



PennState
College of Agricultural Sciences



The History of **FREC**

The **Fruit Research and Extension Center**



Fruit Research and Extension Center

The Penn State Fruit Research and Extension Center's history shows us one ongoing trend that should continue long into the future: the close bond between the fruit industry and the land grant university. Ever since 1918, when Penn State responded to grower requests for help managing pests, we have had a growing mission. Both our grower stakeholders and Penn State can be proud of this shared accomplishment because it took everybody working with a common vision for generations to make this anniversary come about.

They started out in an old hotel, then upgraded to an old schoolhouse, purchased with the help of a grower (Chester Tyson). In the depths of the Great Depression (1936-1937), there was a gut-check moment and a reaffirmation by growers of the need to have university boots on the ground in their orchards. Expansion of the Center through the investment of a grower-operated, nonprofit corporation throughout the 1940s and '50s culminated with local industry leaders engaging the Musselman Foundation to assist Penn State with building what evolved into today's center in 1971.

In 2011, the college expanded our acreage in Biglerville, when the opportunity arose, and our industry went to bat for Penn State during the recent state budget impasse.

Over the past 30 years or so, the State Horticultural Association of Pennsylvania (SHAP) has invested in research and extension projects, starting with about \$4,000 in the first year, and now contributes over \$250,000 annually. The SHAP Endowment Committee's \$252,000 gift of the graduate student house in 2016 strengthened our ability to attract and train top-notch graduate students at FREC.

In 2017-2018, Dean Rick Roush added two specialty crop ag engineers, one at University Park and one at FREC, to address grower needs for engineering solutions to the tightening ag labor supply. SHAP responded by committing \$90,000 to the start-up of this new program at FREC.

As broad-based state and federal support for the land grant mission struggles to meet the need, our grower-stakeholders have played, and will continue to play, a role in lobbying to get that support, as well as directly investing in programs they value. The history of this center shows that the Pennsylvania fruit grower has been at the forefront of such efforts in our commonwealth for a long time. The 100th anniversary celebration of FREC provides an example of the good that can happen when we come together as a unified people with dedication and vision.



Message from the Dean



Richard Roush, Ph.D.

*Dean, College of
Agricultural Sciences*

Seven years before President Abraham Lincoln signed the Morrill Act of 1862, establishing land-grant colleges throughout the United States, Penn State was chartered by the Commonwealth of Pennsylvania as one of the nation's first colleges of the agricultural sciences.

Also known as the Land-Grant College Act, the Morrill Act essentially supplied federal land upon which to establish institutions that would teach agriculture and the “mechanic arts” (engineering)—without excluding scientific and classical studies—so that a liberal and practical education would be available to people in the industrial classes. This mandate would evolve to become the three-fold mission of Penn State: research, teaching, and in our case, Extension.

The Penn State Fruit Research and Extension Center in Biglerville represents the epitome of that mission. It brings together researchers, extension educators, students, growers, and other industry stakeholders who work together to sustain and advance the robust fruit industry upon which so many in the Commonwealth and beyond depend. A century ago, when the college rented space in the Arendtsville Hotel for two researchers hired to solve insect and disease issues, no one could have imagined that FREC would become the gold standard for how research, teaching, and Extension are supposed to intertwine.

The decision 100 years ago to establish FREC in the heart of apple country, coupled with bringing the right people together in close proximity to one another, has resulted in meaningful outcomes and immeasurable value. Resolutions and strategies for disease and entomological challenges. New technologies and machinery. Buildings, orchards, vineyards, and laboratories providing the infrastructure for a wide array of research in entomology, plant pathology, pomology, ag engineering, and more.

FREC's sustained growth and impact have been made possible by those who believed, and still believe, in its mission and purpose. The State Horticultural Association of Pennsylvania (SHAP), for example, invests more than \$250,000 per year in research funding. SHAP also organized a successful drive to raise philanthropic gifts from community members, growers, and industry stakeholders to build onsite housing for graduate students. The Musselman family made possible FREC's main office building. The chemical industry, the Pennsylvania Apple Board, Robert and Elizabeth Hodge, and many others have helped make FREC what it is today.

Congratulations to all who have made the Penn State Fruit Research and Extension Center a model of excellence. Though the fruit industry will always have new challenges to confront, I am confident that the people associated with FREC will tackle these challenges like they always have: with creativity, science, ambition, and most of all, the spirit of cooperation that has been the hallmark of your longevity.



*Bruce and Brad Hollabaugh
of Hollabaugh Bros., Inc.*

Grower Perspective

Bruce & Brad Hollabaugh

Relationships. In pondering a fitting way to speak to the significance of FREC, that one word instantly comes to mind. Over the past 100 years, the Penn State Fruit Research and Extension Center (FREC) has had an incredible impact on the commercial fruit industry in Pennsylvania. The interwoven dynamic between FREC, its scientists, and its mission is integral to the grower community in the Mid-Atlantic region. The long-standing relationship between growers and the facility has been progressive, collaborative, rewarding, academically stimulating, and exciting.

Much more than productive and academic, however, the growers' affiliation with the researchers, staff and programs at FREC has been constantly filled with rich professional and personal friendships. Most importantly, the collective elements of collaboration have combined to provide a sustaining foundation to the on-going success of the tree fruit industry in the Mid-Atlantic region.

It's difficult to talk about FREC and not mention our PSU Cooperative Extension relationship as well, especially since many of the scientists have extension components to their positions. Over the past few decades, that partnership has expanded and evolved in a way that has made all parties stronger. The saying goes that two people working together make the job go three times faster. Over the years we've worked as a team by combining the knowledge of FREC scientists and extension educators with the growers' applied expertise. Consequently, the work has not only gone faster, but we have accomplished more together than any single one of us could have possibly achieved alone.

FREC's relationship to the industry extends to regional support as well at winter and spring county grower meetings. The results of important research together with seasonal guidance on horticultural techniques provide crucial, timely support to the grower community. These meetings not only provide excellent opportunity for learning the most up-to-date strategies for optimizing orchard operations, but also promote an environment in which the scientists help growers learn from one another. Relationships strengthen.

Some of the longest-enduring and most-significant relationships between PSU FREC and the industry are the cooperative ties to the State Horticultural Association of PA (SHAP). The 150th Anniversary update to SHAP's history booklet is appropriately filled with numerous references to the industry's relationship to FREC. The SHAP Board of Directors and numerous committees have members of Penn State FREC and Extension team sitting as ex-officio members.

FREC faculty and extension staff play a key role with the annual Mid-Atlantic Fruit & Vegetable Convention each year. Program development, day-to-day support during the convention, and a ready resource of scientists to present their on-going research all combine to keep our educational programs interesting, challenging, and beneficial to our members.

Additionally, SHAP's Strategic Planning efforts were instrumental in creating a new partnership with Penn State in 2015 to make possible the new Graduate Housing Project at FREC. The generous contributions of growers and the cooperation between the SHAP board, SHAP's Endowment Committee, FREC, and Penn State University resulted in an incredible improvement to on-site housing for FREC graduate students and visiting scientists who need a temporary home during their work at the research farm.

Perhaps the most continuous and relevant tie between FREC and the grower community is witnessed through the on-going, relevant research that is undertaken by the FREC scientist team. This work is regularly impacted by the research priorities created by the SHAP Research Committee. Over the course of the past 40 years, some of the most significant research done at FREC was funded wholly or in part by grower dollars via SHAP's Research Committee. With regularity, from that initial research, numerous FREC scientists have leveraged large sums from national funding sources – all of which gets funneled back into research done for the betterment of our local industry.

