Image: Iron Ox' robotic picking arm

Opportunity Analysis

AGRICULTURAL TECHNOLOGY IN TEXAS

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Summary

This report provides an overview of all important agricultural technologies for the near and distant future, and then discusses developments in the Netherlands that could be promising in Texas. Opportunities are also identified, which Dutch companies could successfully utilize.

The emergence of these technologies is often described as the fourth agricultural revolution. The most promising agricultural technologies include 3D and 4D printing, smart materials, robotics and autonomous (micro)robots, sensor technology, information technology and bioinformatics, smart farming technologies, renewable energy and biofuels, genetics and synthetic biology, aquaculture, vertical agriculture, weather modification, hydroponics, aeroponics, and aquaponics.

Robot and autonomous (micro) robots is a broader category, including robots that can be applied for precision agriculture, pollution monitoring, livestock ranching, weed control, horticulture automation, harvesting, planting, and seeding. Information technology also includes many sub-categories that are promising for agriculture as well, including big data, artificial intelligence, machine learning, and the internet of things.

Some of these technologies are used individually, but often may be seen combined with other technologies to create more powerful technological solutions in agriculture. Some technologies can already be seen in practice, with technologies such as IT and sensor technologies being applied for multiple decades. However, other technologies are still in their infancy, but promise to be very disruptive in the near and/or distant future.

Important characteristics of the Texas agricultural industry include the large scale of production, the lack of sufficient internet connections in remote areas, a shortage of agricultural workers due to a decrease in both legal and illegal immigration, a large diversity of soil types and climate types within the state, the loss of agricultural land around urban areas, and the availability and quality of agricultural water.

Important drivers of innovation in agricultural technology in the Netherlands include the push towards circular agriculture, the innovative nature of the horticulture industry, the increasing lack of agricultural labor, and triple helix cooperation between governments, universities, and the industry.

The opportunities that can contribute to solving the aforementioned problems in the Texan industry, which have been actively developed in the Netherlands by the above-mentioned characteristics, are as follows:

1. Future need for 3D printing for increasing self-sufficiency among farmers in rural Texas.
2. Growing market for digital technologies requiring a (fast) internet connection, as a large number of farmers currently does not have, but will receive, internet connectivity in the (near) future.
3. Need of further development of digital ag technologies, which includes reducing cost, increased simplification and usability, and proven financial return, will also interest small and skeptical farmers who may currently not be taking part in the digital revolution.
4. Future need for agricultural technologies to boost sustainable farming, which are increasingly being developed in the Netherlands, however not to the same rate in Texas.
5. Growing market for robotics, especially in labor intensive industries such as nursery and floriculture, which is a large industry in Texas.

6. Growing market and need for digital monitoring solutions in the Texan dairy industry.
7. Possible future need for on-farm personalized food production technologies in agriculture, which was identified as a major trend in the near future.
8. Growing market for innovative livestock sensors for monitoring and traceability.
9. Need for promising big data applications, in which the data from farmers are processed in a secure manner.
10. Need for further development of technological implementations that help to improve the degrading soil health.
11. Need for ground-breaking developments in renewable energy, regarding algae for fuel, legumes for bioenergy, forage crops as biofuels, new sorghum-based bioenergy crops, and sustainable production of bioenergy feedstocks.
12. Need for increasing number of bioenergy production facilities.
13. Need for further development of drought resistant crops.
14. Need for development of sustainable products that help maintain soil health through genetics technologies, such as biopesticides and bio stimulants.
15. Need for future development of soil monitoring techniques using genetics technologies, for increased accuracy and improved decision making, as well as preserving and improving soil health.
16. Growing industry of vertical agriculture, in the form of peri-urban plant factories, which are promising due to disappearing agricultural land in urban areas and may improve consumer awareness.
17. Growing industry of hydroponics, aeroponics, and aquaponics, due to high yields with less inputs, helping to save water and land.
18. Need for the building of additional greenhouses as the hydroponics, aeroponics, and aquaponics industry grows.

1. Introduction

1.1. Background

Texas is one of the largest agricultural states in the United States. Texas produces more cotton, cattle, sheep, and goats, and has more farms than any other state. After Alaska, Texas is the second largest state when it comes to total land area. At first sight, Texas shares few similarities with the Netherlands, but the Netherlands and Texas have been partners in the business field for many years. One of the similarities is that the Netherlands is also one of the largest entities in the field of agriculture. The Netherlands is the largest exporter of agricultural products in the world after the United States. The Netherlands is also a leader on the international stage in the field of innovation in agriculture, horticulture and fishery (Minsiterie van Landbouw, Natuur en Voedselkwaliteit, 2018).

The *Netherlands Business Support Office* (referred to as NBSO from now) in Houston, Texas, is committed to supporting Dutch companies in Texas. Until now, the agricultural industry has been an underexposed subject. The "Agriculture in Texas" sector sketch report provides insight into the state of affairs in the agriculture. The sector sketch report shows that agricultural engineering has the greatest opportunities in Texas agriculture. To determine exactly where those opportunities lie, this report will elaborate on the agricultural technologies of today and the near future. This report will provide a basis for the NBSO Texas agricultural services in the future. This report may also be interesting for companies that want to do business in Texas in the field of agriculture technology.

1.2. Objective

The objective of this study is to:

1. Give a quantitative overview of the use of agricultural technologies related to areas of production, geographic area, crops, livestock, and productions volumes.
2. Identify the need for Texan farmers and ranchers to adopt current or future agricultural technology innovations.
3. Identify opportunities for Dutch suppliers of agricultural technology products and services.

1.3. Method

By means of a literature review basic information on agricultural technology in Texas has been collected. In addition various sources have been consulted in order to get a broad overview of the state's characteristics and economic performance (e.g. general macro-economic indicators, trade information, and crop production statistics). During in depth interviews information was gathered, validated and valuated.

2. Agricultural Technology

The global population projected to reach 9.8 billion in 2050 (United Nations, 2017), and the world which we live in is changing rapidly. The challenge to feed the growing population requires a new agricultural revolution. The first agricultural revolution took place around 8000 BC, when humans started to domesticate plants and animals. The second revolution was set in motion with the industrial revolution, when mechanization, fertilizers, and pesticides were used, so that the average farming business grew strongly and the yields improved. The Green revolution came as the third revolution and brought genetic engineering and genetically modified organisms to the table.

At this very moment, according to experts, the fourth revolution is underway: we do not adjust the food, but the environment in which we produce it. New technologies and solutions replace the developments that previous revolutions have brought. The fourth revolution, referred to as "the digital revolution" or "agriculture 4.0" changes the way we think when it comes to agriculture. Important drivers of the fourth revolution are the decline in arable land due to intensive use, the increase in food and fiber demand (Briers, 2018), the increase in global population, climate change, and urbanization (FME, 2018, p. 5).

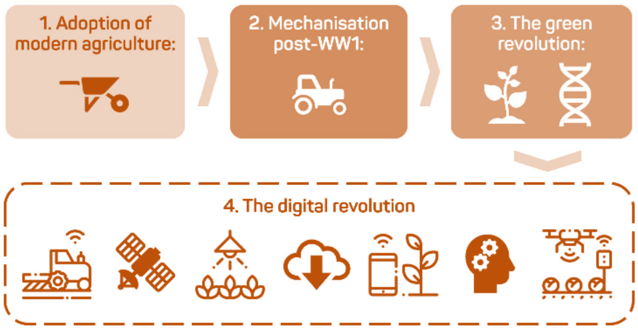

Figure 1: The course of the 4 agricultural revolutions

De Wilde identified 20 technological developments[1] that will have a big impact on the future of the Dutch agricultural and food sector (Wilde, 2016). 16 of these technologies can be applied to agriculture. The production methods of hydroponics, aeroponics, and aquaponics were also added, as these proved very promising after previous research. These technological developments are listed below.

