TECHNOLOGY & INNOVATION ROADMAP

FOR ONTARIO TREE FRUIT

Ontario Tender Fruit Growers

ONTARIO APPLE GROWERS

Acknowledgements

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- Ontario Tender Fruit Growers members and Focus Group
- Agribusiness and Researchers

Evaluations provided for identified key technologies are estimates based on recommendations from dealer representatives, manufacturer product information, grower focus interview responses and anecdotal evidence.

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Introduction

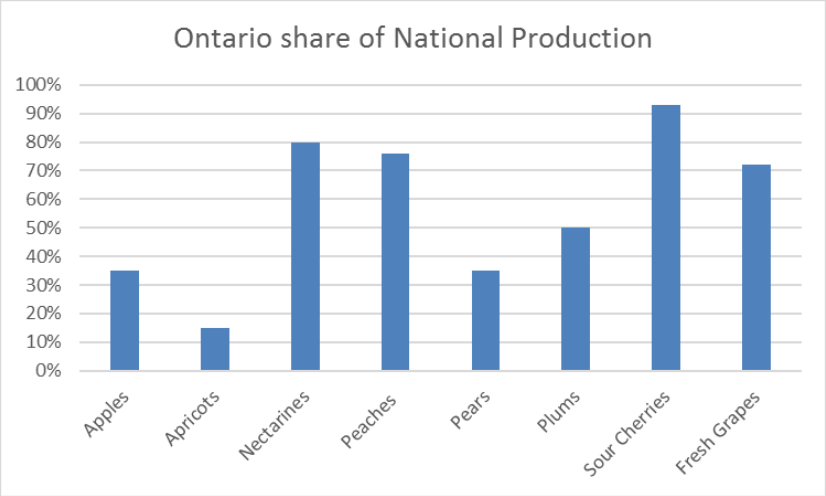
Ontario's Tree Fruit Industry

Studies show that Ontario is world-class in tree fruit production. Ontario has unique natural endowments, well-developed infrastructure, and experienced human resources that provide the basis for sustainable competitive advantage. The Ontario apple and tender fruit sectors are becoming increasingly efficient. There are ongoing investments in advanced technologies (at all levels – growing, packing, shipping, and processing), improved storage techniques, irrigation, frost protection, mechanization, and the gradual conversion of older orchards to newer varieties and higher-density orchards for certain crops.

Ontario grown tree fruits are desired and highly valued by consumers in Ontario and other regions of Canada, as well as the grocery retailers that supply them. Nevertheless, the Ontario tree fruit value chain cannot be complacent. While Ontario is a small player by global standards, Ontario's scale gives the value chain the advantage of nimbleness: it can be highly innovative and adaptative.

Ontario's tree fruit sector supply fresh, locally grown tree fruits and processed tree fruit products to Ontarians, Canadians and to some international markets. The industry encompass planting, growing, harvesting, packing, storing, shipping, and marketing tree fruit (apples, peaches, pears, plums, nectarines, apricots, cherries, and fresh grapes) as well as processing of tree fruit into products including juice, cider, apple chips, jams, sauces, and pie fillings.

Collectively, Ontario is the largest tree fruit producer in Canada.



Source: Statistics Canada, Table 32-10-0364-01 Estimates, production and farm gate value of fresh and processed fruit.

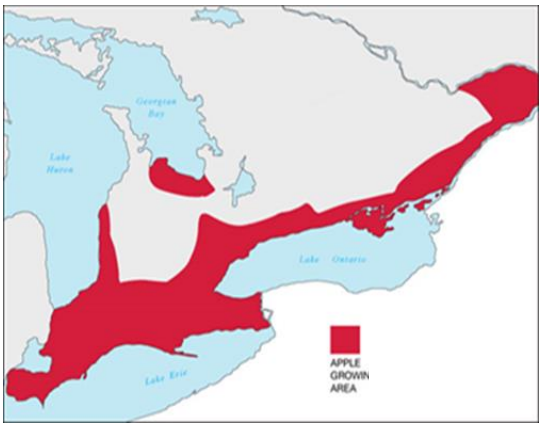
The province's major apple and tender fruit producing areas are located along the shores of Lake Ontario and Lake Erie, with apples and pears able to be grown further afoot around Lake Huron and Georgian Bay. Though production area in acres has decreased over the years, it is now levelling off and stable. With increased consumer demand for newer apple varieties and the rise

of the buy-local culture, there has been a planting shift and a gradual increase in apple acreage. Urbanization over the last few decades has seen an expansion of towns and cities resulting in a reduction of farms, especially in key tree fruit growing areas with desirable climate and soil. Specifically, for the tender fruit speciality crop production area in the Niagara region, the establishment of Ontario's Greenbelt (2005), (2017) has assisted in the protection of unique farmland and natural heritage systems.

Although acreage may be decreasing, in some areas and crop offerings, overall, the production volume per acre has steadily increased as growers adopt new technologies. Ontario is not alone as these trends are similar for the tree fruit sectors all over the world.

The number of tree fruit growers, over the years, has seen a sharp decline in numbers. But the remaining growers are managing more acres to maintain economic efficiencies. These efficiencies of scale allow growers to afford purchases of equipment and technologies to mitigate labour challenges such as: new sorting machines, platform aids and other new equipment to reduce labour costs.

Currently, Ontario is home to over 525 farmers registered with the OAG and OTFG for growing apples and tender fruit on over 25,000 acres of land.



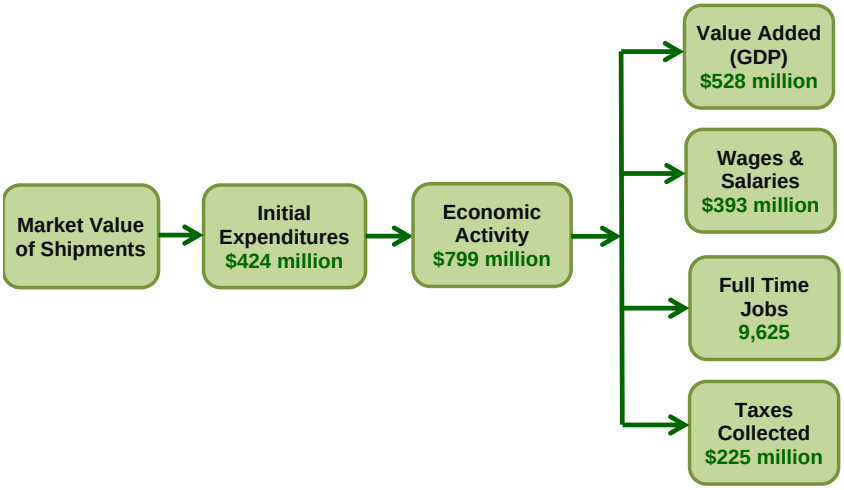
Source: Ontario Apple Growers

Combined, annual apple and tender fruit production in Ontario has averaged around 370 million pounds of fruit, with an average annual farm gate value of $183 million. The value of the crop represents an important positive contribution to Canada's balance of trade in agricultural commodities as it displaces imported fruit that would otherwise be purchased by Canadian consumers.

Economic Impact of Ontario's Tree Fruit Sector

Together, Ontario tree fruit industries generate significant overall economic activity of $799 million in Ontario, resulting in a $528 million contribution to Ontario's Gross Domestic Product (GDP), and 9,625 full time direct and indirect jobs with associated wages and salaries of $393

million. The sector generates $225 million annually in taxes revenues captured by all three levels of government.



Opportunity

As a net importer of tree fruit and tree fruit products, Ontario, and Canada as a whole, have a substantial opportunity to increase local apple and tender fruit production and recapture some of that import market share while moving towards greater food autonomy for Canadians.

In the case of apples, Ontario is a net importer of apples and currently relies on imported apples grown in other jurisdictions to fulfill the overall demand. On average, Ontario apple farmers would need to produce another 200 million lbs. of consumer desired apple varieties to meet the full current supply usage of fresh apples in the province. Tremendous potential that exists for the expansion of Ontario's apple production base.

In the tender fruit sector, there is equal opportunity for import replacement and value-added products in peaches, nectarines, plums, pears, apricots, cherries as well as table grapes. Over the past several years the tender fruit sector has been working on developing new varieties with increased disease resistance and increased consumer demand to introduce into the marketplace and now as these varieties are being commercialized there is great opportunity for growers to capitalize on that work.

With these new initiatives taking hold, there is a clear vision to bridge the gap and revitalize tree fruit orchards from current conventional orchards to newer state-of-the-art orchards.

A 15-20% expansion in tree fruit production can realistically be accomplished through investments in both additional acreage and/or novel technologies including high-density orchard infrastructure to expand production and create efficiencies. This level of growth is equivalent to additional production of 73 million pounds of tree fruit and is estimated to result in:

- ✓ Increased overall economic activity of $118.8 million,

- ✓ An additional 1,450 full time jobs in Ontario with associated wages and salaries $59 million,
- ✓ $33.2 million of additional tax revenues, and
- ✓ Increases to the provincial GDP of $77.9 million in the Ontario.

Challenges

Often, the biggest changes in farming are brought about by crisis. Adverse weather (hail, drought, winter freezes and spring frosts) and insect infestations (Oriental Fruit Moth in Niagara in the mid 1990's) have brought about significant changes to Ontario's tree fruit sector and inspired innovation and development of new technologies to mitigate risks of crop loss.

The onset of the COVID-19 pandemic has pushed industry and governments alike to consider food security as a priority and look more closely at local supply chains. One of the main challenges facing agricultural supply chains, both locally and globally, is the heavy reliance of seasonal agricultural workers to harvest fruit and vegetables. Industries employing large work forces are facing multiple concerns because of the COVID-19 pandemic. Chief among them is the need for solutions to reduce risk of COVID-19 transmission to maintain a safe work environment for employees and to manage labour shortages. The number of people interested in agricultural employment has been shrinking for decades. The COVID-19 pandemic may have exacerbated challenges, but for the agricultural sector this is not new. The increasing shortages and labour challenges continue to make it difficult for farmers to get the job done on time, at optimal production capacity and within budget. As a result, the drive is on, now more than ever, to develop and adopt novel technologies and new innovative processes such as robotics solutions that address agriculture's labour challenges.

Objectives of the Report

The objective of this Report is to develop a technology and innovation road map for Ontario's tree fruit sector which will support strategic short and long-term planning with specific technologically innovative solutions. It will provide a flexible, adaptable plan that applies not only to new processes but to new products as well and uses technology forecasting/scouting to identify suitable emerging technologies and innovations.

The Technology and Innovation Road Map for the Ontario Tree Fruit Sector was developed as a resource for Ontario tree fruit growers and will be shared with industry partners and stakeholders that support the industry. Included as part of this project are resources on conducting operational assessments as well as a Best Practices Guide for procurement and implementation of new technologies, including key considerations.

Guiding Principles

For the purposes of this Report "Innovative Technology" means any technology either not yet being used or not yet widely used, technologies being piloted in evaluation trials and/or those technologies with which the expansion of use could benefit the Sector. A key focus of this report are technologies and innovations that would bring about a positive change to reduce risk of COVID-19 transmission once implemented and have co-benefits to help address labour challenges faced by the sector.

Guiding principles for evaluating key technologies and innovations for the sector included:

- Current status and performance
- Feasibility and implementation
- Impact on Labour Productivity and Labour Supply Challenges
- COVID-19 Exposure and Risk Mitigation
- Need for operational/process changes, research, and training skills to advance the technology

Background on Research and Survey

To develop a report for the Technology and Innovation Road Map for Ontario's Tree Fruit Sector, multiple strategies were needed. A review of technologies in Ontario and other comparable apple and tender fruit grower areas were investigated. The Ontario Apple Growers (OAG) and Ontario Tender Fruit Growers (OTFG) provided reports on their respective industry including background statistics, economic impacts of the industry and costs of production.

Multiple interviews were held with Ontario researchers and, industry partners and growers from all over Ontario as well as other jurisdictions, including Pennsylvania and Nova Scotia to discuss successful implementation of technology.

A focus group comprised of approximately 31 Ontario tree fruit growers provided current grower practices as well as barriers and technological opportunities for the industry. Growers that packed large volumes of fruit discussed their packing operations as well as their needs for automated equipment.

A global on-line search of media publications and news articles for up-and-coming technologies and innovations in tree fruit orchards, pack houses and processing facilities was conducted.

Multiple virtual presentations were attended to gain insight on production issues and learn of new technologies on the horizon. The most important conference attended was the International Fruit Tree Association (IFTA). Key presentations on "How to optimize fruit quality in modern apple orchards", "Advances and future vision for managing pear trees in modern high-density "and "Advances in Orchard Technologies" were the highlights of the 3-day virtual conference.

A road map for Ontario's tree fruit sector with strategic short and long-term planning with specific technologically innovative solutions can assist growers with a flexible, adaptable plan for the future.

Survey

In February 2021, the OAG and OTFG conducted an on-line survey of apple and tender fruit growers as well as more directed interviews with key growers and industry partners. The surveys and interviews focused on the technological needs for all aspects of the industry and specifically at identifying new and innovative technologies that would provide co-benefits to the industry with regards to reducing and mitigating COVID-19 transmission as well as labour efficiency and supply challenges. The findings of these surveys and interviews provide insight and direction to the Ontario Tree Fruit Technology and Innovation Road Map.