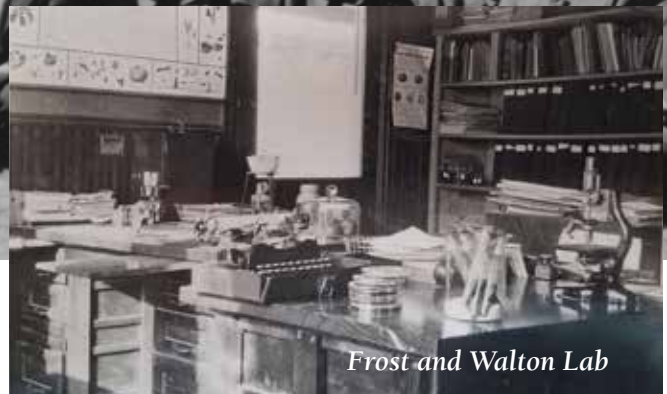
One of the most positive and exciting realities of working with scientists at FREC is that research is never done in a “vacuum” on site. Research certainly takes place on FREC's research farm in a controlled setting, but is commonly replicated in grower orchards. This real-world replication builds a stronger partnership and relationship with growers. It also proves the constant level of dedication the scientists at FREC have for the grower community and their commitment to solving real-world problems.

The mission statement of the PSU College of Agricultural Sciences states... *to discover, integrate, translate and disseminate knowledge to enhance the food and agricultural system... thereby improving the lives of people in Pennsylvania...* The relationships, collaborations and friendships that have developed from 100 years of working with our Penn State neighbors at FREC have, indeed, resulted in a better world – locally and nationally. FREC serves as a cornerstone – not just for what our land-grant university was envisioned to become – but as a symbol of the success that can be cultivated when dedicated people come together with diverse talents for the betterment of all involved.





Fruit Research Lab grower advisory panel at their annual meeting, March 13, 1945



Frost and Walton Lab

CHAPTER 1: 1918-1976

Early History of FREC

The year was 1918, and fruit growers in southcentral Pennsylvania were finding themselves facing ever-increasing production problems involving insects and disease. Recognizing the need to better support southcentral Pennsylvania's expanding fruit industry, The Pennsylvania State College hired two staff scientists—plant pathologist R.C. Walton and entomologist S.W. Frost—and tasked them with developing research programs on pest problems that plagued fruit growers. The college rented space in Adams County's former Arendtsville Hotel to be used as offices, laboratories, and dwellings for the two scientists and their families.

Initially, Walton focused his work on apple scab as well as frog-eye leaf spot, which was causing defoliation in some apple orchards. Frost concentrated on aphids, red bugs, and leafrollers. Their early work is described in *The History, Development and Accomplishments of the South Mountain Fruit Research Laboratory*, written by Frank N. Hewetson, professor emeritus of horticulture, in 1951.

“During the first few years these two men secured much worthwhile information concerning fruit insects and diseases and at the same time attempting to establish policies regarding field laboratories,” Hewetson wrote. “The equipment at this time was not elaborate and there was little opportunity to conduct extensive laboratory work. Much of the time was devoted to experiments in commercial orchards and in making insect and disease surveys.”

Despite setbacks, challenges, and ever-evolving diseases and insect and mite pests threatening the fruit industry throughout the years, the Arendtsville Fruit Laboratory continued its important work and has grown to become what is now the Penn State Fruit Research and Extension Center (FREC)—marking its 100th anniversary in 2018.

In 1981, Hewetson and Ken Hickey, professor of plant pathology, worked together on a publication that highlights the first 58 years of FREC. Entitled *History and Accomplishments of the Penn State Fruit Research Laboratory at Biglerville, 1918-1976*, the publication

tells the story of how the Fruit Research and Extension Center expanded and evolved over its first half century.

Here, we pick up where the previous publication left off. This booklet covers major research and extension accomplishments through FREC in entomology, plant pathology, horticulture, and nematology/virology, as well as how the center—and the work performed there—has changed during its second half century.

Some of those changes began in the late 1960s, with the purchase of the Biglerville farm and construction of buildings, including a garage, greenhouses, the Musselman Building with laboratories and offices, a headhouse, and a CA (controlled atmosphere) building with three walk-in coolers.

At today's FREC facility, researchers conduct independent studies using facilities such as growth chambers and recently renovated greenhouses for plant pathogen and insect investigations, an insectary for raising and studying predatory mites and insects, precision spray applicators, and research instruments for measuring fruit quality and post-harvest storage.

Today's FREC supports five Ph.D.-level scientists involved in research and extension in tree fruits and grapes, covering horticulture, plant pathology, entomology, virology/nematology and agricultural engineering; about 20 technicians and assistants; up to eight graduate students; and 20-25 undergraduate summer research assistants.

One recent addition to the property—a house that can accommodate up to eight graduate students or visiting scientists—signifies a major improvement over trailers that were previously used for graduate student housing. The new duplex, which was funded by a State Horticultural Association of Pennsylvania (SHAP) capital



Dean Russell Larson speaking at the dedication of the Musselman Building, Sept. 15, 1971

campaign, opened in 2016 and represents the support and generosity of the local fruit industry.

Totalling 225 acres of farmland in Adams County's narrow fruit belt, with 68 acres in orchards and vineyards, FREC is in an ideal location for fruit growing. "We're in the sweet spot between the Appalachian Mountains and the Susquehanna Valley," says FREC Director Jim Schupp. Slope, elevation, rain shadow, and soil conditions all contribute to an optimal environment for fruit trees.

The unique requirements of a research farm dictate the layout of the orchards at FREC. Blocks of fruit trees are organized by discipline: horticulture, plant pathology, entomology, and nematology. "For example, in entomological blocks we want bugs, but in other blocks we don't," Schupp explains. Plant pathology blocks lie to the south so the wind blows away from the facility, not onto other orchards. As well as providing site-specific conditions for research, the facility increases opportunities for growers, consultants, consumers, and students to observe experiments and consult with scientists. Extension specialists apply experimental findings to local conditions and, in turn, make suggestions to scientists about new research needs.

With the seasonal demands of farm work, and the collecting of samples and data as an integral part of each day's requirements for a research farm, "there's always something to be done" at FREC, in the words of a field technician. From springtime brush cleaning and planting new orchards, to spraying chemicals and pheromones and harvesting peaches in the summer, to apple harvest in the fall, to tree pruning and equipment maintenance in the winter, FREC faculty and staff work hard year-round to generate new research information and to educate and support Pennsylvania's diverse fruit industry.



Musselman Building under construction

Joy Cline and Juan Montoya participating in orchard labor platform trials at Bear Mountain Orchard



George Greene demonstrates one of the controlled atmosphere storage chambers

CHAPTER 2: 1976-2017

Major Horticulture Research

“In production horticulture, we need to be out in front of the industry, creating model systems that exemplify best practices,” says Jim Schupp, professor of pomology and director of FREC. This chapter summarizes some of the major horticultural projects and areas FREC researchers have focused on since 1976, with the goal of benefitting the fruit industry.

Tree Fruit Mineral Nutrition

Cork spot, bitter pit, and other calcium-related disorders in apples can cause significant economic losses for fruit growers. Researchers applied calcium to apple trees using various methods, including irrigation and airblast sprayers, to reduce the severity of calcium-related disorders. Their results have been incorporated into current fertilizer and lime recommendations, and many apple producers now routinely spray their apple trees with calcium chloride. (*Greene, Smith, and Morrow – 1975-1989*)

In what former FREC horticulturist George Greene calls “perhaps my biggest project,” he and colleagues measured the influence of environmental stresses on calcium nutrition of apples. Greene worked with Cyril Smith, who was the plant nutrition specialist in

the Department of Horticulture at University Park, to reduce or eliminate the devastating impact of corking in the dominant processing apple variety at the time: York Imperial.

