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RESEARCH & INNOVATION CENTRE

Report on Innovative Technologies

A Roadmap for Reducing Labour Challenges for the Ontario Processing Vegetable Growers

April 10, 2021

Acknowledgement

This project was produced in collaboration between members of Vineland Research and Innovation Centre (Vineland) and the Ontario Processing Vegetable Growers (OPVG). We are grateful to the Vineland team for their contributions to this report. We also thank OPVG and its stakeholders for their support throughout this project. In addition, this project benefitted immensely from the discussions with Keith Robbins, General Manager, OPVG, who shared his expertise and insights in domains related to vegetable production and operations.

Disclaimer

All queries related to the content or to any use of this report must be addressed to Hussam Haroun.

For additional information, please contact:

Hussam Haroun, P.Eng., M.Eng., M.E.E.I.
Director, Automation
e. hussam.haroun@vinelandresearch.com
t. 905.562.0320 x685
c. 647.963.0334

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Project Overview

In January 2021, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) recognized the pressing need to make innovative changes that would both reduce the impact of the COVID-19 pandemic and have co-benefits helping address labour challenges within the sector.

The Ontario Processing Vegetable Growers (OPVG), with financial support from OMAFRA, reached out to Vineland Research and Innovation Centre (Vineland) for assistance in developing a technological road map to address these concerns.

Beginning in February 2021, Vineland conducted a series of interviews with vegetable growers across Ontario, gathering information on the impact of the pandemic as well as growers' needs and priorities. After analyzing the results of the interviews, potential technological solutions were identified and evaluated on a series of criteria outlined in this proposal.

Main findings of the interviews, as well as select technological innovations addressing grower concerns have been summarized below for OPVG's use and distribution.

Background

Labour challenges in the Canadian agriculture sector have been a continuous and long-standing problem. In the ten years between 2007 and 2017, the labour gap in Canadian agriculture is estimated to have doubled, increasing from 31,500 to 63,000[1]. Unfortunately, even with growth in the temporary foreign worker program this gap is expected to double again by 2029, reaching an estimated 123,000 people[2].

The ongoing shortage has led growers to increasingly rely on the temporary foreign worker program with over 57,000 temporary workers employed in the sector in 2018[3]. In an ominous foreshadowing of the 2020 COVID-19 pandemic, the Canadian Agricultural Human Resources Council noted the program, "is only a partial solution and one that could easily disappear due to policy changes or global events"[4]. While it is unlikely such a program would disappear, travel restrictions, quarantine requirements and ongoing uncertainty around future public health requirements have exposed the vulnerabilities of overly relying on a single program.

In the next section, the figures for vegetable production in Canada and Ontario are presented and discussed.

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[1] Canadian Agricultural Human Resources Council (2019). How Labour Challenges Will Shape the Future of Agriculture: Agriculture Forecast to 2029. 15

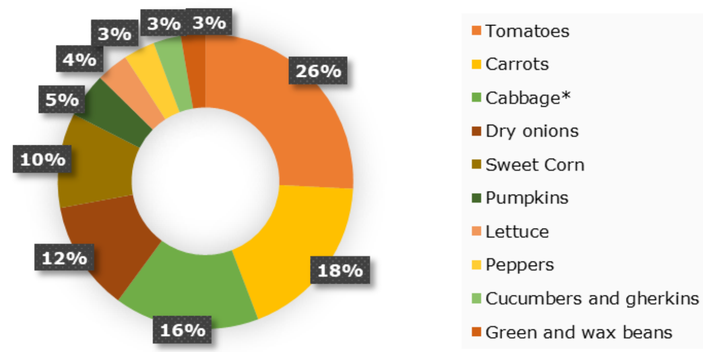
[2] Canadian Agricultural Human Resources Council (2019). How Labour Challenges Will Shape the Future of Agriculture: Agriculture Forecast to 2029. 1

[3] Statistics Canada. Fruit and Vegetable Production, 2020. https://www150.statcan.gc.ca/n1/daily-quotidien/210210/dq210210c-eng.htm (accessed March 1, 2021)

[4] Canadian Agricultural Human Resources Council (2019). How Labour Challenges Will Shape the Future of Agriculture: Agriculture Forecast to 2029. 1

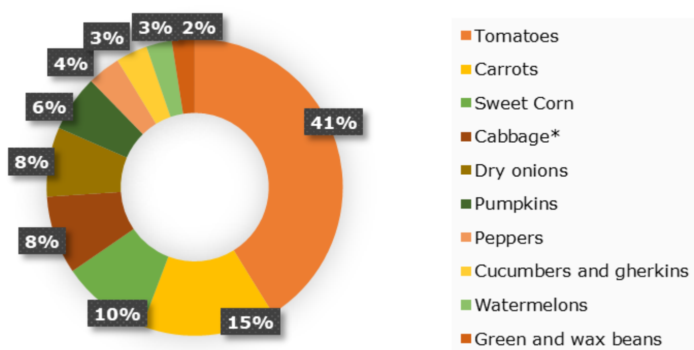
Tomatoes accounted for almost 26 per cent of the overall vegetable production for "Top 10 vegetables" by tonnage in Canada in 2020 as seen in Figure 1[5]. The data from Statistics Canada indicates that carrots, cabbage, dry onions and sweet corn followed next in terms of vegetable production by tonnage in Canada in 2020[5].

Figure 1. Top 10 vegetables produced in Canada in 2020[5]



Note: The figures for cabbage don't include Chinese cabbage produced.

Figure 2. Top 10 vegetables produced in Ontario in 2020[5]



Also in Ontario, tomatoes outweighed all other vegetables grown, representing almost 41 per cent of the overall vegetable production for "Top 10 vegetables" by tonnage in 2020 as seen in Figure 2[5]. The data from Statistics Canada indicates that tomatoes, carrots and sweet corn combined together accounted for two-thirds vegetable production for "Top 10 vegetables" by tonnage in 2020.

Note: The figures for cabbage don't include Chinese cabbage produced.

In addition to the producers of vegetables mentioned in Figure 2 above, OPVG also collaborates and engages with growers and processors of other crops such as green peas, cauliflower, beets and squash.

Key Findings

A snapshot of key findings is presented below:

In terms of total farm gate value of fresh vegetables, Ontario contributed approximately 44 per cent annually to national figures for respective years between 2018 and 20205.

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[5] Figure 1, 2. Statistics Canada. Table 32-10-0365-01. Area, production and farm gate value of marketed vegetables.

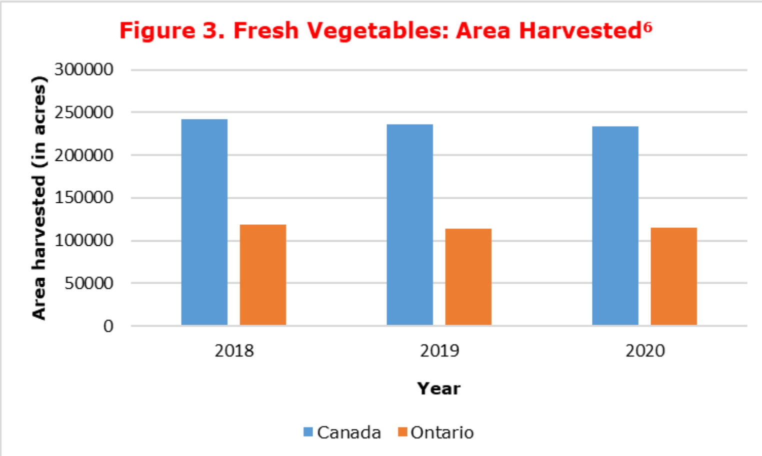


Figure 3 shows the total area harvested (in acres) for fresh vegetables grown in Canada and Ontario between 2018 and 2020[6]. Compared to the rest of Canada, Ontario has the highest proportional contribution in terms of area harvested for fresh vegetables in Canada and the average figure has been more than 48 per cent during the last three years.

Interviews with growers clearly indicated labour shortages were worsened by the COVID-19 pandemic with delays in the arrival of temporary foreign workers at the root of most issues. Attempts to bridge or replace temporary foreign workers with local labour did not succeed with reliability and consistency issues being the most common reasons given for the failure.

Grower interviews and subsequent technical reviews of recent advances in software development have highlighted a need for an integrated software platform to manage new smart technologies.

Recent advancements in weeding technology provide a positive outlook for reducing labour associated with weeding, as well as drastically reducing the environmental impact of traditional chemical weed suppression.

Interview Outcomes

The Operations

Over the course of February and March 2021, Vineland conducted six interviews with a sample of vegetable growers and processors from across Ontario with operations ranging from 70 to 5,000 acres. The majority of growers produced more than one type of crop and the top three vegetables grown by the interviewees include sweet corn, beans, especially green beans and lima beans and cucumbers.

The growers employed between two and 40 full-time workers and between four and 20 part-time workers. Labour needs varied across crop types with labour costs accounting for 20 to 60 per cent of total costs depending on crop type and operations. Manpower requirements for harvesting ranged between one and 91 labourers per acre. Compared to the harvesting costs associated with grains, similar costs for vegetables are almost 10 times as reported by one grower, and hence, returns on vegetable production are not as high as some other crops. Harvesting is generally planned according to processors' needs and is

[6] Statistics Canada. Table 32-10-0365-01. Area, production and farm gate value of marketed vegetables.

commonly outsourced to a third party. Furthermore, the timing as well as the duration of harvesting varies across different crops.