Participation was high for the on-line survey emailed to 327 growers. Eighty-one growers responded, and although this represents about 25% of all growers, they reported growing;

- 5,838 acres of apples (45% of Ontario's 13,000 acres);
- 4,945 acres of tender fruit (56% of Ontario's 8,756 acres).
- forty-six (46%) were from Central Region;
- twelve (12%) from Western;
- ten (10%) from Central West;
- seven (7%) from Eastern; and six (6%) from Northern Region.

Orchard operations range widely in size across Ontario, and this was reflected in survey results.

- Apple operations ranged from 2 to 1,500 acres.
- Tender fruit operations ranged from 5 to 500 acres.
- Median farm size was 60 acres.
- Many operations reported growing both apples and tender fruit however;
    - 16 of the 81 (20%) were identified as solely apple growers with more than 50 acres
    - 16 (20%) were identified as solely tender fruit growers with more than 50 acres.

Farm acreages have been rising for decades, but smaller farms often have more difficulty justifying the purchase of expensive technologies to reduce labour related challenges and costs.

- The 16 solely apple growers (with more than 50 acres) collectively operate 3,581 acres (70 to 1,500 acres each) and plan to employ;
    - 692 workers in 2019;
    - 725 in 2020 and,
    - 740 workers in 2021, about 4.8 acres/worker (a 7% increase vs. 2019)

- The 16 solely tender fruit growers (with more than 50 acres) collectively operate 2,421 acres (50 to 300 acres each) and plan to employ;
    - 682 workers in 2019,
    - 661 in 2020*,
    - 692 workers in 2021, or about 3.5 acres/worker. (a 5% increase vs. 2019)

*The drop in 2020 was due to COVID-19 labour supply challenges and a reduced crop due to frost damage.

These numbers may not be statistically significant, but they do suggest apple growers may have an advantage over tender fruit growers in labour efficiency and despite COVID-19, there appears to be optimism amongst growers in the tree fruit industry. There are many reasons, such as farm size, one crop (apples) versus many (peaches, nectarines, plums etc.) but it may also be because apple and pear trees can be planted at much higher tree densities per acre and be built into trellised fruiting walls for more efficient pruning, thinning, and harvesting. Research is being conducted in many peach growing areas around the world on size-controlling root stocks and other technologies to allow for higher density tree plantings for stone fruit like peaches, nectarines, and plums.

See Appendix 1 for Survey Results of Apple and Tender Fruit Growers.

Innovative Technologies for Ontario Tree Fruit

With direction from the Ontario tree fruit industry surveys combined with research and evaluations of new and innovative technologies locally and in other jurisdictions, a prioritized catalogue of innovative technologies was established for each aspect of the industry including:

- Crop Production: Pruning and Training; Thinning; Harvesting; Tractor Operations
- Crop Protection
- Post-Harvest
- Adverse Weather
- COVID-19 Transmission Mitigation

Fundamental Technologies

With heightened attention being given to labour-saving robotics and other innovative tools for tree fruit growers, strategic concentration must be given to the development of:

- data management systems to track, understand and guide technological decisions (and sufficient high-speed connectivity to operate them)
- orchard planting systems that will be able to accommodate such breakthroughs

These two fundamental technologies are, in many cases, essential to implementing other new technologies.

Data Management Systems

Data Management systems are an essential tool for collecting and monitoring data to manage all aspects of fruit growing operations and a necessary piece of the puzzle when planning to incorporate new technologies and future innovations. It would be hard to know and understand how newly implemented technologies are benefiting an orchard operation without having some way of tracking data over a period of time. In many cases, new technologies feed into existing data management systems making them even more robust for growers.

Many start-up companies and long-standing industry service providers are developing promising solutions for managing data with integration strategies that bring data-driven insights to the forefront for decision-makers. Future innovative solutions are looking at bringing together real-world sensor and non-sensor data such as labour, crop protection, water and soil data, harvest data and imagery data to bring growers insights that are of value to their operations. Tech and software companies with different areas of expertise are combining forces so that different layers of data can be coordinated for greater insight. They envision a future with software platforms built on partnerships that could draw data from a dozen or so different weather, irrigation, imaging, and labour tracking apps an orchard manager might have on a phone into one centralized command centre.

Orchard Infrastructure

Vertical canopy systems were essentially developed for mechanization. Growers looking to implement platforms, autonomous sprayers, in-orchard computer vision, modernized irrigation systems, adverse weather mitigation technologies and many more upcoming innovations need to first consider and strategize orchard planting structures.

A presentation at the Wallace Presidential Lecture at the 60th Annual IFTA Annual Conference in Wenatchee, Washington by Roland Fumasi from Rabobank, sums up the changes in Tree Fruit Production below, 2017:

"*While U.S. apple-bearing acreage has declined 33% since 1997 to 2016, a yield-increase of 50% during the same period allowed the industry to produce a record crop in 2014. A significant driver of higher yields has been continued industry investment in high-density, trellis (supported) plantings on size-controlling rootstock. These modern plantings are more capital-intensive to establish, but increase long-run profitability, relative to traditional systems, due to reaching significant production earlier in the tree's life and having the potential for much higher yields. Other major apple producing countries have also implemented high-density systems, which have become more prevalent in new citrus and stone fruit plantings as well.*"

Apples - There has been an evolution in apple orchard systems worldwide. European countries developed and planted trees on size-controlling rootstocks, adopting high-density plantings well before North American growers. Size-controlling rootstocks for apple growers have been available for planting for the last 50 years in Ontario. Apple orchard systems were transformed

quickly with the development of size-controlling rootstock, leading to much higher numbers of trees per acre using trellis support. Although, there are still some medium apple tree density plantings using tree stakes for supporting the tree, almost all the trees planted today are high density (900-1800 trees per acre). High-density, trellised production is shown to be more profitable compared to non-trellised orchard. According to the 2018 Cost of Establishment for Ontario Apples, high-density orchards have a greater initial investment, but the returns exceed expenses in the 5th year after planting for high-density compared to the 9th year for medium-density apple production. The most common systems in Ontario are tall and super spindle structures, but there are many types including vertical low and high trellis, V and T trellis, Ebro trellis and bi-axis.

In recent years, researchers have indicated the optimum planting density will likely remain close to 1,000 apple trees per acre. As growers become more adept at managing this density, they will likely plant slightly closer, with densities close to 1,300 trees per acre. If they adopt summer shearing to reduce cost and maintain a narrow canopy wall, they will slowly move from 12 feet between the rows to 11, 10 or even 9 feet between rows.

The planar cordon concept features multiple stems to control and distribute the canopy growth. Future systems likely will continue to utilize highly branched trees for high early yields.
"Planar canopy for automation is really the future." Dr. Stefano Musacchi (IFTA Conference 2021).

Pears – There are still many older, standard pear orchards that are trained to an Open centre style. New pear plantings use a size controlling rootstock Old Home x Farmingdale (OH x F) 87 and 97, which reduces the tree size to 80-90% of standard size. The Tall Spindle training system that is used in Ontario apple orchards is the most common high-density training system for pears, and there are some using the bi-axis system. In Oregon, some growers have used a V system of tree training to optimize light and increase fruit production. The tree height is reduced but the fruit canopy is increased. Keeping the production area close to the ground reduces the use of ladders or harvesting aids.

Peaches and Nectarines – These trees are the most challenging to train to high-density trained systems. The botanical differences between Pome fruit (apples and pears) and Drupe fruit or "stone fruit" (fruit with one pit such as peaches, nectarines, apricots, plums, and cherries) are subtle. Peaches and nectarines are the only tree fruits that do not develop spurs to produce a crop compared to other tree fruits. The trees need space and light for good growth to produce a crop for the following year.

Currently, there is not a suitable size-controlling rootstock for peaches. Research to introduce new and innovative rootstocks for these commodities is ongoing. Krymsk® rootstocks have been introduced recently, but it is too early to determine their commercial value for fruit size and vigour.

Central leader training introduced 20 years ago represents approximately 20-30% of production compared to the open centre system. The advantage of central leader training is that most of the fruit can be picked from the ground reducing the use of ladders and therefore also reducing labour. The tall spindle method for peaches of training with trellises has had some success. This would be the preferred method to move towards since it would permit future mechanization reducing labour and increasing profitability.

Tart Cherries – These trees are trained to a modified open centre system using minimal pruning. Tart cherries are the only tender fruit crop that has been successfully machine harvested for years. Three processors make up most of the remaining acreage to maximize the efficiencies of an integrated processor/growing structure.

Plums & Apricots – These trees are trained to an open centre system.

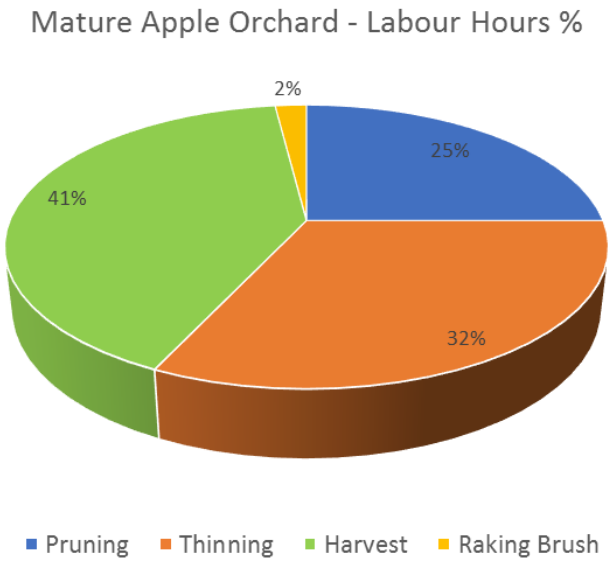
To change and mechanize to reduce labour, orchard systems must also change and become more uniform. In many cases, it is not financially feasible to change an entire orchard infrastructure midway through its life. Once growers choose the tree densities and rootstocks, they are committed to that orchard system for the next 10-25 years, depending upon the crop. Revitalization of orchards can progress much faster with the proper support and a clear vision for change.

Crop Production – Pruning, Thinning, Harvesting & Tractor Operations

Ontario tree fruit growers overwhelmingly agree that new technologies can help reduce hand labour for on-farm crop production farm activities; most notably in pruning, training, thinning, and harvesting.

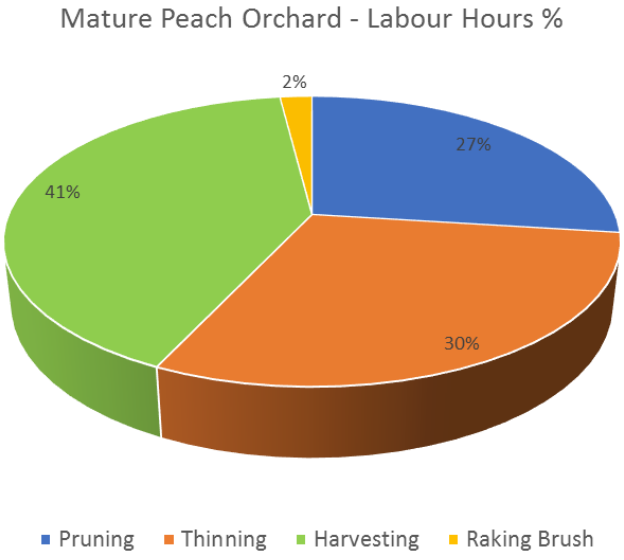
Harvest and fruit thinning are the two most hand labour-intensive production practices for mature Ontario orchards as is shown in Charts 1 and 2 below. Pruning ranks the third highest cost for mature trees.

Graph 1: Fresh Market Apple - Mature Orchard (per acre)



Source: 2018 Ontario Apples Establishment and Production Costs

Graph 2: Fresh Market Peach - Mature Orchard (per acre)



Source: 2018 Ontario Tender Fruits Establishment and Production Costs

Crop load management is the single most important yet difficult management strategy that determines the annual profitability of apple and tender fruit orchards. The number of fruits that remain on a tree directly affects yield, fruit size and the quality of fruit that are harvested, which largely determine crop value. Managing crop load using "precision" techniques is a multi-step process that begins with precision pruning to leave a pre-set bud load on the tree, followed by precision thinning techniques first, to reduce initial flower number per tree and second, to leave a precise number of fruits per tree.

Innovative prediction models are being used in many apple growing areas around the world for targeting more precise crop loads including:

- ✓ Pollen Tube Growth Model
- ✓ Fruitlet Growth Model
- ✓ Carbohydrate Thinning Model

Manually counting and using crop forecasting models, is complex and time-consuming, as different parameters must be measured and estimated for individual orchards. The performance of these models is limited by variability in climate, cultivar, and geographic location, among others. Current precision crop load management research focuses on automated counting and sizing of blooms, fruitlets and fruit using camera images and machine vision algorithms.

Pruning and Tree Training

Many tree fruit growers in Ontario are using hand pruners, pneumatic pruners, loppers, and mechanical hedgers (i.e., sawblades). Growers have identified the need for the following technologies specifically directed at labour efficiency and reducing labour supply challenges.

