Penn State **Extension**

Specialty Crop Innovations

Progress and Future Directions 2019










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Specialty Crop Innovations

Research and Extension Programming to Increase Specialty Crop Precision and Efficiency

Industry Challenges and Opportunities

Historically, growing fruit in Pennsylvania and the surrounding Mid-Atlantic region was a profitable, rewarding agricultural pursuit. However, in the late 90s increased competition (domestic and global), higher costs, poor returns, and competing land uses put significant strains on this once strong industry. Outside forces exposed the lack of competitiveness of many conventional orchard plantings. Considerable industry consolidation occurred in some areas and many remaining farms struggled to survive. A great deal of uncertainty developed regarding the long-term viability of producing apples in the Mid-Atlantic fruit belt. In the face of the bevy of challenges there were also many new opportunities and reasons to be optimistic about the future.

It has become apparent in the last fifteen years that the Mid-Atlantic fruit industry is transitioning toward a greater proportion of fresh fruit production. Low prices in the processing market prompted growers to reassess their production mix and look more favorably at the potential "upside" in fresh market apples. Growing calls by consumers for "locally grown" food have brought increased demand for Mid-Atlantic fruit that in turn has positively influenced prices and movement. Rising transportation costs have also helped to eliminate the cost advantage that fruit from other regions of the country once enjoyed over locally produced fresh fruit.

Unfortunately, growers cannot simply reorient an orchard from processing to fresh market by changing to whom they sell their fruit. Changing from processing to fresh market production usually involves removing old orchards of one variety and replanting with new trees of a different variety that are appropriate to current fresh market trends. At the same time, it makes sense to replant new fresh market fruit blocks using improved production systems that are more likely to produce high quality fruit, come into production earlier, take advantage of our increased knowledge of plant physiology, and that are adaptable to new developing technologies.

Replanting an orchard is not a task that can be taken lightly. Many critical decisions—variety, rootstock, spacing, support system—must be made at the outset that will dramatically impact the long-term performance (both physical and economical) of the orchard. From an economic standpoint, it is important to select systems that come into production as quickly as possible, as this will minimize a grower's period of negative cash flow and make the orchard "pay off" as quickly as possible. Such a system takes advantage of high density production principles and size controlling rootstocks to pack more, but smaller, trees onto an acre of ground. These smaller trees come into production earlier, are easier to manage, and are much more efficient than traditional large trees.

A further benefit of high density production is the opportunity it presents for labor savings. Most horticultural crops are labor intensive, and tree fruit are no exception. It is generally accepted that

60% to 75% of the cost of producing an apple crop relates to labor. There is also a great deal of uncertainty surrounding labor availability to accomplish orchard work (i.e., the lack of a legal, willing farm workforce). These two factors make the efficient utilization of labor a top concern for the tree fruit industry. Transitioning to uniform, high density orchards will put growers in the best possible position to take advantage of new labor reducing technologies as they are developed. (Matt Harsh – Harsh Consulting, former Penn State Extension Ag Economist)

The Orchard System Blueprint

Labor for orchard operations is a major focus of discussion among fruit growers. Many cultural practices and pest control methods utilized in the past require abundant labor resources to be profitable, and these no longer exist in today's agricultural community. Additionally, fresh fruit packers and processors are focused on meeting consumers' expectations for popular new varieties. Consequently, our tree fruit team is focused on increasing orchard labor efficiency and grower profitability through research and extension outreach on efficient orchard production systems coupled with innovations in technology and practices.

Intensive orchard plantings on size-controlling rootstocks are a central tenet of orchard efficiency, including labor efficiency. While it is well known and generally agreed that smaller trees require less labor because they require less pruning and minimize ladder use, few high density training systems were developed with labor efficiency in mind and fewer still specifically to facilitate the use of labor-saving mechanization.