Through two multi-year experiments that dealt with applying nutrients to the soil or to the above-ground parts of the tree, the researchers determined that foliar sprays of calcium could significantly reduce or eliminate calcium deficiency symptoms in apples. They also discovered that ground applications of plant nutrients had very little impact on the nutrient content and calcium deficiency symptoms of apples and that the vigor and cropping level of the trees had a major impact on the calcium deficiency symptoms of apples. (*Greene, Smith, and Morrow – 1975-1989*)

Tree Fruit Germplasm Evaluation

In variety testing experiments, researchers evaluated selections of fruits for adaption to Pennsylvania conditions, improved storage and marketing efficiency, and improved aesthetic value for roadside markets, “pick-your-own” operations, and commercial production. (Greene, Haeseler, and Tukey – 1976-1986)

Apple scab and powdery mildew, among others, are devastating diseases. Through the USDA Regional Project NE-183, researchers in multidisciplinary fields tested new apple varieties for resistance to these diseases by establishing uniform multi-state plantings. Scientists at the Geneva Experiment Station in New York developed new apple varieties that have significant resistance to apple scab and powdery mildew, and varieties from private breeders and selections found by industry personnel were evaluated as well. Several plantings were established in many states to evaluate new and promising selections. (Greene and Crassweller – 1994-2003)

Honeycrisp is a relatively new apple variety that can increase grower profit over standard varieties, but it is difficult to grow. Researchers studied several production challenges of Honeycrisp, including managing crop load (optimum number of fruit per tree) for assuring fruit quality, calcium nutrition for minimizing fruit disorders, promoting return bloom to obtain annual cropping, reducing pre-harvest fruit drop, and evaluating improved strains for red color development. Research results have helped fruit growers in Pennsylvania and the region to produce this variety with less risk of financial losses due to off-grade fruit. (Schupp, Baugher, and Marini – 2004-present)

Planting an apple variety trial (Pete Cutshall, Bob Peters [on tractor], George Greene [on tree planter])



Bob Peters measuring a tree canopy in a peach rootstock study



Pete Cutshall measuring apple firmness in George Greene’s mineral nutrition studies

Researchers continue to test apple varieties and rootstocks that can thrive in the mid-Atlantic region. Both varieties and rootstocks must be able to overcome environmental limitations and efficiently produce the quality of fruit demanded by the fresh and processing industries. USDA Regional Project NC-140 is an international tree fruit research project to evaluate rootstocks through multi-state plantings of apples, pears, and peaches to evaluate the usefulness of new rootstocks in contemporary planting systems. (Greene, Crassweller, and Schupp – 1984-present)

Because apples represent most of the tree fruits grown in Pennsylvania, most horticulture research at FREC focuses on apples, but peaches are a valuable crop as well. “This is a region where peaches are also important, so about a quarter of my work is also on peaches,” Schupp says. He and his colleagues are working with peach rootstocks as well as peach systems, aiming for biological and labor efficiency. (Greene, Crassweller, and Schupp – 1984-present)

Fruit Tree Pruning and Training

From early studies of the influence of pruning on tree growth and nutrition (Greene, Smith, and Morrow – 1975-1985) to today, researchers at FREC work to maximize marketable yield. “There’s a fruit quality component, particularly in the fresh market, that moderate-sized crops tend to have better fruit quality, color, and size than if you maximize the number of fruits you could possibly get from a tree or orchard,” Schupp says.

Penn State researchers investigated intensified peach production systems to increase marketable yield and profitability of mid-Atlantic peach orchards and found that medium density growing systems produced the most yields of large peaches per acre. (*Schupp and Baugher – 2007-present*)

Research was conducted as part of the USDA Specialty Crop Research Initiative grant on Automated Pruning of Apple and Grape. This research refined sequential dormant pruning procedures for tall spindle apple trees. (*Schupp – 2012-present*)

Postharvest Apple Storage

In 1989, a state-of-the-art controlled atmosphere (CA) building, one of the largest in the country, was constructed at FREC with funding provided by the Pennsylvania Department of Agriculture.

At the CA facility, where oxygen and carbon dioxide levels were manipulated in 240 separate chambers, researchers worked to improve apple storage life using controlled CA storage technology, predict how apples would tolerate storage based on preharvest conditions, optimize postharvest storage techniques for peaches, nectarines, and other crops, and apply biotechnology to problems that affect postharvest storage, processing, and marketing quality. (*Greene, Lehman, Gaus, and Salada – 1988-1996*)

Ongoing studies established optimum storage regimes for several apple cultivars used for processing and fresh market fruit. Researchers also worked with the USDA in Beltsville, Maryland, to explore the effect of controlled-atmosphere storage on storage quality of new apple varieties Ginger Gold, Gala, Braeburn, and Fuji. (*Greene, Lehman, Salada, Barden, and Reed – 1990-2004*)

Wine Grape Culture

George Greene, along with Carl Haeseler, who was stationed at the Erie County Field Research Laboratory, and Penn State food scientist Robert Beelman, established a vineyard to test grape varieties for the Pennsylvania wine industry. This cooperative research vineyard contained about 15 of the most promising grape varieties. “At proper maturity,” Greene says, “samples of grapes were delivered to the Food Processing Laboratory on campus and wine was produced. This initial program laid the groundwork for the Pennsylvania wine industry of today.” (*Haeseler, Beelman, and Greene – 1983-1995*)

Horticulturist Rob Crassweller continued work with wine grapes through the Vinifera wine grape variety trial. (*Crassweller 2009-2015*)

Orchard Automation and Mechanization

In 2008, a new funding source was made available through USDA: The Specialty Crop Research Initiative (SCRI) was the first source of new funding for applied research into specialty crops, which the federal government defined as all crops that aren’t program crops, such as corn, soybeans, and cotton.

“The SCRI program came into being largely because the specialty crops producers asked Congress for research and extension funding to help them solve growing problems,” Schupp explains. Local grower Phil Baugher was a member of the group that represented the apple industry. FREC scientists and extension educators received two of the initial SCRI grants, and continue to be active participants in the SCRI program. The College of Agricultural Sciences added a new faculty position in agricultural engineering in 2018, with Dr. Long He joining the FREC faculty to enhance our capabilities in this field.

With those initial SCRI grants, FREC researchers worked on projects designed to increase orchard labor efficiency. They developed and perfected a mechanized apple and peach thinning system. They also collaborated with agricultural engineers at Carnegie Mellon University and other institutions to develop a low-cost, gravity-fed harvest assist device that relieves some weight harvesters would normally carry and prevents bruising to apples by cushioning their fall into a collection receptacle. (*Schupp, Heinemann, Zhang, Baugher and He – 2007-present*)

The controlled atmosphere storage building erected in 1989 with support from the Pennsylvania Department of Agriculture



Plant Growth Regulators

Plant growth regulators (PGRs) are useful materials to modify characteristics of plants. Excessive shoot growth causes problems for growers and results in more diseases because the younger growth is more susceptible to fire blight. Excessive shoot growth can also result in low light conditions that reduce flowering and fruit quality. And because sprayers can't penetrate and reach denser tree canopies, excessive growth can cause poor deposition of pest control chemicals. FREC horticulturists evaluated PGRs to reduce excessive vegetative growth and improve fruit quality while reducing pruning labor and disease susceptibility (Greene, Hickey, Travis, Ngugi, Schupp and Peter – 1988-present)

Researchers evaluated PGRs that regulate fruit maturity and prevent preharvest fruit drop as apple harvest management tools. They also evaluated the effects of spray water hardness and acidity on control of preharvest drop. (Schupp – 2004-present)

Researchers also worked with 1-MCP, a plant growth regulator that inhibits the ability of apple fruits to respond to the ripening hormone ethylene. Apples treated with 1-MCP prior to storage come out of storage with minimal ripening. Thus, apples sold after storage are much more crisp and juicy, exhibiting “at harvest” characteristics. (Reed, Salada, and Schupp – 1990s-2009)



Jim Schupp with his Graduate Student - Tom Kon and Research Assistant - Edwin Winzeler and summer crew.



