challenges of using chemicals and of growing plants in soils degraded by poor agricultural practices can be addressed by using biological-based crop protection and micronutrients. They include bio-pesticides (including

pheromones), crop-enhancement inputs and micronutrient soil additives. Bio-pesticides actively eliminate pests such as weeds, mildew and insects, prevent diseases and are derived from microbial and biochemicals. Crop-enhancement inputs improve a plant's ability to assimilate nutrients by evoking physiological benefits. Micronutrients are soil additives designed to increase soil fertility.

The use of biological products could significantly improve the health of farmers and the safety of food by reducing their exposure to pesticides and herbicides. This level of impact would require more start-up activity and greater investment in R&D. In addition, consumer preferences would need to shift to biologics. Biologicals, like other technologies, have their risks. The manipulation of bacteria and viruses could lead to health scares. Additionally, a thorough understanding of biologicals' spillover effects (e.g. their impact on bees) is essential for limiting the loss of biodiversity.

For biotechnologies to have a positive impact on agriculture and the food system, they need to avoid the fate of the genetically modified (GM) crop. Despite only being founded in 2002, Arcadia Biosciences is now a public company and a leading maker of genetically modified food crops in the world. BioConsortia is making swift progress as a maker of microbial consortia design to improve agricultural yields on a consistent basis, while Symbiota is focused on using microbial solutions that improve plant health and growth.

Indigo's work focuses on beneficial microbes — the bacteria, viruses and fungi that naturally coexist with plants. Some of these microbes work with plants, helping them overcome typical stresses during the growing season. Indigo's technology screens samples to identify beneficial microbes, which then develops into a seed coating. Indigo launched its first product, a treatment for cotton plants in 2016 and since then, it has brought to the market microbial products for corn, wheat, soybeans and rice. AgBiTech produces a naturally occurring nucleopolyhedrovirus (NPV) that targets Helicoverpaarmigera caterpillars (a.k.a. cotton bollworm) on an industrial scale. As one of the most serious agricultural pests, the caterpillars affect a wide range of crops including soybeans, corn, cotton, tomatoes, sweetcorn and sorghum. To produce NPV, AgBiTech develops insect viruses in vivo. This involves the mass rearing of insects and infecting larvae

to produce the virus and then AgBiTech uses the larvae as an ingredient in its bio-pesticide.

Crop Enhancement, an innovative developer of sustainable, bio-compatible agrochemical products, is using a type of coating to protect certain crops from pests in what is described as a bio-based crop protection product. What makes Crop Enhancement distinctive is the elegance of the solution and wide application across multiple crop types. Its solution uses nontoxic formulations to shield crops from pests and environmental damage. It forms a film that modifies plant surfaces (leaves, stems, fruit, and seeds) to improve their resistance to pests and diseases and to decrease the need for harmful pesticides.

Taking advantage of the massive computational advantage created in the past 20 years, we're now able to produce new approaches to the agricultural process which reduce or eliminate the need for chemical fertilizer. Pivot Bio is developing new biological nitrogen-fixing approaches which were not possible even 10 years ago, continuously producing essential elements to grow corn, wheat and other staple crops while increasing yields. Not only can we make agriculture more sustainable, but we can also increase the profits of farmers. This will transform our food supply.

Solar Foods has created a protein-rich food made from electricity, air and water laced with bacteria. Their protein powder, called 'Solein,' is similar in form and taste to wheat flour, but it is 100 times more climate-friendly. The plan is to hit the consumer market in the next two years, but astronauts might be getting an early look, as the Finnish start-up is working with the European Space Agency to develop the technology as a potential way to supply food in long space missions. Tackling sustainability in food production, Hudson River Biotechnology is a Dutch agricultural biotech start-up involved in the development of gene editing platform technologies. They employ the latest genetics techniques and their proprietary platform to genetically optimise crops to increase yields, improve disease resistance and nutritional value.