In considering how labour is distributed between various tasks across the operations, harvesting dominates required labour and labour costs become particularly higher for select crops harvested by hand. Some of the other time and labour consuming activities include transplanting, weeding, especially by hand, picking and stemming, grading crops and removing debris from field crops.

Production Insights

According to the vegetable growers in Ontario, there seems to be an insufficient market demand and lack of expansion opportunities due to a dearth of processors in the region. In Ontario, processing contracts play a significant role in determining the choice of crops grown. Processors and/or packers generally control the harvesting operations; third party contracts for custom harvesting are common. There is a short harvest window for sweet corn, beans and peas and growers use machine harvesting for select vegetables such as cucumbers (except small cucumbers).

When growers were asked about equipment costs, depreciation didn’t seem to play a significant role as ROI is generally not calculated. However, growers expected a payback period between three and eight years and performed custom planting for other farms to reduce this period. Investments in equipment are generally made to increase efficiency and reduce input costs, besides addressing labour availability-related challenges. Large contractors invested in expensive specialized equipment and amortized costs over larger acreage.

The quality programs seem to be driven by processors’ demands, and currently, most growers have their own on-farm protocols.

Challenges

Labour challenges, especially attracting and retaining workers were the most common concerns raised by producers of all crop types. Growers reinforced past research findings showing labour shortages have been an increasing challenge for the past five years or more. The temporary foreign worker program has been successful in bridging the gap but potential issues with overly relying on a single program appeared during the COVID-19 pandemic. In fact, a shortage of skilled labour with a reasonable knowledge of computers and English language was also highlighted as a concern. With regards to recruiting temporary local workers, growers cited two major issues: availability and consistency, which are particularly relevant in the context of high school students employed by vegetable growers. Furthermore, growers find it difficult to keep workers engaged between fall and spring.

Producers across crop types identified COVID-19 implications for their businesses besides stemming- and harvesting-related challenges concerning small cucumbers for pickling. Some of the other challenges mentioned included removal of field debris and trucking-related licensing barriers, which are expected to increase in the future as expressed by one grower.

The vegetable growers identified operations-related challenges with the use of machine harvesting due to the presence of foreign debris and other select factors. Also, processors play a major role in deciding the output and tend to spread their contracts across growers making it increasingly difficult for growers to benefit from economies of scale.

Finally, technology adoption-related challenges included high equipment costs, increased risk associated with purchases from relatively new vendors, low user-friendliness of operating systems and a general attitude of workers in terms of resistance to any change associated with acceptance of a new technology or equipment.

COVID-19 Pandemic Impact

During the previous growing season, the impact of COVID-19 was most sharply felt in the disruption of labour arriving from the temporary foreign worker program. As global travel closed and restrictions were implemented at borders, foreign workers either arrived late or not at all causing a labour shortage experienced by interviewed growers.

The COVID-19 pandemic led to an increase in labour requirements and the normal protective measures were too labour intensive to undertake without them. Growers expressed labour-related concerns associated with logistic problems and issues pertaining to socialization outside of work. Furthermore, producers felt that bunkhouse investments required to mitigate the impact of COVID-19 pandemic were huge and were worried about the adverse effects of the quarantine period on their farm operations. Also, considering the impact of false positives on operations, one grower raised concerns about the implementation of rapid on-farm testing of workers for COVID-19 infections.

Some of the measures implemented by growers to address COVID-19 related problems include: technological investments, building and/or renovating bunkhouses, physical distancing measures, the use of face masks, hand-sanitizers and plexi-glass, limiting farm visitors, isolating workers in vans and effectively scheduling shopping by workers. In response to the COVID-19 crisis, and concerns over a repeat of delays in the temporary foreign worker program occurring again in 2021, growers suggested improved synchronization in offshore workers’ arrival and their quarantine.

Technology Awareness

Growers are aware of current technological developments and have seen unmanned sprayers and drone equipment being used for imagery and spraying operations, drone scouting of weed sprayer and targeted pesticide application in specific field locations.

When asked about technologies and innovations implemented by other growers on their farms, one producer mentioned the use of four-wheelers to broadcast spread clover during the spring season. Another producer has been working on a conveyance system to improve the efficiency of hand harvesting process and reduce labour costs, thereby targeting an increase in efficiency between 20 and 25 per cent.

Other Considerations

While outside the scope of this project, the following points were captured during the interview process and have been included to maximize the value of this process for the OPVG.

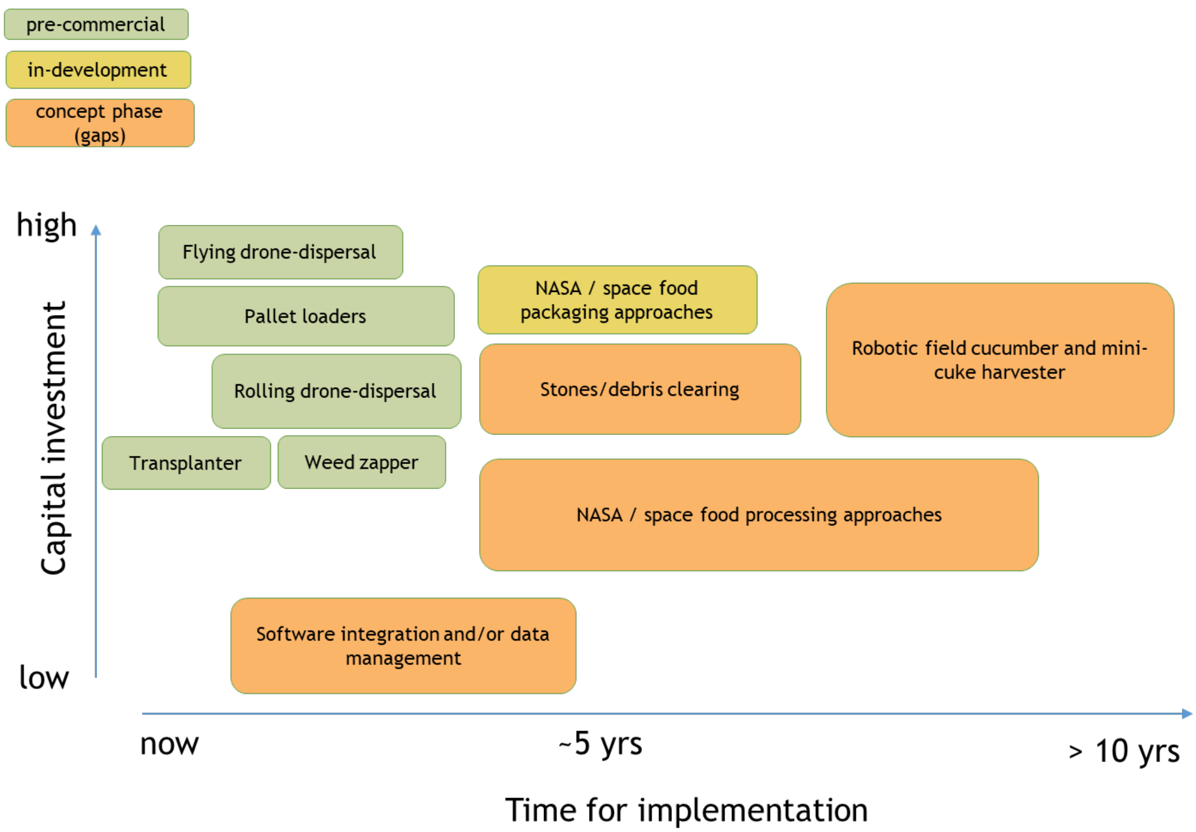
While speaking about the suggestions, growers focused on mechanisms for anticipating and proactively addressing labour-related challenges: developing reliable, economical and versatile equipment (e.g. using sensors to identify stones/debris to avoid equipment damage) besides developing specific equipment (e.g. automatic weed control, mechanical harvesting aids for squash and automatic watermelon line); advancing IT developments to provide improved interface between farm and finance software and the use of QR codes in packaging for improved traceability of products; and developing plant varieties with higher yield.

Growers feel there is a need to strengthen government support programs by improving the funding to foster new technology adoption and by increasing the number of training programs for farm equipment operators. Last but not least, growers expect decision makers to strike a balance between shareholders’ and producers’ interests.

Technological Evaluations

Figure 4 summarizes the potential technologies for investigation based on the consolidated findings of the interviews and included OPVG suggestions. This is used by Vineland researchers as a basis for technological evaluations.

