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Specialty Crop Innovations

Progress and Future Directions for Retooling Mid-Atlantic Orchards with Innovative Technologies

Industry Challenges and Opportunities

Historically, growing fruit in Pennsylvania and the surrounding Mid-Atlantic region has been a profitable, rewarding agricultural pursuit. However in recent years 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 fruit in the Mid-Atlantic fruit belt. Yet in the face of the bevy of challenges facing the industry there are also many new opportunities and reasons to be optimistic about the future.

Fruit farming in the Mid-Atlantic region was traditionally centered largely on the production of “processing” rather than “fresh” fruit. Processing apples are those raised specifically for sale to local apple processing firms and are used to make products such as sauce, slices, and juice. Fresh apples are raised for sale to consumers in raw form, mainly through packinghouses and food retailers, but also through direct retail outlets (e.g., on-farm markets, farmers markets, direct sales to restaurants).

Until recently, three quarters of all apples raised in this region were destined for the processing market. Growing processing apples tends to be a low margin, commodity-type undertaking, where cost control and yield maximization are critical. Additionally, superficial quality (i.e., appearance) tends to be less of a consideration, allowing growers to “get by” with orchard production practices, systems, and to a certain extent varieties that would not be conducive to fresh market production. Consequently blocks of processing fruit tend to be older and less intensively managed than fresh market blocks.

Conversely, apples raised by the Mid-Atlantic industry for the fresh market can be viewed as a more differentiated product. Fresh market apple production is quality driven and variety selection is critically important to success. As a result, fresh market apple blocks are often younger and much more intensively managed compared with processing blocks. Production costs are higher, but profit potential is higher for a well raised crop.

It has become apparent in the last few years that the Mid-Atlantic fruit industry is transitioning toward a greater proportion of fresh apple production. Low prices in the processing market have caused 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 (in most cases). 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 apt to produce high quality apples, 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 plant 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.

Increased productivity, however, comes at a cost. High density orchards require supplemental tree support that adds greatly to their initial investment. Average establishment costs for a high density block in the Mid-Atlantic region are between $7,000 and $10,000 per acre compared to traditional low density systems that cost $2,000 to $3,000 per acre to establish. Early and significant yields—a key benefit of high density production—are critical in achieving maximum economic return and expedited payback in these systems.

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 percent 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 - Chesley Orchards)

The Orchard System Blueprint

Labor for orchard operations is a major focus of discussion among fruit growers. The 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 consumer’s expectations for popular new varieties. Research and development of efficient orchard production systems, coupled with innovations in technology, address the need of increasing orchard labor efficiency.
Training systems for apple have been extensively researched, and about 30 systems have been named. Intensive orchard plantings on size-controlling rootstocks are a central tenant of orchard efficiency, including labor efficiency.

While it is a well known and generally agreed principle 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. Indeed, many high-density apple systems make extensive use of hand labor for tree training and pruning to enhance the tree size control and precocious bearing imparted by the dwarfing rootstock. The sheer numbers of tree training protocols and techniques requiring hand labor sometimes create confusion for growers seeking to adopt modern high density practices.

**Progress**

At an intensive fruit production workshop in 2006 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
- Single rows of tall narrow canopies
- Canopy shape that complements natural tree form
- Minimal pruning
- 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 Lincoln Canopy. 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.
While these tall narrow canopies satisfy both the interception and distribution requirements for light, increasing tree height reduces labor efficiency because it introduces the need for ladders. The tree height problem can be addressed with labor platform technology. Orchard platforms were tried in the past, but failed to save time because the orchard systems they were applied in consisted of larger trees and more distant spacing. With the new narrow fruiting wall systems we can achieve horticultural and technological compatibility:

- The tall narrow tree wall is horticulturally sound, and its biological efficiency surpasses the performance of most existing systems.
- Sunlight and labor have the same reach. Light becomes limiting after penetrating a fruit tree canopy to a depth of about three feet. With narrow canopies, we have addressed both problems of light distribution and platform labor reach simultaneously.
- Tree height creates a simple labor access problem with an engineering solution.

The maximum orchard row spacing for orchard platform work in vertical tree canopies such as vertical axis or tall spindle is about 14 feet, similar to the optimal between row spacing for good light interception for blocks with a maximum tree height of about 12 feet.