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Intensive Apple Growing Systems and Efficiencies

During a series of intensive fruit production workshops designed to help growers transition to more efficient growing systems, we identified the following as the underlying key components—"blueprint"—of a successful intensive apple system:

- Size controlling rootstocks and tree density between 518 (6 by 14 feet) and 1320 (3 by 11 feet) trees per acre
- Quality nursery stock
- Supported canopies to maintain consistent canopy shape and position
- Single rows of tall narrow canopies ("tree wall")
- Canopy shape that complements natural tree form
- Minimal pruning and branching structure
- Simplified pruning and training tasks

Planting dwarf apple trees and adopting practices such as minimal pruning and simplified training is a key step toward labor efficiency. Older training systems that were designed to facilitate mechanization, such as the Tatura trellis, were developed to facilitate shake-and-catch harvest, but this method was abandoned by engineers for use on large-fruited species such as apple and peach because it results in unacceptable levels of bruising. Other systems were developed to create pedestrian orchards for labor efficiency, such as the Penn State Low Trellis Hedgerow and the Dutch Spindle. These training systems failed to catch on because tree training was intensive and required skill, and the extreme pruning and horizontal bending necessary for restricting canopy height often led to excessive vegetative growth and shading. In order to be economically productive, the orchard needs to achieve high light interception without creating dense areas in the canopy. Over time horticulturists found that when an orchard system is entirely within the reach of a person on the ground one of two bad things happens. Either a) the canopy is productive but too dense, causing a loss of fruit quality, or b) the canopy is too small, causing loss of yield. The solution has been to increase canopy volume without condensing the canopy by growing the tree taller, while keeping it narrow and orienting the rows in a north-south direction wherever possible to minimize cross-row shading. On-going research on labor platforms has been useful to confirm that the following orchard system parameters facilitate mechanically-assisted labor and video sensing of fruit: 1) narrow continuous tree walls, 3 to 4 ft wide and 10 to 14 ft tall and 2) rows spaced no more than 14 ft apart.

With orchard systems that create a narrow fruiting wall, we achieve both horticultural and technological compatibility. The biological efficiency of the tall narrow tree wall surpasses the performance of most existing systems. With 3 ft wide canopies, both light distribution and platform labor reach are addressed simultaneously. Ladder use can be eliminated with platform adoption. Close spacing in the row creates a tree wall that is readily identified by self-steering mechanisms, and sensor technology mounted on robotic platforms. In-row spacing of 3 to 4 ft increases early yields, benefits labor efficiency by assuring a continuous flow of work and permits simplified pruning decisions based on limb size.

Apple System Accomplishments

The aim of a Penn State NRCS Conservation Innovation Grant (CIG) project has been to develop growing systems and technologies that will allow greater mechanization and labor efficiency in the short term and fully automated systems in the future.

In twelve 1-acre model CIG plantings we are evaluating the effect of two high density apple growing systems on productivity, fruit quality and labor efficiency. These training systems utilize the same support system, and trees are planted at the same spacing (691 trees per acre). Two popular varieties, one with high vigor (Cameo) and one with low vigor (Honeycrisp), are being used to determine if a difference in tree vigor level influences the performance of these systems based on fruit quality and labor efficiency. The trees are being trained to form either a continuous tree wall, or as cone-shaped canopies with discrete gaps in the tree tops. Results to date indicate that neither yield nor sunlight will be reduced by training the top of cone-shaped trees to a continuous palmette, provided the width is maintained at ~60 cm. The large number of CIG trials and the relatively large size of the plantings also have provided adequate space for evaluating labor saving technologies developed through three USDA Specialty Crop Initiative projects. Gains in efficiency range from 25% for peach thinning to 105% for pheromone dispenser placement.

Critical to the creation of an orchard blueprint is the selection of the cultivar and the rootstock. In recent years new cultivars such as Gala and Honeycrisp have become more prominent in the fresh market industry. Not all may be suitable in all regions. Many of these cultivars are coming from European breeding programs and their performance is unknown in the United States. Increased emphasis is being placed on resistance to insect and disease pressures. Similarly, new rootstock candidates have been developed that allow for better tree efficiency, controlled tree size and resistance to diseases such as fire blight and insects such as woolly apple aphid. NC-140 regional research trial plots established at Penn State have provided uniform testing to evaluate attributes of a number of promising rootstocks.

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Intensive Peach Growing Systems and Efficiencies

Peach production systems have remained largely unchanged for generations, due to the lack of tree size control and large labor requirements. The lack of dwarfing rootstocks for peach limits the extent of orchard intensification. The need to hand thin and to make multiple harvests makes working on tall peach plantings from ladders costly. Since 2007, we have evaluated new production systems that improve both productivity and labor efficiency. Since we do not yet have size-controlling rootstocks for peach, the intensive systems we have been evaluating have densities between 242 to 483 trees per acre. Our prior research demonstrated that the 18- to 20-foot row spacing common to perpendicular V peach plantings is also applicable to mechanical labor platform use.

