In the hot house: Robotics and AI for the greenhouse industry

A case study investigating the opportunities and challenges of Ontario's greenhouse vegetable growers in an automated and digital future.

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Ontario's Greenhouse Vegetable Growers face a mix of challenges and opportunities unique in their 50-year history. How the industry responds may provide important insights for other sectors of Canada's agri-food sector. Renegotiation of NAFTA, labour issues and regulations, big data and blockchain technologies, and robotics and automation are among the most pressing issues for the greenhouse industry. However, like much of the rest of Canada's agri-food sector, businesses in the greenhouse industry must also manage the usual issues related to competitiveness, regulation, and a changing consumer landscape.

In this case study, some context is provided on the greenhouse vegetable industry in Ontario. Four key issues (NAFTA, labour, blockchain, and robotics and automation) and their impacts on the sector to date are discussed. This study also raises important discussion questions about future implications of these issues for the industry.

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Before you Begin…

While reading this case, develop answers to the following questions from the perspective of value chain participants.

1. What types of businesses and supporting organizations make up the greenhouse value chain?
2. What sorts of problems could these businesses solve using robotics and digital technologies? What opportunities exist?
3. Could these technologies support the creation of products and services that consumers cannot yet imagine? Does this technology have the potential to create new products, new markets, new value? Describe.
4. How can organizations such as businesses, governments, trade associations and other stakeholders contribute to managing the introduction of robotics and digital technologies in the agriculture and food sector so that they are used in a socially responsible manner? Will these technologies require original approaches to policy or new regulations?

CONTEXT

There are about 23,000 hectares of greenhouses in North America. Canada accounts for over 1,500 hectares, mainly under high-tech glass; the U.S. about 900 hectares in a mix of glass and plastic; and Mexico over 20,000, which is mainly medium tech and largely under plastic cover. Canadian greenhouses have consistently higher yields.[1]

Over the last 25 years, Canada's greenhouse industry has become part of an integrated North American produce market and a key player internationally. Production in Ontario's greenhouse vegetable industry now takes place all year long; cucumbers are produced year-round and tomatoes and peppers are produced February to December. Extension of the growing season has allowed the industry to meet increasing demand for vegetables domestically and abroad.[2] In recent years, over 80% of total production has been exported to the U.S., and over half of these exports are tomatoes, the majority of which were produced by the cluster of greenhouses in south Essex County. The success of the cluster and the industry has benefited rural communities over the last 50 years through direct economic activity as well through spin-offs and the growth of related industries.

In the late 1960's, the Ontario industry comprised about 700 businesses primarily owned by Italian, Dutch, and Mennonite families. These have increasingly been joined by other businesses that bring expertise from outside agriculture, including external investors. The largest companies have adapted greenhouse technology and management approaches from the Netherlands and have become world-class competitors. Ontario greenhouse businesses are also integrating vertically and developing highly integrated supply chains to manage marketing, distribution, and even production in the southern U.S. and Mexico for year-round supply.[3]

Canada's Greenhouse Industry Distribution (by area)

70% Ontario

20% Southern B.C.

10% Prairie & Atlantic Provinces

In 2015, the greenhouse industry economic contributions in Ontario amounted to:

$3.2 Billion

6,386 Jobs

(Over 50% of which seasonal)

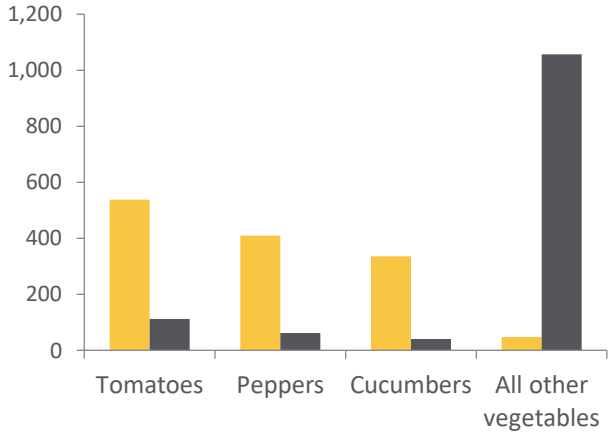

Figure 1. Farm gate sales of Canadian vegetables (greenhouse and field), 2016, in millions of dollars.