In-row spacing of six feet or less between trees is beneficial to platform efficiency by assuring a continuous flow of work. This question of how continuous or discontinuous the canopy should be requires more study, and several options will be tested in commercial pilot orchards. An in-row gap between tree canopies is known to be beneficial for prevention of cross-row shading, while a continuous canopy would optimize labor efficiency. The minimum size gap at the top of the narrow tree wall needed to prevent cross-row shading and loss of fruit size and quality remains to be determined.

Our proximity to the world’s most important fruit market (the U.S. east coast) is a growing competitive advantage for our industry, not only in transportation costs, but also due to growing consumer preference for locally-grown produce. The future for our fruit industry seems bright, except for the growing cost and scarcity of farm labor. The aim of a new Penn State NRCS Conservation Innovation Grant (CIG) project is 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.

Following the establishment of 12 CIG one-acre pilot plantings in 2008, meetings for grower-cooperators were held throughout the season to demonstrate recommended horticultural practices. Proposed tree training practices were pre-tested in existing high density plantings to validate their future adoption in the CIG plantings. In November 2008 two of our team members accompanied several growers to the South Tyrol region in Italy and Germany to study recent developments in intensive
orchard production practices. While in Italy, we also researched a new mobile platform and searched for other new technologies at an international apple trade show (Interpoma).

In the CIG plantings we will evaluate the effect of two high density apple growing systems on productivity, fruit quality, and labor efficiency. These training systems will utilize the same support system, and trees are planted at the same spacing (691 trees per acre). The trees will be trained to form either a continuous tree wall, or as cone-shaped canopies with discrete gaps in the tree tops. Two popular varieties, one with high vigor (Cameo) and one with low vigor (Honeycrisp) will be used to determine if a difference in tree vigor level influences the performance of these systems based on fruit quality and labor efficiency. Labor efficiency between the two systems will be compared using both ladders and a mobile platform. The large number of CIG trials and the relatively large size of the plantings will also provide adequate space for evaluating additional labor saving technologies developed through two USDA Specialty Crop Initiative projects funded in 2008. By blending this research into the CIG demonstration project, we can increase the visibility of the results and speed industry adoption of new practices as they develop.

Accomplishments

- Developed tree support and tree training protocols for narrow tree wall systems that will be tested and demonstrated in 12 NRCS Conservation Innovation Grant (CIG) plantings
- Planned, funded and in 2007, established an intensive peach production systems trial
- Expanded an ongoing research program on size-controlling apple and peach rootstocks, as well as other system components
- Evaluating labor saving technology such as mobile platforms and mechanized thinners in existing high density orchards
- Investigating new trellising materials
- Evaluated GPS-guidance for planting precision orchards that will enhance implementation of orchard automation
- Evaluated the effect of peach canopy thickness and apple crop load on the efficacy of stereoscopic hyper-spectral video imaging of fruit in tree canopies
- Evaluated horticultural practices that may enhance performance of intensive production systems (e.g., reflective row covers)
- Planning research with entomologists and plant pathologists on optimizing pest management in intensive orchard systems
- Developed an energy calculator for evaluation of fuel efficiency in intensive orchard systems (available at http://adams.extension.psu.edu/Agriculture/Grower%20Resources.htm)
Future Plans

- Further refine orchard blueprint specifications (e.g., make fruit more visible, predictable, and accessible to both humans and robots)
- Continue research and implementation of key orchard system components
- Establish a five acre model orchard at Penn State Fruit Research and Extension Center (FREC) to conduct total systems research for apple production, and to demonstrate the state of the art in all aspects of apple production
- Evaluate opportunities for enhanced sprayer technologies (Jim Schupp, Tara Baugher, Rob Crassweller)

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 1960s, 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., 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 percent increases in worker productivity and a significant reduction in worker injuries (Faubion, 2005).