Peach System Accomplishments

The peach systems trial has shown strong differences in yield and fruit size between systems. Yield per acre has followed this trend: Quad V (7 ft row spacing) $\geq$ Hex V (10 ft) > Perpendicular V (6 ft)> Open Center (14 ft). The moderate density systems were the most productive for the first eight years of the planting because these systems produce more bearing surface per acre than the Perpendicular V and they fill their space much faster than the Open Center. While all three V systems in our study produced more small sized fruit than the Open Center trees, the Quad V and Hex V also produced more 2 ¾ inch and 3 inch fruit than the Open Center. Closely planted V systems can produce a large crop of large fruit if good management practices are applied.

With the development of mechanical blossom thinning and mechanized labor platforms, the labor efficiency in tall tree systems can be greatly improved. The results of this study show that a change in peach orchard training systems is overdue. Hex V and Quad V are productive, easy to train systems that create a narrow tree wall. These systems greatly facilitate the use of mechanical blossom thinning, as well as use of mobile labor platforms.

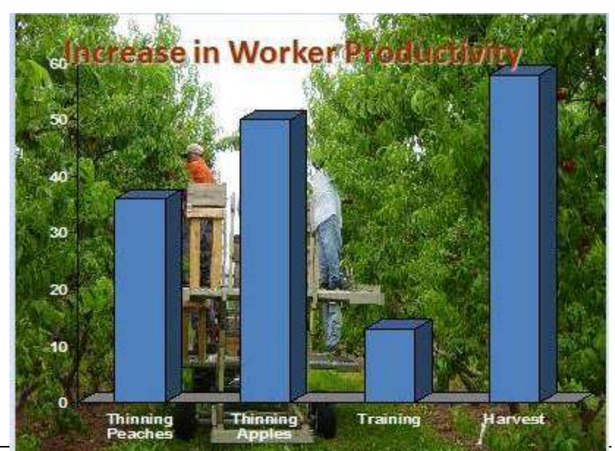
On-Going Apple and Peach Systems Trials

Currently under trial are four narrow wall apple training systems with Jonagold and Fuji. The systems are a Tall Spindle, Tall Trellis, Vertical Axe and Minimally Pruned. Yields, growth, fruit size and pruning labor are being measured. Apple rootstock trials include a planting of Fuji on 30 rootstocks—mostly advanced or released selections from the Cornell Geneva breeding program. A rootstock trial established in 2014 compares four Vineland rootstocks selected for cold hardiness, precocity and fire blight resistance and also the newest semidwarf Cornell Geneva rootstocks. Our research on peach systems has shown that Quad V systems have up to 85% greater annual yield and higher fruit quality than conventional vase systems, and that the narrow canopy of this system is more compatible with mechanization. New peach plantings have been established to determine if advanced tree training techniques and size controlling rootstocks can be employed to make such systems still more efficient and technology-friendly.

It is our hope that the results will continue to provide growers with regionally-adapted recommendations on growing systems for high yields of quality fruit, grown with the efficient use of labor and other inputs. (Jim Schupp, Edwin Winzeler, Tom Kon, Melanie Schupp, Tara Baugher, Rob Crassweller, Lynn Kime, Rich Marini)

Mobile Orchard Platforms

Mobile orchard platforms are a technology utilized in European orchards that responded to a mid-60s apple marketing crisis by planting high density systems with tall, narrow canopies (Oberhofer, 2004; Mitham, 2005). An orchard picking platform was designed and tested by Penn State agricultural engineers in the late 60s, but it was difficult to maneuver around the large tree canopies common in commercial orchards at the time (Allshouse, 1970).