1. 3D printing
2. 4D printing
3. Smart materials
4. Robotics
5. Autonomous micro-robots
6. Sensor technology
7. Information technology and IT infrastructures
8. Bioinformatics
9. Smart farming
10. Renewable energy
11. Biorefinery and biofuels
12. Gen technology
13. Synthetic biology
14. Aquaculture
15. Vertical agriculture
16. Weather modification
17. Hydroponics, aeroponics, aquaponics

These technologies can be implemented individually, but are often combined to create more powerful technologies. Well known is the combination of using sensor technology in (autonomous) robots to, for example, collect plant trait data across a field.

[1] In the study, technology was defined as: *"the systematic application of (exact) scientific knowledge for practical purposes"* (Wilde, 2016).

2.1. 3D and 4D Printing and Smart Materials

Not only is 3D printing applied in the development of new food products, but it can also be used for the development and production of agricultural tools, such as robots and drones. The material used for 3D printing may be recycled materials, which contributes to circular production. 4D printing adds time as a fourth dimension and allows material to change shape under specific conditions, which is also known as programmable material. 4D printing is still in a very early phase, but may eventually be applied in agriculture, for example by creating materials that adapt to weather conditions.

Smart materials are able to adapt to their environment, without requiring human input. This may lead to the development materials that are able to absorb hazardous materials, or the development of smart packaging that allows for better traceability in the food chain.

2.2. Robotics and Autonomous (micro)robots

Robotics are increasingly in use in the agricultural industry for the automation of cultivation and harvesting. Robotics is increasingly implemented on the foreground of production and are interacting with users. Autonomous (micro)robots are independent machines that are able to operate without human interaction, and with the ability to adapt to new conditions and tasks. According to Sammons, Furukawa, & Bulgin, multipurpose and autonomous robotic platforms could lead to significant improvements in terms of work productivity, costs depletion as well as of operator's safety and health. An autonomous robot could perform dangerous tasks, such as chemical treatments, without the presence of human operators (Sammons, Furukawa, & Bulgin, 2005). An example is the development of microdrones with increased operability than traditional drones. The development of autonomous tractors is also on the rise, with recent examples being the CNH Industrial Autonomous Tractor Concept which is completely driverless.

Robotics may solve the problem of rising amount of farm labor required and risks that illegal labor may bring. Texas sees increasing worker wages and farm labor shortage. Many farms and ranches rely on workers from Mexico (Zahniser, Taylor, Hertz, & Charlton, 2019), many of whom are undocumented and unauthorized. As the Mexican economy grows and per capita income rises, the percentage of agricultural workers decline. And as these factors are somewhat responsible for a decreasing trend in emigration from Mexico, Texan farmers will have to find alternatives as farm labor is likely to become more costly and scarce in the near future (Stratfor, 2015).

Agricultural field robots can be divided in the following sub-categories (Robotics Industries Association, 2018):

- **Precision Agriculture**
- **Pollution Monitoring**
- **Livestock Ranching**
- **Weed Control**
- **Horticulture Automation**
- **Harvesting**
- **Planting and Seeding**

2.2.1. Precision Agriculture

Robots developed for use in precision agriculture are used on small scale operations, such as nurseries and wineries, as well as large-scale operations. Often these robots are used for monitoring factors such as soil respiration, photosynthetic activity, leaf area indexes (LAI) and other factors (Robotics Industries Association, 2018).

2.2.2. Pollution Monitoring

Pollution monitoring robots are used to monitor agricultural pollution[2] through the use of natural and chemical products. The causes of agricultural pollution are chemical fertilizers and pesticides, heavy metals, excessive tillage of land, soil erosion and sedimentation, introduction of foreign species, genetic modification to increase resistance, and animal management (Natural Energy Hub, sd). These robots are very suitable for reducing the environmental footprint of producers. The farmer thus gains more insight into the influence of the use of, for example, fertilizers and pesticides, and this technique is therefore very suitable for more sustainable development.

2.2.3. Livestock Ranching

The application of robotics for livestock ranching is a fairly new practice, but has proven to be very useful in various experiments with prototypes. Robots used for livestock ranching can be divided in two main categories; robots used for herding and robots used for monitoring. Robots are also used on smaller-scale dairy operations, as many possibilities for robotization exist in these operations.

> *"From a safety standpoint you don't have to have an individual there pushing cattle forward. So, if the animal decides to turn, it's not a person hurt. It's just a machine that we can fix."*
> *- Sammy Renteria, Cargill Nebraska*
> (Cargill, 2018)

Cattle herding is a dangerous practice, as the animals are large, heavy, and strong, and are also unpredictable. Cattle herding is in general often carried out by people, which can pose great risks. The use of a herding robot on animal feeding operations can greatly lower these risks. Driving robots use movements and sounds to mimic a human cattle driver. An example of a driving robot prototype is the R2DMoo, developed for a Cargill beef plant in Nebraska (Cargill, 2018). Cattle monitoring robots may be used to identify and eradicate weeds, monitor pastures, and monitor animal welfare. Recent prototypes have been completely autonomous and use AI and other intelligent tools to identify and monitor the environment and herds of cattle, sheep, and horses. Some robots can complete both herding and monitoring tasks, making them extremely useful on ranching operations. An example of these ranching robots is the Swagbot, a technology developed by Agerris at the University of Sydney's Australian Center for Field Robots (Frangoul, 2019).

A great deal of innovation is possible for the dairy industry, and robot implementations are becoming increasingly common on smaller scale operations. On these operations, robots are able to take over manual labor that is rather monotonous and therefore suitable for robotic implementation. Often, these tasks are also time consuming when performed by humans. As the robot frees up labor, this labor can then be assigned to more important tasks on the production plant. The Netherlands is at the forefront of developing robotic applications within the dairy industry. An examples of this are the company Lely, which develops automated systems for dairy operations, including automatic feeding and milking. Lely was started and is currently still headquartered in the Netherlands and is present today in over 40 countries including the state of Texas (Lely, 2019).

2.2.4. Weed Control

Robotic weed control is able to autonomously identify weed growth and eliminate weeds by precisely spraying herbicides. This technology has great benefits for sustainable farming, as some

[2] Agricultural pollution applies to the direct environment and related surroundings. The pollution is damaging to organisms which depend on the food on cultivation.

robots are able to use 90% less herbicide than traditional herbicide sprayers. Furthermore, by precisely spraying the herbicide, the crop exposure to herbicide decreases, and the growth of herbicide-resistant weeds is reduced. An example of this robotics application is the weeding robot developed by ecoRobotics, headquartered in Switzerland, which features two spraying arms, positions itself using a camera, GPS and sensors. It is powered through solar panels, enabling it to control weeds for up to 12 hours per day without the need for human interference (ecoRobotix, 2019).

2.2.5. Horticulture Automation

Horticulture automation involves robots to replace manual labor in plant nurseries, vertical farms, and greenhouses. In crop production, these robots may also be used to automate the harvesting process, but harvesting robots will be discussed in their own category below. In this category, robots with other tasks than harvesting will be discussed. These robots are mainly involved with transporting and sorting plants or plant groups in a horticulture facility. Automating horticulture has many opportunities, because this sector within the agricultural industry relies heavily on labor. However, in order to be able to use these opportunities, it is important that the costs of the robots are comparable to, or lower than, human labor, so that automation becomes economically viable.