Table 1 – Evaluating New Technologies - Pruning

	Feasibility and cost	**Implement**	**Labour Reduced**	**Changes in production**	**Training for staff**	**Impact on risk of COVID-19 Transmission**
Identified Technology	low, medium, high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Platforms	medium-high	easy	30-50	easy	medium	high
Battery-operated Pruners	low	low	20-40	easy	low	medium
3-wheeled bucket	high	medium	20	easy	medium	medium
Hedgers (summer pruning)	medium-high	medium	30-50	easy	medium	high
Mechanical leaf removal	medium-high	medium	50+	easy	low	high

Battery-operated tying machine (for training)	low	easy	20-40	easy	medium	medium
Plant Growth Regulators (PGR)	medium	medium	50+	easy	low	high
High-Density Tree Plantings with Trellis	high	med	NA	high	high	high
Precision pruning (using computer vision and robotics)	unknown	challenging	50+	easy	low	high

Current Status and Performance

Platforms - High-density trellised orchards can be easily mechanized using labour positioning platforms to reduce labour requirements. Platforms are multi-use and very suitable for partial mechanization of several orchard tasks including dormant pruning, hand thinning, building trellis, leader selection, tree training, summer pruning and harvest. It is estimated by manufacturers that one platform is needed for 50 acres.

Battery-operated pruners - The battery-operated pruners are light, easy to handle and can be used with 4-foot poles or longer to reach the top of the tree from the platforms. Typically, the wood from high-density apple plantings is not large and can be easily cut with these powerful tools.

3-wheeled-bucket (1 person) or "Cherry Picker" – The bucket is mainly used for open centre trained tender fruit trees, pruning the tops of trees while other workers prune from the ground in separate operations. Growers are using individual and now newer multiple buckets for pruning and other hand operations replacing ladders.

Hedger - Sickle Bar (multiple cutting shears for summer hedging) - The hedger operates with a hydraulic system and usually includes a topping bar for a one-pass operation for summer pruning. It is important to have good drainage and a level orchard floor without ruts to ensure an accurate job is done. If the summer growth is heavy, it would be used more than once per season.

Mechanical Leaf Removal – Removing leaves is a new practice for high-density apple trees to allow additional light into the canopy to ensure good fruit colour. This task might not be done normally by hand because it is labour intensive. Pulsating high pressure air shatters the leaves and allows light into the canopy. A second pass through the orchard is usually needed a few weeks later. This is used in conjunction with a hedger to maximize light interception.

Battery-operated tying tools - Training trees on trellises requires tying tools, tape, clips, etc. to hold and place trunks and limbs. Most growers train the trees using platforms as the tree grows to the top of the trellis.

Plant Growth Regulators (PGR) – New products that can induce lateral branching, inhibiting shoot growth for vigour control are valuable tools for some crops. Inducing lateral branching assists in the development of new training systems. Inhibiting growth for vigour control can improve light penetration into the canopy and help reduce the need for summer pruning.

High Density Tree Plantings with Trellis – The trend is to plant more trees per acre to produce yields earlier in the production cycle. The trees need support trellises to support the weight of the crop and to withstand strong winds.

Precision pruning (using computer vision and robotics) – Research and evaluation trials are underway for robotic pruning equipment. Robotics in the orchard rely heavily on the development and optimization of computer vision/sensor equipment and algorithms. Computer vision/sensor applications acquire apple tree canopy images in orchards to detect and count blooms, fruitlets, and fruit for estimating crop-load in near real-time for precision pruning, thinning, spraying, and harvesting. Many new tech companies are currently developing and piloting computer vision/sensor systems for crop-load estimation and management with good results so far. Innovative research is moving towards developing autonomous vehicles adapted for orchards, equipped with canopy-analyzing cameras and sensors and machine-learning computers that can geo-reference each tree. Another new approach being researched, is to adopt existing vision algorithms onto a smartphone platform and mount this equipment on tractors or all terrain vehicles.

Feasibility of Implementing

Platforms – Platforms are costly, but it has been a relatively swift transition for apple growers with high density orchards. Because platforms are multi-purpose and used for several in-orchard tasks the return on investment is greater for growing operations. The payback can be fairly quick (2-3 years) if the grower has 80 acres or more. For tender fruit, it is a technology that is more difficult to adapt to open centre training systems. Some tender fruit growers have also been using "home-made" versions of platforms that create labour efficiencies and replace ladders in the orchard.

Battery-operated pruners – Growers are changing to the new light-weight battery pruners replacing bulky and noisy pneumatic pruners. The cost is high compared to a manual pruner, but the speed of pruning and less worker fatigue outweigh the costs. The payback should be one or two seasons.

3 wheeled-bucket (1 person) or "Cherry Picker" – The costs can be high for the one-person unit and payback might be more than a few years.

Hedger - Sickle Bar (multiple cutting shears for summer hedging) – The initial cost of this technology is in the medium to high range, but payback should be quick within a few seasons or less. Its implementation would reduce labour needs for training and can be used later in the season after harvest to define the edges for dormant pruning.

Mechanical Leaf Removal – The cost is similar to the multi-shear hedger. It would take a few years to perfect the timing and the number of trips for each cultivar.

Battery-operated tying tools – The battery-operated tying gun is available for training trees to trellis. The initial cost is expensive but provides the ability to cover large areas quickly.

Plant Growth Regulators (PGR) – PGRs are easy to apply and usually have the desired affect but are expensive per acre.

High Density Tree Plantings with Trellis – Although the initial cost is high, pruning can be increasingly mechanized, and profitability is quickly realized earlier than medium-density planted orchards.

Precision pruning (using computer vision and robotics) –Thinner, more uniform, fruiting walls lend themselves more easily to the application of new precision robotic pruning technologies using computer vision/sensors. The cost of implementing new computer vision/sensor technology and robotics for precision pruning in Ontario is currently unknown. To be economical and feasible, future development of new technologies is being driven towards solutions such as innovative multiuse equipment and/or service model solutions. For instance, autonomous vehicles equipped with canopy-analyzing sensors and machine-learning computers that could be used all season long by changing the tool on the end of a robotic arm - a cutter for winter pruning, swaps for a string thinner at bloom and then a fruit grabber for harvest. Many tech companies are also looking at offering service model packages for providing robotics solutions to growers, with pricing rates that may be more affordable for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with repair and servicing needs, training, process implementation etc.

Impact on Labour Productivity and Labour Supply Challenges

Platforms – High-density trellised orchards can be easily mechanized using labour positioning platforms to reduce labour requirements. Studies have quantified labour savings of 30-50%. In addition, sidewall shearing to produce a narrow fruiting wall can reduce summer pruning costs and further facilitate partial mechanization of harvest. Pruning on platforms is reported by growers to be approximately 25% faster than workers using ladders. Training and tying tree leaders to stakes was 77% faster in an OMAFRA study in 2011. Workers reported in the study,

that they liked working on the platforms, had only one task to do and had less fatigue at the end of the day. Less labour is required when growers use platforms.

Battery-operated pruners – This type of pruner can significantly increase worker efficiency as they move through the orchard. These pruners are growing in popularity as workers report less fatigue and injury compared to long-term use of manual pruners. The use of battery-operated hand and pole pruners reduces the number of workers needed to prune orchards versus older pruner technologies.

3 wheeled-bucket (1 person) or "Cherry Picker" – Buckets increase worker efficiency with less worker fatigue compared to climbing and moving a ladder for long periods of time. Buckets are not used for every crop, mainly for open centre tree systems where trees are quite tall.

Hedger - Sickle Bar (multiple cutting shears for summer hedging) - This hedger reduces hand labour for pruning as well as hand labour for removing leaves.

Mechanical Leaf Removal – Mechanical leaf removal would reduce labour for those growers who traditionally remove leaves by hand.

Battery-operated tying tools – Tying tree trunks and branches from a platform with battery operated equipment increases efficiencies and the payback period is estimated to be 1 to 2 years.

Plant Growth Regulators (PGR) – Application costs are expensive per acre, but the benefits might include reducing the number of times summer pruning is needed and hence reductions in labour needs for pruning.

High Density Tree Plantings with Trellis – Once established, mechanization can occur quickly reducing labour.

Precision pruning (using computer vision and robotics)– The development and use of robotic or automated machines in orchard operations is primarily a result of insufficient labour availability and/or rapidly increasing labour costs in tree fruit production and may be critical for continued or improved fruit yields with reduced dependence on seasonal labour. Mechanized or robotic technologies are specifically being targeted for optimizing labour-intensive work such as pruning, thinning, spraying, and harvesting. Robotic machinery further accelerates operational efficiencies because it can be functional for non-stop continuous work hours and operate both day and night. Implementing robotic machinery would shift the skill set of current on-farm labour.

Mitigating exposure and risk of COVID-19 transmission

Platforms – The benefits of platform technologies help to reduce labour for pruning throughout the orchard, as such this technology helps lower the risk of COVID-19 exposure and transmission

for growing operations. As well, workers on platforms can be spread far enough apart from each other and barriers can be installed for increased protection to reduce the risk of transmission and mitigate exposure.

Battery-operated pruners – Using battery-operated pruners may increase labour productivity but would not significantly reduce overall labour requirements and would not have a significant impact on lowering the risk of exposure or transmission among workers.

3 wheeled-bucket (1 person) or "Cherry Picker" – The benefit of this technology is to help to reduce labour for pruning, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations.

Hedger - Sickle Bar (multiple cutting shears for summer hedging) - The hedger can reduce several workers in the field that traditionally work from ladders therefore reducing the overall risk of exposure and transmission.

Mechanical Leaf Removal – The benefit of mechanical leaf removal technology is to help to reduce labour for pruning, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations.

Battery-operated tying tools – Battery-operated tying tools may increase labour productivity but may not significantly reduce overall labour requirements and would not have a significant impact on lowering the risk of exposure or transmission among workers.

Plant Growth Regulators (PGR) – Provides for a lower risk of COVID-19 transmission if PGR application across the orchard helps reduce the need for summer pruning labour overall.

High Density Tree Plantings with Trellis – Provides for an overall lower risk of exposure and transmission due to the increased ability to mechanize which creates labour efficiencies and reduce labour needs.

Precision pruning (using computer vision and robotics) – One of the potential benefits of precision pruning using computer vision and robotics technology would be to reduce labour for pruning, as such implementing this technology would help lower the overall risk of COVID-19 exposure and transmission for growing operations.

Need for Operation/Process Changes, Research & Training Skills to Advance Technology

Platforms – Implementation would require training and a specialized set of skills for the operator of this equipment. It would also require the need for various operational process changes for the

farm. However, very little additional training is needed for workers when working from the platforms. Innovative autonomous platforms would require a skilled operator.

Battery-operated pruners – Implementation would require limited training for the operator of this equipment. These pruners are easy to use, and some manufacturers sell a unique glove to prevent accidents when pruning with the shears.

3 wheeled-bucket (1 person) or "Cherry Picker" – Implementation would require training and a specialized set of skills for the operator of this equipment.

Hedger - Sickle Bar (multiple cutting shears for summer hedging) - Implementation would require training and a specialized set of skills for the operator of this equipment.

Mechanical Leaf Removal – Implementation would require training and a specialized set of skills for the operator of this equipment. The operator needs some level of skill, but once the pattern is set, it would be easy for the single operator.

Battery-operated tying tools – Implementation would require training and a specialized set of skills for the operator of this equipment. The operator using the battery-operated tying gun needs a fair amount of training and skill to operate and carry out routine adjustments.

Plant Growth Regulators (PGR) – Knowledge and experience to apply a PGR is needed by the owner/field manager for application.

High Density Plantings with Trellis – Operational changes and a high level of knowledge and training are needed initially for growers that install high-density trellised orchards for the first time. In some cases, engineers may be consulted to develop a well-anchored, stable orchard structure.

Precision pruning (using computer vision and robotics) – The need for operational/process changes, research and training for growing operations would likely be substantial to implement computer vision and robotics throughout the orchard. Many tech companies are looking at service models for offering robotic solutions with pricing rates equivalent to or below current labour costs for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with training, process implementation, repair, and servicing needs for example. It is difficult to predict the level of change required until demonstration trials are completed, and the results investigated.

Thinning

The majority of apple and pear growers in Ontario are using thinning chemicals with follow-up hand thinning currently. Tender fruit growers are mostly hand thinning fruit. Growers have identified the need for the following technologies specifically directed at labour efficiency and reducing labour supply challenges.

Table 2 – Evaluating New Technologies – Thinning

	Feasibility and cost	**Implement**	**Labour Reduced**	**Changes in production**	**Training for staff**	**Impact on risk of COVID-19 Transmission**
Identified Technology	low, medium, high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Platforms	medium-high	easy	30-50	easy	medium	high
Chemical thinning	medium	medium	50+	easy	low	high
Mechanical blossom thinner	low-medium	medium	35-40	medium	medium	high
Hand operated blossom thinners	low	easy	20-30	easy	low	low-medium
Precision thinning (using computer vision and robotics)	unknown	challenging	50+	easy	low	high

Current Status and Performance

For many decades, hand thinning was performed with large numbers of workers using ladders and was very timing consuming. Thinning is necessary to produce larger, high quality fruit for the fresh market. Workers started to use plastic bats and poles for thinning tender fruits in the 1970's. Cultural practices (pruning trees "hard") for tender fruit trees is intended to keep the height of the tree down. This practice reduces some ladder work but may also reduce overall potential crop yield at the same time.

Platforms – High-density trellised orchards can be easily mechanized using labour positioning platforms to reduce labour requirements. Platforms are multi-use and very suitable for partial mechanization of several orchard tasks including dormant pruning, hand thinning, building trellis, leader selection, tree training, summer pruning and harvest. It is estimated by manufacturers that one platform is needed for 50 acres.