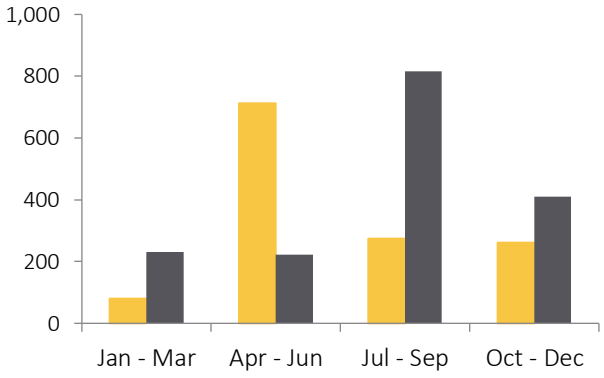

Figure 2. Farm gate sales of Canadian vegetables by season (greenhouse and field), 2016, in millions of dollars.

The Modern Greenhouse Business

The greenhouse business includes production and marketing of vegetables and fruit, floriculture and nursery stock and, more recently, cannabis. Greenhouse businesses in Ontario range from large family owned firms that compete on a global scale to small niche businesses that supply a limited product range to a local market. Some Canadian greenhouses are publicly traded, such as Village Farms™, a large greenhouse vegetable grower, which recently decided to switch one of its British Columbia greenhouses into cannabis production.[4]

Greenhouse production in Canada peaks during the early summer, although production of peppers and cucumbers is now year-round. Some Canadian companies also access production during winter from Mexico, warmer regions of the U.S., and other countries; this allows them to service key accounts throughout the year.

The strategies of greenhouse vegetable businesses differ in overall scope and direction, and as such, the functional strategies that are used within each business' internal value chain also differ. The greenhouse industry consists largely of privately-owned firms, many of which have been owned by one family for several generations. These firms may benefit from having their own capital for new facilities or technology and may need a lower return on their investment than would a firm not owned by a family.

ONTARIO GREENHOUSE VEGETABLE GROWERS

BACKGROUND INFORMATION

- Established in 1967, it is located in Leamington, ON: The heart of the largest greenhouse cluster in North America
- Currently, the OGVG licenses about 220 members who grow, pack or market greenhouse tomatoes, cucumbers, and peppers in Ontario.

Comprises:

- Board members who serve on a variety of member committees
- General Manager and eight staff who have portfolios that address industry research, food safety, energy, environment, and regulatory compliance.

INDUSTRY ROLE

OGVG conducts a variety of activities to support industry members and continued growth including:

- Marketing activities to help foster connections between members, government, consumer, retailers and food service operators in North America and beyond
- Lobbying activities
- Host trade shows
- Manages any disputes related to the pricing regulation whereby 90% of greenhouse vegetable sale price is to be paid to the grower by the marketer

Technology, Research and Development

Modern greenhouses offer growers increased control over crop growth, which in turn increases predictability of growing cycles and reduces costs of nutrients, water, and other inputs that help to boost crop yields.

In recent decades, greenhouse innovations have been implemented largely on a piecemeal basis (i.e., new recycling system for nutrients, installation of new lighting technologies). More recent innovations, however, include the development of smart, integrated controlled environment technologies that allow coordination of growing activities. Much of the technology used in the Ontario greenhouse industry today has been adapted from the Dutch greenhouse industry.

Figure 3: Tomatoes-on-the-vine are one of the industry's many niche products

Ultimately modern technologies are about increasing control of the production environment and minimizing the environmental footprint. The ability to control the weather (temperature, moisture, air movement, and light), environmental impacts, both harmful and beneficial insects, the growth media, and the development of individual plants is pushing greenhouse vegetable production into manufacturing technology space, requiring workers with increasingly high-tech and continually evolving skills. Information technology and automation is becoming essential for operating and managing a greenhouse.