> *"So one of the great things about the robots is that they don't really get tired and they don't really care what hours they work. And so as long as they've got juice in the batteries, they can keep going."*
>
> *- Jon Binney, CTO Iron Ox*
> (Brigham, 2018)

In pot plant nursery operations, growers rearrange plants regularly. This type of operation demands a high level of manpower and the tasks workers perform is often very repetitive. Robots have been developed to take over the rearranging process. An example of an autonomous handling robot is the HV-100 by Harvest Automation (based in Massachusetts), deployed at over 30 top growers in the United States (Harvest Automation, 2016).

Building partially or fully automated greenhouse operations or other protected environment operations is also popular in Texas. Texas A&M University announced in May 2019 to build a new robotic greenhouse called the Automated Precision Phenotyping Greenhouse. Furthermore, Iron Ox is a hydroponic production facility based in San Francisco and is almost fully automated with the help of two robots and a central computer system. This facility features a porter robot that is able to move pellets of hydroponic produce and a robotic arm that picks individual plants and sorts them from vat to vat (Vincent, 2018).

2.2.6. Harvesting

Farmers experience problems when trying to secure a labor force for harvesting, The harvesting period only lasts for a short time. Due to the demand for solutions to this problem, there have been many experiments with harvesting robots in the past. Currently, there is a variety of robots available on the market that are able to select ripe fruits and crops and autonomously harvest. Harvesting robots can be divided into two main categories: crop harvesting and fruit harvesting.

It is not easy to develop robotic technologies that are able to harvest corps and fruits with precision. The harvesting environment is relatively complex; with crops and fruits hanging at different heights and being covered by layers of foliage. Human crop and fruit pickers do not only rely on vision when choosing which crops or fruits to pick and which not, but also rely on touch. Robots have been developed to pick peppers, cucumbers, tomatoes, strawberries, and more high value produce.

2.2.7. Planting and Seeding

Planting and seeding robots are able to accurately plant and seed crops. This technique assures optimal growth. An example of a seeding robot concept is the Xaver seeding robot, developed as part of the MARS (Mobile Agricultural Robot Swarms) project. These small and robust robots can work in swarms covering small to large fields, depending on the number of robots deployed. The robots seed the crop completely anonymous in an efficient way and with high precision (Fendt, 2017).

2.3. Sensor Technology

Sensors have been extremely important in the development of smart farming technologies. Sensor technology has been implemented in agriculture for a number of years, allowing farmers to collect real-time information on crops and livestock which includes aerial photographs, thermal images and near-infrared data (NIR data). Sensor technology will make increasing collection of data possible, and combined with genetics it may offer increasing possibilities for diagnostics. Sensors may also allow for the production of agricultural produce with specific compositions. Sensor technology is extremely useful in areas where farmers are working with minimal resources. In arid climates, sensors can help to improve irrigation management and reduce water demand (PrecisionAg, 2018). As wireless sensors become smaller, easier to use, and less expensive, farmers are more likely to deploy them on a larger scale for better data collection .

There are various types of agricultural sensors, including but not limited to; location sensors, optical sensors, electro-chemical sensors, mechanical sensors, dielectric soil moisture sensors, and air flow sensors . Furthermore, there are four types of agricultural sensor applications: yield monitoring and mapping, soil monitoring, and disease control and detection (Reuters, 2019), and livestock monitoring.

Drawbacks of sensors used in agriculture includes required internet connectivity, slow market adoption, and the limited availability of basic infrastructure such as smart grids, traffic systems, and cellular towers (RF Wireless World, sd). Furthermore, in case sensors fail, expert repairmen might be needed. Maintenance and repairing requires skilled labor and costs time and money. In case a sensor runs on batteries, replacing these batteries often requires breaking a seal and resealing, as most sensor housing is sealed to prevent malfunction. The development of sensors that work on solar power, for example, can ensure that sensors require less human attention. This can especially make a difference on operations with large herd head counts, for example in the United States, China, and Australia.

2.4. Information Technology and Bioinformatics

> *"The industry will be transformed by data science and artificial intelligence. Farmers will have the tools to get the most from every acre."*
>
> *- Gayle Sheppard, Intel AI*
> (Intel, sd)

IT is the branch of engineering that deals with the use of computers and telecommunication to retrieve, store, and transmit information. Information technology and IT infrastructures include big data, IoT, self-learning systems and new possibilities that come with increasing processing power. IT technologies are used in agriculture to improve farm management and decision making, and are applied in both arable and pastoral farming operations. As these technologies become cheaper, more farmers implement them due to possible high return on investment. Often, IT solutions allow operators to manage, control, and oversee operations from a central and/or remote location using personal computers, smartphones, and tablets. This leaves operators with time for other important matters on the operation, but also for personal matters. This makes these technologies a very attractive change on farms.

2.4.1. Big Data

According to Gartner IT glossary, *"big data is high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation* (Gartner Inc., 2019)*."* Big Data is not only used in primary production, but also plays a role in efficiency and food safety improvements across the entire agrifood chain (Wolfert, Ge, Verdouw, & Bogaardt, 2017). In the United States, the increasing popularity of big data systems in agriculture introduces a socio-economic challenge due to growing concerns among farmers when it comes to data processing and data ownership. Data initiatives, such as the Big Data Coalition, Open Agriculture Data Alliance, and the AgGateway advocate open data and data driven innovation (Wolfert, Ge, Verdouw, & Bogaardt, 2017). According to Thomasson, research engineer at Texas A&M University, there are high rates of data collection but low rates of data usage in agriculture. Big data solutions can only be fully utilized when the production of information from this data is more practical for farmers (Fannin, 2018).

Wolfert et al. defined opportunities for big data in agriculture, including benchmarking, sensor deployment and analytics, predictive modelling, and using better models to manage crop failure risk and to boost feed efficiency in livestock production. The main challenges for big data in agriculture are lack of internet connectivity of farmers, developing lower cost big data technologies for farmers, ensuring privacy and security of big data, and developing useful applications from big data (Wolfert, Ge, Verdouw, & Bogaardt, 2017).

2.4.2. Artificial Intelligence and Machine Learning

At this moment in time, artificial intelligence and machine learning is driving digital farming. According to Andrew Moore, former Dean of the School of Computer Science at Carnegie Mellon University, *"artificial intelligence is the science and engineering of making computers behave in ways that, until recently, we thought required human intelligence".* Machine learning, defined by computer scientist and machine learning pioneer Tom M. Mitchell, is *"the study of computer algorithms that allow computer programs to automatically improve through experience"* (Iriondo, 2019). Machine learning is considered as a branch of the science of artificial intelligence. Some companies may use artificial intelligence as a marketing term, while they actually use machine learning techniques which causes confusion about the correct meaning of the terms.

> *"We know that we absolutely need to go and seek out capabilities in machine learning, in deep learning, in robotics and advanced analytics. And Silicon Valley has been receptive."*
> *- Alex Purdey, Head of John Deere Labs*
> (Alvarez, 2018)

According to Grassi, the company NVIDIA is a major driver of machine learning and artificial intelligence hardware in agriculture (Grassi, 2019). NVIDIA developed the Jetson system, a system-on-module that can be used directly in, for example, autonomous machines such as the harvesting robot Agrobot (NVIDIA, 2019). Without artificial intelligence and deep learning, the Agrobot would not be able to precisely recognize and harvest ripe strawberries (Lahde, 2018).

2.4.3. Internet of Things

The Internet of Things has many applications across many industries, which makes IoT hard to define, as mentioned by Mehl. According to Daniel Burrus, founder and CEO of Burrus Research Inc., *"The Internet of Things (IoT) is a combination of networked sensors and machines that enable machine-to-machine communications. Enabling technologies include the Internet, advanced cloud services, wired and wireless networks, and data-gathering sensors, making the system instantaneous anywhere, anytime. Advantages of IoT include the ability to monitor and control, real-time asset management,* *faster response times, major cost savings and, perhaps the biggest advantage, the ability to predict and prevent"* (Mehl, 2018). The Internet of Things is above all an up and coming technology that offers an incredible number of possibilities in all conceivable industries. Certainly in agriculture this technique still promises a lot, and by no means all the possibilities are exploited at this moment.