Chemical thinning sprays – Growers have improved the accuracy of removing the right amount of fruit over several decades using chemical thinning sprays. Hand thinning is often needed as a follow-up to produce larger fruit for the fresh market.

Mechanical Blossom Thinning - The mechanical blossom thinner removes flowers at blossom time. This replaced the labour-intensive process of hand thinning and reduced the cost of production. Thinning trials were conducted in the spring of 2009 during bloom for both apples and peaches in Pennsylvania and Ontario. The blossom thinner is a single bar with 54 nylon strings that rotate at high speeds. As the spinning nylon strings make contact with the tree and blossoms, it is nonselective in removing a percentage of the blossoms. The amount removed is determined by the tractor speed and rotation speed of the nylon strings.

Hand- operated blossom thinner – This technology (nicknamed the "Cinch") has strings attached to a battery-operated drill and is used for thinning by one person and is a very simple tool to operate. It comes in three sizes and can be used in many tree systems since the worker is on the ground and can move around the tree.

Precision thinning (using computer vision and robotics) - Research and evaluation trials are underway for robotic thinning equipment. Robotics in the orchard rely heavily on the development and optimization of computer vision/sensor equipment and algorithms. Computer vision/sensor applications acquire apple tree canopy images in orchards to detect and count blooms, fruitlets, and fruit for estimating crop-load in near real-time for precision pruning, thinning, spraying, and harvesting. Many new tech companies are currently developing and piloting computer vision for crop-load estimation and management with good results so far. To be economical and feasible, future development of new technologies is being driven towards more affordable solutions, such as innovative multiuse equipment and/or service model solutions. For instance, autonomous vehicles equipped with canopy-analyzing sensors and machine-learning computers that could be used all season long by changing the tool on the end of a robotic arm - a cutter for winter pruning, swaps for a string thinner at bloom and then a fruit grabber for harvest. Another approach being researched, is to adopt existing vision algorithms onto a smartphone platform and mount this equipment on tractors or all-terrain vehicles. Many tech companies are also looking at offering service model packages for providing robotics solutions to growers, with pricing rates that may be more affordable for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with repair and servicing needs, training, process implementation etc. Although fully autonomous orchard technologies are still under development, some mass mechanization technologies are available for non-selective blossom thinning.

Feasibility of Implementing

Platforms – Platforms are costly, but it has been a relatively swift transition for apple growers with high density orchards. The payback can be quick (2-3 years) if the grower has 80 acres or more. For tender fruit it is a technology that is more difficult to adapt to open centre training

systems. Some tender fruit growers have also been using "home-made" versions of platforms that create labour efficiencies and replace ladders in the orchard.
Multi-purpose equipment used for several in-orchard tasks has a greater return on investment for growers.

Chemical thinning – Chemical thinning, although a common practice for many apple growers, can always be perfected implementation wise. Weather station information and prediction models measuring pollen tube growth development could assist growers to best determine the exact time to apply chemical thinning applications.

Tender Fruit growers have expressed a need for chemical thinning products; research is ongoing, and no successful products are currently available.

Mechanical blossom thinning – Penn State Co-operative Extension trials indicated that this equipment could do 13-14 acres per day at the low tractor speed of 1-2 mph. It saves 35-40% of thinning costs and improves fruit size earlier in the season. Approximately 40 to 70% of blossoms were removed for peaches at bloom time using the mechanical blossom thinner. The cost to implement is low to medium and could be a 1 to 2-year payback if enough acres could be thinned in the spring. Implementing has been slow and could be accelerated if orchards were trained to a spindle type system with a thin wall of fruit. Many growers are reluctant to use a mechanical blossom thinning; especially apple growers concerned about damage done to the spurs which could lead to prime infection conditions for the disease Fire Blight. Tender fruit growers in Ontario are hesitant to remove 50% or more of the blossoms in case there is a late spring frost. There is a short window to use the blossom thinner, since peach trees must be pruned before the grower uses the mechanical blossom thinner. Peach growers prune late compared to other crops to prevent the spread of peach canker.

Hand-operated blossom thinner - The speed of using this product would be faster than hand thinning but the results could be less uniform than using the machine.

Precision thinning (using computer vision and robotics) - Tall spindle tree walls or similar uniform planting structures make orchards "robot ready*",* lending themselves more easily to the application of new precision robotic thinning technologies. The cost of implementing new computer vision/sensor technology and robotics for precision thinning in Ontario is currently unknown. To be economical and feasible, future development of new technologies is being driven towards solutions such as innovative multiuse robotics equipment and/or service model packages. Many tech companies are also looking at offering service model packages for providing robotics solutions to growers, with pricing rates that may be more affordable for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with repair and servicing needs, training, process implementation etc.

Impact on Labour Productivity and Labour Supply Challenges

Platforms – Most apple growers that use platforms report that this is one of the best labour savings devices for thinning. Thinning was 46% faster from a platform compared to using a ladder in an OMAFRA study in 2011. Workers reported in the study that they liked thinning from the platforms, had only one task to do and had less fatigue at the end of the day. This technology creates an overall positive impact by increasing labour efficiencies and reducing labour requirements for thinning tree fruits.

Chemical thinning – This technology has a high impact on labour productivity and labour requirements for thinning apples versus other thinning options. Some follow-up hand thinning is required to improve the spacing of the fruit.

Mechanical blossom thinning – It is estimated that growers using mechanical blossom thinning technology save 35-40% in labour versus hand thinning the crop.

Hand-operated blossom thinner - It is estimated that there is some increase in labour productivity using this technology, but it has not been tested in Ontario orchards.

Precision thinning (using computer vision and robotics) – Hand thinning fruitlets is labour intensive and expensive but is used when other methods have not removed enough fruit or more precise thinning is still required. The development and use of robotic or automated machines in orchard operations is primarily a result of insufficient labour availability and/or rapidly increasing labour costs in tree fruit production and is critical for continued or improving yields of high-quality fruit with reduced dependence on seasonal labour. Mechanized or robotic technologies are specifically being targeted for optimizing labour-intensive work such as pruning, thinning, spraying, and harvesting. Robotic machinery further accelerates operational efficiencies because it can be functional for non-stop continuous work hours and operate both day and night. Implementing robotic machinery would shift the skill set of current on-farm labour.

Mitigating exposure and risk of COVID-19 transmission

Platforms – The benefits of platform technologies help to reduce labour for thinning throughout the orchard, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations. As well, workers on platforms can be spread far enough apart from each other and barriers can be installed for increased protection to reduce the risk of transmission and mitigate exposure.

Chemical thinning – The benefits of chemical thinning help to reduce labour for thinning fruit, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations. With less fruit on the trees due to the chemical thinner, less workers are needed to do the follow-up thinning.

Mechanical blossom thinning - The benefits of mechanical thinning help to reduce labour for thinning fruit, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations. With less fruit on the trees due to the blossom thinner, less workers are needed to do the follow-up thinning.

Hand-operated blossom thinner - Using a hand-operated blossom thinner may increase labour productivity and would have a low to medium impact on lowering the risk of exposure or transmission among workers.

Precision thinning (using computer vision and robotics) – One of the potential benefits of precision thinning using computer vision and robotics technology would be to help to reduce labour required for thinning, as such this technology would help lower the risk of COVID-19 exposure and transmission for growing operations.

Operational/Process Change, Research & Training Needs

Platforms – Very little additional training is needed for workers when working on the platforms. Innovative autonomous platforms are on the horizon for implementation and would require a skilled operator.

Chemical thinning – New predictive modelling for plant development with information from localized weather stations to optimize thinning results may require increased knowledge and training for the decision maker that is applying chemical thinning sprays.

Mechanical blossom thinning – Implementation would require training and a specialized set of skills for the operator of this equipment. There may be differences for tractor speed and rotation RPM for the thinner between crops and cultivars.

Hand-operated blossom thinner – Implementation of the "Cinch" would require minimal training to learn to operate.

Precision thinning (using computer vision and robotics) – The need for operational/process changes, research and training for growing operations would likely be substantial to implement computer vision and robotics throughout the orchard. Many tech companies are looking at service models for offering robotic solutions with pricing rates equivalent to or below current labour costs for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with training, process implementation, repair, and servicing needs. It is difficult to predict the level of change required until demonstration trials are complete, and the results investigated.

Harvesting

Apple growers in Ontario are hand harvesting fruit, most harvest from the ground while some are using platforms. Most tender fruit growers hand harvest with ladders. Growers have identified the need for the following technologies specifically directed at labour efficiency and reducing labour supply challenges.

Table 3 – Evaluating New Technologies – Harvest

	Feasibility and cost	**Implement**	**Labour Reduced**	**Changes in production**	**Training for staff**	**Impact on risk of COVID-19 Transmission**
Identified Technology	low, medium, high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Platforms and harvesting machines	medium-high	easy	30-50	easy	medium	high
Harvest containers – bins and plastic totes	medium	easy	20-40	medium	medium	medium
Bin carriers, trailers	medium	medium	30-50	medium	medium	high
Vacuum harvesting	unknown	challenging	30-50+	medium	medium	high
Robotic harvesting (using computer vision and AI)	unknown	challenging	30-50+	medium	medium	high

Current Status and Performance

Hand harvest – Apple growers with medium-density orchards still rely on hand harvest using ladders from the ground. Peach and nectarine growers rely on hand labour for multiple picks since the fruit ripens over a 5 to 8-day period. Growers report that peach harvest is an art and requires very skilled workers to ensure good fruit quality.

Plant Growth Regulators (PGR) – New and innovative products can increase fruit set and reduce June drop to increase the crop yield. Other PGRs delay maturity to spread out the harvest. One PGR can potentially recover some fruit after a light frost.

Mechanical harvest - Tart cherries have been mechanically harvested for 50 years or more. The tree trunk is shaken, and the fruit falls on to a catching frame, then the fruit is collected into bins with chilled water and an automatic system secures lids on field tanks. Tart cherry is the only tender fruit crop that uses mechanical harvesting instead of harvesting by hand harvest.

Platforms and harvesting machines – Apple growers, with established high-density orchards on trellis, use platforms to replaces ladders and hand harvest from different levels on the platform. New harvesting equipment with GPS and a data retriever can record the size of fruit and yield on the platforms.

Harvest containers - Some tender fruit growers are using new container technologies such as shallow bins and plastic totes which replace 11-quart wax baskets. For tender fruit, the plastic totes are palatized in field manually, loaded on trailers, brought into facility, then cooled and manually unloaded/tipped into the pack-line so the fruit is only touched once by the picker.

Bin carriers/trailers – Bin carriers are used by apple growers and a few peach growers to haul bins of fruit from the fields directly to the pack house and into storage. Bin carriers are typically an add-on to go with the platforms but can be separate and include bin trains. Add-on bin carriers are attached to the platform or harvesting machine and usually carry several bins. Trailers to haul bins in from the orchard are attached to tractors and pick up several bins at a time. There are single bin trailers that can be attached to others and form a chain to bring bins out of the orchard. Bin loaders are a self loading and unloading trailer designed for transporting fruit bins in and out of the orchard quickly and efficiently, without the operator having to leave the tractor seat.
Current innovative research aims to develop an intelligent bin-managing system supported by a robotic self-propelled fruit bin carrier.

Vacuum harvesting – Currently, there are research trials and pilots of vacuum harvesting technologies in apple producing areas including Washington, U.S., and New Zealand. One type of vacuum harvest technology uses a self-propelled platform which has two individually operated hydraulic workstations with controls giving pickers on the platform maximum tree access and allowing the entire tops of trees to be picked from one side in plantings from 8’ to 14’ high. With the vacuum system, apples are placed into a small, lightweight bucket-style inlet with no apple-to-apple contact all the way into the bin. This technology is more like a harvest-assist machine and allows for the elimination of ladders and bags for harvest. Some vacuum systems can bolt on to an existing harvester and can go anywhere growers are using platforms currently.

Robotic harvesting (using computer vision and AI) – In the past several years, research has focused on computer vision systems to detect, and localize apples for robotic harvesting in orchard environments. Robotics in the orchard rely heavily on the development and optimization of computer vision/sensor equipment and algorithms. Computer vision applications acquire apple tree canopy images in orchards to detect and count blooms, fruitlets, and fruit for estimating crop-load in near real-time for precision pruning, thinning, spraying, and harvesting. Many new tech companies are currently developing and piloting computer vision for crop-load estimation and management with good results so far. Innovative research is moving towards developing autonomous vehicles adapted for orchards and equipped with canopy-analyzing cameras and sensors and machine-learning computers that can geo-reference each tree. There have been new advances for robotic arms for picking fruit in the research and evaluation stage

that can pick 5-10,000 apples per hour. One newly developed picker robot moves down rows of orchards and uses artificial intelligence with LIDAR (Light Detection and Ranging), a remote sensor method, to search for ripe apples of a selected size and spec. Once spotted, a robotic arm with a vacuum gently sucks the apples from the tree into a bin. Another robotic picker is a computer-guided machine with three-fingered grippers to pick apples and deposit them on a conveyor system that leads to a stem-cutting table and then a bin. Each side of the robot has six arms, arranged in pairs. There is also experimentation occurring with flying fruit picking robots (or drones) using AI to distinguish between varieties.