Eric Anderson applying a plant growth regulator treatment in Jim Schupp's research orchard

Paul Heinemann (ABE) and Jim Schupp on tractor, demonstrate an automated string thinner prototype at FREC Grower Field day





FREC staff evaluating apples for insect injury in research blocks

Gene Staub counting spider mites on apple leaves

CHAPTER 3: 1976-2017

Major Entomology Research Themes

An important goal of FREC researchers is to learn as much as possible about tree fruit and orchard management through trial and error before sharing information with growers. “We have to be the ones to make the mistakes,” says Greg Krawczyk, extension tree fruit entomologist. “Growers can’t afford to make mistakes when it could mean hundreds of thousands of dollars.” When it comes to controlling pests such as codling moth, leafrollers, spider mites, and aphids, FREC researchers work toward reducing input to save growers money and to maintain sustainable orchards. This chapter summarizes major research themes in entomology since 1976.

Integrated Pest Management

Integrated Pest Management (IPM) involves approaching the problem of insect and mite pests from different angles and employing various combinations of management techniques such as biological agents and chemical controls. Dean Asquith, former FREC entomologist (1948-1977), started FREC’s IPM program in 1968 by discovering the native mite predator *Stethorus punctum* (a black ladybird beetle). Asquith and his graduate students, Richard Colburn (1968-1971) and Larry Hull (1973-1977), spent the next nine years researching the biology and behavior of this predator and making it the cornerstone of Pennsylvania’s IPM program. Hull was

appointed to the faculty at FREC in 1977 and continued his research on *S. punctum*.

The primary defense of insecticides in early research evolved continuously because of the discovery and registration of new compounds. Hull and his colleagues assessed each compound as it became available, seeking to understand its toxicity to every pest in the orchard and to determine the lowest use rate that would be effective. Says Hull, “Our primary goal has always been to control the pest with the least amount of insecticide to save the grower money, but also to allow the natural predators to survive.”

Through grower surveys conducted throughout the 1980s to the early 2000s, miticide use was reduced by millions of pounds, saving millions of dollars for growers. In the early 2000s, Hull and entomologist David Biddinger (one of Hull's former graduate students and a current FREC faculty member) discovered a predatory mite--*Typhlodromus pyri*—that attacks the European red mite at much lower densities than needed to sustain populations of the ladybird beetles. “Because of these advances, many growers now depend on biological control of European red mites, and we’ve reduced miticide use by about 90 percent,” Biddinger says. (Hull – 1977-2011 and Biddinger – 2001-2010)

In today's orchards, IPM has become more complex as more pesticides are introduced. “Numerous combinations of pesticides—with fungicides added in as well—make it complicated for fruit growers,” says Biddinger. “It remains important to get the latest information out to growers, so they can make the best decisions possible.” (Hull, Rajotte, Biddinger, Krawczyk, Hickey, and Travis – 1977-2011)

Insecticides, Acaricides, Biological Control Agents, and Economic Thresholds

In the lab and in orchards, FREC researchers work to understand the toxicity of both experimental and registered insecticides and acaricides (substances poisonous to mites) towards pests that attack deciduous tree fruits and cause economic losses for growers.

Betsy Beers and Larry Hull determining the effect of mite injury on the photosynthesis activity of apple leaves.



Researchers give special consideration for these substances' effects on natural enemies such as *S. punctum* and *T. pyri* and their compatibility with ongoing IPM programs. (Hull, Biddinger, and Krawczyk – 1977-present)

Researchers identified and helped growers use biological control agents (predators and parasites) to help suppress the tufted apple bud moth—a major pest throughout the 1970s, 1980s, and 1990s—as well as other insect and mite pest populations. They reared populations of these biological control agents at FREC and seeded them into grower orchards.

FREC researchers have also developed economic action thresholds and economic injury levels for various direct (tufted apple bud moth, codling moth, Oriental fruit moth) and indirect pests (European red mite, aphids) of pome (apple and pear) and stone fruits. They also focused on understanding how the host plant influences pest development, survival, and dispersal. (Hull, Beers, Starnes, Knight, Krawczyk, Robertson, Myers, and Ellis – 1980-2008)

Sex Pheromones

Researchers evaluated and implemented sex pheromone traps to monitor tufted apple bud moth's response to organophosphate insecticide resistance and to more fully understand the role of immigration/emigration, alternate hosts, insecticide dose, and application method in maintaining pesticide susceptibility in this leafroller pest. They also worked to establish the relationship between moths caught in pheromone traps and population densities in the orchard.

Larry Hull and Greg Krawczyk demonstrating an automated pheromone trap (Z-Trap) at a field day





David Biddinger showing how native bees overwinter in cardboard tubes

Researchers evaluated various methods of employing sex pheromone mating disruption—such as hand-applied dispensers, sprayables, and puffers—as a management approach for various lepidopterous pests of deciduous tree fruits. They used their results to determine the economic feasibility of sex pheromone mating disruption on general insecticide usage, secondary pest populations, natural enemies, and as a means to manage insecticide resistance.

“We spent a lot of time assessing the pests in the orchard through visual monitoring of pheromone traps,” Hull says. “We worked quickly to assess the population of these pests and what the implications were for growers from an economic standpoint.” (*Hull, Knight, McPheron, Felland, Barrett, Biddinger, Krawczyk, Meagher, and Ellis – 1982-2010*)

Biological Research on Insect Pests

Investigations into the biology and behavior of the Oriental fruit moth on apple and peach trees helped researchers understand the factors influencing the development and movement of adults among and between various host crops. Researchers assessed the baseline susceptibility of the moth’s populations from Pennsylvania to commonly used insecticides and developed an egg hatch model for the accurate timing of control measures. (*Hull, Krawczyk, Myers, and Ellis – 1998-2007*)

Researchers continue to investigate the control, biology, behavior, movement, and management of invasive pests such as the brown marmorated stink bug (causing major fruit damage in 2010) and the spotted wing drosophila (causing injury in 2013) on tree fruit crops, with the goal of understanding what factors influence their development, behavior, and movement of adults

among and between various host crops. (*Krawczyk and Biddinger – 2010-present*)

Another ongoing research focus is on developing and evaluating monitoring tools for the brown marmorated stink bug and enhancing biological control agents for this pest, which has become a major threat to the fruit industry. “By the end of 2010, I was spending 75 percent of my time just dealing with the stink bug,” Krawczyk says. “During the winter of 2010-2011, my program evaluated more than 60 pesticides for their efficacy against the brown marmorated stink bug.”

In one major project, researchers are attracting stink bugs from within the orchard to outside the orchard, where nets treated with insecticides trap the bugs. (*Krawczyk and Biddinger – 2010-present*)

Pollinators

A priority for researchers at FREC is to encourage a greater public awareness of the importance of pollinators in agriculture. In ongoing pollinator research, FREC scientists are establishing baseline data on the biodiversity and abundance of native bees in and adjacent to tree fruit orchards. They determine which species are tree fruit pollinators, as well as the biological and pesticide threats to pollinators and how to mitigate them.