CASE STUDY 4 - BLOCKCHAIN

Agricultural technologies, such as precision farming, mapping of farmlands, crop management systems, sensors and location intelligence, and transportation technologies, are empowering farmers to achieve better outcomes in terms of food production and the entire agricultural supply chain. Information and Communication Technology (ICT) substantially increases the effectiveness and efficiency of collecting, storing, analysing and using data in agriculture.

But increased demand for food brings new issues with it; counterfeit products that threaten farming supply chains at different stages. Lack of transparency and low efficiency put farmers and consumers at a disadvantage. After the food leaves the farm for the market, it becomes a part of the vast supply chain involving a lot of intermediaries. Imagine the journey that food takes after it leaves the farm — passing through many hands and processes as it gets to the dinner table. Blockchain for agriculture is one of the most compelling use cases of blockchain that makes the process of growing and supplying food simpler. Perhaps most important, blockchain allows users to build trust.

Blockchain is the technology that gave birth to Bitcoin and other cryptocurrencies and has been used to transform various parts of the financial industry. But the implications of the technology go much further. For example, IBM and Maersk jointly developed a blockchain-enabled digital shipping platform (TradeLens) designed to promote more efficient and secure global trade. In 2019 the platform is being used by more than half of the world's ocean container cargo). IBM has also used blockchain technology when working with Kvarøy Arctic to develop a system that ensures customers know that the seafood they are consuming is not only safe but also produced in a sustainable and healthy manner. California-based Giant Berry Farms has worked with IBM to use blockchain to share data between all the points of its supply chain.

Blockchain is 'an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way'. A blockchain is a ledger in which agents take turns recording information on the process of generating, transacting and consuming a product or service.

Figure A.6 – Bitcoin

(*Source: Baron's*)

The ledger is collectively managed by all participating parties typically through a peer-to-peer network. A new record must be verified by the network before adding it to the blockchain. Any alteration to the recorded data should follow consensus decision-making protocol, meaning most of the parties involved should agree. In addition, an alteration to one record will lead to the alteration of all its subsequent records. It is, therefore, almost impossible to change data recorded in a blockchain in practice. Blockchain is a transformative ICT that has the potential to revolutionise how data is used for agriculture.

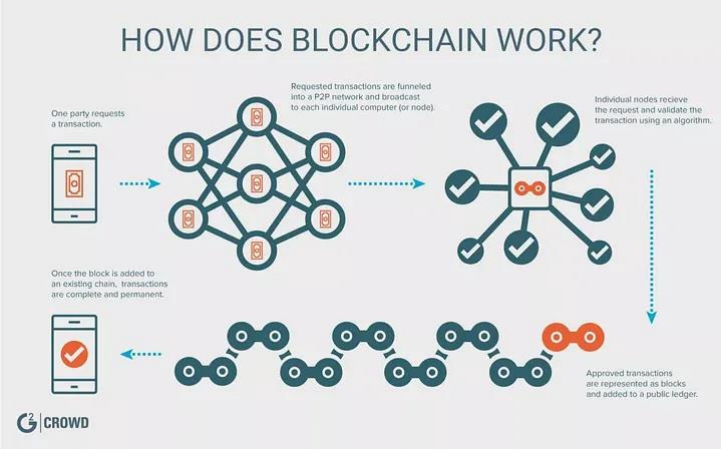

Figure A.7 – How does blockchain work?

(*Source: CNET*)

Blockchain can help food production in a variety of different ways, particularly as farmers produce more data through the use of the latest technologies (e.g. drones, precision farming). However, there are two areas where blockchain is having a considerable impact on the industry:

1. the provision of insurance, and
2. in simplifying and incorporating trust into the supply chain.