Figure 4. Technology opportunities



IT and Software

The use of IT infrastructure, data analytics and software is considered one of the most promising and game-changing applications that can immensely help growers and processors. Collectively referred to as precision agriculture (PA), the concept involves the use of new software technologies to increase crop yields and profitability by lowering the levels of traditional inputs such as land, water, fertilizer, herbicides and insecticides. After mechanization and green revolution, PA is considered to be the third wave of the modern agricultural revolution[7]. The emergence of PA is enabled by the recent emergence of low-cost sensors and smart farming equipment. The concept of PA has been manifested in the following application areas:

- Management software programs
- Sensors and diagnostic tools
- Application of machine learning techniques

[7] Yu Zhang. 2019. The Role of Precision Agriculture. American Society of Agricultural and Biological Engineers.

Management Software Programs

Farm management software programs are used to optimize and manage farm operations and production activities. These programs can help in automating data collection and storage, record management, monitoring and analyzing farm activities, work scheduling, production streamlining, forecasting and measuring profits, developing crop plans and most importantly better preparing for risks such as labour shortages.[8]

Globally popular programs include Agrivi, Granular, Trimble, FarmERP, FarmLogs, Agworld, AgriWebb and Conservis. Canadian solution providers include AgExpert and Croptracker. AgExpert offers web-based and desktop platforms for field management, analysis and accounting[9]. Croptracker, on the other hand, offers unique record keeping capabilities including spray record keeping and harvest yield records. In addition, it also tracks work crew activity. Such tracking tools might help in more effectively complying with restrictions due to COVID-19. Another advantage of Croptracker is its cost effectiveness. It offers a low monthly subscription model starting at USD$10/month and provides options for additional services. Quite a few growers in Ontario have already identified the benefits of Croptracker or similar tools and have started adopting them. They include Ontario Tender Fruit Growers, Ontario Berries, Ontario Apple Growers and Vineland Growers. In 2018, 34 per cent of Canadian producers used one or more of the 20 data management software solutions available in Canada. In Ontario and Quebec, the adoption rate grew from 25 per cent in 2017 to 35 per cent in 2018[10].

Sensors and Digital Diagnostic Tools

Data collected from on-field sensors allows growers to closely monitor ground conditions and crop health. These insights can help in conserving resources and reducing the impact on the environment. Digital sensors can be installed in equipment, drones and robots, weather stations, between plants and within the soil. They can provide information about location, soil moisture content, pH, light intensity, water and fertilizer usage, airflow and many other operating conditions. Several applications utilize these sensors, including yield monitoring and mapping, weed mapping, spray controlling, topography and boundary mapping, salinity mapping, guidance systems in equipment and variable rate fertilizer.

Compared to management software programs, sensors and related applications have not yet been widely commercialized. However, pre-commercial trials have already begun. One such effort is being led by Area X.O, an Ottawa-based smart farm founded in October 2019. The farm offers innovators in the agricultural technology space a means to accelerate commercialization of new products and services, especially related to new sensors[11]. Another example is BlueRover[12], a Kitchener, Ontario-based company offering cost-effective ways for Ontario growers to implement sensor-based on-field diagnostics.

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[8] Verónica Saiz-Rubio and Francisco Rovira-Más. 2020. From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management. Agronomy.
[9] https://www.agexpert.ca/en.html
[10] https://www.fcc-fac.ca/en/knowledge/why-more-farmers-are-going-digital.html
[11] https://www.foodandfarmingtechnology.com/features/focus-on-canada-ottawa-smart-farm-fertile-ground.html
[12] https://bluerover.ca/solutions/agriculture

Machine Learning

Machine learning (ML) refers to training computer algorithms that learn from real-world data to build an understanding of how a system works. Trained algorithms can describe how the system might behave if inputs to the system change. Such abilities are popularly called artificial intelligence. When applied to agricultural systems, ML algorithms can improve efficiency for a wide range of agricultural tasks. The use of these can be categorized as:

- **Analysis:** Numerous studies have come up with algorithms to estimate relevant farming parameters with minimal process input data. For instance, one study[13] has developed a method to generate a carrot yield map from input satellite images. Another study[14] discusses a new method named Crop Selection Method (CSM) to solve the crop selection problem and maximize the net yield rate of crops over seasons. The method resolves selection of crop(s) based on predicted yield rate influenced by different parameters (e.g. weather, soil type, water density, crop type). The inputs used in the model are crop, their sowing time, plantation days and predicted yield rate for the season and the output is a sequence of crops whose production per day are maximum over season.
- **Prediction:** Many ML techniques have the capability of predicting important agricultural parameters such as yield, by processing previously collected data. Prediction is crucial for future planning. For example, one research group[15] has described a system that combines satellite-derived precipitation and soil properties information with seasonal climate forecasting data from physical models to produce a pre-season prediction of soybean/maize yield.
- **Detection:** Detection algorithms can help in two ways. First, ML techniques can be employed for detecting a specific target, for example, if a plant has disease[16] or parasites[17]. Second, algorithms can detect if the system conditions are suggestive of a future condition such as disease. ML-based detection can outperform traditional automated detection and even human detection.
- **Automation:** Currently, robotic solutions for labour-intensive tasks are becoming increasingly common (e.g. harvesters, transplanters, surveyors, etc.). ML offers foundational tools for the development of these robots.

Compared to the use of software and sensors, the use of ML remains limited within the realm of academic studies as a proof-of-concept. Translating these tools to commercial solutions will take long-term research and development (five to 10 years). It is expected that smart facilities like Area X.O will play a pivotal role in educating growers about the usefulness of these tools and accelerating the development of commercial solutions.

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[13] Marcelo Chan Fu Wei et al. 2020. Carrot Yield Mapping: A Precision Agriculture Approach Based on Machine Learning. AI.

[14] Rakesh Kumar et al. Crop Selection Method to Maximize Crop Yield Rate using Machine Learning Technique, 2015 International Conference on Smart Technologies and Management.

[15] Igor Oliveira et al. A Scalable Machine Learning System for Pre-Season Agriculture Yield Forecast. Institute of Electrical and Electronics Engineers 14th International Conference on e-Science, 2018.

[16] Justine Boulent et al. 2019. Convolutional Neural Networks for the Automatic Identification of Plant Diseases. Frontiers in Plant Science.

[17] M.A. Ebrahimi et al. 2017. Vision-based pest detection based on SVM classification method. Computers and Electronics in Agriculture.

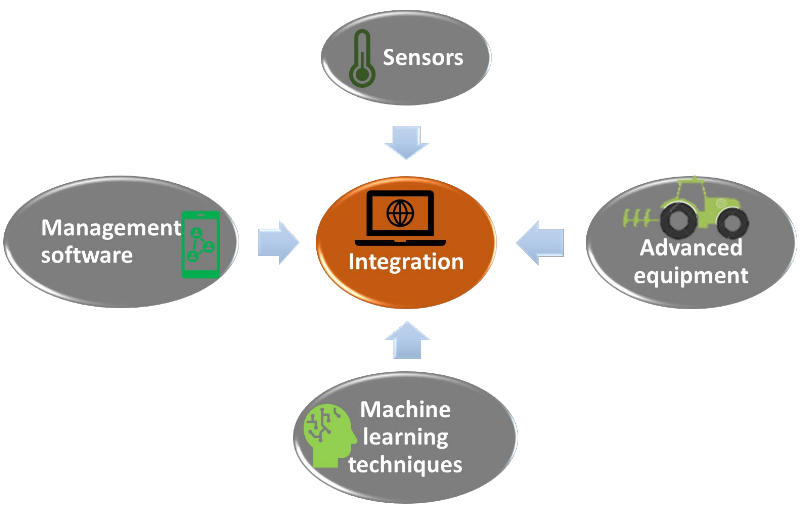
Integrated Platform

Despite their tremendous benefits, the adoption of software programs, sensors and ML-based techniques in agriculture is still not widespread. Some commercially-available software technologies offer solutions for distinct components of the production process, but a comprehensive, integrated software solution still remains a pipe dream. There are several challenges standing in the way of an integrated software platform:

1. Smaller farms are often priced out of their adoption. For instance, about 33 per cent of farms in Ontario and Quebec are of the opinion that software programs are too expensive[18].
2. The ROI on these tools is not yet clear, especially for smaller farms.
3. Farms may not have on-field internet/IT infrastructure, especially in remote locations and under-developed areas. Emerging technologies, like LoRaWAN, that facilitate wireless communication between sensors and a central cloud computing system, require specialized infrastructure.

Additionally, the lack of standardization in ways software programs and algorithms communicate with each other makes the integration difficult.

Figure 5. Proposed integrated platform



These challenges can be eliminated by designing and developing an open-source software platform that can connect agricultural machines, sensors, management software programs, IT systems and ML tools (see Figure 5). The real power of these tools can be harnessed when software programs, sensors and ML tools are integrated. Such integrations will allow ML tools to easily receive data from sensors and produce critical insights and recommendations for businesses. Such insights can also be integrated with management tools to plan, provision and track resources optimally. Currently, such a platform does not exist. However, platforms with a subset of these integrations are starting to emerge. For example, the Dutch company Hoogendoorn offers a smart controller capable of monitoring, controlling and maintaining a greenhouse. However, it is not clear to what extent this can be extended for field-farming. Besides, currently none of these solutions integrate the rich available ML toolsets. The comprehensive development and commercialization of this platform requires substantial time, effort and budget and is estimated to be at least five years away. However, during the short term, growers can start to take advantage of cost-effective software programs currently available on the market. Some of these programs are offered

[18] https://www.fcc-fac.ca/en/knowledge/why-more-farmers-are-going-digital.html

in the form of software-as-a-service (SaaS) to provide suggestions, insights and recommendations based on a small monthly subscription fee. Thus, minimal training is required for farm staff.