A need to retool the Pennsylvania fruit industry with innovative technologies was identified in 2005 following a series of grassroots strategic planning sessions among industry and community leaders. The Pennsylvania Ag Innovations Initiative (now called the Specialty Crop Innovations Initiative) was launched (Baugher et al., *Compact Fruit*, 2006), and grower advisors to a multi-disciplinary research team recommended that a systems approach be developed for retooling orchards with efficient training systems and labor efficient technologies. The advisory group and research team of horticulturists, ag economists and ag engineers agreed that the initial phase of the project should be to test an orchard platform prototype versus ladders in orchards trained to tall tree walls. The project cooperators identified a number of reasons for eliminating the use of ladders in orchards, including low labor efficiency, increased injuries and higher insurance premium rates. Preliminary orchard platform trials being conducted at the time in Washington State orchards had demonstrated 30% increases in worker productivity and a significant reduction in worker injuries (Faubion and Lewis, *Good Fruit Grower*, 2005).

Project Progress

Trials with an orchard platform prototype were conducted in 24 Pennsylvania orchard blocks. Tree architectures included peaches trained to perpendicular V and apples trained to vertical axis. The purpose of taking the orchard platform to as many orchards as possible was two-fold—the research team could evaluate platform efficacy with various modifications of tree training systems and growers would have the opportunity to assess where tree training and plant spacing adjustments should be made for improved adaptation to automation. An added benefit of commercial orchard trials was that growers and employees provided valuable feedback on possible future directions for team research.

Ladder and platform efficiencies were compared in four uniformly randomized trials for each of six labor-intensive orchard tasks. Worker productivity with the moveable platform compared to ladders increased by an average of 35% for peach thinning and pruning and 50% for peach harvest and apple thinning, tree training or pruning. The platform was more efficient than ladders for all tasks (95% level of confidence). Work performance over time generally increased with the orchard platform and remained the same with ladders. Work quality, assessed for fruit thinning operations by counting fruit in upper versus lower canopies and fruit per scaffold following thinning, was similar or improved from the platform compared to ladders. Thinning and harvesting from the platform resulted in significant economic savings ($126 to $282 per acre for the powered prototype). Results for other operations varied depending on tree age and architecture.

On-Going and Future Investigations

A significant obstacle to orchard platform research was the inconsistency in tree architecture and row spacing from one commercial orchard to the next. Trials are now being conducted in the commercial-scale apple orchard systems plantings funded through a NRCS Conservation Innovation Grant (CIG) and a Penn State FREC peach orchard systems trial funded by State Horticultural Association of Pennsylvania (SHAP) and Robert C. Hoffman Foundation grants.

Autonomous orchard platform trials comparing work efficiency in the narrow tree wall systems are being conducted with both diesel and electric platforms. Sensor technologies were added by Carnegie Mellon University engineers collaborating on a Specialty Crop Research Initiative project titled *Comprehensive Automation for Specialty Crops.* Labor efficiency with platforms compared to ladders increased by 25% to 105%, depending on the nature of the task. Field trials continue with an electric platform modified to accommodate the low-cost harvest assist system. (Tara Baugher, Jim Schupp, Paul Heinemann, Rob Crassweller, Lynn Kime)

Harvest Assist Technologies

Labor costs associated with fruit harvest are roughly 40% of an orchard enterprise annual budget. For this reason, a national specialty crop engineering solutions task force identified harvest mechanization and automation as a research priority (*Engineering Solutions for Specialty Crop Challenges Proceedings*, 2007). Mechanical harvest aids offer the potential for more efficient harvest and increased consistency in fruit handling. However, in-field bin filler technologies available at the start of our research resulted in excessive bruising of fruit. The complex fruit handling and equipment/ operator interface is a major hurdle engineers must address for successful technology transfer.

Preliminary Engineering Investigations

Penn State and Olin College engineering students worked with the Specialty Crop Innovations team to assess bin filling methods and design and simulate new concepts for gently transferring fruit to bins in the field. The most innovative and promising design was a "false floor" bin filler. The Specialty Crop Innovations team developed a cooperative agreement with USDA Appalachian Fruit Research Station Research Engineer Amy Tabb to conduct commercial trials on a dry bin filler with a similar "disappearing floor" design concept. Bruising studies were conducted to quantify the efficacy of the bin filler in a packinghouse setting. The bin filler also was tested for potential applications in assisted harvest operations. A research paper was published in the *Journal of the American Society of Agricultural and Biological Engineers*.