Climate change and weather extremes threaten agricultural production, putting food security at risk. Agricultural insurance schemes are traditionally a well-recognised tool to manage weather-related risks. Here, farmers pay an insurance premium before the cropping cycle begins and receive an insurance pay-out whenever they experience a loss on their farm. Thus, the insurer bears all the insured risk and farmers can manage their financial exposure to weather extremes. Agricultural insurances differ with respect to how losses are assessed and consequently how pay-outs are triggered. Insurances that indemnifies farmers based on a damage assessment that was made by an expert on the farm are denoted as indemnity-based insurances. Indemnity-based insurances can precisely cover losses, however, they are prone to problems arising from asymmetric information problems.

Motivated by the drawbacks of indemnity-based insurances, the idea of index-based insurances was born either as an alternative or complementary to the classical products; here the pay-out is not triggered by the loss itself but by a measurable index, such as rainfall at a nearby weather station. The Switzerland based start-up Etherisc uses blockchain technology to offer crop insurance through its decentralised insurance applications. The automated insurance technology means that farmers are paid out instantly when certain weather is registered on high-spec monitoring equipment. High wind speeds, natural disasters, floods, and drought will automatically trigger payment to the insured party. New York-based Worldcover also offers protection to farmers from weather-related disasters. The company offers crop insurance that uses satellites to measure rainfall, with high rainfall automatically triggering payouts to affected farmers. In 2019, Worldcover received a $6 million investment despite only being founded in 2015.

With increased globalisation and intense competition in the market, food supply chains have become longer and more complex than ever before. There are some common problems in food supply chains such as food traceability, food safety and quality, food trust and supply chain inefficiency, which add additional risks to the entire society, economy and the health of humans. The use of blockchain technology helps farmers to establish a trusting relationship with consumers and build up the reputation of their products, by transparently providing individual product information in the blockchain. IBM Food Trust is perhaps the largest blockchain AgriTech project. IBM has crafted a network that allows global participants of the global food supply chain to access a suite of blockchain tools. These tools are designed to increase transparency, improve standardisation, enhance efficiency, reduce waste, and recapture profits in the worldwide food supply chain. The American multinational technology and consulting company isn't the only business using blockchain technology to help farmers. AgriLedger is a UK social enterprise project supporting farmers in tracing food origins, getting easier access to financing, and storing transactions data. Having received a $2.5 million investment by Medici Ventures, GrainChain provides a blockchain software platform to enable more fluid transactions for grain. The platform connects suppliers and farmers reducing inventory management friction. BeefChain is the first blockchain company to be USDA Organic-certified, providing a supply chain solution for beef and cattle, attempting to recapture the value lost to middlemen. Herbalist offers a global decentralised marketplace for rare herbs by connecting buyers and sellers from all over the world to ease the trade of exotic herbs and spices.

The e-commerce and trade of agricultural products face some crucial problems to solve. First, consumers with high overall trust are more willing to purchase online, however, the basic information of agriculture products is not easy to be confirmed and trusted by consumers. Second, e-commerce retailers need to handle time-demanding small orders with diverse items which cause high operating costs for e-commerce companies. In addition, in helping with supply chain management, blockchain technology may provide proper solutions for many aspects of these problems. By designing a transparent digital food supply chain, Ripe harnesses quality food data to create the Blockchain of Food mapping the food journey, while Te-Food offers farm-to-table food traceability on

the blockchain. JD.com and InterAgri use blockchain technology to make the production process of Australian Angus beef fully traceable. The private blockchain solution enables Chinese citizens to know that they can trust the quality of the imported product. Consumers can trace each piece of steak back to the farm in Australia.

CASE STUDY 5 – PRECISION FARMING

Farmers are constantly forced to make crucial decisions based on countless variables. All too often, they don't make the best decisions, and this leads to suboptimal results. By deploying information technology, automation, robotics and decision-support technologies, precision farming takes the guesswork out of input use, irrigation, livestock management and operations, making farming more efficient, profitable and sustainable. Precision farming is observing, measuring, and responding to a variety of factors for a whole fam management approach to optimising returns on inputs while conserving resources.