“There are 22,000 kinds of bees in the world,” Biddinger says, “and we’re always working to understand the effects of landscape ecology, plant diversity, and foraging ranges of pollen bees. We also focus on developing, demonstrating, and evaluating management practices to native bee conservation.” (*Biddinger – 2012-2016*)

Greg Krawczyk checking a “Ghost” trap for the capture of Brown Marmorated Stink Bugs





Dr. Kari Peter teaching Young Grower Alliance members how to scout for apple scab in their orchards



Lorraine Berkett, graduate student of Ken Hickey, tests weather equipment for determining disease risks

CHAPTER 4: *1976-Present*

Major Plant Pathology Research Themes

Over the past 50 years, plant pathologists at FREC have continued to evaluate new fungicides and bactericides in laboratory, greenhouse, and orchard trials to continually update and deliver the best orchard disease strategies to growers. Effective, efficient, and environmentally safe control of fungal and bacterial diseases remains a priority—from Ken Hickey’s work beginning in the 1970s through research performed by successors Jim Travis, Henry Ngugi, and Kari Peter. FREC plant pathologists work to determine feasible disease management strategies for tree fruits, including timing of fungicide sprays, using natural resistance of cultivars, modern application technology, and disease prediction models. This chapter includes research highlights in plant pathology.

Fungicide and Bactericide Trials

The fungicide and bactericide trials conducted by FREC plant pathology scientists for more than four decades have been important for the fruit industry. Data from these trials serve as the foundational information base for new fungicide and bactericide labels developed by agricultural chemical companies and approved by the EPA as the legal documentation for the use of these materials by fruit growers. These orchard trials and published results also provided fruit growers with science-based information about the disease management materials, pest risks, and environmental conditions where they grow fruit.

Integrated Disease Management

Researchers developed and continue to refine an integrated disease management system for tree fruits that involves inoculum level, fungicide concentration and timing, application method, tree size and training method, and the innate resistance of various cultivars. Fungicide use in orchards progressed from routine applications of broad-spectrum materials before 1976 to a disease-focused approach that integrates all practical disease management tools. The result has been improved disease management and reduced pesticide use and rates.

“Ken Hickey did a lot of work fine-tuning what fruit growers in the eastern United States needed to do with fungicides—basing their decision on when to apply chemicals on solid data, not just because a salesman said to do it,” says Jim Travis, professor emeritus of plant pathology.

Researchers continue to compile and integrate new test results of available fungicides along with cultivar resistance, environmental infection risk models, and seasonal risk variables to deliver the most up-to-date and effective disease management strategies to growers. *(Hickey, Travis, Ngugi, and Peter – 1976-present)*

During the 1980s and 1990s, new disease-specific and softer management materials became available and were combined with on-site weather data into more complex integrated disease management systems. As a result, grower decision making became more complex. Researchers and extension educators developed expert systems (also called decision support systems) to help growers use on-site, time-specific decision making in orchards. Expert systems led to changes in how growers used logic and decision making to manage disease in their orchards. *(Travis, Rajotte, Hickey, Clarke, and Crassweller – 1982-1995)*

Researchers evaluate and implement disease predictive models in on-site computer-based weather stations in orchards, and remotely sensed site-specific weather models to manage the many diseases that affect tree fruits and wine grapes. *(Travis, Ngugi, and Peter – 1988-present)*



Debbie Breth, graduate student of Jim Travis and Larry Hull, measures electrical conductivity of peach trees inoculated with cytospora canker and lesser peach tree borers



Jim Travis examining a leaf wetness device for determining apple scab infection periods

Various Research Milestones

Ken Hickey and graduate students performed research to determine the effectiveness of biological control agents for bacterial crown gall of apple, pear, and stone fruits. *(Hickey, Scalza, and Davis – 1977-1981)*

Researchers determined the value of innate resistance of apple cultivars to apple scab and powdery mildew. They also studied the effect of environmental parameters on the incidence and severity of the major stone fruit diseases: brown rot, scab, and powdery mildew. *(Hickey and Travis – 1985-1999)*

Researchers developed control measures for cytospora canker and determined the influence of this pathogen, and how it interacted with an insect pest—the lesser peach tree borer—on peach tree growth, productivity, and winter hardiness. *(Travis, Breth, Hull, Hickey, and Greene – 1983-1990)*

Researchers investigated the buildup of cherry leaf spot in Pennsylvania orchards, and evaluated the development of resistance to the most commonly used fungicides in orchards; refined management alternatives for bacterial spot of peach and monitored the status of antibiotic resistance in Pennsylvania peach orchards; and assessed the level of fungicide resistance for apple scab and brown rot pathogens. *(Ngugi and Peter – 2007-present)*

Bacterial spot of stone fruits is a difficult disease for fruit growers to manage and became more so in recent years, as shifting market trends compelled growers to grow white-fleshed varieties that are more susceptible to this disease. Research shows this disease develops

in a series of wave-like progressions, and this finding has helped fruit growers accurately assess the severity of bacterial spot in their orchards and reduce the risk of costly mistakes from failure to control this disease due to misdiagnosis. (Ngugi, Bardsley, Jimenez-Gasco, and Peter – 2008-present)

Plant pathologists work to determine the practical usefulness of beneficial microbial antagonists to bacterial fruit diseases, and compounds that stimulate the natural systemic acquired resistance (SAR) of the plant in suppressing disease development. (Hickey, Travis, Ngugi, and Peter – 1988-present)

Various studies examined alternatives to postharvest chemical treatments and seek to understand the effects of reduced pesticides on postharvest quality in storage. (Hickey, Travis, Ngugi, and Peter – 1992-present)

To enhance the safety of everyone working in an orchard, researchers evaluated applicator exposure to pesticides applied with airblast sprayers. “We educated growers on the need to wear gloves and use a respirator when applying chemicals,” says Jim Travis, professor emeritus of plant pathology. “Growers are more aware now.” (Hickey, Hull, and Travis – 1985-1999)

Brian Lehman inoculating young apple trees in the greenhouse with fire blight bacteria



Ken Hickey presenting fungicide efficacy results to chemical industry personnel at FREC's annual Plant Protection Field Day

Wine and Grapes

In response to growing interest in local wines, Pennsylvania wineries increased in number during the 1990s. As expansion in vinifera grape plantings increased across the state, grape disease management guidelines were needed based on local research trials. Vinifera and French hybrid grape plantings were established in 1998 at FREC, and researchers developed integrated grape disease management recommendations specific to the area. Research includes on-site grower demonstrations and meetings and on-site vineyard disease diagnosis.

“FREC’s work with wine grapes is a good example of how the lab is sensitive to the needs of industry,” says Jim Travis, professor emeritus of plant pathology. “The industry moves based on market influences. As industry changes, FREC helps growers adapt and adjust. In response to industry demand, growers are working more with wine grapes, so FREC is now doing more work in that area.” (Travis, Ngugi, and Peter – 1998-present)

Organic Tree Fruit Production

Interest in growing organic fruit has increased as demand for organic produce has grown in nearby cities and as fruit growers have transitioned from processing fruit production to fresh fruit. In response to this market demand, FREC established apple demonstration plantings in 2003 to initiate research and extension outreach on best organic production practices for Pennsylvania. Varieties, training systems, organic management materials, insect and disease risk factors, crop load management, and organic cultural practices were evaluated in research orchards and in cooperating grower orchards. (Travis, Krawczyk, Schupp, Ngugi, and Peter – 2003-present)

Fire Blight

Fire blight, a contagious bacterial disease of pome fruits and a long-time problem for fruit growers in Pennsylvania, again became a major concern for growers beginning in 2014. Over the years, FREC scientists have sought management of fire blight by evaluating antibiotics, bacteria, and plant growth regulators. (*Hickey, Travis, Ngugi, McNellis, and Peter – 1976-present*)

Fire blight, which is endemic in North America, can be devastating to fruit trees because bacteria spreads quickly and easily by wind and insects. Conditions in Pennsylvania, including warm, wet weather during and after apple and pear bloom, favor fire blight. FREC researchers and extension educators have made a concentrated effort to educate growers on how to manage the disease.