During the 2007 harvest, Penn State University and Pennsylvania growers hosted a "Specialty Crop Engineering Solutions" tour for robotics and precision agriculture engineers. The outcome of the tour and various planning sessions was the funding of a USDA Specialty Crop Research Initiative project led by Carnegie Mellon to investigate new solutions for assisted harvest and other labor intensive operations. During the initial year of this project, two passive bin filler prototypes showed promise in laboratory tests to assess potential reductions in damage to fruit during the bin filling process.

From 2010 through 2013, design and testing were performed on apple transport systems with a bin filler design to keep fruit singulated all the way to the bin. In 2010, the project team began working with a commercialization partner, DBR Conveyor Concepts, on a vacuum tube transport system and automated bin filler that can be retrofitted to existing grower equipment. For Penn State trials, the harvest system was initially adapted to the orchard platform automated by Carnegie Mellon.

A second generation vacuum assist system designed specifically for eastern orchard systems was tested in Pennsylvania and Michigan orchards in 2012. We performed efficiency and bruise analysis trials on the newest prototype DBR vacuum harvest system to assess efficiency gains over the use of traditional ladders and picking buckets. This assessment included examination of bruise volume from hand harvested and vacuum harvested apples. Testing the new prototype with plantings of Golden Delicious, York and Cameo, four harvest workers could simultaneously pick a 23-bushel bin of apples every 11 to 12 minutes. Compared to harvesting with ladders, this represented a 15% to 33% increase in harvest labor efficiency. Bruising was slightly elevated, and varied between 2.5% and 7.9%, depending on variety. Several refinements were made for reducing bruise incidence.

Efficiency in apple orchard plots harvested with vacuum assist system and platform compared to hand harvest and ladders.

PA Trials, 2012		**Harvest time/bin**	**Harvest time/acre**	
Cultivar	**Harvest System**	(min/1 person)[z]	(hrs/4 workers)	(% change)
Golden Delicious	Vacuum assist	45.6 c[y]	8.3	33
York	Vacuum assist	45.5 c	5.8	33
Cameo	Vacuum assist	58.0 b	11.6	15
	Hand	68.0 a	13.6	--

[z] 23 bushel plastic bin.

[y] Completely randomized design with 4 replicates. Mean separation by Fisher's protected least significant difference at $P \leq 0.05$.

On-Going and Future Investigations

A low-cost and low-energy harvest-assist unit was developed in 2012-13 with funds from the Pennsylvania Department of Agriculture and the State Horticultural Association of Pennsylvania. The unit was refined and further field tested in Fall 2014, and a commercialization plan is currently being developed, with funds from the Penn State College of Ag Science's Research Applications and Innovations (RAIN) grant program.

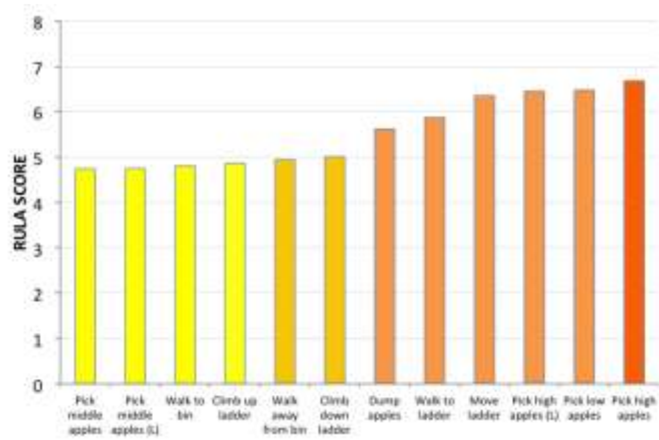
Lab- and field-testing in Fall 2013 successfully demonstrated that the unit could work in a commercial-scale orchard and demonstrated possible market potential. Challenges with bruising of apples, in particular, drove refinements in the design. One of the key issues in the first year of field-testing was the incidence of bruising that occurred between the distributor and the bin. This has been the primary limiting factor with mechanized apple harvest units in the past. The focus of research in 2014 was in three primary areas: bruise reduction, ergonomics and efficiency. Redesign greatly reduced bruising in 2014-15 field-testing. Field tests showed that only 5% of the apples harvested were lowered in grade due to bruising after modifications in the device.

Field testing of harvest assist system compared to conventional harvest.