Feasibility of Implementing

Platforms and harvesting machines – Platforms are costly, but it has been a relatively swift transition for apple growers with high density orchards. The payback can be fairly quick (2-3 years) if the grower has 80 acres or more. Platforms are a multi-purpose and can be used for several in-orchard tasks and therefore can have a high return on investment for growers.
For tender fruit, platforms are more difficult to adapt to open centre training systems. Some tender fruit growers have also been using "home-made" versions of platforms that create labour efficiencies and replace ladders in the orchard. More apple growers are using platforms and harvesting machines for harvest. It has been made easier to implement with bin carriers.

Harvest containers – Initial cost to implement would be medium to high for the plastic totes and would require a washing station.

Bin carriers/trailers – Implementation cost is medium and is simple to incorporate with the harvest platforms orchard process.

Plant Growth Regulators (PGR) – Easy to apply and usually have the desired affect, but PGR applications can be expensive per acre.

Vacuum harvesting – Thinner, more uniform, fruiting walls lend themselves more easily to vacuum harvesting technologies. Some providers are offering this technology as a custom harvest solution model with a cost-per-bin type fee. This solution would provide the machine, support, operator, and maintenance services. Quality standards would be a significant consideration when considering the feasibility of implementing this technology.

Robotic harvesting (using computer vision and AI) Tall spindle tree walls or similar uniform planting structures make orchards robot ready, lending themselves more easily to the application of new precision robotic thinning technologies. The cost of implementing new technologies such as computer vision systems and robotics harvesting devices in Ontario is unknown currently. To be economical and feasible, future development of new technologies is being driven towards more affordable solutions, such as innovative multiuse equipment and/or service model solutions. Another approach being researched, is to adopt existing vision algorithms onto a smartphone platform and mount this equipment on tractors or all-terrain vehicles. Many tech

companies are also looking at offering service model packages for providing robotics solutions to growers, with pricing rates that may be more affordable for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with repair and servicing needs, training, process implementation etc.

Impact on Labour Productivity and Labour Supply Challenges

Mechanical harvest - This technology has a high impact for tart cherry growing operations in reducing labour requirements versus hand harvesting.

Platforms and harvesting machines – Impact on reducing labour needs is high. Most apple growers using platforms report that this is one of the best labour savings devices for harvesting. Harvest was 18% faster from a platform compared to using a ladder in an OMAFRA study in 2011. Workers reported in the study that they liked working on the platforms, had only one task to do and had less fatigue at the end of the day.

Harvest containers – Studies have shown that harvesting tender fruit into plastic containers improves labour efficiency at harvest. Research and time trials have been conducted and results show that the plastic tote method is the most efficient and cost-effective method versus 11-quart baskets. It takes the pickers less time to pick a kilogram of peaches which makes this method 40% more efficient for harvest. The plastic totes can be immediately palletized in the field making the process more streamlined for placement into cooling and storage areas and eventually to bin tipping equipment.

Bin carriers/trailers – New bin carrier/bin train technologies can reduce labour needs by improving productivity of the fruit picking process with more efficient management, placement and collection of bins within harvesting sites. Add-on bin carriers have been used by apple growers and a few tender fruit growers for several years. Most tender fruit growers pick up 11-quart baskets of fruit from under the trees in the field and place them on the orchard wagon. Once the fruit arrives to the packing house, they would have to unload the 11-quart baskets, place them on the skid on racks and them move them into cold storage. Changing to shallow bins and a bin trailer would reduce labour.

Plant Growth Regulators (PGR) – The use of PGRs can prolong the harvest period which can in turn reduce labour requirements versus having a harvest peak which requires larger crews to pick large volumes in a short period. The actual time to harvest is not reduced but spreading out the time reduces labour needs and results in minimizing housing requirements for additional seasonal agricultural labour to help with harvesting peak volumes.

Vacuum harvesting – This harvest-assist technology means that pickers only need to pick. It would increase labour productivity and efficiencies by saving time during the actual harvest process by reducing the need for pickers to climb ladders, walk back and forth, and eliminates the time it takes for pickers to turn around to empty harvest bags into bins. The goal of this

technology is to make fruit harvesting faster while achieving the same or better-quality metrics as those achieved through hand harvest.

Robotic harvesting (using computer vision and AI) - The development and use of robotic or automated machines in orchard operations is primarily a result of insufficient labour availability and/or rapidly increasing labour costs in tree fruit production and is critical for continued or improving yields of high-quality fruit with reduced dependence on seasonal labour. Mechanized or robotic technologies are specifically being targeted for optimizing labour-intensive work such as pruning, thinning, spraying, and harvesting. Robotic machinery further accelerates operational efficiencies because it can be functional for non-stop continuous work hours and operate both day and night. Implementing robotic machinery would shift the skill set of current on-farm labour.

Mitigating exposure and risk of COVID-19 transmission

Mechanical Harvest - The benefits of mechanical harvesting technologies help to reduce labour, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations.

Harvest containers – The risk is lower since the fruit is put directly on pallets in the field and loaded/unloaded by machine reducing the contact with workers handling baskets. This technology may reduce labour needs and therefore helps lower the risk of COVID-19 exposure and transmission for growing operations.

Platforms and harvest machines – The benefits of platform technologies help to create labour efficiencies and reduce labour for harvesting, as such this technology helps lower the risk of COVID-19 exposure and transmission for growing operations. As well, workers on platforms can be spread far enough apart from each other and barriers can be installed for increased protection to reduce the risk of transmission and mitigate exposure.

Bin Carriers/trailers – New bin carrier/bin train technologies can reduce labour needs; therefore, implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Plant Growth Regulators (PGR) – Delaying the harvest using PGRs can spread out the harvest schedule and minimize how many workers are needed to harvest peak volumes all at once. This technology may reduce labour needs and therefore helps lower the risk of COVID-19 exposure and transmission for growing operations.

Vacuum harvest technology – One of the potential benefits of vacuum harvest technologies is to increase labour productivity and efficiencies and overall reduce labour requirements for harvest, as such this technology would help lower the risk of COVID-19 exposure and transmission for growing operations.

Robotic harvesting (using computer vision and AI) - One of the potential benefits of robotic harvesting is to reduce labour requirements for harvesters/pickers, as such this technology would help lower the risk of COVID-19 exposure and transmission for growing operations.

Operational/Process Change, Research & Training Needs

Mechanical Harvest – No significant operational/process changes would be required.

Harvest containers – Some operational changes may be necessary when implementing different harvest containers based on storage capacity and equipment capacity. Washing and sterilizing plastic totes would be an additional task to ensure food safety standards.

Platforms and dedicated harvest machines – Changes to adjust to the machinery for harvest would be needed since bin carriers are attached and workers would need to be trained on the new equipment.

Bin Carriers/trailers - There would be some in-orchard operational/process change to implement new bin carriers or trains. Very little training is required for the loading and unloading of the bins.

Plant Growth Regulators (PGR) – The owner/operator for applying a PGR needs some knowledge and skill of the rates and timing for the spray, training and certification for spray applications is necessary in Ontario.

Vacuum harvesting – The need for operational/process changes, research and training for growing operations would likely be substantial to implement vacuum harvesting technologies. Capacity for speed of harvest and monitoring the quality of fruit harvested may be challenging. With some vacuum harvesting solutions being developed as “pick and play” technology to be attached to pre-existing platforms this technology would not be as challenging to implement in comparison to full robotic harvesting. Some providers are offering this technology as a custom harvest solution model and would provide the machine, support, operator, and maintenance services.

Robotic harvesting (using computer vision and AI) - The need for operational/process changes, research and training for growing operations would likely be substantial to implement robotic harvesting throughout the orchard. The fruiting wall should be thin and uniform for the robotic picking mechanism to reach into the canopy to harvest fruit without obstructions from overlapping branches. Many tech companies are looking at service models for offering robotic solutions with pricing rates equivalent to or below current labour costs for growers versus offering the equipment for purchase. A service model solution may also assist growing operations contend with training, process implementation, repair and servicing need etc. It is difficult to

predict the level of change required until demonstration trials are complete, and the results investigated. Implementing robotic machinery would shift the skill set of current on-farm labour.

Tractor Operations

Most tree fruit growers in Ontario use tractors and other equipment without GPS guided systems or robotics currently. Growers have identified the need for the following technologies specifically directed at labour efficiency and reducing labour supply challenges.

Table 4 – Evaluating New Technologies – Tractor Operations

	Feasibility and cost	**Implement**	**Labour Reduced**	**Changes in production**	**Training for staff**	**Impact on risk of COVID-19 Transmission**
Identified Technology	low, medium, high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Autonomous tractors	high	medium	50	medium	medium	high
Dual PTO tractors	high	challenging	50	medium	high	high
GPS guided tree planters	high	easy	30-50	easy	medium	medium
Mechanical brush Sweeper	medium	easy	50+	easy	low	high
Mechanical weed control	high	medium	30-50+	medium	medium	high

Current Status and Performance

Autonomous tractors – Autonomous tractors have been in development since the idea of precision agriculture came about in the 1980s. Autonomous tractor detects obstacles with a perception system using LADAR and cameras. The perception system detects hazards in the cluttered orchard environment and guides the tractor down the centre of the tree rows. Depending on how big the orchard is, autonomous tractors can be operated alone or organized into multi-tractor systems used to for mowing and for crop protection application sprays.

Dual PTO tractors - Mowing and spraying capabilities are combined in one dual PTO tractor technology which would be driven through the orchard with controlled power takeoff (PTO) that drives the mower in the front, or the sprayer at the rear of the tractor implements. These tasks occur regularly throughout the year and can be combined to reduce the number of trips throughout the year providing good cross-utilization of the equipment.

GPS guided tree planters – Tree fruit growers are using tree planters with GPS guided systems. GPS guided tree planters make tree planting in rows and blocks more accurate, faster, and more efficient. The manual preparation time to mark rows is eliminated.

Mechanical brush sweeper – This equipment sweeps the clippings from under the tree to the row middle for chopping.

Mechanical weed control – In-row equipment with tilling blades used for preventative weed control while swing arm mowers are used for weeds that are resistant to certain herbicides.

Feasibility of Implementing

Autonomous tractors – Capital purchase costs for autonomous tractors are high making it challenging for smaller growing operations to afford. Autonomous tractors fit into the existing orchard operations and current practices used for manual spraying can improve the overall safeguarding of the autonomous tractor system by restricting access to areas of operation.

Dual PTO tractors - The cost of this equipment would be high, and it would require some skill training to implement initially but once employed it would be easy to operate and offer efficiencies and cost savings.

GPS guided tree planters – Capital purchase costs for GPS guided tree planters are high. Several Ontario growers that have large acreages are currently using this technology. Solutions including offering custom tree planting services using GPS guided equipment across several growing operations could make this more affordable for all orchard sizes.

Mechanical brush sweeper – The purchase cost of this equipment is low, and it is easy to implement to reduce labour in the field.

Mechanical weed control – This equipment is in a medium cost range for both in-row equipment and swing arm mowers, both would be easy to implement.

Impact on Labour Productivity and Labour Supply Challenges

Autonomous tractors – These systems improve labour productivity, reduce labour requirements, and create cost efficiency in tree fruit orchards by automating multiple tasks such as mowing and spraying. Additionally, this equipment can be used for prolonged periods of time during a 24-hour day compared to an operator.

Dual PTO tractors – Dual PTO technologies would reduce the need for multiple pieces of equipment requiring maintenance and multiple trips out in the orchard providing for both savings on repair, fuel, and labour costs.

GPS guided tree planters – These innovative tree planters using GPS technology significantly increase labour efficiencies for tree planting; they reduce much of the preparation and set-up time for marking rows, etc. Labour for planting crews can be reduced significantly, in some cases by up to 50%.

Mechanical brush sweeper – This equipment would reduce labour in the orchard for hand raking the brush into the centre of the row.

Mechanical weed control - Both in-row equipment and swing arm mowers would reduce labour needed to manually execute these tasks.

COVID-19 Exposure and Risk Mitigation

Autonomous tractors – This technology helps to reduce overall labour requirements for orchard operations therefore implementation has a high impact on lowering the overall risk of COVID-19 exposure and transmission for orchard operations.

Dual PTO tractors - This technology can help to reduce overall labour requirements for orchard operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission.

GPS guided tree planters – This technology helps to reduce overall labour requirements for tree planting operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Mechanical brush sweeper – This equipment reduces labour needs; therefore, it can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Mechanical weed control - Both in-row equipment and swing arm mowers would have a positive impact for growers to reduce the risk of exposure.

Operational/Process Change, Research & Training Needs

Autonomous tractors – This equipment would require a significant initial time allocation for setup, mission planning and programming, and would require some changes to orchard operations and processes. Training would also be needed.

Dual PTO tractors - There would be some training needed for implementing dual PTO tractors for the operator.

GPS guided tree planters – There is some training needed for the GPS guided systems and for the tractor operator.

Mechanical brush sweeper – Few changes in process and training are required once initial setup modifications to equipment are complete.

Mechanical weed control – Few changes in process and training are required once initial setup modifications to equipment are complete.

Crop Protection

Most tree fruit growers in Ontario use single row sprayers and other equipment without GPS or automated detection spray systems. Growers have identified the need for the following technologies specifically directed at labour efficiency and reducing labour supply challenges.