By focusing on the susceptibility of new apple cultivars and rootstocks and refining control methods in high-density orchards, scientists have boosted growers' ability to manage fire blight in apple and pear orchards. This research is important because of recent changes in growing systems that involve many smaller trees growing close together in a small area. Whereas large, older trees can withstand somewhat higher levels of the disease, younger, smaller trees are more susceptible. Growers can lose a lot of money in a short time due to fire blight.

In determining the efficacy of bacterial disease treatments for fire blight, researchers found that applying the antibiotic streptomycin can be effective. Researchers assessed the status of resistance to streptomycin in populations of the fire blight organism

Kari Peter lecturing University of Maryland students about her fire blight research



Graduate student Sarah Bardsley Capasso inoculating flowers with fire blight bacteria

from Pennsylvania orchards through a statewide survey of bacterial populations, and they found no evidence of streptomycin resistance—a positive sign for growers.

“There’s still a lot about the disease we don’t know,” says FREC plant pathologist Kari Peter. “Fire blight is the disease that keeps growers up at night. But I think growers are now more vigilant and aware of treatments available to them.” (*Hickey, Ngugi, Peter, Travis – 1990-present*)

Copper Treatment of Fruit Diseases

Over the past several years, researchers have been evaluating improved formulations and ultra-low application rates of the many commercially available copper products to manage fire blight in apples and pears, as well as bacterial spot of peach. (*Hickey, Ngugi, and Peter – 1988-present*)

Copper is a general biocide that kills all surface bacteria on a plant and thus limits the bacteria’s spread. One recent year, when growers were treating peaches with copper to mitigate the bacteria that caused bacterial spot, they were experiencing problems with damage caused by copper. In response, Peter invited growers to the peach orchard plantings at FREC. “The bacterial pathogen on the leaves versus the copper damage of the leaves can be confusing,” she says. “I wanted growers to be able to see the disease itself along with a side-by-side comparison of different coppers, so I held an impromptu workshop. That was a great example of a research moment and an extension moment.” (*Travis, Ngugi, and Petre – 2003-present*)



John Halbrecht and his laboratory assistants analyzing leaves for Plum Pox Virus



Peach orchards infected with the Plum Pox Virus were destroyed

CHAPTER 5: 1976-2017

Major Nematology/Virology Research Themes

“Everything is more complex than it appears to be.” John Halbrecht, a plant nematologist at FREC from 1988 through 2014, remembers that quote from his first college physiology class. It’s a truth that seems particularly appropriate for plant scientists who study the viruses and nematodes—microscopic roundworms—that weaken trees and vector disease in fruit orchards. “The more you learn about something, the more detailed it gets,” Halbrecht says. This chapter summarizes research themes and accomplishments in nematology and virology over the past 50 years at FREC—including a major cooperative effort to eradicate plum pox virus in 2000.

Various Nematode and Virus Research Projects

A virus research program led to the discovery of the virus and vector (dagger nematodes) that cause Prunus stem pitting and its relationship to the union necrosis diseases of apples as well as to the development of the Pennsylvania Fruit Tree Improvement Program, a cooperative effort involving Penn State, the Pennsylvania Department of Agriculture, and the Pennsylvania tree fruit and nursery industries. (Stouffer – 1966-1983)

Researchers evaluated and recommended pre-plant soil fumigation and post-plant nematicides for control of nematode and virus diseases. (Stouffer – 1970s-1983) They also evaluated integrated management programs using soil fumigants, contact nematicides, systemic nematicides, application methods, and weed control

in the control of Prunus stem pitting and apple union necrosis. (Stouffer and Jaffee – 1982-1986)

Various studies were focused on determining the most effective and economically feasible control practices for soil-borne fungal, bacterial, and virus diseases under nursery and orchard conditions. (Stouffer and Jaffee – 1982-1986)

Nematologist John Halbrecht conducted surveys to collect and identify potentially useful nematode biological control agents in Pennsylvania orchards. He also demonstrated that commercial microwave chambers effectively eradicate the pine wood nematode from lumber. (Halbrecht – 2004)

Plum Pox Virus

In an important FREC and fruit industry success story, plum pox virus was eradicated from Pennsylvania's fruit-growing industry. Plum pox virus, which is transmitted by an aphid, first came on the scene in October 1999, when the disease was positively identified for the first time in North America in peaches growing in Adams County. At that time, Jim Lerew, co-owner of the orchard with the first known case of plum pox infection, noticed a strange ring pattern on some of his peaches. Lerew took samples to several fruit research institutions, including Penn State, to determine the cause.

After the virus was identified, a group of fruit growers, state and federal agriculture departments, and members of the Penn State College of Agricultural Sciences came together in a cooperative effort to eradicate plum pox virus. Infected orchards were contained and quarantined and infected trees were burned to inhibit further disease spread. The eradication program also included creating buffer zones, establishing a moratorium on replanting stone fruits in quarantined areas, holding educational meetings with growers, and developing extension materials describing the disease and its impact on growers.

"When an orchard was found to be infected, the grower was required to destroy the entire orchard," Halbrendt explains. "Then we wondered, if the orchards were next to the woods, could the virus be harbored in the native trees? So if you replant, could the orchard become reinfected?" Because the same virus and aphid could be found in pea plants, Halbrendt grew young



Rodney Schaffer fumigating an orchard to control nematodes and virus diseases



Peach orchard showing the loss of trees infected with *Prunus stem pitting* (i.e., *Tomato Ringspot Virus* likely transmitted by dagger nematodes)

pea plants as "bait plants" meant to attract aphids from newly destroyed infected orchards. When he examined the pea plants in the laboratory, he detected no aphid transmission of plum pox virus. Halbrendt also collected native plants in nearby woods to check them for plum pox virus, but fortunately found no evidence of transmission.

Fall 2009 marked the third consecutive year of no new positive detections of plum pox—marking the end of a three-year-long quarantine—and Pennsylvania was declared plum pox free. "The plum pox epidemic raised the level of awareness that all growers need," says Halbrendt. "Orchard sanitation and good cultural practices are key issues in the prevention of virus introductions." (*Halbrendt – 2001-2009*)

FREC researchers continued surveys for plum pox virus post-eradication and other exotic tree fruit diseases in nurseries and orchards in south-central Pennsylvania in collaboration with the Pennsylvania Department of Agriculture. (*Peter – 2014-2017*)

Tomato Ringspot Virus

Beginning in the early 1980s, several research projects led to improved control and management of tomato ringspot virus.

Certain crops, including peaches, some apple varieties, and grapes, are extremely sensitive to tomato ringspot virus, which is transmitted by a nematode. "In some cases, nematodes devitalize a plant by parasitizing the root system. In this case the dagger nematode is not very aggressive except when it feeds on roots of certain plants, it transmits the virus," Halbrendt explains.

In Pennsylvania, the nematode that vectors tomato ringspot virus naturally inhabits broadleaf weeds, especially dandelion. “It coexists and unfortunately it doesn’t kill the dandelion,” Halbrendt says. “If it feeds on a dandelion that is infected it will pick up the virus, and later, if it feeds on a peach tree, it will transmit the virus.”

A study of dagger nematode biology showed that several species that are efficient transmitters of tomato ringspot virus have only three juvenile stages in their development, whereas similar species that do not spread viruses have four juvenile stages. This discovery is one of the clear biological differences to be observed in a group of nematodes that are difficult to classify into distinct species. Studies were also conducted to determine the optimum environmental requirements of dagger nematodes and the potential to manage populations by altering environmental conditions. (Halbrendt – 1990s-2004)

Researchers studied grass and legume management in orchard tree plantings to prevent the spread of tomato ringspot virus through broad leaf weeds. (Stouffer and Jaffee – 1982-1986)

Nematologist John Halbrendt developed a feeding bioassay for dagger nematodes to be used to screen for nematocidal Bt toxin genes that can be used to develop transgenic plants with nematode resistance. (Halbrendt – 1990-early 2000s)

Screening of the USDA Prunus germplasm collection at the USDA Laboratory in Kearneysville, West Virginia, for resistance to tomato ringspot virus showed that only the plum variety Marianna 2624 was resistant. (Halbrendt – 1990-early 2000s)

The parasitic Dodder plant was shown to transmit tomato ringspot virus between alternate weed hosts in the orchard floor. (Halbrendt – 2004)

For many years, the easiest solution for getting rid of tomato ringspot virus was soil fumigation. “Growers would use methyl bromide to fumigate, which sterilized the soil and killed the nematodes, viruses, fungi, and weeds,” he explains. “When methyl bromide was identified as a chemical that depletes the ozone layer, chemical companies had to come up with alternative solutions and many came to me for product testing. A lot of my research involved looking for alternative ways to manage tomato ringspot virus, and I had quite a few trials to try them out.”