The Market

The greenhouse vegetable industry is well-poised in many ways to take advantage of current vegetable market trends. Fresh produce—and particularly greenhouse vegetables—play an increasingly significant role in consumer diets in developed countries. The simple act of eating more staple fresh vegetables is seen as a good, healthy eating strategy by more people. Canadians place a high value on the taste, safety, and cost of food, followed by health and nutrition attributes. The growth of online grocery shopping and online meal subscription services (ready-to-cook meal delivery services) holds potential for the highly traceable greenhouse vegetable industry. As with many other goods and services, more affluent consumers and high-end, niche retailers will pay a premium for gourmet, fresh, and local products. This can benefit the greenhouse vegetable industry, particularly as more than 30% of Canadians eat fresh fruit or vegetables five or more times daily.[5]

Figure 4: Ontario greenhouse sweet peppers from Sunset Produce, bred for convenient snacking size and packaged for longer shelf life and convenience

Figure 5: Sustainable packaging innovation in the snacking tomato market

In tandem with the opportunities to buy fresh, local foods, consumers generally favour foods that are also convenient and affordable. The increased year-round availability of fresh and ever more flavourful greenhouse tomatoes, peppers, and cucumbers has met this demand to some extent; however, the competition from processed and convenience foods, as well as frozen and other prepared vegetables, remains important. Products that are sized appropriately, easy to store and those that can be prepared in their packaging also provide some of the same benefits as processed foods. More recently, consumer concerns about food waste and the environment have become more important. Consumers also want more clean labels and minimized, recyclable or biodegradable packaging choices.

Marketing, Sales and Service

The larger greenhouse businesses sell a large variety of tomato types in different packaging sizes and options, perhaps more than 500 combinations. Much marketing emphasis has been on packaged tomatoes that allow a final product with specific attributes based on size, style (i.e. snacking sized, tomato-on-the-vine), ripeness, taste, skin quality, final use (sliced or individual), or variety and production characteristics (i.e. non-GMO, organic). Branding is now widely used by grower-marketers with the licensing or development of exclusive varietals becoming more common. Packaging options have also been increasing: one greenhouse now offers peppers in a reusable, fabric bag to maintain pepper freshness longer (such as Sunset EcoPeppers ™)[6] or bags of assorted mini peppers or mini "cukes" for snacking or lunches. Many greenhouse businesses also promote use of their products by providing recipes, storing or cooking tips, or through educational programs that support healthy, tasty and nutritious eating.

Figure 6: Cherry tomato marketing in the form of special event packaging

Traditionally, the perishability of produce has been a key driver of industry rivalry. The need to aggressively sell product at any price before it spoils to recoup costs remains a characteristic of the fresh food market. The degree of control that technology can provide over this factor of production may be

influenced by robotics technology. Greenhouse growers have more control over when to enter markets than do field vegetable producers, but they still must contend with competitive pricing dynamics. During market flushes, many growers will make side deals with marketers to pick and move product. Contractual arrangements for the upcoming growing season between larger growers/marketers and retailers in an integrated North American produce market have somewhat reduced side deals and "back of truck sales", but they still exist.

Operations and Outbound Logistics

Most greenhouse tomatoes are produced hydroponically: grown in soil-less media such as rockwool, sawdust, foam, peat moss or plant fibres (i.e., coconut fibre) using an irrigation system that provides water and nutrients. It takes 8-10 weeks before most tomato plants can start producing fruit. Because tomato blossoms must be pollinated before they can produce fruit, bees usually live in the greenhouse and perform this task.

Greenhouse set-up, production and harvest, maintenance, and clean-up require a great deal of labour. Conveyors are placed between the rows of plants so that workers can sit on carts to prepare the planting material, plant the tomatoes, de-leaf, and monitor the plants for any problems (including pests and disease), and harvest the fruit. Carts are then moved to the packing area where the freshly-picked produce is sorted and graded and then packaged and labelled for traceability.

Product distribution is critical to ensuring that products are retailed fresh at their required quality characteristics and ensuring demand from customers is met. Many of the largest Canadian greenhouses have continental logistic systems with distribution centres in the U.S. that manage supplies from contractual and owned greenhouses located across North America.

Energy and Managing the Environment

Greenhouses use energy to manage lighting, temperature, humidity and other factors. Energy costs can be significant to greenhouse producers, and with electricity prices increasing dramatically in Ontario, many growers have built or moved growing operations to the U.S. (i.e. Ohio, Pennsylvania). Recently, the greenhouse industry joined the Ontario Electricity Stakeholders Alliance, a diverse group of consumers, businesses, producers and distributors in Ontario who are concerned about rising electricity costs.[7]

To reduce energy costs and achieve environmental goals, most water used in greenhouses is reclaimed, sterilized, and reused. Greenhouses boilers are high efficiency (some over 90%) and the carbon dioxide produced by these systems is captured and sent back into the greenhouse to help the plants grow. The growing media and packaging from greenhouses may also be recycled (i.e. coconut shells used as media can be turned into potting soil for gardens). Greenhouses may be linked to energy sources directly and some may even be carbon negative.