Table 5 – Evaluating New Technologies – Crop Protection

	Feasibility and cost	**Implement**	**Labour Reduced**	**Changes in production**	**Training for staff**	**Impact on risk of COVID-19 Transmission**
Identified Technology	low, medium, high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Autonomous sprayers	high	challenging	50	medium	medium	high
Detection systems to apply sprays	medium - high	medium	20-30	low	medium	high
Multi-row spraying equipment	high	medium	10-20	low	medium	high
Data management software/spray tracking module	low	medium	10-20	medium	medium	low-medium
Weather stations	low	easy	10-20	easy	easy	low-medium

Current Status and Performance

Autonomous sprayers – These sprayers are developed and ready to introduce. However, regulations currently do not permit autonomous sprayers for Ontario.

Detection systems for spray application – New and innovative detection systems can detect green foliage and adjust the volume sprayed. The new Sensor Tech can adjust to the density of the foliage and control the output for each nozzle in real time.

Multi-row spraying equipment – Sprayer and output technology continues to improve for more spraying efficiency. Typically, one single-row sprayer is needed for 50 acres. Multi-row sprayers are needed at times early in the season when fungicide sprays, chemical thinning sprays and plant growth regulator sprays need to be applied at the same time during a very short window under variable weather conditions.

Data management software/spray tracking module – Data management software with a spray tracking module allows for quick and easy management of crop protection applications and product inventories. Crop protection spray records easily record applications by orchard block or row and can analyze usage and costs over time. Users can access crop protection product lists and create easy to follow treatment templates customized to individual orchard crop and target pest. Growing operations can record sprays and spray plans, safety equipment, spray rates, tanks used, and the cost of sprays.

Weather stations - Weather stations located in grower's orchards can assist growers with decision making for the optimum timing for applying chemical thinning sprays. Weather station information is critical data for use in conjunction with predictive models for pruning and thinning, for applying preventative sprays for diseases and insects as well as for crop timing and wind/frost protection. Useful information collected by a weather stations includes; rainfall, current temperature, minimum and maximum temperatures, wind speed, temperature inversions and relative humidity.

Feasibility of Implementing

Autonomous sprayers – The capital cost to purchase this equipment is high, making it more economical for larger farms. This equipment requires a significant initial time allocation for setup, mission planning and programming, and would require some changes to orchard operations and processes. Training would also be needed.

Detection systems for spray application – The capital cost to purchase this equipment is high, it would be easy for the operator to use since it is fully automatic.

Multi-row spraying equipment – Multi-row sprayers are very expensive, sloping topography could inhibit the use, so it may not fit for every farm.

Data management software/spray tracking module – Software applications for tracking pesticides are affordable for most growing operations. Many applications are user-friendly; however, some level of training may be required.

Weather stations - Most companies that supply weather instruments provide information for setting it up. An inversion tower would be needed to provide wind speed and temperature inversions useful to determine when to start wind machines for frost protection.

Impact on Labour Productivity and Labour Supply Challenges

Autonomous sprayers – These unmanned systems improve labour productivity, reduce labour requirements, and create cost efficiency in tree fruit orchards by automating tasks such as spray applications. Additionally, this equipment can be used for prolonged periods of time and run continuously stopping only to be refilled with water, crop protection products and to be re-fuelled.

Detection systems for spray application – Manufacturers suggest there is a 25% increase in spray application efficiency so each tank of spray can go further. This would translate to a savings of equal proportion for labour operations.

Multi-row spraying equipment – Spraying multi-rows at once could reduce the time by half or more for spraying. Growers are also using less water for applications therefore increasing the length of time a tank of sprays last, in turn reducing some labour.

Data management software/spray tracking module – Software applications for recording and tracking sprays help identify and reduce duplications of multiple sprays and other inefficiencies which can potentially create increased labour productivity.

Weather stations - Reliable weather data used in conjunction with predictive models for pruning and thinning activities as well as for crop protection applications can improving efficiencies in orchard operations and help reduce overall labour requirements.

COVID-19 Exposure and Risk Mitigation

Autonomous sprayers – This technology helps to reduce overall labour requirements for orchard operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Detection systems for spray application – This is low risk to the applicator since the operator spraying in a sealed cab with air filtration. The operator has protective gear and air filtration masks when not using the spray cab. This technology helps to reduce overall labour requirements for orchard operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Multi-row spraying equipment – There is low risk to the applicator since the operator spraying in a sealed cab with air filtration. The operator has protective gear and air filtration masks when not using the spray cab. This technology helps to reduce overall labour requirements for orchard operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Data management software/spray tracking module – This technology may help increase labour productivity but would not significantly reduce overall labour requirements and would not significantly lower the risk of exposure or transmission among workers.

Weather stations - This technology used in conjunction with predictive models may help increase labour productivity and reduce overall labour requirements for orchard operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Operational/Process Change, Research & Training Needs

Autonomous sprayers – This equipment would require a significant initial time allocation for setup, mission planning and programming, and would require some changes to orchard operations and processes. Training would also be needed.

Detection systems for spray application – The spraying module is automatic, and no training is necessary.

Multi-row spraying equipment – There is some training needed for the new technology that sprayers offer.

Data management software/spray tracking module – Initial set-up require GPS mapping of orchards. Training may be needed depending on the user.

Weather Stations – Some training would be required to set up the weather station and to recover the data for use.

Post Harvest

Tender fruit and apple grower/packers in Ontario have been using packing and grading lines with different levels of automation and technologies. Several larger "packing houses" have been upgraded recently, but most need new technology with automation that can further replace labour. Local labour is getting harder to find in smaller communities with less available labour. Growers/packers have identified the need for the following technologies specifically directed at upgrading facilities in the packing house for automation and robotics for labour efficiency and reducing labour supply.

Table 6 – Evaluating New Technologies – Post Harvest

	Feasibility and cost	Implement	Labour Reduced	Changes in production	Training for staff	Impact on risk of COVID-19 Transmission
Identified Technology	low, medium high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Automatic bin dumpers	high	medium	50	medium	medium	high
Integrated Packing system with optical sorter and sizer	high	medium	30-50	medium	medium	high
Carton assembly	high	medium	30-50	medium	medium	high
Automatic/Robotic Palletizer and pallet wrapping machines	high	medium	30-50	medium	medium	high
Robotic packers	high	challenging	30-50%	hard	high	high
Data management system-packing, inventory, storage, shipping	low	medium	30%	medium	medium	high
Cold storage and monitoring equipment	medium	medium	low	medium	medium	low
Specialized processing equipment for cider and juice	high	medium	30 – 50	medium	medium	high

Current Status and Performance

Automatic bin dumpers – New innovative automatic bin dumper systems involve robotics for continuous feeding into the line. Both wet and dry automatic systems are available. Currently most tender fruit growers are using 11-quart wax baskets and hand dumping onto the line. Some growers are using individual container dumping systems for plastic totes that are palletized in field manually, loaded on tractors, brought into facility, and cooled and manually unloaded and tipped into the pack-line system. This has a positive benefit for food safety since the fruit is only touched once by the people harvesting.

Integrated Packing systems with optical sorter and sizer – Innovative packing systems can be programmed to learn what is trying to be achieved for daily pack-out plans based on set

parameters. The systems can optimize and organize packing tables, for example 40 pack positions in packhouse would all be optimally organized by volume and type of pack. It is a very efficient system which can increase fruit volume throughput exponentially with same number of packers (60-70% more fruit through packhouse) and double throughput on bulk orders. Packing technology also includes optical sorters (computer vision) with high tech cameras that take multiple images of individual fruit and wavelengths of infrared. Images allow the machine to cull out defects, bruising and internal injury as well. The weight sizers send fruit into different packing areas at high speeds for many fruits per second per lane. Digital images can detect multiple diameters and plot equatorial and shoulder diameters using a stem detection feature for apples and stone-fruit. New systems detect and grade minor to major defects ranging from skin blemishes, insect damage and misshapen fruit. The systems also detect physical damage, identifying problems that are often difficult pick up with the naked eye but will cause fruit to breakdown in market.

Robotic packers – Innovative packing robots make use of computer vision technology to position fruit for a tray pack automatically. Apple packing equipment includes robotic bag fillers, tray de-nesting equipment and inserters, tray/box fillers, bag to box and tray packs. The most significant barrier for this technology for tender fruit is that "tree ripe" product is in demand and the handling of fruit by robotic packers is not quite optimized for handling softer fruit as it is for other types of fruit such as apples. Currently, robotic packers would work well for tray packs for tender fruit and the technology is fairly developed.

Carton assembly – This equipment automatically makes boxes. One tender fruit shipper-dealer delivers pre-made boxes directly to its growers on demand. Some packers are also using re-usable containers that are picked up with from the grocery chain store every time a delivery is made to their grocery warehouse.

Automatic/Robotic palletizer and palletizing wrapping machines – an automatic compact palletizer combines the advantages of a robotic palletizer with traditional palletizing technology. This equipment has an innovative automatic gripper that guarantees exact positioning of each unit onto the pallet. A four-axis system is used to precisely pick the unit from a pick-up conveyor and place it on the pallet. In its basic version, the empty pallet is manually placed into the machine and the full load is removed with a forklift truck. A robotic palletizer can handle one or more units at a time according to pallet configuration and forms multiple layers on a pallet after picking the products off a conveyor. Robotic palletizing solutions can easily accommodate different pallet patterns and product types.

Data management system (packing, inventory, storage, shipping) – Data management systems for packing include RFID technology to track fruit through from harvest to storage, to packing and shipping and provides the data trail for traceability and recall purposes. Systems for packhouses can also include punch-clock systems for tracking labour hours used in warehouse. Data systems are an invaluable tool for growers making it possible for them to track product and analyze costs.

Growers get real-time data, so they know exactly how long a team takes to pack and track inventory. Mobile apps and RFID makes the process more efficient.

Cold storage and monitoring equipment – More packers are using controlled atmosphere and low oxygen storage technology when adding new storages to their operation. There are new technologies used for monitoring gas levels and fruit conditions when the fruit is stressed in the cold storage. The computer sends an alert so the gas levels can be automatically adjusted before problems arise. SmartFresh™ - 1-Methylcyclopropene (1-MCP) is a commercial product that inhibits ethylene action and can maintain the quality of many crops. 1-MCP is commercially available as SmartFresh™ for use on apples. It is a tool that growers and packers can use to store fruit longer and achieve better eating quality. SmartFresh™ improves firmness, reduces storage defects such as scald, CO2 injury, internal browning, and storage rots.

Processing equipment - Other than bin dumping, on farm-processing for cider and juice has a different specialized equipment.

Feasibility of implementing

Automatic bin dumpers – Individual container dumping technology is easy to implement for plastic totes since it is the same practice as waxed 11-quart baskets, but the cost would be higher initially for the plastic totes. Both wet and dry automatic dumping systems are expensive to purchase but would be easy to implement.

Integrated Packing systems with optical sorter and sizer - The capital cost of this equipment it high. Space is also an issue in some cases new buildings or additions must be added to house the equipment. Pack lines and packing processes would need to be reconfigured when adding new equipment.

Robotic packers – The capital cost to purchase is high and the technology needs to be optimized for all types of packs to achieve economies of scale with the equipment. The packing season for apples has a short window of 8-9 months while tender fruit packing is even shorter around 3-4 months, this makes the economics in comparison to manual packing difficult when the new machinery is only used for short times during the year. The technology also needs to be optimized to be able to achieve quality parameters for handling a tree ripe tender fruit product.

Carton Box Assembly – Cost is high, Implementation is moderate.

Automatic/robotic palletizer and palletizing wrapping machines – Cost is high but easy to implement.

Data management system (packing, inventory, storage, shipping) – The cost to purchase data management software for packhouses can range from medium to high. Ease of implementation

also ranges depending on the size and scale of the packhouse. Knowledge and training may be required.

Cold storage and monitoring equipment - Controlled atmosphere/low oxygen storage rooms have a high capital cost and implementation would be challenging, knowledge and training are required. SmartFresh^{TM}(1-MCP) cost is low about $9-10 per bin and simple to apply. Improving overall storage capacity and the quality of stored fruit coming out of inventories to pack lines creates efficiencies across pack lines and increased labour productivity.

Impact on Labour Productivity and Labour Supply Challenges

Automatic bin dumpers - automatic dumping systems would reduce labour by automating manual bin dumping. Individual container dumping would have a minor impact on labour for plastic totes since it is the same practice as waxed 11-quart baskets.

Integrated Packing systems with optical sorter and sizer– These innovative systems allow packhouses to reduce the labour required for sorting, while significantly improving the consistency and accuracy of the sorted product. New systems can increase fruit volume throughput exponentially with same number of packers (60-70% more fruit through packhouse) and doubled the throughput on bulk orders. New and innovative packing lines generally reduce labour, but crews are still needed to run the equipment and troubleshoot if needed. Visual sorters make packing more efficient by sending pre-sorted product to packers removing the decision-making process. Packers overall have been able to reduce their labour in the packing house by 40-50% with new automated equipment.

Robotic packers - Few apple packing facilities have adopted robotics, as they have not found solutions that enable high speed packing without damage to fruit, so instead they elect to stick with manual methods. Apples and tender fruit are not an easy fruit to handle because they bruise/damage very easily. This combined with the need to execute a range of crate/packing patterns is the challenge for implementing this technology. However, research and piloted trials are underway. One automation supplier is piloting technology that can pack apples at speeds of 75 ppm, without damaging the product achieved through innovative design and motion control robotics.

Carton Box Assembly – The cost is high but implementing is moderate.

Automatic/Robotic Palletizer and palletizing wrapping machines – These systems reduce labour by automating the manual palletizing and wrapping process.