Apart from improving the profit margin due to increased yield, such a system would substantially mitigate labour-related challenges, especially reducing labour costs and reducing the impact of fluctuation in labour availability on production continuity. These challenges have worsened during the COVID-19 pandemic leading to the disruption of product supply and logistics chains and a shift in consumer demand. Implementing the proposed integrated platform can mitigate these adverse impacts by better preparing growers and processers well in advance.

Automatic Weed Control

Automatic weed control methods include automatic chemical dispersal by ground and flying robots (drones). Among non-chemical technologies, the most promising is weed zapper.

Weed Zapper

Weed zapper is a niche weed removal technology that applies pulsating electricity to kill weeds. The name has been popularized by a product called “The Weed Zapper”. However, other similar products that apply electricity to kill weeds are also loosely referred to as weed zapper. The mechanism can effectively kill weeds down to the root system, leaving only dry matter above the surface. The electricity is generated by an on-board generator mounted on a box, attached to the back of a tractor. A transformer, mounted on the same box, converts the voltage to the level desired for killing weeds. The electricity is applied through extended metal rods or plates. When these metal parts come into contact with weeds, electricity flows down into their roots, thereby killing them.

The mechanism depends on the level of applied voltage and moisture content in weeds and the soil. The lack of moisture may require a longer application of electricity. For weeds with soft and pliable stems, this mechanism is found to be less effective. The mechanism is non-selective making it ideal for pre-season weed control. During the season, it can effectively kill weeds that emerge above the crop canopy without harming the crop itself. Since it is an emerging technology, its performance for various types of weeds have not yet been reported. However, it has been successfully applied in killing Johnson grass, pigweed, rye, giant ragweed, horseweed, water hemp and many other types[19].

[19] https://theweedzapper.com/the-weed-zapper/

Figure 6. Example of a weed zapper device[20]

Lasco, a company based in the U.S., has been selling electric weed killing equipment for decades. In 2015, another company from the U.S. developed the "The Weed Zapper[21]" using principles similar to the Lasco product. Some interesting developments in this field are also taking place in Europe. RootWave, a company based in the U.K., is developing similar products that run at tens of kilohertz — a much higher frequency compared to their North American counterpart. This brings two advantages. For one, it makes the equipment lighter, because the transformers required to raise the voltage to weed-zapping levels (thousands of volts) can be much smaller. Also, it makes the equipment safer because higher frequencies pose less of a threat of electrocution. The Small Robot Company (SRC) is a U.K.-based agricultural robotic start-up founded in 2015 that manufactures robots for weed zapping. They use a team of robots. First, a scouting robot goes out and maps out weed locations utilizing on-board sensors which then informs the actual zapping robot.

Figure 7. SRC weed mapping (left) and weed zapper (right) robots[22]

[20] https://www.fwi.co.uk/machinery/technology/digital-weed-zapper-offers-alternative-to-chemical-herbicides
[21] https://theweedzapper.com/
[22] https://www.smallrobotcompany.com/

Targeted Chemical Dispersal

Another alternative for automatic weed removal is the application of targeted chemical dispersal by field robots ground-driven robots and drones. This method for weed control can reduce herbicide use to 5 to 10 per cent compared to blanket spraying. Figures 8 and 9 demonstrate examples of both ground-driven and drones for weed control and targeted spraying.

Figure 8. Example of weed control and targeted spraying robots[23]

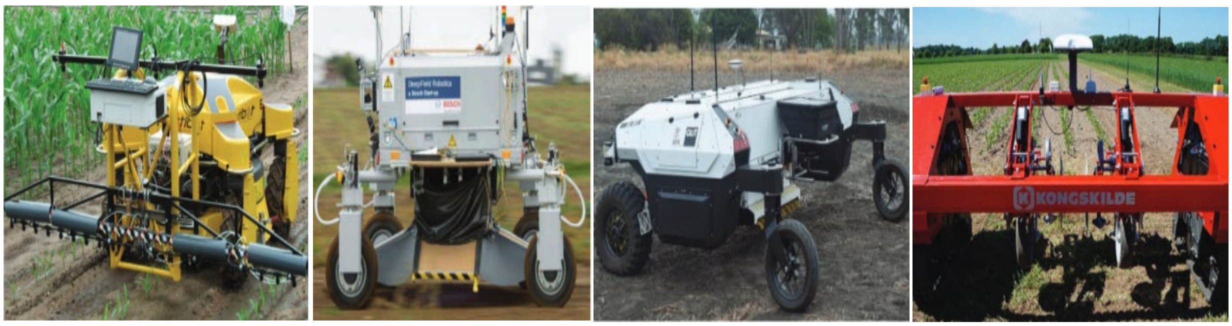


Figure 9. Small-scale spray dispersal drone with 10L capacity[24]

One important advantage of targeted chemical dispersal (both drones and ground-driven) is that they can be equipped with diagnostic tools such as smart cameras to scan the field and detect weeds, then targeted dispersal methods can be used to deliver interventions only where they are needed.

Compared to aerial drones, ground-based systems are better-suited for targeted applications of herbicides, potentially reducing the overall use and costs of herbicides in operations. Because of high technical requirements for drone surveying and delivery methods, commercially available drone applications are typically offered under fee-for-service contracts. Large-scale drone-based technologies for liquid spraying dispersal are currently awaiting licensing for use in the agricultural industry, whereas small-scale (10 litres) solutions are currently on the market.

[23] Redmond Ramin Shamshiri et al. 2018. Research and development in agricultural robotics: A perspective of digital farming. International Journal of Agricultural and Biological Engineering.

[24] https://rantizo.com/products/

Although commercially available in North America, weed zapper products have yet to make a mark on the Canadian market, partly because not only are they new but also they are expensive for smaller farms (CAD$40,000 to $75,000)[25] [26]. In 2020, Phil Oegema, the regional director of the Ontario Soil and Crop Improvement Association reported using a weed zapper from the U.S. in his organic farm and found it very effective[27]. Since then, he has been educating the community of its usefulness and it is expected that by now more farms are considering its use. Weed zapping products are simple to use and require minimal training.

Although a handful of products are available for targeted chemical dispersal, the technology is still under development, for both drone and ground-driven robots. They are costly and require significant upfront training. Future developments for targeted chemical dispersal can focus on reducing the cost, making them more user-friendly for general users, combining advanced machine vision techniques to improve their accuracy and increasing their utility by adding more sensors and equipment.

Automatic weed removal can significantly reduce labour costs. For example, for romaine hearts and organic spinach, the average hand weeding costs are $143 and $440 per acre, respectively[28]. As another example, the average labour use in onion production in 2014 and 2015 was around 1,100 h/ha[29]. One study shows that even using old technology like finger weeders can reduce[30] hand weeding in crops by 45 per cent. Implementing advanced technologies like weed zapper is expected to produce significantly better performance. One study showed that by introducing new technologies such as robotic weeding, the labour demand can be reduced by 60 per cent when growing carrots[31]. In the current era of the COVID-19 pandemic, as farms are grappling with labour shortages, automation in a traditionally labour-intensive task such as weed removal will prove to be beneficial. Targeted chemical dispersal is a potentially promising solution if the costs can be driven down. However, chemical means of weed control still have an adverse environmental impact[32].

Foreign Object Detection and Removal

The presence of foreign material (rocks, debris, etc.) and their detection/removal can happen at different stages of the agricultural process. They can cause different issues at different stages. For example, during harvesting they can damage the harvesting machines, or during processing and packaging, they can reduce the quality of the product drastically and even harm the final customers. Potential foreign objects include foreign crop seeds at sowing, metal and plastics from sowing equipment, weeds and foreign plants, animals and insect habitats in fields, debris, plastics, rubbers, tubes, glass, metal and stones.

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[25] https://theweedzapper.com/the-weed-zapper/pricing/
[26] https://www.marketbook.ca/listings/farm-equipment/for-sale/list/manufacturer/weed-zapper
[27] https://www.ontariosoilcrop.org/blog/2020/06/01/the-weed-zapper/
[28] https://www.growingproduce.com/vegetables/labor-efficiency-and-the-future-of-weed-control/
[29] Bryan Brown et al. 2019. An economic comparison of weed management systems used in small-scale organic vegetable production. Organic Agriculture.
[30] https://www.growingproduce.com/vegetables/labor-efficiency-and-the-future-of-weed-control/
[31] Claus G. Sorensen et al. 2005. Organic Farming Scenarios: Operational Analysis and Costs of implementing Innovative Technologies. Biosystems Engineering.
[32] https://topclassactions.com/canada/roundup/do-canadian-farmers-use-glyphosate/

Currently, foreign material detection and removal are being done manually. Some of the actions[33] include: 1) servicing and cleaning the equipment so they do not leave objects behind, 2) periodic inspection of fields, 3) inspection and removal of debris before harvest (field walks), 4) blowers on machinery, 5) loud machinery to scare away animals, 6) manual sorting of debris after harvest and 7) minimal hold time in the transport phase.