Halbrendt and colleagues also came up with an alternative solution to fumigants. The researchers found that certain rapeseed varieties effectively reduced dagger nematode populations when used as a pre-plant green manure treatment in replanted orchards. This treatment provided growers with another option for controlling nematodes and the viruses they transmit—including tomato ringspot virus—without soil fumigation. “If growers plan ahead with crop rotations, it can clean up an orchard site really well,” Halbrendt says. (Halbrendt and Jing – 1990-early 2000s)

John Halbrendt applies mulch containing entomopathogenic nematodes to control peach tree borer larvae within trees





An extension visit in Berks County; (right-left) grower Lee Spencer, Larry Hull, Ken Hickey and Mena Hautau



Ken Hickey and Karen Weaver work on the Expert systems software

CHAPTER 6: 1976-2017

Extension Education

Extension specialist Tom Piper, who retired in 1996 after serving for almost 40 years as an extension educator, remembers the days when he used to carry around a reel-to-reel recorder for his meetings and interviews with fruit growers. “At the time it was considered top-notch technology,” he says. Piper also recalls going on air at 6 a.m. every morning during growing season, to host a radio show giving growers the most current information and recommendations for their orchards.

While methods of disseminating the latest research-based information to growers have changed over the years, the commitment of extension educators to fruit growers has remained strong. Through face-to-face meetings, online courses on the science related to fruit production, publications that are updated continually, and the latest online information pertinent to growers, FREC extension educators work hard to stay in touch with growers, hear their concerns, and share knowledge.

“At FREC, we’ve been blessed through the years with a superb group of faculty who never forgot that their principal job was to make sure the folks growing fruit for a living could continue doing that,” says Terry Salada, FREC farm manager. “They’ve made great strides in their research, and they make sure they communicate their results and what they’ve learned to growers. Data and information is the crop for this center. We grow beautiful apples, we grow wonderful peaches, we grow a fine wine grape crop up on the hill. But that’s not our crop. Our crop is knowledge, and we’ve all tried never to forget that.”

This chapter summarizes highlights of extension education at FREC since the 1970s.

Tree Fruit Extension Milestones

While fruit grown for processing (sauce, juice, and hard cider, for example) remains a robust part of the economy, and companies such as Knouse Foods provide strong support for FREC and extension, over the last fifteen years the Mid-Atlantic fruit industry has seen a shift toward fresh fruit production. With consumers demanding more fresh, local produce, growers have increasing opportunities to market their fresh produce throughout the Mid-Atlantic.

“There’s been a tremendous effort at looking at ways to get our fruit out into the metropolitan markets that are so close to us,” says extension educator Tara Baugher. “Quite a few growers send several trucks out a day to Washington, D.C., Philadelphia, and Baltimore to get top dollar for their fruit.”

Orchard Systems

The shift toward fresh market fruits involves removing old orchards and replanting new trees of different varieties, as well as different production systems designed to produce high-quality fruit. High-density production, involving smaller trees planted closer together, also means trees come into production earlier and are easier to manage. When planning orchards, growers need to account for factors such as rootstock and spacing to make their orchards profitable. *(Greene, Piper, Crassweller, Kleiner, Schupp, and Baugher – 1980-2018)*

Rob Crassweller addresses fruit growers at an extension meeting



In a project funded by a NRCS Conservation Innovation Grant, Penn State Extension has been developing growing systems and technologies to allow greater mechanization and labor efficiency. Researchers and extension educators evaluate the effect of high-density apple growing systems on productivity, fruit quality, and labor efficiency.

In ongoing apple and peach trials, narrow wall apple training systems are being measured for yields, growth, fruit size, and pruning labor. Apple rootstock trials include evaluations for qualities such as cold hardiness and fire blight resistance. Peach system trials have demonstrated greater annual yield and higher fruit quality, and they have shown the narrow canopy to be more compatible with mechanization. Extension educators use results of these trials to provide growers with recommendations on growing fruit with high yields, quality, and efficient use of labor. *(Baugher, Schupp, and Crassweller – 2006-2012)*

Mobile Orchard Platforms

The Specialty Crop Innovations Initiative, launched in 2006, focused on a systems approach for retooling Pennsylvania orchards. One project involves an orchard platform prototype designed to replace ladders for thinning and harvesting from tall tree walls—a design that resulted in significant economic savings. *(Baugher and Schupp – 2006-2012)*

Harvest Assist Technologies

In another Specialty Crop Innovations Initiative project, a team from FREC assessed bin filling methods and design and simulated new concepts for gently transferring fruit to bins in the field. During the 2007 harvest, Penn State and Pennsylvania growers hosted a Specialty Crop Engineering Solutions tour for robotics and precision agriculture engineers. Prototypes continue to show promise for reducing damage to fruit during bin filling.

“This is an exciting development, and we’ve taken the lead on testing,” Baugher says. “Growers wanted to try a bulk bin method of harvesting, which entails harvesting into picking bags, then taking the bags to a 20-bushel bulk bin. At the bottom of the picking bag is a vacuum tube that pulls the apples out and gently conveys them to the bulk bin. So the bag never gets heavy, and the apples are kept separated so there’s no bruising.” *(Baugher, Schupp, Heinemann, and Zhang – 2010-present)*

Crop Load Management Innovations

Mechanical thinning strategies, along with narrow tree architectures, can help profitability by reducing labor and improving fruit size and quality. In a Specialty Crop Research Initiative led by Penn State, trials were performed in several orchards. A new development—a joystick-controlled thinner designed to improve operator control of thinning equipment—shows promise. (Baugher, Schupp, Heinemann, and Kon – 2007-2014)

Sensor and Imaging Technologies and Weather Modeling

These technologies can help growers determine crop load, assess when to thin, and determine and monitor insect populations. Penn State entomologists collected and annotated images of codling moth and Oriental fruit moth adults in traps, then helped engineers test visual algorithms for insect detection. (Hull, Krawczyk, and Lehman – 2008-2014)

Plant pathologists created a database of images for use in developing and testing image processing methods and algorithms for fire blight. Automated traps, computer vision, and improved modeling systems reduce the need for labor and increase accuracy of crop monitoring. This results in improved crop management, more effective pest monitoring, higher fruit quality, and reduced pesticide application. (Ngugi, Lehman, and Travis – 2008-2011)

Sprayer Technologies

Inaccurate pesticide application can lead to problems such as residue on fruit and air and water pollution. In a project aimed toward more efficient sprayer technologies, FREC scientists Ken Hickey and Larry Hull tested several air-blast sprayers and demonstrated significant reductions in spray drift. Summer engineering interns built a “patternator” to help growers assess ways to adjust spray distribution patterns. FREC held a workshop on application technologies for tree fruit and grapes, conducting field demonstrations of new air-blast spraying technologies. In 2013 and 2014, the State Horticultural Association of Pennsylvania (SHAP) extension committee awarded funding to help offset cost to growers of on-farm calibration of their air-blast sprayers. (Hull, Hickey, Baugher, Clarke, Landers, Hamilton, Richards and Pollock 1980-Present)

Integrated Pest Management

Beginning in the late 1960s, fruit growers in the Mid-Atlantic region were encouraged to employ a new



Tara Baugher demonstrates a vacuum harvester prototype at FREC Grower Field Day

strategy: integrated pest management (IPM). IPM involves using more than one management tactic—for example, chemicals or natural enemies—to control pests in the most environmentally friendly and economic way. Initially using the native predator *Stethorus punctum* (a small black lady beetle), the program has grown to include other natural enemies. IPM saves growers millions of dollars in spray costs, while decreasing chemical use.