Major risks in the greenhouse industry:

Market prices
Exchange rates
Value of biological assets
Transportation disruptions
International trade legislation
Retail consolidation
Energy prices
Labour rates
National and sub-national legislation
Extreme weather

Regulatory and Sustainability Pressures

Greenhouse businesses deal with a variety of regulations that include environmental regulations at the national, provincial and local levels; provincial health and safety regulations; federal and provincial labour laws; and traceability and labelling regulations. Failure to comply with any of these can result in disruptions to operations, fines, reputational losses, or non-planned expenditures.

Food Safety

Fresh produce is associated with healthy choices by most consumers. However, fresh produce has also been implicated in several high-profile food safety cases. Food safety hazards involved with fresh produce can occur throughout the value chain and can be microbial, chemical (e.g. due to inappropriate use of pesticides or cleaners), or physical (e.g. presence of unwanted material such as insects, feathers, glass, or pins) in nature.

Greenhouse vegetable production allows for better controls and traceability than field production. Even 10 years ago, leading Ontario growers were able to trace a tomato to a specific location in a greenhouse. Since then the industry has adopted Good Agricultural Practices (GAP) for Food Safety or Fresh Fruit and Vegetables, a Hazard Analysis and Critical Control Points (HACCP)-based certification audited program.[8]

By 2021, all food manufacturers (including greenhouse vegetable growers) in Canada will need to be fully compliant with the Safe Foods for Canadians Act (SFCA), passed in 2012, which consolidates 14 sets of existing regulations into one comprehensive food regulation.

It is hoped that the use of stronger rules and coordinated services, new approaches to food inspection, and use of risk information to plan inspections will increase the ability of the Canadian Food Inspection Agency (CFIA) to meet the needs of both consumers and industry businesses. The government also hopes that the regulations in the SFCA will help to reduce the time it takes to remove unsafe foods from the marketplace.

Issue 1: The North American Free Trade Agreement

It's not just President Trump who thinks NAFTA is the "the worst trade deal ever made". Some of the impetus for renegotiating the deal comes directly from U.S. tomato growers, particularly those in Florida and other parts of the U.S. that compete most directly with peak seasonal Mexican production.

Trade in vegetables among Canada, the U.S., and Mexico has increased greatly over the last two decades. The degree of this change is starting to garner attention among "foodies", as well as the usual government, research and industry interests. According to Ken Gilliland, director of international trade for Western Growers, which represents produce farmers in Arizona, California, Colorado and New Mexico, "NAFTA over-all has been positive, and we oppose U.S. withdrawal from the agreement. … Eliminating NAFTA and implementing tariffs would have a negative impact on our members' ability to export." However, many in the industry contend that most of this advantage has "gone to large growers".[9]

Global Value Chains

NAFTA has facilitated the development of continental value chains in the greenhouse industry, which has made it possible for consumers to buy fresh tomatoes almost year-round. The estimated area of greenhouses in Mexico quadrupled from 2003 to 2013, while in the U.S. it increased by approximately 1.3 times. Growers in the U.S. and Canada may locate or source production in all three NAFTA countries. For example, DiMare, "a third-generation Florida tomato grower," said that he also acts as a wholesaler, sourcing tomatoes from different growers and reselling them to grocery stores and food-service providers, and that some of his product comes from Mexico.[10] Sunset Produce, an Ontario-based family business, has one of its flagship operations in Michigan, and was prominently showcased on the U.S. Secretary of Agriculture's third "Back to our Roots" RV tour in early April 2018.[11] Jobs created in Mexico, the U.S., and Canada are generally in the larger, more technologically sophisticated businesses that are part of fresh produce value chain. Some of these jobs are, however, less skilled or seasonal, requiring seasonal workers to be brought in from other countries.