Ergonomics

Eliminating ladders and picking buckets can greatly reduce potential hazards, and utilizing picking platforms with harvest-assist devices is a good way to do this. The ergonomics of ladder picking versus harvest with this device and platform were compared in different ways. The "Rapid Upper Limb Assessment," or RULA, approach was used to make ergonomic comparisons. This method evaluates postures and rates them on a scale of 1 (negligible risk) to 6 or above (high risk).

Conventional apple harvest activities were categorized using the RULA method, and awkward activities were identified. Awkward activities of ladder descending, moving a ladder and picking high apples while standing on a ladder were eliminated with the harvest-assist unit. The highest RULA scores recorded in ladder picking reached a value of 7, while the highest score using the harvest-assist device was 6, and the time in those potentially dangerous postures was greatly reduced. Overall, the time spent in awkward postures (RULA score of 5 or higher) was decreased from 65.0% of the whole harvest process in conventional apple harvest approach to 43.3% of the whole harvest process in harvest-assist unit approach.



Efficiency

Efficiency (apples picked per unit time) was based on two pickers on the platform and two pickers walking on the ground, compared with four pickers picking from the ground and using ladders for higher apples. Use of the harvest-assist unit increased the overall apple harvest efficiency by 28.6% for these two scenarios. (Paul Heinemann, Jude Liu, Judd Michael, Zhao Zhang, Jim Schupp, Tara Baugher)

Crop Load Management Innovations

Hand thinning of fruit is among the most labor-intensive orchard practices and consequently contributes significantly to fruit production costs. Research on mechanical string or drum shaker thinners demonstrated that these methods reduce the hand thinning requirement in crop load management programs. These technologies also lessen the competition from a portion of the excess crop early and rapidly—thereby improving fruit size, quality and return bloom. Being non-chemical, the obstacle of registration for a new compound is avoided. New mechanical thinning strategies coupled with narrow tree architectures have potential to favorably impact grower profitability both by reducing labor requirement and by improving fruit size and quality.

Accomplishments

In a Specialty Crop Research Initiative project led by Penn State, trials with a mechanical blossom string thinner were performed in 30 Pennsylvania, 9 South Carolina, 22 Washington and 9 California commercial and research orchards. A USDA drum shaker was tested in PA orchards during the bloom and green fruit stages. Conventional hand thinning at the green fruit stage was the control treatment. Varying operational speeds, blossom stages and pruning modifications to improve access by the thinner were assessed. Data were uniformly collected across all regions to determine blossom removal rates, fruit set, labor required for follow-up hand thinning, fruit size distribution at harvest, yield and economic impact.

String thinner trials to assess optimum operational parameters for varying growing regions and tree forms showed reduced labor costs compared to hand thinned controls and increased crop value due to a larger distribution of fruit in higher market value sizes. Blossom removal ranged from 20% to 55%, hand thinning requirement was reduced by 25% to 65%, and fruit size distribution improved in all but one trial. Net economic impact at optimum tractor and spindle speeds was $462 to $1490 and $230 to $847 per acre for processing and fresh market peaches, respectively. Trials with the string thinner at varying bloom stages showed the thinning window is from pink to petal fall. Trials on modifications in tree training to improve access by the string thinner indicated detailed pruning for targeted crop loads was superior to standard pruning. Studies with a new drum shaker prototype adapted from a blackberry harvester demonstrated increased thinning consistency compared to previous research with a citrus drum shaker. Joystick control of the Darwin thinning unit was developed and successfully tested to improve the positioning performance of the spindle. This allows the tractor operator to more easily maneuver the spindle for proper alignment with the tree without having to use the vehicle steering for that purpose, reducing operator fatigue and improving thinning performance. Sensors to automate the positioning of the spindle were also tested.

While our research resulted in the Darwin string thinner being successfully deployed to reduce hand thinning labor in peach, results from apple have been a mixed bag. Apple flowers form from a mixed bud, and the spur leaves under the flowers are crucial to fruit growth during the cell division phase of growth. Although thinning has been achieved in our apple studies, fruit size has been increased in only one of several apple trials conducted in Pennsylvania. It is thought that the spur leaf damage that accompanies the thinning explains the lack of fruit growth promotion.