Precision agriculture was born with the introduction of Global Positioning Systems (GPS) guidance for tractors in the early 1990s, and the adoption of this technology is now so widespread globally that it's probably the most used example of precision farming today. Rockwell International Corp., better known as a defence contractor, developed one of the first precision-agriculture applications. However, in 1992, GPS was accurate to within a few feet, good enough to create crop yield maps, which helped farmers make decisions about drainage, weed control, fertilizer, and seeding. Rockwell began exiting this field because of the commercial challenges faced in securing adoptation by farmers; the equipment came with a steep learning curve, technical support was lacking, systems were buggy and expensive. By working with NASA, John Deere developed an accurate, and commercially viable, GPS that allowed a tractor to follow the contours of the ground and trace a line exactly parallel to its previous path.

Today, the combination of more accurate GPS and autonomous vehicle control has made precision farming commercially viable. The use of GPS is not confined to the USA. Self-guided systems now farm approximately 60 to 70 per cent of the crop acreage in North America, 30 to 50 per cent in Europe, and more than 90 per cent in Australia. A GPS-connected controller in a farmer's tractor automatically steers the equipment based on the coordinates of a field. This reduces steering errors by drivers and therefore any overlap passes on the field and, in turn, this results in less wasted seed, fertilizer, fuel, and time.

Figure A.8 – John Deere 'Green Eggs and Ham' GPS

(*Source: National Museum of American History*)

Improving productivity and efficiency inherently mitigates the environmental impacts of farming. The benefits of precision farming tools can help growers increase field productivity while also reducing environmental stress by:

1. Monitor the soil and plant physicochemical parameters (by placing sensors – electrical conductivity, nitrates, temperature, evapotranspiration, radiation, leaf and soil moisture, etc. – the optimal conditions for plant growth can be achieved,
2. Obtain data in real-time (the application of sensing devices in the fields allow continuous monitoring of the chosen parameters and will offer real-time data ensuring an updated status of the field and plant parameters at all times),
3. Provide better information for management decisions,
4. Save time and costs (reduce fertilizer and chemical application costs, reduce pollution through less use of chemicals),
5. Provide better farm records required for regulations,
6. Integration with farm management software to make all activities on the farm easier and to improve farm productivity.

Such benefits are applicable to all parts of the agriculture industry. For example, controlled environment farming in livestock increases energy use and, therefore, emissions due to controlling for temperature, ventilation etc. However, the

integration of precision systems can allow real-time monitoring of emissions, improving the ability to determine which automation or management practices reduce these most efficiently.

John Deere furthered its precision farming offering by acquiring Blue River Technology. The start-up develops technology that uses computer vision and artificial intelligence to detect, identify, and make management decisions about every single plant in the field. Despite the research and developments made by John Deere, there continue to be several start-ups improving the accuracy of GPS and identifying novel application practices.

Using a manufactured, large-format unmanned vehicle, the system developed by Kiwi Technologies is the first autonomous aerial system to distribute the volumes of chemicals and seeds required by commercial growers. Mothive is an automated agronomy service that helps farmers maximise efficiency, reduce waste, and improve the predictability and control of crops. Their device, the Mothive Ladybird, provides a simple, affordable, and turnkey solution that de-risks farming operations and extracts more value from the crop. The device predicts and informs farmers about the right time to harvest and related logistics, predict diseases and improve yields, and automates farm tasks based on real-time crop needs.

Figure A.9 – Mothive Ladybird

(*Source: Mothive*)

Based in the Netherlands, Atmos UAV has developed an industrial drone, which is a helicopter and an aeroplane crossover. Dubbed Marlyn UAV, this drone is a hybrid industrial-grade photogrammetry drone, which is easy and efficient. The drone serves a multitude of purposes including land and construction surveying, protection of forestry, open-pit mining, and precision agriculture. Also based in the Netherlands, Avular has developed a modular drone platform called Aerial Curiosity, which lets users easily connect new sensors and programs. It comprises two components — a modular platform and a software layer. With the modular platform, it is possible to assemble the drone quickly for multiple use cases while the software layer shortens the development time.