Data management system-packing, inventory, storage, shipping – The implementation of RFID technology has improved operational efficiency and productivity in distribution centres and

warehouses around the world. RFID technology typically complements data capture technology (such as barcodes) already used in packhouses and fruit distribution centres.

Cold storage and monitoring equipment – Since SmartFresh™ and monitoring equipment reduces the loss of apples due to storage issues there would be less culling in pack lines and a potential reduction in labour required for the overall packhouse operation.

COVID-19 Mitigation

Automatic bin dumpers - Since labour is reduced by new automated technology, the risk of exposure would be reduced minor. However, Individual container dumping would have a minor impact on the current risk of exposure.

Integrated Packing systems with optical sorter and sizer – This technology significantly increases labour efficiency and reduces labour requirements and therefore would significantly reduce the risk of exposure and transmission of COVID-19 in pack houses. It is a challenge to keep workers sorting fruit at least six feet apart. Most workers are using PPE. Plexiglass barriers occasionally are used, and each packer has their own cubical for isolation. All protective equipment has a level of expense. COVID-19 has made things less efficient for many aspects on the packing line.

Robotic packers –Since less labour is needed to pack fruit, the risk of exposure and transmission of COVID-19 would be reduced overall.

Carton Assembly – The risk for exposure is very low since very few workers are involved.

Automatic/Robotic Palletizer and palletizing wrapping machines – This would reduce some labour and therefore reduce the risk of exposure and transmission of COVID-19.
Data management system-packing, inventory, storage, shipping – The implementation of RFID technology and other innovative data management solutions can significantly reduce overall labour requirements for packhouse operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Cold storage and monitoring equipment – This technology may help increase labour productivity but may not significantly reduce overall labour requirements and would not significantly lower the risk of exposure or transmission among workers.

Operational/Process Change, Research & Training Needs

Automatic bin dumpers – Implementation would be easy for both wet and dry systems with minimal skill training requirements.

Integrated Packing systems with optical sorter and sizer – Implementation would require significant operational/process change, knowledge and training would be required.

Robotic packers - Implementation would require significant operational/process change, knowledge and operational training would be required.

Carton Assembly – This improves productivity and can significantly reduce labour. Training is easy once established.

Automatic/Robotic Palletizer and palletizing wrapping machines – Implementation would require minimal operational/process changes, and operational training.

Data management system-packing, inventory, storage, shipping – Implementation could be challenging, computer skills and system training would be required. Implementation of data management systems can produce process/operational changes through identifying weaknesses and efficiencies.

Cold storage and monitoring equipment - Implementation of monitored controlled atmosphere storages and the use of SmartFresh™ technology would require changes to operational processes in storages as well as knowledge and training.

Adverse Weather

Growers overwhelmingly said that weather technology can help them maintain production levels by reducing their risk of perils and ensuring crop quality and volume. Most tree fruit growers in Ontario use tile drainage and/or irrigation of some type currently. Growers have identified the need for the following technologies specifically protecting their crops from adverse weather to reduce crop loss.

Table 7 – Evaluating New Technologies – Adverse Weather

	Feasibility and cost	**Implement**	**Labour Reduced**	**Changes in production**	**Training for staff**	**Impact on risk of COVID-19 Transmission**
Identified Technology	low, medium, high	easy, medium, hard	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
Drainage	high	easy	NA	easy	low	low
Trickle irrigation equipment	high	medium	20-30	easy	low	medium
Frost protection	high	easy	NA	easy	low	low
Frost protection remote controls	low	easy	10	easy	low	low
Hail protection	high	medium	NA	easy	low	low

Current Status and Performance

Growers emphasized in the survey the importance of technologies designed to protect tree fruit crops from adverse weather. After soil preparation, nutrition and organic matter has been achieved, growers need to plan for other factors that will affect their orchards in the future.

Drainage – In Ontario, unlike many tree fruit growing areas around the world, we have sufficient rainfall in most years. Drainage is key to remove standing water quickly after snow melt and heavy rains. Drainage is usually installed prior to planting if the rows are marked-out but can also be added shortly after planting.

Trickle Irrigation – In most fruit tree growing areas this is the most critical issue after planting. There is nothing worse than planting a new orchard and then ending up with only a few inches of growth because of dry growing conditions. However, as soon as irrigation starts, the weeds will flourish so there will be an immediate need for weed control. If mechanical weed control is to be used with trickle irrigation, the trickle lines need to be attached to a trellis above the ground where the soil is to be tilled for weed control. Growers are using single irrigation lines for apples. Overhead watering guns are the main method of irrigation for tender fruit growers however, some are transitioning to trickle irrigation. There are three common methods of trickle: standard lines with emitters, sub-surface lines with emitters and lines with 2-foot risers that sprinkle a pattern in the root zone.

Frost and cold winter weather protection – In Ontario, it is necessary to protect tree fruit crops from extreme cold temperatures for eight months of the year from late September to late May. Extreme cold temperatures during winter can kill trees, especially at a younger age. A spring frost typically will damage the current season's crop. There are a few methods of protection including frost fans, vertical air drains and portable heaters that are attached to tractors and driven throughout the orchard. Wind machines and frost fans are the most common method to prevent cold temperature extremes. Currently there are approximately 13,000 to 15,000 acres of horticultural crops such as grapes, tree fruits, field flowers and berries that are protected by equipment to mitigate frost damage.

Hail Protection – Hail events are destructive for tree fruit crops; they are typically isolated weather events in localized areas. Hailstorms are isolated to a couple of square kilometres, but large hailstorms have devasted the tender fruit and apple crops causing millions of dollars in lost revenue. Hail netting and hail cannons are now being used in some orchards. Hail netting can also provide shading to help reduce sunburn on fruit and heat stress on the tree.

Excessive Wind Protection – This can be problem for growers, especially for heavily cropped apples on trellis and can cause extensive damage by breaking and toppling the rows. Young trees with small root systems have also been pushed over especially if the ground is soft from excessive rainfall.

Feasibility of Implementing

Drainage - Traditionally installed by Contractors, so implementation has been easy.

Trickle irrigation - is often installed by the grower with the help of the supplier. Initial installation requires a crew to make connections and lay out the plastic hose. Overhead irrigation guns are typically installed in the fields each year by a three-man crew of farm workers that move reels and pipes around the field from the water source.

Frost and cold winter weather protection – Frost fans and vertical air drains are typically installed by the dealer. Portable burners are attached to a tractor and no install is necessary. The costs can be high, but it only takes 1 or 2 frost/cold weather events to repay the investment.

Hail Protection - Netting is a labour intensive, costly undertaking for most growers, but it might only take 1 or 2 hail events to repay the investment. Hail cannons are easier to install and less expensive.

Excessive Wind Protection - Trellis supports must be engineered/constructed strong enough to prevent high winds from causing damage. Trellis systems are expensive but also necessary for high-density systems for training and supporting the weight of the fruit.

Impact on Labour Productivity and Labour Supply Challenges

Drainage – Has minimal impact on labour productivity, however labour is needed on occasion to make necessary repairs to tile drains.

Trickle Irrigation – This technology will save labour if it replaces solid set pipes and travelling water guns, especially during a dry growing season.
Frost and cold winter weather protection – Frost fans have automatic controls for starting and stopping, while vertical air drains can be run by a tractor PTO or independently. An operator is needed to ensure the machines start. A new technology for wind machines is a monitoring and control system that can be operated with a smartphone.

Hail Protection – Some labour might be needed to remove the net every fall and re-apply again in the spring. Hail cannons would require routine inspection either by the grower or the dealer.

Excessive Wind Protection – Once the trellis is installed, there could be a small amount of annual inspection of the system likely done by 1-2 farm workers.

Mitigating Exposure and Risk of COVID-19 Transmission

Drainage – Minimal impact on mitigating the risk of exposure and transmission of COVID-19

Trickle irrigation - The implementation of trickle irrigation can reduce overall labour requirements for orchard operations therefore implementation can lower the overall risk of COVID-19 exposure and transmission for orchard operations.

Frost and cold winter weather protection – Minimal impact on mitigating the risk of exposure and transmission of COVID-19.

Hail Protection – Minimal impact on mitigating the risk of exposure and transmission of COVID-19.

Excessive Wind Protection – Minimal impact on mitigating the risk of exposure and transmission of COVID-19.

Need for Change, Research and Training Skills to Advance Technology

Drainage – Skilled labour is needed on occasion to make necessary repairs to tile drains.

Trickle Irrigation – Implementation and operation of the control system would require knowledge and training. Staff training is needed to know how to check pumps and filters at the water source, monitor the hose for leaks and plugged emitters.

Frost and cold winter weather protection – Minimal training is required except by the owner/operator.

Hail Protection - Minimal training is required except by the owner/operator. Implementation would require some operational/process changes.

Excessive Wind Protection - Minimal training is required except by the owner/operator and perhaps one worker.

COVID-19

All tree fruit growers in Ontario follow strict COVID-19 guidelines and provide PPE for workers, organize crews into cohorts, bulk buy groceries and follow other safe practices. Growers have identified the need for the following technologies specifically directed at reducing the risk of spread for COVID-19.

Table 8 – Evaluating New Technologies – COVID-19

	Feasibility and cost	Implement	Labour Reduced	Changes in production	Training for staff	Impact on risk of COVID-19 Transmission
Identified Technology	low, medium, high	easy, medium, challenging	% estimate	easy, medium, hard	none, medium, high	none, low, medium, high
PPE	low-medium	easy	NA	easy	easy	high
Air Filtering and Monitoring	low	easy	NA	easy	easy	high
Sanitization	low-medium	easy	NA	easy-medium	easy	high
Wearable Contact Tracing Technology	medium	medium	NA	easy-medium	easy	high

Current Status and Performance

Reducing the risk of COVID-19 in farm activities is discussed in each of the previous sections.

The list below provides Covid-19 guidelines and resources for growers. The information has been disseminated through government websites and by many grower organizations including the Ontario Fruit and Vegetable Growers Association (OFVGA), Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the Ontario Apple Growers (OAG), and the Ontario Tender Fruit Growers (OTFG).

- OFVGA COVID-19 Resource Library for International Agricultural Workers and Employers
- OMAFRA Prevention, Control and Outbreak Support Strategy for COVID-19 in Ontario's Farm Workers
- OAG Covid-19 Grower Resource and Worker Safety
- OTFG Covid-19 Grower Resource and Worker Safety

Personal Protective Equipment (PPE) – Growers have installed barriers between beds, provided masks and face-shields worn in field and packing house to protect workers. Some fruit packers are staggering shifts, so more sanitation can be done in between the shifts.
Air Filtering Systems – Filtering systems are designed to reduce the amount of virus in the air. Air monitoring systems can detect the amount of virus in the air and set off an alarm similar to a smoke detector.

Sanitization – Service providers are available for cleaning equipment in place and can including installing automated cleaning equipment. This can be installed in the packing house and housing

units. They also provide stainless steel equipment that can be used which is easier to clean and sanitize; automatic cleaning of equipment for bacteria and general sanitizing equipment; mask cleaning and sanitizing using ultraviolet light and hydrogen peroxide.

Wearable Contact Tracing Technology – Wearable suits or technology are available that would add a layer of exposure defence and alerts when workers are within six feet. If someone in the workplace has reported a COVID-19 positive, safety officials would receive an exposure notification and could log on to the reporting dashboard to see with whom they have been in contact.

Feasibility of Implementing

Personal Protective Equipment (PPE) - Implementation is relatively easy, the cost PPE can be very expensive depending on the size of operation. Keeping PPE inventories stocked is an added operational requirement.

Air Filtering and Monitoring system – easy to install in houses and other common places, the cost to implement can be expensive depending on the size and location of the install.

Sanitization – Sanitizing equipment can be installed in the packing house and worker housing to automatically clean packing equipment and other common areas. The cost of sanitizing equipment and services can be expensive.

Wearable Contact Tracing Technology to protect workers – This technology would need to be tested for indoor and outdoor farm tasks for practicality at different temperatures. Employees may decline to wear or use the technology. The cost of wearable contract tracing technology can be expensive.

Impact on Labour Productivity and Labour Supply Challenges

Personal Protective Equipment (PPE) - Barriers, Masks, Shields might reduce labour productivity during hot days.

Air Filtering and Monitoring system – Minimal Impact on labour productivity and labour supply.

Sanitization – Minimal Impact on labour productivity and labour supply.

Wearable Contact Tracing Technology – This would need to be tested for labour productivity and worker comfort under different temperatures both indoor and outdoor.

Mitigating Exposure and Risk of COVID-19 Exposure and Transmission

Personal Protective Equipment (PPE) - Barriers, Masks, Shields are a very effective method to reducing the transmission of COVID-19.

Air Filtering and Monitoring System – Medium to high effectiveness in reducing transmission of COVID-19.

Sanitization – Improving sanitation reduces the risk of transmission and exposure.

Wearable Contact Tracing Technology – Wearable technology use for indoor and outdoor farm tasks under different temperatures, it would reduce exposure risks and provide information for contract tracing.

Operational/Process Change, Research & Training Needs

Personal Protective Equipment (PPE) - Barriers, Masks, Shields – Minimal changes to operations are needed, some training may be required

Air Filtering system – Minimal operational changes are needed, some operator training would be required

Sanitizing Services – Minimal operational change is required, and limited training is needed once equipment is installed.

Wearable Contact Tracing Technology – Some processes would have to be put in place under the different farm environments.