Future Plans

Research on the string thinning units has led to improvements in the commercially-available products. A new development that will soon be on the market is a joystick-controlled thinner with a side-shifting spindle. The concept is based on Penn State research to improve the operator control of the thinning equipment. Development of a selective thinning unit is on-going. Prototype designs for the components of the unit, including image analysis, controls, robotic arm selection and blossom removal mechanism, are being investigated and tested. (Jim Schupp, Tara Baugher, Paul Heinemann, Edwin Winzeler, Jude Liu, David Lyons)

Automation of Dormant Pruning

There are two driving forces to reduce labor inputs: cost and risk associated with a limited supply of labor. A USDA Specialty Crop Research Initiative project was initiated in 2012 to develop innovative technologies for automating pruning on apple trees. The goals are to:

1. Formulate and evaluate rules that describe optimal pruning in terms of measurable physical attributes of canopy structure
2. Develop 3D imaging, decision system and robot control technologies for automating dormant pruning operations in order to construct autonomous pruning systems
3. Determine social and economic impacts of the proposed autonomous pruning system
4. Communicate results and involve growers, industry groups, academia and students so they can adopt these technologies and incorporate the knowledge gained into their orchards, vineyards, businesses, classrooms and laboratories

Additionally it is anticipated that results may help to train human pruning crews.

Accomplishments

Studies with tall spindle apple canopies have indicated that pruning rules may not need to be overly complicated to adequately describe optimal pruning. Preliminary results suggest that the number of primary branches emanating from the trunk may be the most important factor, while including additional detail such as secondary, tertiary or quaternary branching patterns adds considerable complexity but may not add significant benefits.

Our engineering team has invented a state-of-the-art 3D object modeling system that is capable of creating accurate 3D reconstructions of objects, even from extremely noisy laser data (Park and Kak, 2008; Park and DeSouza, 2004). Fundamental to the proposed decision system is the concept of branch junction points on a 3D reconstruction. Once we identify branch junction points, the rest of the reasoning is driven by placing coordinate frames at each such position to identify the limbs.

On-Going and Future Investigations

Research is continuing to determine the optimum severity of pruning, and these data will be used in algorithms to determine optimal pruning points. Recent advances in 3D data acquisition methods have led to inexpensive, light-weight 3D scanners for data collection. Going forward, an important goal is to use techniques of robust estimation to eliminate the errors caused by sudden motions.

A series of surveys and case studies of commercial growers in different growing areas of the United States are being conducted to determine growers' attitudes toward autonomous pruning systems and to determine the likelihood that they would adopt such technology when available.

Original apple tree, left, and 3-D construction using a Kinect sensor.

Economic analyses will be performed to determine break even points and to determine whether such systems are likely to be cost effective for growers. (Jim Schupp, Tara Baugher, Peter Hirst, Noha Elfiky, Johnny Park, Jayson Harper, Leland Glenna, Anouk Patel-Campillo, Julie Tarara)

Sensor and Imaging Technologies and Weather Modeling

Sensor and imaging technologies, along with weather modeling, are being investigated for applications in intensive orchard systems. These technologies have the potential to cross multiple areas of tree fruit production:

- determining crop load or assessing when to thin
- determining insect presence/disease infection and eradication
- monitoring insect population thresholds

As engineers investigate these potentials, they will likely find that different technological approaches will prove successful for different orchard management tasks.

Trials with Crop Imaging, Sensors for Counting Insects, Weather Modeling

In a Specialty Crop Research Initiative project to develop "Comprehensive Automation Technologies for Specialty Crops (CASC)," a transdisciplinary research team addressed sensor technologies for the automation of fruit production. Team collaborators developed and evaluated automation solutions that growers can use to increase labor efficiency, detect insect pests and diseases, monitor plant health, predict crop load and reduce crop damage at harvest.

Team engineers and horticulturists tested algorithms to successfully identify fruit in a tree canopy. Penn State entomologists collected and annotated images of both codling moth and Oriental fruit moth adults within traps. These images, and numerous others, were utilized by Purdue University engineers to test visual algorithms for insect detection. Plant pathologists created a database of images for use in developing and testing image processing methods and algorithms for fire blight.

Engineers and entomologists developed and tested a novel tool for monitoring insect pests—the Z-Trap. Like current traps, it uses pheromones to attract target insects. Its novelties are a high-voltage coil to stun insects entering the trap, bio-impedance sensors to count insects automatically as they fall into the trap, wireless connections to send pest information directly to a server on the farm, and handheld/web-based software to manage the entire system. A web-based user interface called “MyTraps” was developed to allow the user to effectively manage and visualize insect population data collected by Z-Traps.

