WTFRC Technology Roadmap

Short-list Priority: Crop Load Management

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Current Crop Load Management Technology Landscape

Crop load management is a broad category of activities that encapsulates some of the most important tasks in the orchard. From winter pruning to seasonal thinning, all the way through harvest, the many tools and tasks that monitor apple trees and get them from dormancy to harvest are all inclusive of the broad term. Further, every Washington apple grower has a unique perspective on how these tasks are best carried out, when, and by whom to result in the best yield, quality, and least cost. Though growers might have this general end goal in common, crop load management is very much an art amongst apple growers, and there is much variation on the "standard practices" that are common in the industry from orchard to orchard.

Managing the precise amount of fruit each tree bears is essential to achieving consistent high yields of target quality fruit. Crop load management is accomplished in a stepwise manner through dormant pruning, blossom thinning, and fruitlet thinning. First, dormant pruning activities aim to remove all but the specific number of flower buds needed for full production. Next, blossoms are thinned or treated to ensure each desired flower sets a fruit. Lastly, any excess young fruit is removed through the green fruit thinning process, and the fruit loaded is monitored until harvest. If crop load is managed correctly, crop uniformity improves, which leads to better yields and more consistent cropping for the entirety of the life of the orchard.

Voices of the Industry

"We need to maximize our production per acre with our growing costs being so high. But also, there's a fine line in how much fruit we can pick per acre without affecting the next year's crop."

–Washington Apple Grower

"Look at what the market pays the most for, and that's what you want to grow. So it might be a small range of apple sizes with a high degree of color and you can afford to grow less of those, and have less fruit in total, but more of those. So if you just fill the trees up, you can have lots of bins of fruit, lots and lots of pounds per acre, but low quality. And then also if you have one perfect apple per acre, it's not gonna pay very many bills either. So it's a balance of yield with quality. You have to have both at the highest level possible to maximize your profit."

–Washington Apple Grower

"Sophisticated mapping of the orchards at various times at high speed, is gonna do the biggest thing in terms of being able to more efficiently use and more productively use your labor."

- Washington Apple Grower

Crop Load Management Technology Categories

Pruning tools: When it comes to pruning, the primary goal of technology is to improve the quality of the completed task rather than reducing the time or resources required to accomplish it (due largely to the fact that labor is less constrained during pruning season). How effectively

pruning is completed can have a significant impact on both yield and quality at harvest, and on the labor demands required during thinning and harvesting. Therefore there are significant gains to investing in pruning technology, however, it is also the crop load management task that is currently least concentrated on by both growers seeking tech and technologists themselves.

There are currently no commercially available tools specifically marketed for improvement of pruning beyond some mechanical pruners. Therefore adoption of pruning tech is essentially nil.

The possibilities for future pruning tools are significant. Growers and experts cited multiple possible ways that pruning tech could offer value in the orchard; the two biggest categories being tools that improve the effectiveness of hand labor and tools that replace hand-pruning altogether. The first category could include anything from new pruning strategies that remove some of the "art" from the pruning process, to orchard systems that make pruning more straightforward, to computer vision tools that show day laborers exactly where to cut with the precision of a trained horticulturist. In the second category, robotic pruners that can determine the optimal bud count and make precise cuts without damaging trees or infrastructure would be a desirable long term goal. Most solutions like these are still in an experimentation phase.

Chemical thinning tools: Chemical thinning, through the application of plant growth regulators (PGRs) as well as some other chemical and mechanical means, is a powerful labor-reduction tool during the labor-intense thinning process. Chemical thinning can significantly reduce the need to hand-remove blossoms and fruitlets below a certain size. The apple industry has pressed chemical companies to increase their focus on making chemical thinning tools more numerous and more effective, since most available products were originally formulated for other purposes. Though there is a sense among growers that there are too few chemical thinning tools available, there are more chemical thinners/PGRs available to Washington apple growers than to most other apple growers in the world.

Example offerings include:

- Valent Bioscience: Plant growth regulator products include PoMaxa and Accede.
- Fine America: Plant growth regulator products include Excilis 9.5 SC
- NovaSource: Makers of products including lime-sulfur solutions for chemical thinning

Plant growth regulators also extend beyond thinning, and some other tools are currently being explored which might offer valuable alternatives in the future. WSU researchers, for example, are exploring the possibilities of precision pollination, a process which could be (in application) similar to chemical thinning, though with the potential for improved results.

The vast majority of Washington apple growers utilize chemical thinning tools annually, with exceptions during years with unusually light fruit loads. The biggest challenge growers currently have with chemical thinning tools, apart from the lack of selection, is a lack of consistent effects in the orchard, which is to some significant extent impacted by plant physiology. These inconsistencies can prove extreme, where in some years growers might not see any appreciable effect of their thinning programs, while in others, the same application schedule might result in detrimental over-thinning. Though there is some level of understanding about the weather and plant health conditions that factor into chemical effectiveness, lack of application tools that can respond to variable conditions (like commercially-available precision sprayers) and other tools make the optimization of chemical sprayer very difficult.