Swiss start-up Gamaya addresses the necessity to increase the sustainability and efficiency of large industrial farming. This company is focused on increasing the productivity and scalability of small-scale farming with the world's most advanced solution for mapping and diagnostics farmland. It helps farmers use fertilisers, chemicals, water, and fuel more efficiently and focus on both quality and quantity. Also, it helps them reduce the risks of extreme weather, climate and drought conditions.

Delair, in France, is a leader in professional UAVs and provides data based on aerial imagery to help industries make informed decisions. The French start-up delivers end-to-end solutions from business analysis to data acquisition. It is specialised in offering solutions to various industries including mining, agriculture, geomatics, etc. HummingBird Technologies is a London-based company, which uses drones with customised sensors as well as a satellite to gather data and imagery that will help in precision agriculture. The company uses advanced machine learning algorithms and computer vision in order to provide information on crop health. Their products include the detection of crop diseases, nutrient optimisation and more. Also in the UK, Accelerated Dynamics has developed an operating platform to simplify the management of multiple drones. Its software solution lets farmers use UAV vehicle fleets without any training. Accelerated Dynamics' platform integrates IoT devices such as moisture sensors and irrigation devices to monitor crops at all times and ensure farmers increase the quality and quantity of their produce.

Precisión Aérea Innovación y Nuevas Tecnología SL (PAINTEC), in Spain, provides remote sensing services through drone platforms. It uses different sensors to collect useful information for further processing and conversion to deliver highly valuable information. Precision agriculture and topography are some of their applications.

CASE STUDY 6 – ROBOTS AND DRONES

Barriers to new farmers entering the profession, environmental degradation and a growing world population are putting increasing pressure on agriculture to do more with less. But farmers and researchers are working on increasingly innovative high-tech solutions to find ways to produce more food. Agriculture is quickly becoming an exciting high-tech industry, drawing new professionals, new companies and new investors. The technology is developing rapidly, not only advancing the production capabilities of farmers but also advancing robotics and automation technology as we know it. At the heart of this phenomenon is the need for significantly increased production yields. Agricultural robots are increasing production yields for farmers in various ways. From drones to autonomous tractors to robotic arms, the technology is being deployed in creative and innovative applications.

Agricultural robots automate slow, repetitive and dull tasks for farmers, allowing them to focus more on improving overall production yields. Harvesting and picking are one of the most popular robotic applications in agriculture due to the accuracy and speed that robots can achieve to improve the size of yields and reduce waste from crops being left in the field. These applications can be difficult to automate, however. For example, a robotic system designed to pick sweet peppers encounters many obstacles. Vision systems have to determine the location and ripeness of the pepper in harsh conditions, including the presence of dust, varying light intensity, temperature swings and movement created by the wind. Harvesting and picking robots are becoming very popular among farmers, but there are dozens of other innovative ways the agricultural industry is deploying robotic automation to improve their production yields.

Three robots developed by the Small Robot Company may be a part of the solution. While one robot monitors how the crops are growing, another moves through the field to target any weeds that might spring up. A third robot is responsible for planting the seeds in the first place. These are driving a new era of precision farming where crops are not cared for at the field level but at the individual plant level. It's not only start-ups that are developing robots for the industry.

One company attempting to lead this shift in the way farming is done is Brazilian farm equipment supplier Stara. It has been turning the humble tractor into a smart machine by packing their machines with sensors that can monitor the soil, manage the amount of fertiliser and water each plant needs, and help to determine the best time for harvest.