Project Progress

Trials with an orchard platform prototype were conducted in 24 Pennsylvania orchard blocks during 2006 to 2007. 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.
A non-powered, two level orchard platform was utilized in early summer and by July agricultural engineering intern Daniel Rice propelled the platform with an undercarriage built from the hydraulic drive system of a cherry picker. 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 percent for peach thinning and pruning and 50 percent for peach harvest and apple thinning, tree training, or pruning. Task times per acre with ladders ranged from 11 hours for tree tying and pinching to 90 hours for apple thinning, and with the orchard platform ranged from 6 hours for tree tying and pinching to 51 hours for apple thinning. The platform was more efficient than ladders for all tasks (95 percent 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. In additional pruning trials with a commercial platform and hydraulic loppers, economic savings were more consistent and averaged $146 per acre. Fruit growers in the East are developing their own modifications of orchard platform technology and comparing costs and benefits. Some growers have built their own platforms and others have purchased semi-autonomous platforms with harvest assist capabilities from Washington State or directly from Europe. An update on the orchard platform research was presented at the 2008 Mid-Atlantic Fruit and Vegetable Conference, and one of the presenters was a Massachusetts grower who purchased an innovative platform directly from Italy. Washington State and Pennsylvania scientists presented a joint paper on orchard platform technologies at the International Symposium on Application of Precision Agriculture for Fruits and Vegetables in January 2008.

Future Directions

A significant obstacle to orchard platform research was the inconsistency in tree architecture and row spacing from one commercial orchard to the next. Future trials will be conducted in 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.

The apple orchard systems include a narrow vertical axis and a vertical axis hedgerow, with trees planted at 4 ½ by 14 feet. The support system is a 9 feet trellis with four training wires. Feathered Cameo/M.9 and Honeycrisp/M.26 trees were planted in spring 2008. Trees will be minimally pruned for
the first three seasons to promote early production. Vertical axis trees will be trained to cone-shaped canopies with distinct gaps between the tops of the trees. Vertical axis hedgerow trees will be trained to distinct cone shapes in the bottom of the canopies and the tops tied to trellis wires to form a continuous narrow wall of canopy (similar to an oblique palmette system). Four V-shaped peach orchard systems, ranging from two to six scaffolds and 9 to 13 feet height will be compared to the standard open center system. Daybreak Fuji/M.9337 and Rubinstar Jonagold/B.9 were planted at Penn State Rock Springs in a new orchard system trial in the spring of 2008. Trees are spaced at 5 by 14 feet or 622 trees per acre. The systems to be compared are high trellis, vertical axis, minimally pruned, and tall spindle. Four wires spaced at 3.0, 4.5, 6.0, 7.5 feet with the top wire set at 9 feet were utilized for support. Autonomous orchard platform trials comparing work efficiency in the narrow tree wall systems will be initiated in 2009. Prior to testing the platform, sensor technologies will be added by Carnegie Mellon University engineers collaborating on a Specialty Crop Research Initiative project titled Comprehensive Automation for Specialty Crops (Tara Baugher, Jim Schupp, Rob Crassweller, Sanjiv Singh, Rich Marini, Karen Lewis, Jayson Harper)

Harvest Assist Technologies

Labor costs associated with fruit harvest are approximately 40 percent 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, current in-field bin filler technologies result 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 during 2006 to assess current bin filling methods and design and simulate new concepts for gently transferring fruit to bins in the field (Van Pelt, 2006). The most innovative and promising design was a “false floor” bin filler. Specialty Crop interns Jackie Van Pelt and Dan Rice fabricated a mock-up bin filler to test the concept of a disappearing floor. The strategy is to fill one complete layer of the bin at a time in order to ensure bin filling uniformity. A single layer of apples accumulates on a shelf constructed of parallel rods. When full, the layer descends into the bin until a sensor indicates that the layer is directly over the bottom of the bin or the highest layer of apples. The floor of the layer then “disappears” as the layer of evenly spaced rods slide underneath one another and a new layer of apples is deposited onto the previous one.

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 designed by Donald Peterson 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. Trials were conducted on apple varieties that represent a range of susceptibilities to bruising (e.g., Delicious, low susceptibility to Golden Delicious and Mutsu, high susceptibility). Fruit for bruise analysis were sampled from multiple places from the bin filler to determine where adjustments are needed (e.g., more padding, reductions in drop height), utilizing a sampling scheme developed by Baugher et al., 1989. Treatments were compared based on bruise incidence, bruise severity (bruise width, depth, and volume) and percent USDA grade packout losses. Following bin handling, fruit downgraded from Extra Fancy due to bruising was 0.3 to 3.9 percent and 1.0 to 4.0 percent in replicated trials at a USDA research facility and a Pennsylvania fruit packinghouse, respectively, and there were no differences among sampling locations. A research paper was submitted to the Journal of the American Society of Agricultural and Biological Engineers. The bin filler is being further tested by potential commercialization partners.