Hand-thinning (blossom, fruitlet, green fruit) tools: Depending on the effectiveness of pruning and chemical thinning regiments, sometimes additional thinning must be carried out by hand, in a labor intensive and costly way. Optimizing when and how this work is done is critical not only to

minimizing costs, but also to ensuring that growers can achieve their yield and quality goals. Currently, few tools are widely available to improve outcomes or reduce costs during this period.

Two general strategies are being pursued to address these challenges; 1) create computer vision and data analysis tools that can fine-tune hand-thinning activities to improve the effectiveness of labor while reducing costs; and 2) create a robotic/autonomous machine to take over mid- to late-season thinning tasks. These two strategies can also be understood as two steps towards an autonomous harvesting future, as effective computer vision and data analysis is a vital early step in preparing for a robot-ready orchard.

Example offerings in the realm of computer vision and crop load data analysis include:

- Fruitscout - Smartphone app for precision crop load management
- Pometa (Previously Farmvision) - Precision crop load management using computer vision
- Green Atlas - Machine-mounted precision crop load management vision system
- Vivid Machines - Machine-mounted precision crop load management vision system
- Outfield - Drone-based visual orchard management system

Adoption rates for these tools remain low, especially given that most of these options are in a relatively early or even pre-market phase. However, multiple Washington apple growers are experimenting with these tools and are interested in participating in pilot activities.

The near-term value proposition for these tools is two-fold. First, a data-driven accounting of current crop load can be invaluable for informing decisions about where thinning is most critical and how thinning activities should best be managed. Second, a more detailed understanding of fruit load, including some information around harvest time, quality, size, and yield, is valuable for growers to know as early as possible, both for planning marketing activities and labor requirements.

Crop Load Modeling tools: Determining and controlling a precise number of apples per tree is critical throughout the season right up until harvest, not only because of the yield and quality impacts in the current year, but also due to the impacts that current fruit loads have on future yields and quality. This work is done throughout the season, from pruning through to harvest, and can be done through manual bud, flower, and fruit counts and through computer vision and modeling tools. Three current models include the carbon balance model, fruit growth rate model (see the Malsium app), and the pollen tube growth model, which each aim to help growers predict and optimize the number of fruits per tree, though using these models can be expensive and time consuming.

The current commercial tech options are primarily focused much later in the season than the academic models, which emphasize prediction as early in the season as possible. Existing solutions aim to predict harvest factors like fruit size, maturity, firmness, dry matter, and color primarily in the weeks immediately prior to harvest.

Example offerings include:

- FruitSpec - ATV-mounted in-season fruit monitor
- Orchard Robotics - ATV-mounted in-season monitor, possible scouting solution in future
- Aerobotics - Drone scanning coupled with smartphone imagery
- Rubens Technologies - Hand-held harvest timing and fruit quality monitoring tools
- PixoFarm - Hand-held fruit count monitoring and harvest prediction tool

Though these tools are generally more simple to adopt than those that require significant investments in capital (e.g., new equipment, retrofitting machinery, etc.), the commercially available tools are still not very widely adopted in Washington orchards. The academic models

are more likely to be utilized. As both commercial and academic models become more reliable and actionable earlier in the season, and results become less costly to access, growers are likely to be increasingly interested in utilizing these tools.

The value proposition of crop load modeling tools is evident– the earlier and more reliably crop load can be predicted and understood, the better decisions farmers can make around deploying resources, from pruners to chemical thinners to hand thinners to harvesters. This is true at every stage in the process, though the effect becomes more pronounced earlier in the season.

Barriers to Adoption of Crop Load Management Tech in Washington Orchards

Overall Opportunity for Growers: The key opportunities of adopting crop load management technologies are

1) yield and quality improvements related to optimized plant and fruit health

2) overall better seasonal labor demand planning due to more effective pruning and thinning activities

3) reduced input costs related to chemical thinning.

However, for most growers to realize these benefits, several barriers will have to be overcome.

Lack of commercially available options: All four categories of crop load management technologies suffer from a lack of available options– though some more than others. Of the four, pruning tools are the most unavailable, and will likely be so for the near-term. Hand thinning and fruit load monitoring tools are more available, though there are few options that are widely commercialized and considered reliable. Chemical thinning options are the most available, but there is still significant room for new entrants, especially those with products specifically tailored to the needs of Washington apple growers.

Lack of complementary technologies: Especially when it comes to chemical thinning tools, one of the key limiters to their effectiveness is the fact that there are no tools available to apply chemistries with a high degree of precision. This both requires a more significant investment in inputs and leads to imperfect chemical thinning, which often leads to greater need for hand thinning. Were it possible to apply thinning tools with greater precision, that could dramatically improve the efficacy of existing chemical solutions.

Lack of skill and confidence with complex data and decision-making*:* Much of the data that is currently available through crop load management tools is complex, and does not necessarily translate in a linear way into action. Therefore it takes both a measure of comfort with data analysis and some commitment to wanting to make more data-driven decisions to see the value of many existing crop load management technologies.