Figure 10. Stone collector machine[34]

Research towards automation of foreign object detection and removal is still in its infancy. One proposed solution is a stone picking /collecting machine for land clearing[35]. It is used to clean stones in the soil and can harvest underground plants. This machine can be used before planting. This product is commercially available. Another recent solution is a robotic prototype developed by Australian researchers that can effectively limit the risks caused by foreign bodies. The robot, named RIPPA[36], can detect weeds and foreign objects such as stones, glass or metal using sensors that map an area of a crop. This is not yet commercially available. Researchers are currently fine-tuning the performance of the prototype, which is expected to take a couple of years, thereafter, it will be productized.

Multiple patents exist on developing stone detector/remover as an add-on module for harvesting machines. One example proposes the detection of non-magnetic foreign

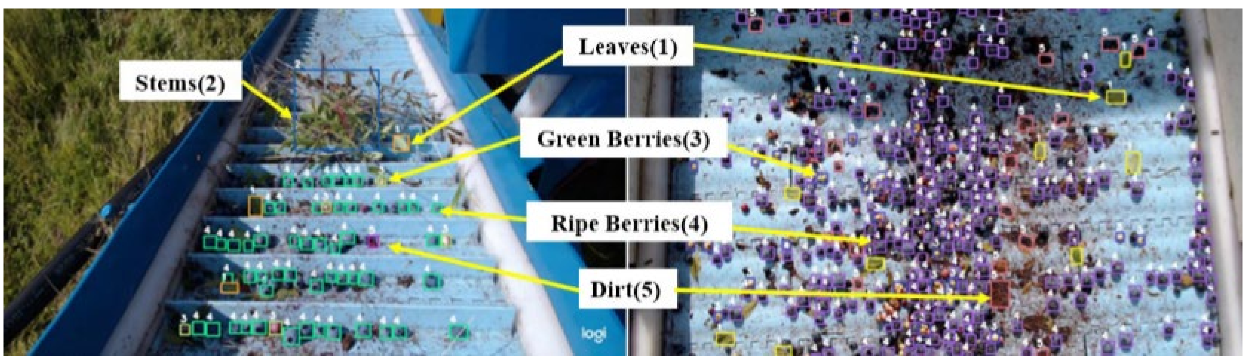
[33] Foreign Body Prevention & Detection, Best Practices For Nestle Suppliers, Nestec Ltd., Vevey (Switzerland) January 1, 2016.
[34] https://sjz-kudou.en.made-in-china.com/product/UjiJfrWxsMkV/China-Stone-Picking-Collecting-Machine-Rock-Picker-Collector-for-Land-Clearing.html
[35] https://sjz-kudou.en.made-in-china.com/product/UjiJfrWxsMkV/China-Stone-Picking-Collecting-Machine-Rock-Picker-Collector-for-Land-Clearing.html
[36] http://www.fruitnet.com/asiafruit/article/169460/foreign-body-detection-robot-trialed-on-queensland-farm

objects[37] by picking up vibrations in a feed roller when stones hit it. Another example[38] proposes the use of acoustic sensors for detection. However, none of these have been commercialized yet.

Figure 11. RIPPA robotic prototype[39]

Recent works have also reported the application of image processing combined with ML tools for debris and foreign object detection. For example, in 2019 a study[40] was performed to develop an automated method for the collection and interpretation of high-resolution, unmanned aerial vehicle (UAV)-borne imagery for estimating quantities of woody debris. Similar studies were also conducted in 2020 at Dalhousie University on developing an automated debris detection system in harvesting (see Figure 12).

Figure 12. Using image processing for foreign object detection[41]



Detection of foreign elements during the harvesting process using engine knock signals have also been proposed[42].

Despite the availability of multiple potential solutions for foreign object detection and removal, except the stone collector machine, the rest of them are in the prototyping,

[37] Bernard E. D. et al. 2015. A detection device for detection of a foreign object for an agricultural harvesting machine. European Patent.
[38] Jonathan E.et al. 2010. Foreign Object Detection And Removal System For A Combine Harvester. U.S. patent.
[39] https://www.weeklytimesnow.com.au/agribusiness/horticulture
[40] Lloyd Windrim et al. 2019. Automated Mapping of Woody Debris over Harvested Forest Plantations Using UAVs, High-Resolution Imagery, and Machine Learning. Remote sensing.
[41] Anup Kumar Das. 2020. Development Of An Automated Debris Detection System For Wild Blueberry Harvesters Using A Convolutional Neural Network To Improve Fruit Quality. Master of Science thesis, Dalhousie University.
[42] Abdellatif Bey-Temsamani et al. 2020. AI meets Agriculture: A Smart System for Foreign Object Damage Avoidance. Institute of Electrical and Electronics Engineers.

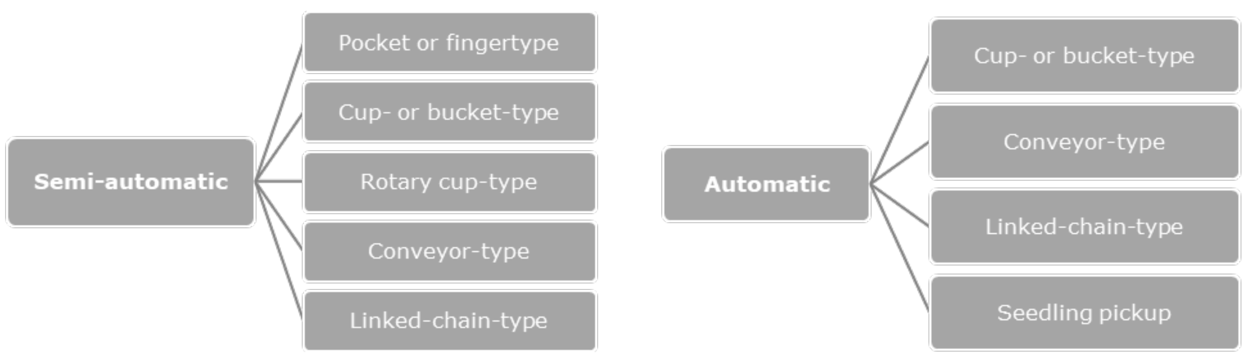
research, development or concept stage and therefore, not commercially available. Such translation will take a long time to be developed and commercialized.

During the COVID-19 pandemic, all stages of the vegetable supply chain have suffered from labour shortage. Developing foreign object detection/removal technology can certainly result in labour cost reduction in many of those stages, e.g. in harvesting, planting, postharvesting and processing, reducing labour requirements, minimizing person-person contact and reducing the risk of spread.

Automatic Transplanter

Seeding and transplanting operations account for 40 per cent of the total number of working hours of cultivation[43]. Currently, in most Ontario farms, vegetable seedlings are manually transplanted into fields[44]. Large-scale manual transplanting is labour intensive, costly and does not result in the uniform distribution of plants compared to automatic mechanical transplanters. Additionally, manual transplanting requires maintaining a bent posture, which is energy-intensive, increases the heart rate and has a harmful effect on the spinal cord of workers[45]. It also causes muscular fatigue because of long durations of maintaining a squatting posture. Automatic transplanters can address these challenges. One study[46] shows that for a 44 ha planting area per year, semi-automated vegetable transplanting can reduce yearly transplanting costs up to 55 per cent compared to hand planting. Different types of semi-automatic and automatic transplanters are listed in Figure 13.

Figure 13. Different types of mechanical transplanting[47]



Automatic transplanters have been heavily commercialized by multiple manufacturers for multiple vegetables and operation types (single, double and multiple row). The European company TTS offers a family of automatic vegetable transplanters commercially available in Canada. These transplanters require only one person to feed the trays and another person to drive and operation does not require any specific tray size. Typical throughput from these

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[43] Abhijit Khadatkar et al. 2018. Automation in transplanting: a smart way of vegetable cultivation. Current Science.
[44] http://wegrowfortheworld.com/2019/04/processing-vegetable-growers-trialing-new-automated-transplanting-technology/
[45] Abhijit Khadatkar et al. 2018. Automation in transplanting: a smart way of vegetable cultivation. Current Science.
[46] Erdem AYKAS et al. 2017. Determining the Field Performance and Cost Analysis of Walk Behind Type Semi-Automatic Hand Feed Vegetable Transplanter. Journal of Agricultural Machinery Science.
[47] Abhijit Khadatkar et al. 2018. Automation in transplanting: a smart way of vegetable cultivation. Current Science.

transplanters is around 6,000 plant per row per hour. These transplanters are suitable for different vegetables including bresicas, (romaine) lettuce, tomato, tobacco, fennel, sugar cane and many more[48]. Similar products are also offered by Agriplanter[49], PlantTape automation[50] and Ferrari Costruzioni Meccaniche[51].