**Future Investigations**

During the 2007 harvest, Penn State University and Pennsylvania growers hosted a “Specialty Crop Engineering Solutions” tour for robotics and precision agriculture engineers. A follow-up tour and strategic planning session were held in March at Carnegie Mellon University. The outcome of the tours and 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. Commercialization partners are IONco and Vision Robotics.
(Tara Baugher, Amy Tabb, Karen Lewis, Sanjiv Singh, Marcel Bergerman, Bill Messner)

**Crop Load Management Innovations**

Crop load management is vital for annual crops of large, high quality fruit that meet consumer expectations in today’s marketplace. Perennial fruit crops tend to set more fruit than a) can be matured to adequate size and quality to meet market expectations; and b) allow for adequate flower production for the subsequent season. The availability and efficacy of chemical thinning programs vary by crop, orchard, and season, so hand thinning is often required to adjust crop load for optimal fruit size, quality, and to promote return bloom. Hand thinning, along with pruning and harvesting, is among the most labor-intensive orchard practices; consequently it contributes significantly to fruit production costs. Interest in reducing dependence on manual thinning is especially strong in organic apple production and for stone fruit—crops for which chemical thinners are not registered. Interest in mechanical bloom and/or fruit thinning was renewed in 2007 as the supply of skilled workers continued to decline and labor costs increased.
Preliminary research in Pennsylvania and West Virginia on blossom or green fruit thinning by mechanical means demonstrated that new mechanical thinner prototypes offer the potential for reducing the hand thinning requirement in crop load management programs (Miller, 2006; Baugher et al., 2007; Schupp et al., 2008). These technologies also lessen the competition from a portion of the excess crop early and rapidly, and can thereby improve fruit size, quality, and return bloom. Being non-chemical, the obstacle of EPA registration for a new thinning compound is avoided. Mechanical thinning technology has potential to favorably impact grower profitability in the near term both by reducing labor requirement and by improving fruit size and quality.

### Follow-Up Hand Thinning Times

*RepandaPlus System*

Follow-up hand thinning was conducted at 35-40 DAFB.

<table>
<thead>
<tr>
<th>Vertical String Thinner Treatments at Varying Bloom Stages</th>
<th>Sugar Giant</th>
<th>Arctic Sweet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pink</td>
<td>42.2 b</td>
<td>49.4 bc</td>
</tr>
<tr>
<td>20% FB</td>
<td>27.7 a</td>
<td>42.3 ab</td>
</tr>
<tr>
<td>80% FB</td>
<td>30.3 a</td>
<td>34.5 a</td>
</tr>
<tr>
<td>Petal fall</td>
<td>28.0 a</td>
<td>36.9 a</td>
</tr>
<tr>
<td>Hand thinned control, 35 DAFB</td>
<td>56.6 c</td>
<td>59.7 c</td>
</tr>
</tbody>
</table>

### Table 1: Follow-Up Hand Thinning Times

<table>
<thead>
<tr>
<th>Vertical String Thinner Treatments Applied to Varying Pruning Modifications (at 20% FB)</th>
<th>White Lady</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard pruning</td>
<td>8.8 a</td>
</tr>
<tr>
<td>Fan pruning</td>
<td>7.7 a</td>
</tr>
<tr>
<td>Partial pruning</td>
<td>5.9 a</td>
</tr>
<tr>
<td>Hand thinned control, 35 DAFB</td>
<td>14.8 b</td>
</tr>
</tbody>
</table>

### Accomplishments

Preliminary evaluations of mechanical peach thinners were conducted in 2007 and 2008 in 12 commercial orchard blocks. A string thinner designed by a German grower for thinning apple trees in organic orchards was tested at a range of bloom stages. A USDA spiked-drum shaker, originally designed for harvesting citrus, was tested at 35 days after full bloom. Mechanical thinners reduced crop load by an average of 36 percent, decreased follow-up hand thinning time by 20 to 42 percent, and increased fruit in higher market value size distributions by 35 percent. Net profits ranged from $71 to $796 per acre. Research conducted on apple trees demonstrated that the string thinner can transmit fire blight; therefore, thinning should not be conducted in blocks with a history of fire blight or during a fire blight infection period.
Future Plans