> *"The Internet of Things will create one of the biggest disruptions and opportunities we have seen in every imaginable field."*
> *- Daniel Burrus, CEO of Burrus Research Inc.*
> (Mehl, 2018)

According to Verdouw et al., applications of IoT have been described in literature, including precision agriculture, sensing and monitoring the production environment, general management systems for agriculture, product quality improvement, food safety and traceability, water management, rural development, urban agriculture, and consumer interaction. The applications of IoT can be even more specific when applied to arable farming instead of agriculture in general. Here, IoT can be implemented for sustainability management[3]. In greenhouse horticulture, IoT systems are powerful when used in combination with advanced sensors to manage environmental parameters (Verdouw, Wolfert, & Tekinerdogan, 2016). The Arduino (as well as the Raspberry Pi), which is an embedded computer system used to make IoT networks possible[4], was a major disruptor in the market of IoT applications for agriculture due to its affordable price point (Ibarra-Esquer, González-Navarro, Flores-Rios, Burtseva, & Astorga-Vargas, 2017).

Verdouw et al. Identified important challenges for IoT in agriculture, including:

- **Ensuring interoperability of a large variety of IoT devices;**
- **Scaling up the usage of IoT technologies beyond early adopters through simplification of existing solutions and improving affordability;**
- **Developing IoT technologies for broader usability in the diverse agricultural industry;**
- **Developing durable IoT hardware for harsh environments;**
- **Ensuring reliable and stable wireless communication in rural areas;**
- **Developing energy efficient IoT hardware;**
- **Combining new data with (3rd party) archive data for analytical purposes;**
- **Security, privacy, and data ownership solutions for all stakeholders.**

2.4.4. Bioinformatics

According to Aslam et al., *"Bioinformatics is an interdisciplinary science emerging from interaction of computer, statistics, biology and mathematics to analyze genome arrangement and contents, biological sequence data, predict the structure and function of macromolecules that use in interpreting and decoding plant* genome" (Aslam, Khattak, Ahmed, & Asif, 2016, pp. 413-434). The use of bioinformatics tools will enable storage, retrieval, analysis, annotation, and visualization of results, and will promote better understanding of the biological system. Bioinformatics will enable better plant care and increase crop quality (Singh, Singh, Chand, & Kushwaha, 2011).

[3] Including ecology, biodiversity, and natural resources such as water (Verdouw, Wolfert, & Tekinerdogan, 2016)

[4] Embedded systems are a combination of hardware and software, designed for a specific function or function within a larger system.

2.5. Smart Farming

New developments in sensor technology, information technology, and robotics will allow for new opportunities in smart farming. An analysis and forecasts reports by Research and Markets showed that the smart agriculture market is estimated to be worth $13.5 billion by 2023, which means that farmers will be likely to implement new smart farming technologies in the coming years (Walker, 2019). Three platform types of systems in precision agriculture and smart farming are aerial systems such as drones, ground based mobile systems such as autonomous precision harvesters, and stationary systems such as soil moisture sensor equipment (Quinnell, 2019).

2.6. Renewable Energy and Biofuels

Renewable energy production includes all production that uses renewable resources. Types of renewable energy production include solar energy, wind energy, hydropower, geothermal energy, and biomass. Farmers and ranchers play an important role in the production of renewable energy, as producers have access to the required space, and agricultural production is part of the Co2 cycle. Most opportunities lie with the use of biomass for the production of renewable energy. The International Energy Agency defines biorefinery *as "the sustainable processing of biomass in a spectrum of marketable products and energy"* (International Energy Agency, sd). De Wilde described that biorefinery aims to process biomass as efficiently as possible for optimal use of components and minimal waste. In the ideal scenario, the utilization of biomass does not require additional agricultural land. The potential to save costs is in any case very relevant for the agricultural sector (Wilde, 2016).

2.7. Genetics and Synthetic Biology

Gene technology is a biotechnology that uses DNA modification to reinforce possibilities of crops and livestock through selection and breeding. There are various orientations in genetics, including DNA sequencing, cloning, cisgenesis, transgenesis, gen inactivation, and epigenetics. Genetics technologies can be applied to a wide amount of purposes. Synthetic biology is a technological-scientific development that applies technical design principles at the biological molecular level. Synthetic biology overlaps with disciplines such as genetics, however the ultimate ambition is much greater. This discipline can contribute to more sustainable farming in the future, as organisms will use less raw materials, herbicides, space and energy (Wilde, 2016).

2.8. Aquaculture

According to De Wilde, aquaculture is the cultivation of aquatic organisms, such as fish, molluscs, crustaceans, and seaweeds, in ponds, basins, or at sea. Worldwide, aquaculture is the fastest-growing sector in agriculture, as demand for seafood rises and it replaces traditional commercial fishing. Aquaculture can also be very suitable in making use of residual flows from other agricultural production, and aquaculture residuals such as remains of processed aquatic organisms such as shells can be reused as well for other purposes. Texas produces mainly fish and crustaceans (USDA/NASS, 2019). The Netherlands produces mainly fish and shellfish. Future developments include increasing occurrence of circular aquaculture systems, urban aquaculture, advanced water purification systems which eliminate the need for chemicals, and applications for saline aquaculture (Wilde, 2016).

2.9. Vertical Agriculture

Vertical agriculture or vertical farming is often identified as an agricultural strategy to bring crop production closer to urban areas. Using vertical scaffolding with horizontal production shelves, or vertical production walls, the footprint of a production facility can be significantly decreased, making it suitable for placement in urban or peri-urban areas. Considering all four levels of the food system, so not only limited to food production but also taking into account processing, distribution, and consumption, peri-urban agriculture has the most potential to positively impact food security compared to urban agriculture (Opitz, Berges, Pior, & Krikser, 2016). Urban and peri-urban agriculture can both increase food visibility, food access, and consumer awareness, and are mainly interesting concepts for implementation as a secondary food source with rural agriculture as a primary food source (DiDomenica & Gordon, 2016). Vertical farming is most economically viable in the formfactor of so-called ‘plant factories’: large scale facilities that are able to lower cost, and offer produce at prices similar to traditional farming produce. The main challenges of vertical farming include the high cost of vertical farming system development, and the highly complicated nature of all components that are required for vertical farming. These components need to be interconnected and require highly inter-disciplinary skillsets (Hardej & Knight, 2016).

2.10. Weather modification

Weather modification is the conscious manipulation of the environment in order to change weather conditions. Weather modification can be used to either change the weather for positive outcomes, or prevent damaging weather conditions. For example, in agriculture, weather conditions such as hail can damage crops. This is especially true for fruits, which can be very delicate. Hail can even cause entire harvests intended for fresh markets to be lost. Hail canons are a form of weather modification that has been around since the 18th century in some form. The hail cannon has been developed to reduce the negative effects of hail fall. The canon produces a shock wave, which reduces the growth of hailstones (Diepersloot, 2012).

2.11. Hydroponics, Aeroponics and Aquaponics

According to Alshrouf, modern agricultural production systems such as hydroponics, aeroponics, and aquaponics use soilless agriculture for increased efficiency in production. All three systems are advantageous, as all require less water, less fertilizer, and less space, with the latter increasing yield per unit area. Furthermore, all three systems can be used for vertical farming production.

Hydroponics uses only water and nutrients fertilizer to cultivate plants. Hydroponic systems are efficient in water and nutrient usage, especially when using no growing media[5]. In that case, the system may be completely closed loop[6] and self sustaining.