Figure 14. Examples of automatic transplanter: single row, double row, multiple rows[52]

Ontario growers have recently started to adopt these fully automatic transplanters. For example, Forthdale Farms in Ontario imported PlantTape automated transplanting equipment from Salinas, California for broccoli. While conventional planting requires eight workers, three workers could manage the process with the transplanter[53]. In 2019, Bercab Farms in collaboration with Jennen Bros Inc. and Sydenham Farms, were approved for funding through the Canadian Agricultural Partnership to trial a vegetable transplanting machine in Ontario called Agriplanter[54]. It is a European-made, tractor-pulled row transplanter that can be used for cauliflower, pepper, onion and tomato plants. The Agriplanter is expected to reduce labour needs by 70 per cent compared with the current planting method and increase planted acres per hour by 20 per cent. Ontario growers can access automatic transplanters through Canadian distributers like Northern Equipment Solutions and R&W Equipment.

The efficiency, throughput and accuracy of fully automatic transplanters have still room for improvement. Several prototypes have been proposed to further improve efficiency[55], precision and speed[56,57]. These prototypes are expected to be commercialized in the next year or two.

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[48] https://www.northernequipment.ca/ttsautomatictransplanters
[49] http://agriplanter.com/
[50] https://www.planttape.com/
[51] https://ferraricostruzioni.com/en/tray-transplanters/8-futura-automated-transplanter.html
[52] https://transplantingservices.com/
[53] The Grower.org. Celebrating 139 Years As Canada's Premier Horticultural Publication. 2018
[54] http://thegrower.org/news/automated-agriplanter-debuts-ontario-vegetable-farms
[55] https://www.koreascience.or.kr/article/JAKO201828566323690.page
[56] Abhijit Khadatkar et al. 2018. Design, Development and Implementation of Automatic Transplanting based on Embedded System for use in Seedling Transplanters. Research Square.
[57] Seyed Mohamad Javidan and Davood Mohammadzamani. 2019. Design, construction and evaluation of semi-automatic vegetable transplanter with conical distributor cup. Springer Nature Applied Sciences.

One drawback of fully automatic transplanters is their high cost. For instance, the PlantTape transplanting system can cost from US$100,000 to $200,000[58] which is not affordable for smaller farms. These farms can still improve productivity by adopting available semi-automatic transplanting solutions like paperpot[59], which are significantly more cost effective but still offer a boost in productivity compared to manual transplanting.

Robotic Cucumber Harvesting

Canada is the world's fourth-largest cucumber exporter[60]. The farm value of Ontario-grown field cucumbers (does not include greenhouse) reached $21 million in 2017[61] with 45,000 tons of production[62]. Harvesting is one of labour-intensive tasks in cucumber production. Based on one study in Canada[63], the regular number of labour hours for cucumber harvesting are 11 per 0.02 acre. Human labour cost and availability are large challenges for the industry. According to a survey by the Canadian Agricultural Human Resource Council, labour shortages led to $103 million in lost sales in 2017[64]. So, any attempt toward automation and mitigating the labour shortage effect will have a high demand, especially for an important product like cucumber.

Figure 15. A prototype of the dual-arm cucumber harvesting robot system[65]

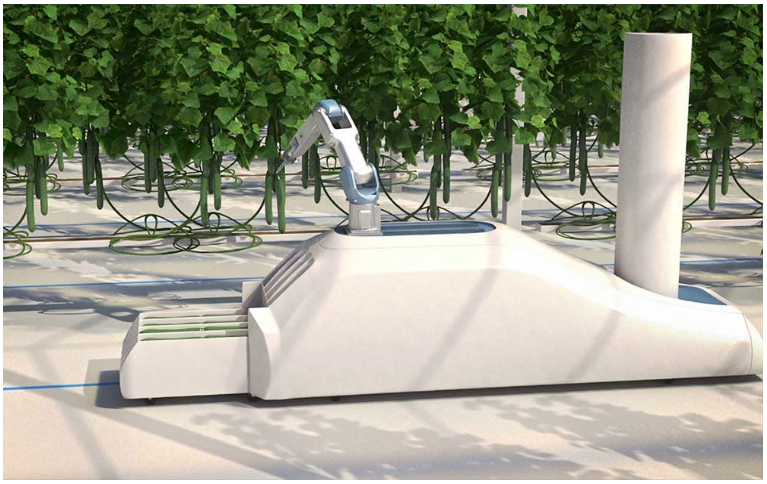
Unfortunately, there is no robotic field cucumber harvester in the market despite a high demand for it. There have been preliminary attempts toward developing such a product. For example, researchers at Fraunhofer Institute are studying the potential for automating cucumber harvesters (see Figure 15). Researchers are aiming to develop an inexpensive dual-arm robot system consisting of lightweight modules that could be used for robotic cucumber harvesting and other agricultural applications.

Prototypes have been developed for greenhouse cucumber harvesting. However, on-field robotic cucumber harvesting applications require addressing a large number of additional challenges. Greenhouse harvester designs cannot be simply extended to on-field

58 https://farmtario.com/machinery/vegetable-growers-get-first-hand-look-at-transplanting-system/
59 https://paperpot.co/
60 https://www.fruitandveggie.com/high-tech-cucumber-harvesting/
61 http://www.omafra.gov.on.ca/english/stats/hort/cucumber.htm
62 Plant the Seeds: Opportunities to Grow Southern Ontario's Fruit & Vegetable Sector. Greenbelt Foundation Occasional Papers, 2020.
63 https://www.kpu.ca/sites/default/files/ISFS/Cucumber%20%28high%20tunnel%29.pdf
64 https://www.fruitandveggie.com/high-tech-cucumber-harvesting/
65 https://www.springerprofessional.de/production---production-technology/machinery/lightweight-robots-harvest-cucumbers/15499638

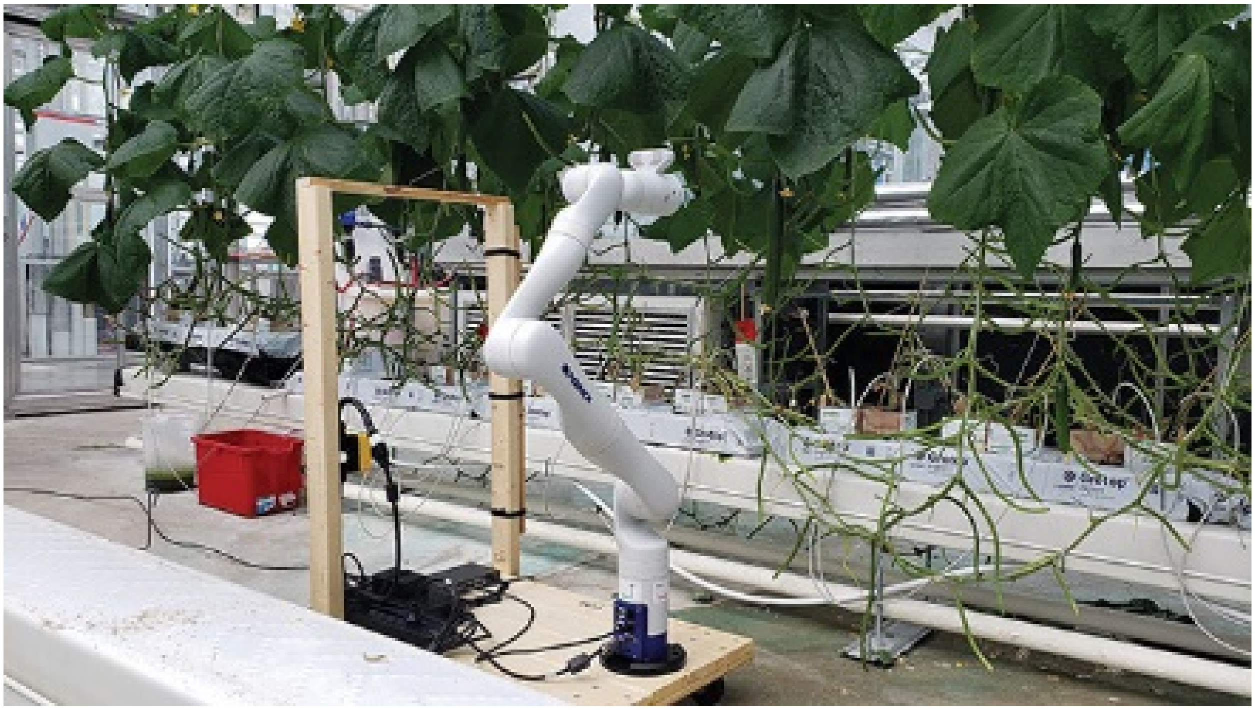
applications, instead will require dedicated research and development. Such development and subsequent productization is a long-term process estimated to take at least five years.

Figure 16. Robotic cucumber harvester developed by Crux Agribotics[66]



A European company (Crux Agribotics) has developed prototypes for greenhouse cucumber harvesting. One of them can harvest cucumbers deeply hidden between the leaves of cucumber plants. The robot uses a ML algorithm to determine which cucumbers are ripe for cultivation and diseased ones**.** The harvesting robot consists of a trolley with rotating cameras and a flexible grab arm.