NAFTA's Impacts and Technology

The impacts of NAFTA have occurred during the same decades that the impacts of information technology and concerns about increasing economic inequality have become more prominent. Mexico's greenhouse industry is moving toward high-tech, as can be seen in the concept of Mexico's "agroparks", an integrated greenhouse cluster dedicated to growing export-quality vegetables and flowers. This park is more efficient and attracts workers from small-scale agriculture who are enticed by benefits such as free meals, transportation, and life insurance.[12] Some of these parks are public-private partnerships, particularly when being initially developed, while others are owned by private investors.

Ongoing Trade Disputes

Trade disputes concerning fresh and/or greenhouse tomatoes among Canada, Mexico, and the U.S. have been part of the international trade environment for nearly 30 years. The U.S. International Trade Commission (USITC) has been monitoring tomato and pepper imports from Mexico since NAFTA's initiation in 1994. In 1996, the USITC found that Mexican tomatoes were being sold in the U.S. below fair market value, and special provisions were imposed, which remain in place today.

Many growers in Florida contend they have never had a "fair trade" agreement: "farm workers' wages in the U.S are far higher as is the cost of meeting government regulations," while the "Mexican greenhouse industry has taken off …only because the state helped subsidize it." Florida tomato growers continue to insist that "Mexico is selling tomatoes in the U.S. at artificially low prices."

Since NAFTA came into effect, tomato growers in other regions of the U.S. have been able to adjust to competition from Mexico through more vertical coordination and increased efficiencies, using information and greenhouse technology which allow for vine ripened tomatoes that align better with consumer trends and the need to service retail accounts year-round.

Issue 2: Labour

A **demanding mix of labour and management** is needed to operate a successful greenhouse business. Management is required **year-round** and includes an increasingly demanding mix of **technical, regulatory, and business and marketing knowledge**. Greenhouses also require **general labour with skills** for a broad range of tasks, including the set-up and monitoring of greenhouses and irrigation systems, propagation of seedlings, growing and monitoring of plants, pest and disease management, harvesting, sorting, packing, and labelling.

Ontario's greenhouse vegetable industry faces three key labour issues: labour regulations and minimum wages; labour availability; and how to manage future human resource needs in conjunction with technological development.

Labour Regulations and Minimum Wage

Wage rates are an important aspect of labour regulations in the Ontario Greenhouse industry. Wages are regulated by Ontario's Employment Standards Act (ESA). Changes to this legislation were implemented in November 2017, increasing the minimum wage to $14/hr in January 2018 with a second increase to $15/hr scheduled for January 2019. While the minimum wage does not apply to all types of agricultural workers in Ontario, the impact of this minimum wage legislation caused concern. Some greenhouse growers reported that they would not expand or make new investments until they could assess the impact of the changes. Others have noted they are seriously considering significant investments in automation to reduce their reliance on human labour.[14] An OGVG press release indicated their members were "shocked" by the plan for these increases, noting "immediate concern for the ongoing viability of their sector".[15]

Regulations also dictate the way that greenhouse businesses access and hire agricultural workers; these regulations define roles for farm workers and harvesters and stipulate the benefits each must receive (i.e., housing). There are also regulations regarding worker eligibility for personal emergency, pregnancy, and parental leave; notice of termination; severance pay; and workers' rights to organize (farm workers in Ontario are restricted from organizing, but this varies by province).

Labour Availability

It can be challenging to fill jobs in agriculture. Long work weeks that are concentrated seasonally, rural locations, and the physically demanding aspects of much of the work make attracting and maintaining labour difficult. The Canadian Agricultural Human Resources Council (CAHRC) reported that 41% of agricultural producers surveyed could not find enough workers.[16] In 2014, 17,000 of the 59,000 jobs in the agri-food sector not filled were in the greenhouse, nursery and floriculture industry. These gaps exist despite the use of foreign workers, who are critical to Canada's horticultural production; in this sector, foreign workers accounted for more than one-quarter of the workforce.

The agricultural sector's labour gap is forecast to increase in the coming years. Growth in labour demand is predicted due to increased production and productivity (although this may differ by commodity). In the face of this growth in demand, the sector has an older-than-average workforce and is expecting above-average retirement by 2025. Fewer young people are considering farming careers, in part

The Canadian Agricultural Human Resources Council recommends strategies such as increasing domestic worker recruitment, enhance access to training, learning resources and human resource management and, coordinating employers with different seasonal patterns, to name a few.

because there is competition for labour from other sectors of the economy, perhaps particularly so in areas where much of Canada's greenhouse industry is located. In addition, career paths in the sector are not well understood.