Figure A.10 – Small Robot Company weed mapping robot

(*Source: The Engineer*)

Switzerland-based ecoRobotix solar-powered weeding bot precisely targets unwanted plants with herbicide, reducing excess runoff that can pollute ecosystems. Similarly, Blue River Technology has developed a machine that can identify weeds among rows of cotton plants, selectively spraying them with herbicide. It is also developing a system that will simultaneously spray fertiliser onto the cotton, transforming traditional mass crop spraying into a targeted process that reduces the number of chemicals used in fields. Harvesting, too, is about to change. Dutch agricultural machinery manufacturer Cerescon has created a robot that picks white asparagus, keeping the vegetable out of sunlight that can damage the crop as it does so. Vision Robotics has developed AI-powered robots that can tackle a host of products including a vineyard pruner that images vines and uses a robotic arm to thin plants, as well as an automated lettuce thinner.

Naio Technologies has a host of robots that not only act as the perfect farm hand, it also uses techniques that preserve and protect the local environment. The robots have the ability to weed, hoe, and assist during harvesting. Energid brings its NASA engineering roots to provide highly sophisticated motion control for industrial, medical, commercial, collaborative, and agriculture robotic systems. The company has developed a fast and efficient harvesting system that can pick a fruit every two to three seconds. The robot is cheap to build, making it significantly cheaper than human labour. Agrobot has developed a robot with 24 arms that work wirelessly with an advanced AI system that not only picks strawberries really fast but it can identify the ripeness of a strawberry in the field.

Determining the individual needs of each plant would take humans too much time and effort, so that's where robots could help. A Pantheon project has developed a robot to move around a hazelnut orchard autonomously, taking measurements of the trees. The robot collects data with a laser scanner for 3D geometric reconstruction and uses cameras to take multi-spectral and high-resolution images to assess the physical or health status of each tree. The technology developed by Pantheon will also create a 3D model of each tree, with the recommended treatments — should it be pruned, is it well-watered, well-fertilised, with the whole farming history of that particular plant.

Figure A.11 – Dropcopter

(*Source: Fruit Growers News*)

Using large, heavy tractors that drag ploughs through the earth can have a negative impact on soil health. While smaller, automotive robots can help overcome this problem, another possible solution is using drones. Drone

technology was studied by Jonathan Gill NSch as part of his 2018 Nuffield scholarship and he found commercial remote drone agronomy options are a tool to be used to complement conventional techniques and cannot currently replace them. But drones are already playing an important part in the industry. For example, Dropcopter is using drones to pollinate fruit and nut orchards. Drones are flown over a row of trees and dispense a cloud of pollen that is pushed down by the rotor blades. The pollen sticks to the trees and it creates a feeding frenzy among the insects that live there and they move it around to pollinate the flowers further. The concept should avoid the need to ship truck-loads of honey bees around the country to pollinate these crops. Crucially it also helps to support local insects that the honey bees would normally compete with by providing them with a dusting of pollen to feed on. As they move around the trees, they inevitably carry some of it with them to pollinate flowers. AgEagle and PrecisionHawk have both developed their version of a drone tool for farmers to collect crop data over time or in real-time and measure the health of crops while in the air.

Covid-19 travel restrictions have prevented seasonal workers from working in the fields. Even before the pandemic, growers were finding it increasingly hard to recruit people for picking. Therefore, farmers are turning to drones to pick their crops. Tevel Aerobotics Technologies invented a flying autonomous robot (FAR) that uses artificial intelligence (AI) to identify and pick fruit as a direct response to labour shortages. The FAR robot uses AI perception algorithms to locate fruit trees and vision algorithms to find the fruit among the foliage and classify its size and ripeness. The robot then works out the best way to approach the fruit and remain stable as its picking arm grasps the fruit. The drones are able to harvest the orchards without getting in each other's way because of a single autonomous digital brain in a ground-based unit.

Some might ask why this is all becoming possible now. Many ideas behind robots and drones are decades old, but they are only becoming commercially viable now. The short answer is that this is now increasingly possible thanks to dramatic year-on-year improvements in the performance and price of computing power, sensing technologies, energy storage, and electric motors.

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