> *“A growing technique like aquaponics or hydroponics allows you to use a minimal amount of space to grow a maximum amount of produce”*
> *-Matthew Braud, Sustainable Harvesters*
> (LANDiO, 2019)

Aeroponics is a subgroup of hydroponics. In this case, plant roots are being incapsulated in a dark enclosure, and nutrients are transferred by spraying a nutrient dense solution onto the roots. Aeroponics is therefore completely grow media free.

Aquaponics is an integrated system of hydroponics and aquaculture, meaning that fish growing tanks introduce nutrients into the system. These two components create a naturally stable ecosystem. Nutrients from fish feed, processed by the fish, replace added fertilizer which is used in hydroponics systems (Alshrouf, 2017). An example of an aquaponic production facility is Sustainable Harvesters, based in Hockley, Texas.

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[5] Definition of grow media: *“Grow media (singular form of media is “medium”) is the term used to describe the range of substrates that plants are produced in. This could be soil, soilless media such as potting soils, stones or mined materials like perlite and vermiculite, fibers such as coir or rockwool or water or nutrient solutions as in hydroponics or numerous other substances suitable for plant culture.”* (MaximumYield)

[6] Closed loop agriculture is a farming practice in which all nutrients and organic matter material are recycled (Harty, 2016).

CHAPTER SUMMARY

The most promising agricultural technologies include 3D and 4D printing, smart materials, robotics and autonomous (micro)robots, sensor technology, information technology and bioinformatics, smart farming technologies, renewable energy and biofuels, genetics and synthetic biology, aquaculture, vertical agriculture, weather modification, hydroponics, aeroponics, and aquaponics.

Robot and autonomous (micro) robots is a broader category, including robots that can be applied for precision agriculture, pollution monitoring, livestock ranching, weed control, horticulture automation, harvesting, planting, and seeding. Information technology also includes many sub-categories that are promising for agriculture as well, including big data, artificial intelligence, machine learning, and the internet of things.

Some of these technologies are used individually, but often may be seen combined with other technologies to create more powerful technological solutions in agriculture. Some technologies can already be seen in practice, with technologies such as IT and sensor technologies being applied for multiple decades. However, other technologies are still in their infancy, but promise to be very disruptive in the near and/or distant future.

3. Agricultural Technology in the Netherlands and Texas

This chapter compares the characteristics and state of affairs within the Texas agricultural industry, with the technologies discussed in the previous chapter. Here, the applicability of these technologies in Texas is examined, or identified whether such technologies already exist in the state.

The NBSO report: "Industry Analysis Agriculture in Texas: Tends and Opportunities" broadly describes the agricultural industry and main opportunities and challenges. This report is therefore referred to in this section for industry information. Takeaways from this report that are of importance for the identification of opportunities for agricultural technologies are described below. This includes a summary of the agricultural industry in Texas.

3.1. Agriculture in Texas

3.1.1. Size of operations is large compared to the Netherlands

Texas is one of the largest agricultural production states in the United States, with a value of $24.92 billion in sales of agricultural goods and related items in 2017. There are approximately 248,500 pastoral, arable, or mixed agricultural operations in the state. In 2017, the average size of farmland operated per operation was 511 acres, which is approximately 6.3 times bigger than the average farm in the Netherlands in the same period (Breden, 2019, p. 9).

3.1.2. Internet connectivity of agricultural operations

In 2017, 72.6% of all operations in the state of Texas indicated to have access to the internet. This includes a large variety of methods, including dialup (3%), DSL (21%), cable (15%), fiber optic (6%), mobile (42%) and satellite (28%). This means that more than a quarter of all Texan farmers have no access, or choose not to connect, to the internet at all. Operators without an internet connection, or operators with a slow connection, cannot (fully) utilize innovative production methods that makes use of digital farming software and internet tools (Breden, 2019, p. 5).

3.1.3. Shortage of (un)documented agricultural labor

In Texas, 20% of operations hire farm labor. The agricultural industry of the state relies heavily on undocumented workers from Mexico and other Latin American origins, however recent developments have made illegal labor less attractive for farming operations. Also, strengthening economies of Mexico and other Latin American countries have ensured that the population is less likely to perform illegal work in the agricultural sector in the United States (Breden, 2019, p. 10).

3.1.4. Large variety of soil types and climates

Texas is divided in 10 climate divisions and 21 Major Land Resource Areas (MLRA's). This shows the great scale and variety of the state, which is very important to recognize when analyzing the state for business opportunities. Along the Gulf Coast lie the Texas Wetlands, with subtropical and humid climates. Further north, the climate is more semi-arid savanna. The state therefore deals with both damaging flooding and extensive droughts. The various soil types in the different MLRA's also introduce their own challenges for agriculture. Main challenges include low soil moisture and water irrigation problems, low fertility, wind erosion, and brush control (Breden, 2019, pp. 11-15).

3.1.5. Loss of agricultural land

Texas leads the nation in the loss of working lands in total acres lost. This can be explained as a result of the explosively growing population in the state. Approximately 87% of this growth was observed in the 25 fastest growing counties in the 1997-2012 period. In these counties, 54% of working lands was converted to another use, primarily to accommodate increasing urbanization. The loss of working lands has an impact on rural economies, food security, water conservation and other natural resources (Breden, 2019, pp. 15-16).

3.1.6. Availability and quality of agricultural water

In 2015, 27.2% of all water used in Texas was estimated to have been used for agricultural purposes, including irrigation, livestock production, and aquaculture. In the near future, water demand is expected to increase while water reserves deplete. Furthermore, poor planning of industrial sites, cattle farms, and farmyard and feed lots affect the quality of agricultural water. Water use and water management practices will therefore need to reduce and improve to ensure sufficient quality and supply in the future. Five opportunities for improving irrigation efficiency are (1) improving irrigation scheduling, (2) adopting drought-tolerant crops, (3) developing improved irrigation water management technologies, (4) continued adoption of conservation practices, and (5) improving irrigation conveyance systems (Breden, 2019, pp. 16-17).

3.1.7. Livestock production

Main livestock commodity groups in Texas are cattle and calves, poultry and eggs, and dairy. The cattle and calves commodity group is worth almost half of all production sales, with almost half of all agricultural producers actively producing in this commodity group. Texas is also the leading state in horse population. In the cattle industry, the main management issues of producers are concerned with cow and calf health, animal welfare, nutrition and feed management, and environmental stewardship and sustainability. Furthermore, Texas is on the forefront of development in cattle traceability along with two other states. (Breden, 2019, pp. 21-23).

3.1.8. Crop production

Main crop production included cotton and cottonseed, and grains and oilseeds such as corn, wheat, sorghum, rice, and soybeans. Texas is the leading state in cotton production, which is produced mainly in the High Plains (Breden, 2019, pp. 23-27).

3.1.9. Adoption of precision/smart farming technologies

A survey among cotton producers in 14 southern US states in 2013 showed that Texan producers have implemented precision farming techniques on par when compared to the average implementation rate of all states. Smart farming techniques are adopted very quickly in the United States and Europe, including Texas (Breden, 2019, pp. 30-32).

3.2. Agriculture in the Netherlands

In order to define opportunities for Dutch agritech businesses, based on the agricultural and agritech market in Texas, it is of importance to understand the main drivers and sources of agricultural innovations in the Netherlands.