Conclusion

Developing a technology and innovation road map for the Ontario tree fruit sector provides a pathway to increased adoption of mechanization to increase labour productivity, reduce labour supply challenges and remain competitive. As the sector examines and adopts new ideas and equipment to become more efficient and viable, the goal of reducing the risk of COVID-19 in our workplace will also be realized.

It is important to note the two fundamental innovations that are essential to implementing other new technologies are:

- Size-controlling orchard systems create more uniformity that allows for increased mechanization and reduced labour, and
- data management systems to provide insights and guide technological decisions for operations.

The grower focus group and survey responses clearly identified the following barriers:

- Cost - the economics and the size of their orchards prohibit the expense
- The availability and complications of adapting new technology
- The difficulty adapting their current orchard system and new training methods

The innovations and technologies outlined in this road map will have benefits for growers as they assess their operations for efficiency and risk mitigation plans with short and long-term goals. Educational resources include supplier lists for new technologies, operational assessments, and best practices to help the tree sector to move forward with mechanization and reduce labour.

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Appendix A – Grower Survey Results

Technology Innovation Road Map: Survey of Apple and Tender Fruit Growers, Feb. 1 - 12, 2021

Following is a summary of the results from 81 of the 327 growers who were emailed the survey on February 1, 2021. This represents 25% of all growers, but 50% of orchard acres in Ontario.

1. In what district of Ontario are the majority of your orchards located?

- 46 (57%) in Central
- 12 (15%) in Western
- 10 (12%) in Central West
- 7 (9%) in Eastern
- 6 (7%) in Northern

2. How many acres of apples and tender fruit crops do you operate?

- 5,838 acres of apples (45% of Ontario's reported 13,000 acres)
- 4,945 acres of tender fruit (56% of Ontario's reported 8,756 acres)
- 10,783 acres

3. How many workers did you employ in 2019 and 2020, and how many do you plan for 2021? This information will help establish benchmark ranges of workers per acre of orchard.

- 2019… 2532 workers
- 2020… 2585 workers
- 2021… 2670 workers (for 10,783 acres, this is 4.0 acres/worker)
    - 16 'solely apple growers' operating 3,581 acres had 4.8 acres/worker
    - 16 'solely tender fruit growers' operating 2,421 acres had 3.5 ac/worker

4. Please tell us why your number of workers went up, down, or stayed about the same.

- Workers were down due to COVID-19 restrictions; reduced crop due to a spring frost; and acreage was down
- Workers were up due to new plantings, mainly in apples

5. Orchard growers monitor for all kinds of reasons. Please rank them all in the order you believe are important for operating a successful orchard operation. Number 1 is most important to you, number 2 is next most important, number 3 is the next, and so on (average scores below)

- 1.9 Disease
- 2.4 Crop conditioning, maturity, load
- 2.6 Insects
- 4.9 Weather

- 5.5 Soil moisture
- 5.5 Weeds
- 7.2 Wildlife

6. Please indicate your opinion on the following statement. Adverse weather technology (such as irrigation, frost protection) can help me maintain my production levels in my orchard operation, reducing my risk of reduced crop quality and volume.

- 50 said strongly agree
- 24 said agree
- 6 said neither agree, nor disagree
- 1 said disagree
- 0 said strongly disagree

7. Spray technology continues to advance. What spray technologies do you believe Ontario orchards need now and in the future in order to reduce risk?

- 43 said smart-guided sprayers that match canopy and liquid flow
- 34 said improvements to quickly measure and mix sprays
- 31 said autonomous sprayers
- 19 said multi-row sprayers
- 18 said improvements to cleaning and calibration of equipment
- Others…a few are below
    - Faster ground speed without losing efficacy; faster dissolving solu-bags; access to more crop protection materials; long-lasting chemistry or controlled release to reduce number of applications

8. Please indicate your opinion on the following statement. Technology can help me reduce labour in my orchard operation for crop protection (monitoring and spraying).

- 28 said strongly agree
- 36 said agree
- 11 said neither agree, nor disagree
- 6 said disagree
- 0 said strongly disagree

9. What technologies for pruning and training have you used recently to reduce labour? Choose all that are applicable.

- 42 said using battery-operated pruners (including telescoping ones)
- 42 said hand-pruners and loppers
- 36 said platforms
- 30 said mechanical pruning

- 25 said pneumatic pruning
- 23 said summer pruning with a hedger
- Others…too many to list, but two tender fruit growers (T), two apple growers (A) said:
    - T: Central leader training results in less ladder work and more profit per acre
    - T: Used platforms 20+ years; best investment; pruning from ladders costs more than some wish to admit
    - A: Winter pruning with a hedger
    - A: Restricting 'N' fertilization to limit vegetation growth

10. Please tell us what technologies you are aware of or would like to see to reduce labour in pruning and training your trees. Here are a few ideas offered:

- Technology for making larger cuts in trees, cuts that are too big for shears
- Tighter plantings with shorter trees; 8-foot row spacing possibly
- On-line training modules for workers
- AI (smart) controls for pruning; take the decisions away from workers

11. Please indicate your opinion on the following statement. Technology can help me reduce labour in my orchard operation for hand labour in crop production (pruning, training, thinning, harvesting).

- 42 said strongly agree
- 27 said agree
- 7 said neither agree, nor disagree
- 0 said disagree
- 0 said strongly disagree

12. What technologies for thinning have you used recently to reduce labour? Choose all that are applicable.

- 55 said chemicals (apple growers were more likely to say this)
- 34 said hand thinning aids (tender fruit growers were more likely to say this)
- 34 said platforms (apple growers were more likely to say this)
- 12 said mechanical thinning
- Others…very few listed
    - Heavy pruning, crop load thinning guides and thinning models for bloom

13. Please tell us what technologies you are aware of or would like to see to reduce labour in thinning your trees. Here are a few ideas offered:

- More chemical options, especially for tender fruit; more research on different fruit growth stages; more availability from other growing areas; shorter re-entry intervals

- Robots that would 'learn' where fruit will be located, thin some, then know how and where to harvest later

14. What new technologies for harvesting have you used recently to reduce labour? Choose all that are applicable.

- 26 said platforms
- 18 said harvest machines with/without bin carriers
- 2 said harvest machines with vacuum technology
- Others…few listed
    - Picking into bins; lower canopy heights to reduce ladders; Crop Tracker to better understand picker efficiencies & tree yields; picking bags

15. Please tell us what technologies you are aware of or would like to see to reduce labour in harvesting your crop. Here are a few ideas offered:

- Platforms (13 growers mentioned) with various options (conveyors, bin fillers, robotic harvesting, GPS-guided, autonomous, multi-levels)
- Robotic harvesting (15 growers mentioned) 24/7 with minimal supervision (working prototypes are in other jurisdictions)
- Autonomous bin carriers
- Drone pickers
- Simpler RFID systems with better data collection on yields/block and inventory control
- Trellises for tender fruit would be a game changer
- Wearables that track worker productivity

16. What new technologies for tractor work have you used recently to reduce labour?

- 12 said GPS and autonomous movement for planting and platforms
- 9 said front-mounted shredding and brush chipping equipment
- Wider mowers for single vs. two passes
- Computerized maintenance management systems (CMMS)
- Bin carriers (up to 20 bins)
- 3-row sprayer

17. Please tell us what technologies you are aware of or would like to see to reduce labour in orchard work done with tractors. Here are a few ideas offered:

- 21 said GPS and autonomous tractors, including for smaller farms
- Drones
- Automated and 'smart' sprayers
- Mowing and spraying at the same time (autonomously would be a bonus!)
- Drought resistant sod that does not need as much mowing

- Pruning attachments and mechanical harvesters used in UK and Europe

18. Please indicate your opinion on the following statement. Technology can help me reduce labour in my orchard operations for tractor work in crop production.

- 25 said strongly agree
- 31 said agree
- 18 said neither agree, nor disagree
- 1 said disagree
- 0 said strongly disagree

19. What new technologies for post-harvest handling of fruit have you used recently to reduce labour? Choose all that are applicable.

- 50 said cold storages
- 27 said controlled atmosphere (CA) storages
- 26 said SmartFresh (1-MCP)
- 23 said inventory control
- 18 said bin dumping and fluming
- 15 said vision defect grading equipment
- 13 said carton/box assembly equipment
- Others…few listed
    - More efficient pack line peripherals; modified atmosphere packaging (MAP); automatically unloading bin carriers; robotic packing of apples

20. Please tell us what technologies you are aware of or would like to see to reduce labour after fruit is harvested from the tree. This can be either fresh fruit OR processed fruit. Here are a few ideas offered:

- 9 said improved defect sorting, scanning, sizing, and packing technologies
- Cooperative packing houses; robust accounting systems to accommodate food traceability/inventory and accounting; internal and external defect sorters; small CA storages; autonomous filling of storages

21. Please indicate your opinion on the following statement. Technology can help me reduce labour in my orchard operation for post-harvest handling.

- 26 said strongly agree
- 25 said agree
- 16 said neither agree, nor disagree
- 1 said disagree
- 2 said strongly disagree

22. Please tell us what you did to protect workers from the spread of COVID-19 during the workday, during travelling, orchard work, breaks, lunch, washroom, and other work times. Choose all their applicable.

- 65 provided enhanced sanitization
- 65 provided PPE
- 48 created cohorts (both at work and off-work)
- 35 erected barriers
- 3 provided new air filtration systems (not AC)
- Others…many were listed, but here are some good ideas
    - Less exposure to off-farm visitors and personnel
    - Stressed importance of being vigilant when out and to be aware of surroundings
    - Education, education, education
    - Staggered work schedules
    - Purchased groceries for workers
    - Smaller groups, or more individual work
    - Daily temperature recording and check on symptoms
    - More physical distancing
    - Contract tracing and recording worker travel in community
    - Provided entertainment at farm to improve morale and add some 'normality'
    - Separate vehicles or travel
    - Scheduled use of common areas

23. Please tell us what technologies you are aware of or would like to see that could help protect workers either while on the job or in their housing. Here are some of the good ideas:

- Better designed houses with more space for workers
- Mandatory vaccination when vaccines are available
- Better exhaust fan systems and filtering in enclosed work areas
- Good, filtered face masks with universal fit that allow workers who wear glasses to not get fogged up
- Plexiglass in living quarters
- HVAC purifiers
- On-farm test kits
- Cost-friendly barriers for between beds
- Wearables that check temperatures while working

24. Considering the previous questions and the potential for yet to be discovered technologies, please indicate your opinion on the following statement. Technology can help me reduce labour in my orchard operation for reducing the spread of COVID-19 in my workforce.

- 15 said strongly agree
- 25 said agree
- 24 said neither agree, nor disagree
- 4 said disagree
- 1 said strongly disagree

25. Precision agriculture is more common in field crops, but it is making its way into the orchard industry. Which of the following precision agriculture tools do you currently use? Please choose all that apply.

- 39 said weather stations
- 28 said mobile apps
- 25 said GPS-guided platforms, planter, etc.
- 21 said wind sensors
- 18 said remote controls for wind machines, irrigation equipment, etc.
- 16 said irrigation sensors
- 14 said pest management sensors
- 7 said robotics
- 6 said drones
- 5 said AI software
- Other
    - Drones would be great for scouting, security & quick spray applications
    - Wi-Fi surveillance

26. You may not have adapted new technology or purchased equipment to save labour in recent years. Please tell us why new technology has not been adopted on our farm. Choose your top three answers.

- 60 said cost
- 39 said the economics of their orchard size prohibited the expense
- 30 said the availability and/or complications of adapting to the new technology
- 29 said difficulty adapting with current orchard system and/or new training methods
- 14 said they had done OK financially without changing
- 13 said there was no clear succession plan to justify adopting new technology
- 8 said government regulations
- 6 said research and education
- 6 said training their workers

27. If money was no object, what technologies (machinery and equipment) would you purchase to reduce labour?

Growers reported about 200 things on their list of technologies, sorted as best as possible:

- 26 mentioned: GPS-autonomous platforms, tractors, vehicles, cyclone vacuum, mowing, spraying, mowing/spraying, planting, bin filling/stacking/carrying, box making
- 22 mentioned: Platforms for pruning, thinning, harvesting
- 20 mentioned: Sprayers of all kinds; canopy; over-the-row; smart filling tech; targeted; GUSS; LIDAR; 2-sided herbicide application
- 15 mentioned: Robots for hand labour, pruning, thinning, harvesting
- 15 mentioned: Drip irrigation and monitoring; autonomous sprinklers; moisture sensors
- 14 mentioned: Post-harvest internal/external defect sorting; sizing; weight; auto packing
- 10 mentioned: Weather protection for frost/cold; hail nets; retractable covers; stations
- 8 mentioned: Remote sensing for pests; wind machines; RFID on bins; crop load; disease; irrigation
- 7 mentioned: Hedgers
- 7 mentioned: Battery operated pruners
- 5 mentioned: Tractors with enclosed cab; filters for spraying; front-mount 3-pt hitch/PTO; electric vehicles; smaller tractors
- 5 mentioned: Brushing/mowing equipment; front mount
- 3 mentioned: Drones for spraying; fertilizin; picking
- 2 mentioned: Cold storages for fresh harvested; packed storage
- 2 mentioned: CA storage
- 2 mentioned: Trellises to give 2-D plain; replant and switch to them
- 1 mentioned: Chemical thinning