An extension of this issue is a lack of digital nativity amongst agronomists. Even growers who are not necessarily crunching data themselves, and are instead relying fully or in part on an outside agronomist, often struggle to derive value from existing crop load management tools. This is in part because of the newness of the data types, but also to the limited digital training many agronomists receive today.

***Lack of proof points for ROI and risk analysis*:** Though it is widely accepted that successfully executing crop load management activities is *the* primary way to make or lose money in the orchard, it remains incredibly difficult to link specific decisions to specific outcomes. From pruning through to harvest, a near infinite amount of variables are at play, so to determine that a tool that improved pruning outcomes or finessed bloom count led directly to more yield, higher quality, or less labor is challenging. As this category develops, finding creative ways to calculate and prove ROI and risk avoidance will be vital.

Application constraints of existing technologies: Though some attention has been paid to the idea of monitoring and managing crop load at the individual tree level, the current technologies are not capable of doing that in cost- and time-efficient ways. Current tech can map blossoms (and in some cases, fruitlets) at the tree-level, but serving that information up in a timely and accurate - and ultimately actionable - way for chemical or hand-thinning is not currently possible.

Value proposition: Especially when it comes to data and vision systems in the realm of fruit load monitoring, there is still at times a lack of clarity around the value proposition to the grower, and whether available technologies actually deliver the promised value in a timely and affordable manner.

Crop Load Management Technology Strategies

An increase in engagement with, and adoption of, crop load management technologies is possible in the next two to five years.

To enhance the impactfulness of existing crop load management technologies and to further commercialization, WTFRC should consider pursuing the following strategies:

Incentivize research on the precision application of plant growth regulators. In terms of improving the efficacy of existing chemical thinning products and getting the most out of cutting edge tools (i.e. precision pollination), determining a more precise method of application, specifically at the blossom or cluster level, will be critically important.

End Goal: Improve the effectiveness of existing chemical thinning tools to reduce labor and input costs.

Priority: 2

Example Activities:

- Fund research to advance computer vision tools that can identify and address individual clusters and blossoms.
- Organize, and incentivize participation in, convenings of technologists and growers focused on collaboration, technology integration, and de-siloing.
- Provide funding/support to third-party researchers to quantify the value of precision application technologies as they emerge.
- Pursue research to understand how additional control / optimization of plant physiology can improve crop load management practices and technologies.

Advance the availability and effectiveness of crop load modeling tools, with special emphasis on early season prediction. Being able to understand and accurately predict the number of apples per tree as early in the season as possible is critical to maximizing returns and controlling costs during the crop load management process. Technologists have, to this point, largely focused on analyzing and modeling data from relatively late in the season, but there are

significant gains to pressing innovators to address refined prediction as early in the season as possible.

End Goal: Farmers have access to high quality data around crop load management as early in the season as possible.

Priority: 1

Example Activities:

- Co-sponsor a competition encouraging crop load management technologists and researchers to offer predictions as early in the season as possible.
- Support technologists and researchers in making crop load management prediction models open source/publicly accessible.
- Support third-party research projects to verify the efficacy of existing crop load modeling tools.
- Fund research focused on connecting crop load management data interseasonally and refining pruning sampling methodologies to better identify fruiting versus vegetative nodes without extensive lab sampling.

Incentivize research and development work in pruning technology. If a grower can execute a finely-tuned pruning strategy well, significant impacts later in the season in terms of both improved yield and quality and reduced thinning costs occur. But pruning remains one of the least studied and technologically-advanced parts of the crop load management process. Creating a special research emphasis will highlight how critical this aspect of crop load management is to the industry.

End Goal: Increase the amount of technologists creating tools to advance pruning efficiency.

Priority: 1

Example Activities:

- Develop and disseminate content that highlights the need for further academic and commercial focus on pruning technologies; where possible, quantify the “prize” to be had for filling this gap.
- Execute targeted outreach, backed with a funding allocation, to encourage pruning tech work among key partners and collaborators.
- Fund research into faster differentiation between vegetative and fruiting buds for precision pruning applications.
- Promote exploratory research into the potential pruning-related benefits of specific tree training strategies.

Advance awareness of, and evidence for, the value of tech-enabled crop load management tools. Crop load management efforts and tasks are highly variable from orchard to orchard and even block to block, and growers often have conviction that common tools and models will not offer the right information or support to assist in decision-making in their particular circumstances. Engaging growers in a transparent conversation about what modern crop load management tools can do will be critical for advancing experimentation and adoption and creating momentum that fuels further innovation.

End Goal: Increase crop load management tool exploration and adoption among growers.

Priority: 3

Example Activities:

- Support third-party verification of claims made by existing crop load management technology providers, especially around return on investment and potential risks.
- Sponsor/support field days and workshops where farmers can interact and experiment with currently available crop load management tools.
- Pursue research that specifically quantifies the return-on-investment of existing and prospective crop load management tools in Washington orchards.
- Support the advancement of digital education in crop load management tools in state agronomic programs (WSU, etc.).