3.2.1. Circular Agriculture

In the Netherlands, the concept of circular agriculture[7] (the 2019 vision of the Dutch Ministry of Agriculture, Nature and Food Quality) is an important driver of agricultural technology development. The vision clearly indicates that crop and livestock production in the Netherlands must develop towards a cycle system in which the value chains are arranged in a circular fashion. Producers use raw materials and residual flows from each other's chains and from the processing industry to minimize the impact on the ecosystem. Soil management and the utilization of residual flows are the

[7] The term used in the Netherlands is ‘kringlooplandbouw’. In the English language, circular agriculture is referred to as 'circular economy in agriculture' or a similar term. Sustainable agriculture is also used, but this often only reflects the producer of agricultural products and not at the food and fiber value chain as a whole.

most important parts of a sustainable system. The Netherlands must play a prominent role in the renewal of production methods in the agri-food industry. The Netherlands is a leader in the field of agricultural research and knowledge, and will continue to transfer this abroad in the future.

It is already visible that individual entities and entire value chains in the agri-food industry are starting to organize themselves circularly. In 2019, Erisman and Verhoeven estimated that approximately 15% of all agricultural producers in the Netherlands currently work with circular agriculture practices (Erisman & Verhoeven, 2019). The greenhouse horticulture sector is at the forefront of this movement and has generally adopted many characteristics of circular agriculture. Examples of this are, for example, the elimination of emissions to the soil, water and air. Furthermore, the use of water is minimized as much as possible, production is climate neutral, and geothermal and residual heat from other sectors are used to heat greenhouses. Other examples include dairy farmers, who are able to separate manure from urine, after which these residues can be used to generate energy. Manure is spread on the land of a crop producer, after which the crops are fed back to the dairy cows. Crop land is planted in winter to combat soil erosion and to give nutrients back to the soil. Poultry producers make their own feed and process residues from the food industry which are not suitable for human consumption.

Agricultural technology companies play a very important role in optimizing processes in the agricultural industry. They are the drivers behind the digital and technological developments within the agricultural sector and look for solutions for optimizing resources and minimizing losses. National and regional governments and knowledge institutions encourage farmers to apply new innovations to their businesses through subsidies and sharing information. The economic position of producers will ultimately support a circular agriculture system.

3.2.2. Horticulture

The horticultural sector in the Netherlands is by far the most important agricultural sector in terms of production and export value. The horticultural sector produces both ornamental plants, flowers and edible crops. Ornamental plants and flowers account for the highest production value of both groups (van der Heide, Silvis, & Heijman, 2010). The export of ornamentals was the highest in 2018 with 9,2 billion euro. Also edible crop production such as vegetables and fruit were part of the top five commodity group exports, worth 6,6 billion euro and 6,0 billion euro respectively (CBS, 2019).

The protected horticulture sector[8] is furthermore by far the most innovative of all agricultural production in the Netherlands, according to an analysis from Wageningen University and Research. These innovations included the production for new varieties of flowers, plants, and vegetable crops. Furthermore, process improvements such as sorting and packaging, as well as the development of new climate systems were also observed. Besides protected horticulture, a relatively high number of in-the-open horticulture[9] operations implemented new innovations. These innovations mainly included the production of newly improved vegetable and fruit varieties (van der Meer & van Galen, 2018).

3.2.3. Lack of Agricultural Labor

In the Netherlands, though also in other western countries, the lacking availability of labor is already a direct danger for competitive position of the agricultural industry. A 2015 whitepaper from Wageningen University and Research emphasised that only 10% to 15% of workers in the

[8] Protected horticulture refers in this study to the use of greenhouses to protect crops from environmental influences.

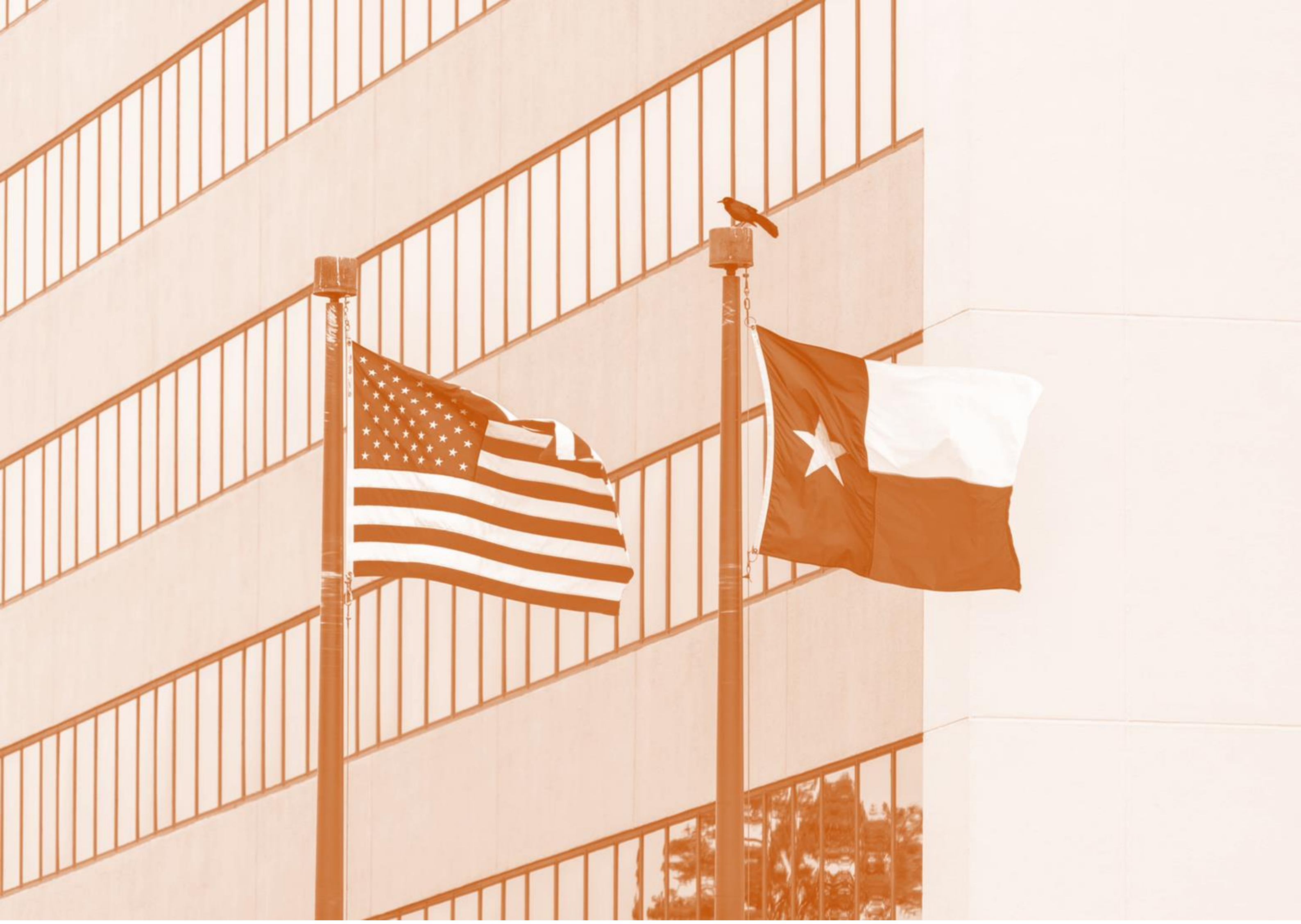
[9] In-the-open horticulture refers to the cultivation of horticulture crops on open agricultural land, without an environmentally controlled environment such as observed in greenhouses or other environmental protection.

greenhouse horticulture sector are Dutch citizens, the remainder of workers are immigrants originating from eastern Europe. As economical situations in these countries are improving, the availability of immigrant agricultural labor is decreasing.

Besides the lack of agricultural labor, another reason for the increasing robotization level are the opportunities of increased precision. As farming operations increase in size while labor decreases, producers are not able to oversee, assess, decide, and evaluate as well as before. In the future, it is expected that robots will be suited to partake in the decision making process and work in changing environments (Beulens, et al., 2015).