Figure 17. Robotic cucumber harvester developed by Vineland



A research team at Vineland is working to develop a robot capable of harvesting greenhouse cucumbers. Testing has shown the robot can achieve a success rate of almost 90 per cent, with a picking time of less than 15 seconds. Wageningen University & Research has also

[66] https://www.ingreenhouses.com/crux-agribotics-develops-cucumber-robot-with-machine-learning/

developed[67] a prototype of an autonomous harvesting machine for cucumbers carrying two camera systems for the detection of fruits and the determination of ripeness and quality. Their experiments show 95 per cent of ripe cucumbers were detected and 75 per cent of cucumbers were harvested.

Pallet Loader

Pallet loading or palletizing is an important part of the agricultural product delivery chain. This process is still being done manually in some farms requiring considerable labour work, time and money. In contrast, automated palletizing can offer the following benefits: 1) increased safety for workers, 2) higher production rate, 3) optimization of warehouse space, 4) greater quality and stability of full pallet loads, 5) quick payback on investment (savings on labour), 6) minimal downtimes and 7) more consistent production rate. The North American palletizer market accounted for USD$419.57 million in 2016 and is expected to touch USD$489.83 million by 2022[68]. Two types of mechanical palletizing practices are common:

Figure 18. Example of a conventional palletizer[69]

Conventional palletizers: these typically use a series of conveyors, guides and pneumatic actuators to position and orient cases in the desired array which is equal to one layer in the unit load. The layer is then placed onto the pallet by a combination of a tray to support the layer and an elevator.

Robotic palletizer: these typically consist of a four or six-axis robotic arm integrated into a cell that picks individual cases or a row of cases and places them onto the pallet. The cases, pallets and tier/slip sheets are often picked by the same end-of-arm tool installed on the robot arm.

[67] https://www.wur.nl/upload_mm/5/5/7/c221711e-98da-4865-805a-8fc8531aa624_flyer_cucumber%20harvesting_robot_uk.pdf
[68] https://www.mordorintelligence.com/industry-reports/north-america-palletizer-market
[69] https://www.automatedsecondarypackaging.com/understanding-pallet-basics-and-automated-pallet-loading/

Figure 19. Example of a robotic palletizer[70]

The implementation of these palletizers only requires a specified footprint and electrical infrastructure. The technology for both types of palletizers is mature and is commercially available in the market for immediate use. The use of automatic palletizers is common among Ontario growers and processors. Some solutions are even manufactured locally. For instance, Premier Tech is a Canadian company offering automatic palletizing services[71]. ROBOVIC and STORCAN are other examples of Canadian companies offering automatic palletizer products.

Palletizers are an ideal example of where automation can replace manual effort. Additionally, certain extreme palletizing scenarios may be infeasible to handle manually. An example is Cecelia Acres, a Canadian tomato farm. They needed to stack pallets higher than what employees could comfortably handle[72]. The purpose was to maximize the volume of product that could fit on a truck for shipment. A Kawasaki CP180L robot integrated by Caxton Mark solved that problem. It increased throughput, eliminated ergonomic concerns for employees and helped with labour issues the farm had.

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70 https://www.automatedsecondarypackaging.com/understanding-pallet-basics-and-automated-pallet-loading/

71 https://www.fortunebusinessinsights.com/palletizer-market-104445

72 https://www.profoodworld.com/home/article/21107196/tomato-grower-automates-palletizer-to-stack-higher-faster

As another example, an Ontario-based seed company, Pride Seeds, introduced an automated bagging and palletizer unit into its operation to reduce the risk with Hazard Analysis Critical Control Point guidelines[73]. Mucci Farms is another Ontario-based farm that utilizes automatic palletizing systems[74].

Palletizers result in cost savings due to reduced labour requirements. Currently in Ontario, the average hourly rate is $10 to $24, management staff needs to be supported, the third shift is paid more and overtime is extra. But with automatic pallet loading, operating costs range from $0.15 to $1.50 per hour[75], minor oversight is required and no premium for night shift or overtime is needed. The main barrier can be the upfront capital investment. However, considering a 10-fold potential reduction in operating cost, the payback period is expected to be short. If utilized 24/7, the average payback time for automatic palletizing is 11 months[76]. As an example of capital cost issue, Earth Fresh farm in Ontario, needed a palletizer but since robotic solutions were expensive[77], they designed a prototype based on the auto industry. The size of the head was designed to pick up potato bags with a capacity of 50 to 100 pounds. This was a good solution for slow output lines.

The implementation of palletizers can help in mitigating COVID-19 related labour challenges in three ways. First, the most obvious benefit is reduced labour requirements, thus less of an impact on process continuity due to pandemic-induced labour shortages. Second, manual pallet loading requires the presence of workers at a close distance while using automatic pallet loaders eliminate the need for worker presence and helps social distancing. Third, the products themselves can act as fomites, because they are handled by many people. Minimizing hand contact with agricultural products can minimize the chance of spreading disease.

Advanced Food Processing and Packaging: Insights from Space/NASA Exploration

Space food processing and packaging are challenging, as foods should be physiologically appropriate e.g. nutritious and easily digestible. Space foods should also be light, well packaged, fast to serve and require minimal cleaning up. The advanced NASA/space approaches for food processing and packaging can be implemented by vegetable processors in Ontario to improve product quality while extending shelf-life.

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[73] https://www.topcropmanager.com/haccp-on-the-farm-still-a-ways-away-547/
[74] https://www.greenhousecanada.com/acceleration-by-technology/
[75] https://www.mmci-automation.com/cmss_files/attachmentlibrary/MMCI-Robotics-ROI.pdf
[76] https://www.universal-robots.com/blog/costs-and-benefits-of-industrial-robot-arm-deployment/
[77] http://thegrower.org/news/inside-packing-house

Figure 20. Top and side view of a rehydratable food package[78]

Processing of space food

There are several processing technologies for space foods[79] that can be applied to a wide range of fruits and vegetables:

1. Freeze-drying technology (1.5 to 2.5 years' shelf-life): is a process in which moisture is removed from food by applying a very low pressure (close to vacuum) and low temperature. The resulting product is a porous dried particle, with natural odour and colour and lower density comparing to the original food.
2. High-pressure processing (target for five years' shelf-life): is one example that can provide a longer shelf-life compared to the current thermostabilizing process. In this method, food is processed under high pressure to achieve a germicidal effect and prevent physiological activities. The minimum and maximum limits of high-pressure processing are 200 MPa and 600 MPa, respectively. This method is already used extensively in the vegetable processing industry.

Figure 21. Example of freeze-dried food for use in space[80]

[78] https://www.eriesd.org/cms/lib/PA01001942/Centricity/Domain/1041/Space%20food%20packagingbrochure.pdf
[79] Maeena Naman Shafiee. 2017. Space Food Technology: Production and Recent Developments", International Journal of Advancements in Research & Technology.
[80] Jiahui Jiang et al. 2020. Current processing and packing technology for space foods: a review. Critical Reviews in Food Science and Nutrition.

3. Irradiation sterilization (two to three years' shelf-life): is a promising and effective sterilization method improving the safety and extending the shelf-life of foods by removing microorganisms and insects without damaging the nutrient properties. It involves the use of either high-speed electron beams or high-energy radiation with wavelengths smaller than 200 nanometres. It has other advantages including simple operation, high efficiency, maximum retention of the original flavour of food and reduction of chemical additives.
4. Microwave-assisted thermal sterilization (MATS) (target for five years' shelf-life): allows in-container processing and provides better nutrient retention than conventional technology. MATS technology advances the traditional retort process (high temperatures and pressures for a long time) by cutting the time, foods are exposed to high temperatures and pressures. In this method, packaged food is immersed in pressurized hot water and then rapidly heated with microwaves to temperatures high enough to eliminate pathogens and spoilage organisms. This short time exposure to heat results in improved nutrient retention, colour, texture and flavour compared to traditional retort processes. However, in some cases, it can result in the transformation of certain ingredients.

Packaging of space food

There are multiple packaging methods for space foods[81] [82]:

1. Edible film: are soluble formulations (e.g. starches, polysaccharides, proteins, fats and composite materials, etc.) that get applied to food surfaces in the form of a thin layer directly on the food surface or between different layers of components. The application of edible film can help the preservation of fresh fruits and vegetables and prevent the migration of moisture, oxygen and solute into the food. Currently, the limitations of edible films are poor tensile strength and sealing performance, low water and temperature resistance and poor barrier performance. This method cannot provide a three to five years' shelf-life yet.
2. Retort pouch: is made from a laminate of flexible plastic and metal foils to reduce the volume and mass of the final product, while ensuring safety and nutritional value. The food packaged with this method can be placed at room temperature and has a long service life. The food can be eaten cold or hot, which is convenient to use. Thermostabilized and irradiated foods are a good candidate for this type of packaging.
3. High barrier packaging: uses packaging materials with high water vapour and oxygen barrier properties. The high resistance to oxygen and water vapour improves the protection of the flavour of food. The materials used in this approach are ethylene-vinyl alcohol (EVOH), SiOx, alumina and titanium oxide, etc. The most widely used material is EVOH. This packaging approach can withstand high temperature and high

[81] https://www.eriesd.org/cms/lib/PA01001942/Centricity/Domain/1041/Space%20food%20packagingbrochure.pdf
[82] Jiahui Jiang et al. 2020. Current processing and packing technology for space foods: a review. Critical Reviews in Food Science and Nutrition.

humidity environments. Acidic foods, medium-moisture foods and dehydrated foods can be packaged using this approach.