Uniformly designed experiments to evaluate the best timing and efficacy of mechanized thinning technologies will be conducted in Washington, California, South Carolina, and Pennsylvania orchards in 2009 to 2012. The project is supported by a USDA Specialty Crop Research Initiative project titled *Innovative Technologies for Thinning of Fruit*. The objectives include addressing tree architecture to enhance mechanized thinning; significant engineering modifications to two prototype non-selective mechanical thinners; development of more advanced, sensor-based thinning equipment, field testing of both non-selective and sensory-based technology through cooperating grower sites; interaction with equipment developers; and evaluation of environmental, sociological, and economic impacts on producers and field production. (Jim Schupp, Tara Baugher, Paul Heinemann, Katie Ellis, Jim Remcheck, Katie Reichard, Jude Liu, Steve Miller, Karen Lewis, Scott Johnson, Greg Reichard, Henry Ngugi, Jayson Harper, Lynn Kime)

Video, Laser, and Satellite Imaging

Video, laser, and satellite imaging technologies will become pertinent to future improvements in orchard production and associated equipment. First, it is important to develop a tree system that is compatible with imaging technologies—a high density planting, trained to a continuous planar fruiting wall. Engineers have indicated that this type of system will lend itself more easily to upcoming commercial technologies, both mechanical and imagery.

Imaging technologies have the potential to cross multiple areas of tree fruit production:

- determining crop load (blossom or green fruit counts) and yield
- determining insect presence/disease infection and eradication
- determining soil moisture content for enhanced irrigation systems
- applying fertilizers, pesticides, and herbicides
- developing assisted and/or automated harvest or pruning strategies

(*Engineering Solutions for Specialty Crop Challenges Proceedings, 2007*)

As engineers investigate these potentials, they will likely find that different technological approaches—satellite imagery, real-time laser images, and video imagery—will prove successful for different orchard management tasks.

Preliminary Trials with Video Imaging

The Specialty Crop Innovations research team collaborated with Amy Tabb to create a computer model that will successfully identify fruit in a tree canopy. The team assisted Amy in conducting preliminary research in perpendicular V peach trees and vertical axis apple trees to test the accuracy of her algorithm for fruit identification at maturity. Larry Hull collected and annotated images of both codling moth and oriental fruit moth adults within traps. These images, and numerous others, were forwarded to Purdue University scientists to begin the initial development and testing of visual...
algorithms for insect detection. Henry Ngugi created a database of images for use in developing and testing image processing methods and algorithms for fire blight. The images in the fire blight database were manually classified according to the level of difficulty they present to image processing methods.

**Future Plans**

Fruit quality is the characteristic that differentiates high value from low cost fruit (Tree Fruit Technology Roadmap Report, 2004). Achieving consistent 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 a cost-effective practice 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 sensor networks will reduce the need for labor and trap maintenance while increasing the time resolution of trap monitoring and pest damage identification, resulting in more effective pest monitoring, higher fruit quality, and reduced pesticide application.

Under a USDA Specialty Crop Research Initiative grant to Carnegie Mellon University (lead institution), Penn State, Washington State University, Purdue University, USDA-ARS Appalachian Fruit Research Station, and other cooperators, a transdisciplinary research team will address sensor technologies for the automation of specialty crop production. Penn State cooperators are faculty at Penn State Extension in Adams County and the Penn State Fruit Research and Extension Center. The project is designed to develop and evaluate automation solutions that growers can use to increase labor efficiency, detect insect pests and diseases, monitor plant health, and reduce crop damage at harvest. (Larry Hull, Henry Ngugi, Greg Krawczyk, Jim Travis, Jayson Harper, Karen Lewis, Gwen-Alyn Hoheisel, Vince Jones, Amy Tabb, Mike Glenn, Sanjiv Singh, Marcel Bergerman, George Kantor, Johnny Park, Katy Lesser - Bear Mountain Orchards)