3.2.4. Triple Helix Cooperation

The so-called Triple Helix cooperation structure is a driver of innovation and its adoption in the business world and real-life applications. Within a Triple Helix collaboration, the government cooperates with businesses and knowledge institutions. This collaboration is less visible in Texas. As a result, knowledge institutions work less well with the business community that can bring new innovations to the market, which means that new solutions can be used less quickly in industry. In addition, the government facilitates knowledge institutions and companies less often, which means there is not always enough funding to develop new solutions. A good example of the triple helix collaboration in the Netherlands in the field of agriculture include the collaborations between government agencies, the university of Wageningen, and businesses in the Food Valley region (Foodvalley, 2019).



CHAPTER SUMMARY

Important characteristics of the Texas agricultural industry include the large scale of production, the lack of sufficient internet connections in remote areas, a shortage of agricultural workers due to a decrease in both legal and illegal immigration, a large diversity of soil types and climate types within the state, the loss of agricultural land around urban areas, and the availability and quality of agricultural water.

Important drivers of innovation in agricultural technology in the Netherlands include the push towards circular agriculture, the innovative nature of the horticulture industry, the increasing lack of agricultural labor, and triple helix cooperation between governments, universities, and the industry.

4. Opportunities in Agricultural Technology in Texas

Considering all promising agricultural technologies and production strategies described in the previous chapter, all technologies can be implemented to varying degrees in the agricultural sector in Texas. Some of these technologies will be very useful in solving current problems in the industry, such as some described in the previous chapter, and may be applied on a larger scale in the (near) future. On a smaller scale, other technologies may be able to have a major impact on for example, local communities, strengthening rural food security and consumer awareness.

4.1. 3D and 4D Printing and Smart Materials

Whereas the possibilities that 4D printing will bring in the future are still a bit unclear, 3D printing however is already very much a reality.

Opportunity 1: The technology of 3D printing brings many opportunities in various industries, but in agriculture specifically it may increase self-sufficiency of farmers, especially those in rural Texas. 3D printing allows farmers to produce traditional tools and equipment. Also, the technology may allow farmers to develop their own tools and equipment, specifically for their needs, as well as create spare parts for repairs. The upcoming hydroponics, aquaponics, and aeroponics industries, including vertical farming, need special equipment of which some is very suitable for 3D printing.

4.2. Sensor Technology, Smart Farming, IT, Bioinformatics, and Robotics

The United States and Europe are at the forefront when it comes to the use of precision farming techniques, smart farming and information technologies. Smart farming technologies are extremely important to be able to cope with environmental changes in the future that will negatively affect agriculture. Yet there are still many opportunities here, both in the development of these technologies and in their adaptation.

Opportunity 2: Because about a quarter of all farmers in Texas do not yet have internet connectivity, and as there are also farmers who have a slow internet connection, the newest techniques that need a fast internet connection to work cannot be used by a large group of farmers. Given that investments are currently being made in rural internet connectivity in Texas, farmers who may receive stable and fast internet connection in the future will be able to invest in the new technologies. In the future, these farmers can become a new target group for developers of software and hardware.

Opportunity 3: Technologies can be expensive to purchase, not yet proven in practice, complicated, or there is no clarity about financial return. When technologies are further developed, and these concerns that prevail among farmers are lifted, a new target group will be created. This includes farmers with less agricultural land in particular, who can still apply many new technologies. It is also important for these small-scale operations to be more mindful about the environment. Technologies that help to increase profits with less raw materials will also be a must for smaller farmers in the future.

Opportunity 4: A lot of smart farming equipment is currently being developed in the Netherlands to be able to fulfill the new vision of the Minister of Agriculture, Nature and Food Quality. Even though some groups the United States are less concerned with sustainable farming and changing climates, many farmers notice and deal with the effects of climate change every day. Therefore, these technologies that make a more circular and sustainable industry possible will be very applicable in the future. Technologies that support sustainable farming practices include soil monitoring systems, data analysis with drones and other equipment and efficient planting and harvesting technologies using GPS, advanced sensors, increased computing power, and AI.

Opportunity 5: Texas has a fairly large horticulture and nursery industry. Total sales of nursery, floriculture and greenhouse production was worth approximately $1 billion, which the 3rd largest in the United States, and accounted for approximately 14% of all crop production sales value in Texas in 2017 (USDA/NASS, 2019). These industries are very labor intensive and increasingly have difficulty finding enough manpower (Collins, 2017). Currently, horticulture and nursery robots, for example for picking fruit and organizing potted plants, are becoming smarter, more efficient and cheaper. In order to combat labor shortage, more and more companies still have to look at the applications of robotics within their operation. There is a great demand from this market for robots, as soon as they are developed to be accurate and cost effective enough.

Opportunity 6: The Dutch dairy industry is very innovative and globally leading. A wide range of solutions have been developed for dairy farmers in the Netherlands, from robotic feed systems and feed pushers, to stable management systems, and from animal friendly barn floors to residual material separation systems. The Texan dairy industry is characterized by its larger scale. For example, many dairy farms have more than 1,000 dairy cows, and do not have barns because they are not always needed due to the favorable climate. Nevertheless, despite the differences, there are applications for Dutch innovations. For example, some robotic applications can help solve the problems that are introduced by rising labor insecurity. An important improvement point in the Texan dairy industry is the discharge age of cows, which is very low in the state (Bergevoet, van Calker, & Goddijn, 2006). The diary industry is very interesting for Dutch companies, as dairy farming is growing in Texas compared to other states, and a large proportion of dairy farmers are originally from the Netherlands, who often are second or third generation Dutch farmers. Developments that may be applicable in Texas, with or without any adjustments, could be marketed in Texas with a chance of success.

Opportunity 7: In addition, market intelligence agencies and trend watchers indicate that one of the major trends within the food industry will be food personalization (Mintel, 2018). To make this possible, a lot needs to be done in the dairy industry, but the solutions have already been developed in the Netherlands. For example the Lely Orbiter, which can pasteurize, homogenize, standardize and package milk on the dairy farm. Personalized milk can even already be found in the shelves of major supermarkets in the Netherlands (van Beek, 2018). If this trend also continues in Texas to some extent, the Netherlands will be able to offer a lot.

Opportunity 8: Cattle, calves, goats and sheep are the largest industries in Texas agriculture, and some of the largest in the United States overall. The development of new technologies that can be used in livestock production can therefore have a huge impact. The Dutch livestock industry looks completely different from that of Texas, but still one can find similarities. An important management theme within livestock operations in both countries is animal health and traceability. Many smart solutions have already been developed for this, which use sensors, IT technologies, IoT networks and more. Of all the technologies that can be used for a livestock operation, these sensors are the most common. Developments in this market that are cheaper or considerably better than current solutions are very promising in the Texan market.

Opportunity 9: Dutch producers of big data applications have two advantages over North American developers: first, they are more involved in the agricultural industry than Silicon Valley superpowers, according to discussions with people from the industry. Second, they must also comply with privacy legislation that applies in Europe, which better protects the farmer in various areas. These characteristics offer benefits to Texan farmers, because they fear for the security of their data, and in addition often do not see how big data applications will deliver benefits for their operation.

Opportunity 10: Other smart farming technologies may help to improve soil health, one of the main soil management problems in one of the major agricultural areas in Texas. According to A&M AgriLife: "*Continuous tillage, monocultural cropping systems, and an ever-increasing demand on water has impacted soil health in Texas Southern Plains*" (Texas A&M AgriLife Research, 2019). Precision irrigation systems and no-till precision planters are technologies that can help to preserve and improve soil health, but there is still a great need for further innovative applications.