The industry continues to rely heavily on the Seasonal Agricultural Workers' Program (SAWP) that was established 50 years ago. Despite this reliance, the program cannot fill the labour gap and the program also presents its own challenges. When compared with opportunities available in their home countries, workers from Mexico and the Caribbean benefit from jobs in Canada by earning an income which is relatively high and allows them to buy land or homes in their home country. Industry organizations often provide support for worker communities beyond what is required by legislation (i.e., sports tournaments, holiday celebrations).[17] Some recent research, however, suggests that some foreign workers may face issues related to working conditions, living conditions, access to health care, and isolation.[18][19] Others stress the positive aspects of this program such as providing higher incomes for workers than would be possible at home and learning new skills that can be transferred home.[20]

Managing Future Human Resource Needs in Conjunction with Technology

In many sectors of agriculture, technology is perceived as a necessary investment that could reduce reliance on human labour. While the CAHRC report describes the agricultural sector as being "on an unsustainable path, with a steadily growing labour gap and an increasing dependence on foreign workers to fill that gap",[21] the report does not address impacts from the anticipated wave of automation (generally) in the agricultural sector and (specifically) in the greenhouse vegetable industry.

The Canadian Federation of Agriculture has recommended the agriculture industry consider addressing the labour shortage by increasing immigration opportunities; examining solutions to address barriers to under-represented groups; accessing international workers only as a last resort; and improving education skills and training.

In Canada's agricultural sector in 2014

26,400

Jobs could not be filled

Resulting in...

$1.5B

In lost revenue

This job gap is estimated to grow to

114,000

By 2024

Issue 3: Blockchain Technology

Value Chain Capabilities

Theoretically, blockchain provides two capabilities related to value chains. First, it provides the ability to log every "data point" for a food product in a shared ledger thereby allowing all participants in the value chain, including consumers, to share in full transparency. This has value for reasons of provenance, discussed below, and also for managing the increasingly complex data available to producers which today remains largely inaccessible. Second, it creates a framework in which transactions between organizations can be managed using *smart contracts*, an executable computer protocol that can verify performance and enforce a contract.[22]

BLOCKCHAIN:
Single, shared, secure and immutable ledger to record transactions may be permissioned or public

If you are Interested in more information: See IBM's Blockchain for Dummies

Food Provenance

Food provenance (knowing where your food came from) is increasingly important to consumers for taste, safety, and ethics-related reasons. The explosion of information about food may be best exemplified by the proliferation of cooking and nutrition information on the web and Netflix documentaries. All this information and misinformation has changed the standards that businesses need to meet if they want to maintain and improve their reputations.

Information on food provenance is needed for traceability relating to food safety, counterfeiting, and the credibility of food attributes deriving from authenticity, terroir, organics, genetic status and various labour, environmental, fair trade, and business practices. Currently, "provenance-based value chains" are deliberate strategies by businesses that provide products and services with specific attributes. These businesses have worked hard to develop relationships and perhaps certification schemes to build and maintain trust. A good example is Bordeaux wine, which must be produced within the Bordeaux region of France to use the name. These approaches go beyond mass market expectations about food in terms of taste, safety, and how it is produced, marketed and supported by a "good regulatory system". Blockchain may have the potential to improve on the mass market model and render the capabilities of "provenance-based value chains" obsolete.

Emerging Questions

Blockchain technology raises important questions for agricultural and food businesses, as well as consumers and regulators. Who will negotiate the smart contracts between levels of the value chain?

How will consumers get access to information that matters to them, and how will privacy concerns be protected?

What types of regulations might be needed to ensure consumer level information is use to "nudge" responsibly? Is such an approach to public health ethical and something we should encourage?

What data points will be included in the blockchain? How will they be determined? How will data entry occur? What types of capabilities will managers need to develop and function in blockchain systems? Will the use of blockchain change the nature, reputation and public image of the food system for better or worse?