A newer initiative is to evaluate the MaluSim carbohydrate model for optimizing apple thinning decisions. In cooperation with Dr. Alan Lakso, Cornell University, the model is being evaluated at multiple orchard sites around the state that have on-site weather stations with solar sensors. In 2013 and 2014, the Cornell model was tested using weather data from ZedX as well as weather data collected on-site by North East Weather Applications (NEWA) weather stations. ZedX has developed an electronically delivered site-specific thinning module that will be evaluated as well. We continue to evaluate the MaluSim carbohydrate model for optimizing apple thinning decisions in cooperation with Dr. Alan Lakso. In 2015 information from nine sites was downloaded from the NEWA weather site and disseminated to growers via electronic newsletters every 4 to 5 days.

Future Outlook

Achieving consistently high fruit quality requires vigilant pest management and information on the various environmental stresses that can reduce quality and size as well as blemish the product, or in some cases exclude it from processing or export. While pest monitoring and integrated pest management (IPM) systems are cost-effective practices in specialty crops, the frequency and cost of trap monitoring and identification of specific pest damage has limited the ability of the grower to perceive pest migration at the onset. The development of automated traps, computer vision and improved modeling systems will reduce the need for labor while increasing the accuracy of crop monitoring, resulting in improved crop management, more effective pest monitoring, higher fruit quality and reduced pesticide application. (Rob Crassweller, Tara Baugher, Jim Schupp, Greg Krawczyk, Brian Lehman, Edwin Winzeler, Larry Hull, Amy Tabb, Johnny Park)

Sprayer Technologies

The application of pesticides to perennial cropping systems, although very necessary for pest control, gives rise to many concerns including inaccurate application, which can lead to high food residues, food safety issues, air and water pollution, non-target effects and poor pest control. There is a need to investigate newer and more efficient sprayer technologies for applying required pesticides.

50% "Cornell donut"

Progress to Date

A Penn State sprayer technology working group began discussing possible initiatives in 2007. Larry Hull tested the "Cornell donuts" on two air-blast sprayers and demonstrated significant reductions in spray drift while still maintaining equivalent levels of insect control. Summer engineering interns built a patternator (based on specifications developed at Cornell University) to help growers assess ways to adjust spray distribution pattern. A workshop on application technologies for tree fruit and grapes was held at the Penn State Fruit Research and Extension Center. The Penn State Pesticide Education Program sponsored field demonstrations in 2011 and 2012 and workshops in 2013 to 2016 to demonstrate the benefits of tools for calibrating air-blast sprayer and minimizing drift.

On-Going and Future Initiatives

Continued outreach efforts will address improving spray deposition while reducing drift. Educational programming will include demonstrations of low-cost fixes for air-blast sprayers, such as improved nozzle orientation, air induction nozzles, end plates, air deflectors, axial fan size and speed adjustments, PTO and hydraulic drive modifications, "Cornell donuts" and new technologies such as foliage sensors. The State Horticultural Association of Pennsylvania Extension Committee awarded funding in 2013 and 2014 to help off-set the cost to growers for on-farm calibration of their air-blast sprayers. With additional funding received in 2015, spray deposition will also be evaluated using a patternator.

As a result of the first year of funding, 70 sprayers were calibrated, and the numbers of calibrations increase each year. After having their sprayers calibrated for the first time, most growers indicated they would be willing to pay more for future calibrations. This is a continuation and expansion of the initial needs assessment pilot project, with the ultimate goal of making the program sustainable once growers see firsthand the value of the calibration unit in improving air-blast sprayer performance. Sprayer calibration workshops are also conducted in English and Spanish. By doing precise calibration, some growers estimate they now mix 10% less material per tank. Based on Penn State Extension Tree Fruit Production budgets, this is a savings of $150 per acre. (Kerry Richards, Héctor M. Núñez Contreras, Bob Pollock, Larry Hull, John Esslinger, Kathy Salisbury, Andy Muza, Tom Ford, Tim Elkner)

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A video of Penn State Extension Tree Fruit Team Accomplishments is here: http://extension.psu.edu/plants/tree-fruit/resources/team-video.

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