4.3. Renewable Energy and Biofuels

Texas is a global leader in the development of renewable energy. The USDA BioPreferred Program shows that 147 Texas companies participated in 2016, contributing over $15,228 billion to the Texan economy (Biotechnology Innovation Organization, 2018). The 2018 Farm Bill Energy Title appropriates $375 million dollars of mandatory funding to support renewable energy, particularly agriculture-related energy, as well as energy efficiency and bioproducts (Congressional Research Service, 2019).

Opportunity 11: Texas A&M is currently working on projects regarding algae for fuel, legumes for bioenergy, forage crops as biofuels, new sorghum-based bioenergy crops, and sustainable production of bioenergy feedstocks (AgriLife Research, 2019). Dutch companies that have already made a lot of progress in these areas, might find a gap in the market in Texas.

Opportunity 12: The Texan government wants to take steps in the field of renewable energy, specifically in biomass energy production. Agriculture must support this, but it must also be possible to process biomass. For this, processing installations will have to be added, in which the Netherlands might play a role.

4.4. Genetics and Synthetic Biology

The main opportunities in genetics for Texas agriculture lie with finding solutions for natural resources and water conservation, disease-free crops and plants and systems for crop production, according to Texas A&M AgriLife Research. Main genotyping research efforts are focused on the beef cattle and diary cattle industries. In terms of crop production, genotyping is used to develop drought resistance cotton sugarcane, and forage crops. Also, research is being conducted into alternative uses of legumes such as peanuts or soybeans (Texas A&M AgriLife Research, 2019).

Opportunity 13: Texas needs more drought-resistant varieties of different types of crops, so that (1) the yield does not decrease when a long period of drought prevails, where the water resources are scarce, and (2) less water is needed in the first place, while realizing similar or higher yields.

Opportunity 14: Through combining ecological science with post-genomics technologies, new biopesticides and bio stimulants can be created (Chandler, et al., 2011). These pesticides and stimulants have a major advantage over their synthetic counterparts; which is their negligible effect on the environment that is effective in improving soil health. Degrading soil health and quality is a major problem in Texas (Ley, 2017).

Opportunity 15: Further development in soil monitoring will also use genetics technologies in the (near) future. DNA sequencing can be used to improve crop decisions and soil health, which offers more opportunities than traditional sensor monitoring (Eckelkamp, 2019).

4.5. Vertical Agriculture, Hydroponics, Aeroponics and Aquaponics

A very important characteristic of agriculture in the state of Texas is the disappearance of farmland around cities. In combination with soil erosion from wind and water, which makes a lot of agricultural land less fertile, and increasing droughts and lack of water resources, new production systems such as vertical agriculture are very promising.

Opportunity 16: Vertical agriculture, in the form of peri-urban plant factories, appears to be very promising. At the moment there are several projects in development in all major cities in Texas. Peri-urban agriculture is a possible solution for the disappearing agricultural land surrounding urban areas. This can also bring the consumer closer to the production process, creating more understanding among consumers.

Opportunity 17: Hydroponics, aeroponics, and aquaponics also all offer many opportunities, especially in saving water and land. Environmental protection is also used, which can protect the produce against extreme weather conditions such as flooding, hurricanes, or extreme rainfall and hail. As land quality and soil health degrades and water become polluted and scarce, these economical, clean, and even full closed and cyclical production methods are a possible solution to these problems. From a technological point of view, the Netherlands is leading in recirculation systems or closed fish systems, allowing many of these opportunities to be exploited.

Opportunity 18: The Dutch are masters in building greenhouses. In Texas, the use of greenhouses is less common, mainly due to the very warm climate where the summer temperatures quickly reach 35 °C. Yet it is seen that greenhouses are often used for hydroponics, aeroponics, and aquaponics. Because this industry is on the rise, there are opportunities here for the construction of new greenhouses. However, these greenhouses are not often made of glass. the Horticulture Census of 2014 showed that in that year only 10% of all greenhouses were made of glass. Furthermore, 9% was built with sturdy plastic, and the remaining 81% was built with film plastic (USDA/NASS, 2012).

CHAPTER SUMMARY

This chapter identified a total of 18 opportunities among most of the agricultural technologies discussed in earlier chapters. These opportunities are as follows:

1. Future need for 3D printing for increasing self-sufficiency among farmers in rural Texas.
2. Growing market for digital technologies requiring a (fast) internet connection, as a large number of farmers currently does not have, but will receive, internet connectivity in the (near) future.
3. Need of further development of digital ag technologies, which includes reducing cost, increased simplification, improved usability, and proven financial return, will also interest small and skeptical farmers who may currently not be taking part in the digital revolution.
4. Future need for agricultural technologies to boost sustainable farming, which are increasingly being developed in the Netherlands, however not to the same rate in Texas.
5. Growing market for robotics, especially in labor intensive industries such as nursery and floriculture, which is a large industry in Texas.
6. Growing market and need for digital monitoring solutions in the Texan dairy industry.
7. Possible future need for on-farm personalized food production technologies in agriculture, which was identified as a major food trend in the near future.
8. Growing market for innovative livestock sensors for monitoring and traceability.
9. Need for promising big data applications, in which the data from farmers is processed in a secure manner.
10. Need further development of technological implementations that help to improve the degrading soil health.
11. Need for ground-breaking developments in renewable energy, regarding algae for fuel, legumes for bioenergy, forage crops as biofuels, new sorghum-based bioenergy crops, and sustainable production of bioenergy feedstocks.
12. Need for increasing number of bioenergy production facilities.
13. Need for further development of drought resistant crops.
14. Need for development of sustainable products that help maintain soil health through genetics technologies, such as biopesticides and bio stimulants.
15. Need for future development of soil monitoring techniques using genetics technologies, for increased accuracy and improved decision making, as well as preserving and improving soil health.
16. Growing industry of vertical agriculture, in the form of peri-urban plant factories, which are promising due to disappearing agricultural land in urban areas and may improve consumer awareness.
17. Growing industry of hydroponics, aeroponics, and aquaponics, due to high yields with less inputs, contributing to saving water and land.
18. Need for the building of greenhouses as the hydroponics, aeroponics, and aquaponics industry grows.

5. Conclusion

This report, together with the "Agriculture in Texas" sector sketch report, provides an overview of the agricultural industry in Texas at the macro level, and presents opportunities for Dutch business in the field of agricultural technology. The opportunity chapter shows that the opportunities in the market lie mainly in the areas of digitization and robotization on the one hand, and on the other in the field of future-proof production strategies such as vertical farming, hydroponics, aquaponics, and aeroponics.

A total of 18 opportunities were identified in this report, but there is certainty that there are more opportunities for Dutch product or service suppliers in the Texan agricultural market.

5.1. Recommendations

If a company wants to take advantage of one of these opportunities, it is important to conduct an additional analysis to see whether the developed product or service really fits in well with the Texan market. Hereby it is especially important to take into account the large scale of production, the commodities produced, the climate, and the infrastructure in rural areas. The NBSO can help with this.

5.2. Further Research

Within agricultural technology, an incredible number of applications have been developed and are being developed. The market is therefore very large and diverse. Further research conducted by the NBSO and / or interested companies into the most promising areas within agritech in Texas can clarify the characteristics of the market and lead to the identification of more opportunities.

Furthermore, it is recommended that the NBSO and / or interested companies conduct further research on the food and beverage industry as a whole, considering all four pillars: production, processing, distribution, and consumption. It is expected that more opportunities can be identified here, compared to the agricultural industry

This report also shows that there are opportunities in water and energy. There are opportunities in water management as the current systems are lacking. Texas plays an important role in renewable energy in particular, and that also brings opportunities for the Netherlands.

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