Issue 4: Automation and Robotics

In September 2017, John Deere acquired Blue River Technology, the inventors of Lettuce Bot, for US $305 million.[22] Lettuce Bot uses machine vision and artificial intelligence (AI) to precisely identify weeds. Industry experts see this acquisition as a significant move towards AI-enabled robotics in agriculture, and one of a growing number of examples in the emerging space of agriculture 4.0 which link sensory data with decision making.

Industrial robotics is growing rapidly in many sectors including agriculture. Beyond traditional factors that drive automation, such as labour costs and hazardous work environments, the critical change in the growing demand for robotics is the development of *agriculture 4.0*, which combines automation with data harvesting to create the capability of data-driven processes.

Robotics applications are expanding due to increased demand as well as improved supply. Labour costs are rising worldwide, while advances in robotics software and hardware is resulting in lower priced robots that can reduce user costs further while also providing more capabilities. This trend is also occurring in fields such as machine vision and machine learning, which has significant applicability in greenhouse production.

Guelph's Intelligent Greenhouse Automation System (GIGAS)

GIGAS is being developed with support from several funding agencies: Ontario Centres of Excellence (OCE), the Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA), and the National Sciences and Engineering Research Council (NSERC). GIGAS is an automation technology for greenhouse operations. It is an integrated robotics system for automating the most labor-intensive tasks in a vegetable greenhouse like harvesting and de-leafing. This micro-precision-control is becoming possible due to increasing accuracy and decreasing costs of sensors and computing power.

Developing a robot for use in a greenhouse is very challenging due to extensive operating environment clutter and uncertainty, the required speed of operation, and high capital costs. To overcome these challenges, GIGAS adopts an innovative data-driven design that monitors every plant in a greenhouse. It includes several machine vision sensors that process images of every plant in the greenhouse daily. This enables building of a plant profile that is key to reduce uncertainty and overcoming clutter. It also enables GIGAS to provide growers with timely pictures of their entire operation including long term yield prediction and labor productivity improvement. This approach allows completing various tasks successfully at speeds that are competitive with manual labor. Various components of GIGAS were field tested in 2013 and 2016.

Recently and due to feedback from stakeholders such as OGVG and OMAFRA, GIGAS was expanded to include other important tasks like scouting for diseases, monitoring plant growth, and enhancing labor efficiency. The system's ability to obtain data from the growing plants during routine plant-care activities is also expected to improve with the development of sensors and data discernment and processing activities that exceed human sensory and decision-making abilities. For example, multispectral cameras can detect diseases before they become visible to the human eye.

A prototype of a scouting robot, focused on scouting and plant registration identification, is currently in field testing at a commercial greenhouse in Leamington, Ontario. As of November 2017, it had autonomously logged over 3 kilometers of scouting and taken more than 1,000 images of plants. This testing will continue, and additional testing is planned in other locations as well.

Developing Robotics for Agriculture 4.0

Many activities in agriculture that already use robots to some extent take place in unpredictable outdoor environments characterized by changing growing conditions. Greenhouses are a relatively more predictable environment, and automation has been used in them since at least the early 1990s to control temperature, humidity, and lighting.[24] More recent advances in greenhouse robotics include the automation of the entire production process[25] or the use of drones to collect climate data in hard-to-access greenhouse locations.[26]

Recent advances in robotics will increasingly be based on increased integration of information and mechanization, enabling managers to access and interpret information about operations and other business activities in real time. As well, increasingly complex physical tasks are being automated. Improvements in vision and sensing systems, connectivity, materials, and increased computing power are aiding mechanization of physical tasks requiring sophistication and dexterity. The business benefits are increasing as well; advanced automation and intelligent sensors enable cost reduction, improved productivity, and enhanced product quality and yield.[27] Examples include: harvesting of various fruits;[28293031323334] weed removal;[3536] and scouting for disease.[3738394041] Robotics systems have also increasingly presented opportunities for managers to leverage the data from robotics system (e.g. databases integrated with hardware like smart sprayers to optimize inputs and yields or targeted pest control). Interest and entry of multinational enterprises into the agri-food technology market is increasing.[42]

Much interest in robotics by greenhouse growers, however, is motivated by concerns about labour availability, labour cost increases, and more effective energy resource use. Using new robotics, automation and information technologies to solve current challenges needs to be balanced with forward thinking on how to prepare for a digital future.

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