**Sprayer Technologies**

Although scientists over the past 40 years have spent an extensive amount of effort developing alternatives to chemical products for pest control in tree fruit and grapes (e.g., natural enemies, pheromone mating disruption, disease resistant cultivars), pesticides are still the dominant method for pest control in these cropping systems. For example, the worldwide use of chemical fungicides and insecticides for plant production increased by a factor of 5 between 1970 and 1997 (Panneton et al., 2000). In tree fruit, pesticide application is quite challenging due to the large diversity in tree structure and size while targeted insects and diseases can be located within and outside the canopy, on the upper and lower sides of leaves, and on many other parts of the tree. The application of pesticides to these 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. For example, Fox et al. (1998) estimated that for trees sprayed with an airblast sprayer in full canopy, 55 percent of the spray was deposited on the foliage and fruit, 20 percent ended up on the ground, and 25 percent remained airborne as small droplets. Clearly, there is a need to investigate newer and more efficient sprayer technologies for applying required pesticides.

**Progress to Date**

A Penn State sprayer technology working group began discussing possible initiatives in June 2007. Initial efforts were directed at exploring the literature on possible new targeted sprayer technologies and on touring grape regions where some new technologies such as tunnel sprayers and electrostatic sprayers are being utilized. The group also explored the latest research on preventing spray drift and various uses of sensors (such as calculating leaf area and canopy volume), possible research collaborators, and granting opportunities. Larry Hull tested the “Cornell donuts” on two airblast sprayers during the 2008 growing season and demonstrated significant reductions in spray drift while still maintaining equivalent levels of insect control.

Members of the Specialty Crop Innovations team were invited to give presentations in April 2008 at an International Conference on Application Technology organized by Andrew Landers (Cornell University). A half-day demonstration workshop on application technologies for tree fruit and grapes was held at the Penn State Fruit Research and Extension Center in June 2008.

**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 “Landers Louvers” and new technologies such as foliage sensors. Summer engineering intern Alex Leslie will build a patternator (based on specifications developed at Cornell University) for use by growers in assessing ways to adjust spray distribution pattern (Larry Hull, Andrew Landers).
Sensor Networks

Sensor/actuator technologies linked to automated devices have the potential to revolutionize agricultural operations by allowing real-time, continuous monitoring of weather and crop parameters, generating data required to control a wide range of devices used in farm operations, and automating expensive, labor-intensive practices. A wide range of sensors can be deployed to monitor leaf wetness, air temperature, relative humidity, nutrients, pesticide and herbicide concentrations, plant stress, fruit sugar content, and other growth-related parameters. Sensors also can be used to monitor the status of mechanical devices such as irrigation systems, sprayers, planting, and harvesting technologies. By connecting sensors with low-power communications devices to computers running sophisticated decision support software, powerful arrays can be developed that monitor and control many farm operations that are presently labor-intensive. Robotic and other automated equipment hold the potential to greatly enhance farm efficiencies, improve product yields, and increase revenues.

Project Progress

In the first phase of a collaborative Penn State FREC, Robotics Institute of Carnegie Mellon University (CMU), and ZedX initiative, we received funding to advance and commercialize an innovative wireless sensor network system and to apply the data generated by the network to assist growers and consultants in the control of field pests, specifically plant diseases. As a demonstration project, the objective was limited in 2008 to one specialty crop—apples—and the prediction of three diseases—apple scab, fire blight, and sooty blotch—for one orchard site and one growing season.

Future Plans

In the second phase of our initiative, we plan to link the data generated by the sensor network to an automated, mobile spray system to precisely deliver agricultural chemicals to control diseases associated with specialty crops.

The key components of this effort are:

- A sensor network design applicable to specialty crop canopies
- Sensors that provide input data for crop and disease models
- Crop and disease models for simulating infection potential in canopies
- Mesoscale, real-time weather analyses and short-range (1 to 3 day) forecasts
- A web-based interface to provide a calendar-driven, geospatial map of infection potential in an orchard
- Field studies to collect infection observations for comparison to model simulations

The objective of the project is a demonstration of how an existing sensor network technology can be leveraged with commercial crop and pest development models and information technology tools to assist growers in the control of specialty crop diseases. (Jim Travis, George Kantor, Joe Russo - ZedX)
Special Thanks!

Industry and Community Cooperators

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