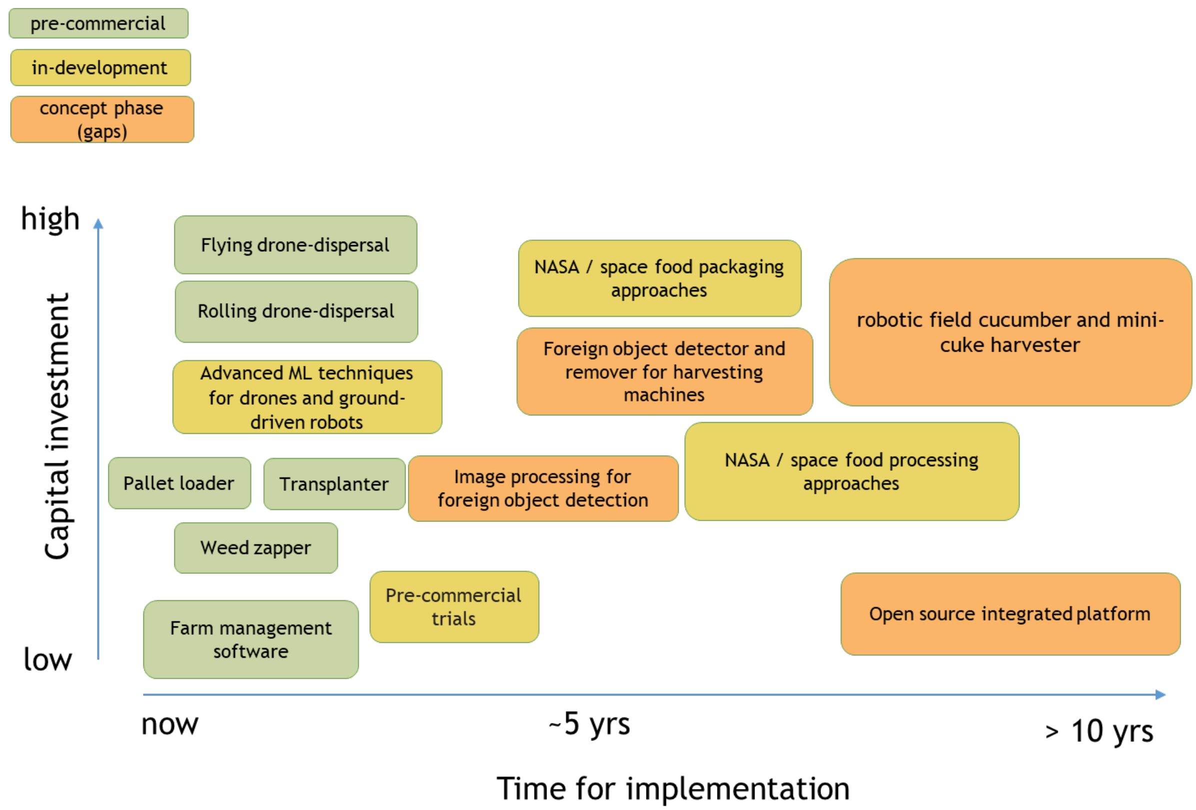
The current COVID-19 pandemic has impacted all stakeholders of the agricultural process value chain, including growers, food processors as well as distributors. The rest of the report has evaluated various automation technologies to mitigate labour shortage-related challenges for growers. While labour shortage is also a concern for the food processing industry, another additional challenge is the huge fluctuation in demand, in some cases producing a tremendous surplus of produce[83]. Processing and storage technologies that can provide longer shelf-life are of critical significance to preserve the surplus for a longer duration. Another benefit for longer shelf-life will be the fact that processors can produce extra during periods of high labour availability and store them to be distributed later when severe labour shortages (such as the one caused by the pandemic) occur causing process discontinuity or severely reduced productivity. Several processing and packaging technologies developed by NASA have been explored here. Future developments need to focus on translating some of those techniques into mainstream consumer food processing applications. Often time space-related technologies are associated with higher costs due to some of the extreme constraints. One of the research goals should be on reducing cost and improving the scalability of these techniques amenable for industrial-scale mass processing.

[83] https://www.forbes.com/sites/startupnationcentral/2020/04/26/covid19-coronavirus-agritech-food-shortage/?sh=1a15418c6b78

The Road Ahead

After reviewing potential technologies and incorporating feedback from OPVG, Vineland has revised and organized them based on their ability to be implemented in the short- to long-term, as well as the capital investment required.

Figure 22. The future of vegetable production automation



Note*. Pre-commercial technologies, technologies in development and gaps in innovation (see legend) are positioned to indicate estimates of the time required until they are commercially available (horizontal axis) and the capital investment required to implement them (vertical axis).*

In the following section, we lay out a roadmap aimed at helping growers reduce their dependence on manual labour in the short-, medium- and long-term. We describe how technologies that we outlined in the technological evaluations section can be implemented. Making strategic changes now, while making an informed plan for upcoming opportunities, can have a positive impact as we adapt to changing labour markets.

Short-Term Outlook

Adopting cost-effective management software: The use of farm management software among Ontario growers is increasing for two reasons. First, due to the pandemic-induced labour shortages and added regulations, there is an increased necessity for closely tracking and managing labour and supply chains and effectively planning ahead. Second, farm management software providers are offering more accessible formats for small farms, including low-cost monthly subscription plans, modular packages, etc. In the next one to two years this trend is likely to grow stronger as more growers adopt them.

Weed zapper is an emerging technology and has started to become commercially available. Initial implementations by Ontario growers have been promising. Considering adverse environmental impact of chemical weed control methods, growers can start adopting cleaner alternative like weed zapper.

Evaluating the cost-effectiveness of NASA/space technologies: COVID-19 has increased the need to increase shelf-life to compensate for high fluctuations in demand. Multiple shelf-life technologies have been developed for space food processing and packaging but the applicability of these technologies on consumer food-processing applications may not be readily cost-effective. Therefore, as a short-term goal, Ontario processors should evaluate the cost effectiveness, ease of implementation and efficacy of NASA's approaches applied to their internal process.

Pre-commercial trials are a valuable tool for companies developing high-tech agriculture solutions. Contacting R&D companies to inquire about setting up a pre-commercial trial can be a great way to get an inside look at emerging technologies. Another way growers can participate in these trials is through collaborations with smart centres like Area X.O. A great example project for such collaboration will be technologies at a pre-commercial stage, e.g. sensors and ML algorithm-based diagnostics tools, drone-based weed control methods, etc.

Medium-Term Outlook

Image processing platform for foreign object detection: Ground-based robots and drones equipped with cameras and sensors are starting to emerge as a powerful tool for field object detection and scouting. Many prototypes have been developed and are currently being commercialized. These are expected to be available to Ontario growers in a cost-effective way in two to three years from now.

Research and development for small farms: Since most of the automation technologies emerging on the market require high levels of upfront investment, such solutions may not be accessible to small- or mid-sized farms. This issue can be solved in two ways. One approach is to reduce the complexity, the level of automation and the scope of developed solutions as per cost requirements for small- or mid-sized farms. For instance, research programs focused on semi-automation might develop hand tools, carts, conveyances or other methods with a strong impact on the demand for labour on Ontario-sized farms.

Another key strategy will be to develop businesses that rent out expensive automation equipment to Ontario growers. This way, growers do not require a significant upfront investment and autonomous solution owners can have a steady revenue by serving lots of small- or mid-sized farms.

Long-Term Outlook

Development of integrated platform: An open-source software platform that can connect agricultural machines, sensors, management software programs, IT systems and ML tools will revolutionize the agricultural industry. Such a platform will result in unprecedented levels of yield, risk awareness and better abilities to plan ahead for labour shortages. The platform is still in a conceptual stage and requires long-term (five to 10 years) research and development.

Robotic field cucumber and mini-cuke harvester: Because of the importance of cucumber in the Ontario horticulture industry and the pain of labour challenge in cucumber harvesting, the need for robotic cucumber harvester is obvious. But the current prototypes have a long road ahead before arriving to market: modifying and improving the current designs; comprehensive examination and evaluation; and finally productization. Early research initiatives have resulted in prototypes for application in greenhouses. However, they cannot be simply extended to on-field prototype due to additional challenges in on-field application and would require dedicated long-term research and development.

Stone detector and remover for harvesting machines: Even though there are patents on add-on modules for harvesters designed to perform stone/debris detection and removal, unfortunately, they have not resulted in commercial products yet. Most of these ideas are at a poor technology readiness level, not even having a proof-of-concept. Therefore, substantial long-term research and development need to be conducted to validate these ideas and translate the potential ones into commercial products.

Vineland Research and Innovation Centre
4890 Victoria Avenue North, Box 4000
Vineland Station, ON L0R 2E0

tel: 905.562.0320

vinelandresearch.com

vinelandresearch.com

@vinelandrsrch

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