IPM in Pennsylvania changes continually. New pests, such as the brown marmorated stink bug and spotted wing drosophila, arrive on the scene; old pests become resistant to control methods; new natural enemies are identified and used; and new innovations and technologies are developed. Fruit growers in Adams County lead the way in adopting new IPM tools and methods.

Expert Systems

During the 1980s and 1990s, researchers and extension educators developed Expert systems (also called decision support systems) to help growers diagnose and manage tree fruit diseases. “We had the comprehensive Tree Fruit Production Guide, but it could be a challenge for growers to know where to look to find what they needed,” says Jim Travis, professor emeritus of plant pathology. “We tried to put a lot of that knowledge into a computer program that would help growers make decisions. Unfortunately, computers at the time weren’t powerful enough to handle all the complex data—we were ahead of our time.”

Expert systems evolved into other artificial intelligence spinoffs, including SkyBit, which provided growers daily information via fax about insect and disease risks. “In the end,” Travis says, “Expert systems changed the way we thought about things and how we went about using logic and decision making to help growers. It gave us a platform to talk with growers about decision making and logic.” (*Crassweller, Travis, Rajotte, Hickey, Clarke – 1982-1995*)

Managing Beneficials

When it comes to biological control, growers usually get the best results when many species of natural enemies each contribute to reducing pest populations at different times and at different developmental stages. FREC extension educators work with growers to give them the most up-to-date information on managing pests in their orchards. “IPM began to take hold when I was at FREC, and now it’s taken for granted—growers are using that balanced, integrated approach,” Travis says.

At the orchard level, IPM means the grower must perform a series of tasks before deciding what action to take. The grower needs to gather and record information about the environment, pest, and crop during the growing season; compare pest levels with threshold values; and then choose a control tactic or set of tactics. These tactics include biological control, horticultural practices such as specialized pruning, and behavior modification such as mating disruption.

“IPM means using every possible kind of management,” says Travis. “It’s partly cultural—for example, pruning trees more openly so they dry off more quickly and mold doesn’t build up. At the other end of the spectrum are insects that eat pests, and changing chemical use to you’re not killing those beneficial insects.”

Extension educators also emphasize that growers

Larry Hull demonstrates the use of a pheromone trap



should put some IPM practices into place in anticipation of future pest problems. “It’s important for growers to know about the infection period for diseases, for example, so they can apply an antibiotic beforehand, and not apply it all the time,” Travis says.

Mating Disruption

In the early 2000s many fruit growers started using a form of pest control that significantly reduced the use of pesticides for codling moth and the Oriental fruit moth. The new technology, sex pheromone mating disruption, involves using synthesized chemicals that mimic the chemical scent emitted by female moths to attract males for mating. Pheromone components are impregnated into dispensing systems that are placed into the orchard to disrupt the natural communication between male and female moths. This disruption results in less mating, fewer eggs and hatching larvae to enter and cause injury to fruit, and ultimately less need for insecticides.

Pest Monitoring

A major component of IPM is monitoring both pests and natural enemies in the orchard, allowing growers to make sound management decisions. Among a variety of monitoring tools and techniques available to growers, pheromone traps use principles that are similar to pheromone mating technology: A rubber lure impregnated with the synthetic female pheromone of a pest is placed into a trap with a bottom liner coated with a sticky substance. The male moth is captured by the sticky substance when it approaches the trap. Growers can then use numbers of captured moths to make management decisions. Researchers are continually improving these traps, and new monitoring traps can auto-transmit data to growers’ home computers, eliminating the labor of checking traps weekly or daily.

Protecting Native Pollinators

Pennsylvania is home to hundreds of species of pollinators (bees, butterflies, moths, flies, and beetles), with more than 500 species of bees alone. Pennsylvania also has one of the most diverse cropping systems in the United States, producing an array of fruit and vegetable crops that depend on the services of pollinators.

“All tree fruits are 100 percent dependent on pollination,” explains David Biddinger, tree fruit research entomologist at FREC. “So you have to have bees.” Pollinator populations in Pennsylvania are experiencing several challenges, with beekeepers reporting losses in their honey bee colonies over the last several years.



Fruit growers at Hollabaugh Twilight meeting 2009

Ongoing research at FREC has found about 235 bee species in fruit orchards, and more than 50 of these species visit apple and cherry blossoms in the spring. Because these bees thrive in the native orchard ecosystem and pollinate fruit trees, many growers find they don't have to rent increasingly expensive honey bee colonies for pollination services.

Biddinger, along with Edwin Rajotte, coordinator of Penn State's IPM program, contributed to a guide for growers entitled *Wild Pollinators of Eastern Apple Orchards and How to Conserve Them*. The guide, a cooperative effort among Penn State, Cornell University, and The Xerces Society, includes advice on caring for species of wild bees, including providing populations with adequate food, safe nesting sites, and protection from pesticides.

Grower Meetings

An integral component of extension education at FREC is regular gatherings with growers on their farms—usually held in the evenings during the growing season. “The orchards essentially become the laboratories and classrooms,” says Rob Crassweller. “Grower meetings require us to go in advance into orchards and see what's going on—what's working and what's not.”

“We've always had a team of extension specialists assigned to help the county agents work, and we'd go out to orchards together to check out diseases and insects and any other issues growers were having,” Tom Piper recalls about his days in extension. “Then we'd have a twilight meeting in someone's orchard.”

The tradition of twilight meetings continues today and remains an important part of extension education. “Even though we have a large web presence now, those orchard visits and face-to-face meetings can't be replaced,” Crassweller says.

Crassweller also points out that the commercial fruit industry is an open and sharing one, with strong communication among growers as they seek the best information possible. “There's a lot of sharing, a lot of give and take,” he says. “When I first came to Penn State, growers would look to the experiment station in their state, whether it be West Virginia, Maryland, or

New Jersey. Today, FREC is the largest state experiment station in the Mid-Atlantic region, but growers are open to seeking information from other experiment stations in the region.”

Grower Publications

The Penn State Tree Fruit Production Guide is a comprehensive resource that provides growers with information on areas such as fruit culture, orchard nutrition, spraying, pesticides, and controlling weeds and insects. The guide, which is published every other year, covers all aspects of IPM and includes color images of fruit diseases and insect pests, and it has grown over the years.

“We built up the guide to be a comprehensive resource for tree fruit growers,” Travis says. “People's crops depended on it.”

The Fruit Times was started by Tom Piper in the early 1980s as a weekly short letter sent to growers. The FREC team—Ken Hickey, George Greene, and Larry Hull—would send their weekly observations and recommendations to Piper, who would then send the letter to growers. Today, the Fruit Times has evolved into a monthly online newsletter that is sent throughout the country.

Young Grower Alliance

The Young Grower Alliance, initiated by extension educator Tara Baugher and extension economist Matt Harsh in 2005, is an organization that gives the next generation of growers exposure to new practices and technologies and encourages innovation. Through volunteer opportunities and educational opportunities such as field trips to universities, grower farms, and research facilities, young people interested in pursuing careers in horticulture learn about the industry. The alliance, now with more than 300 members, also provides networking opportunities for young growers to meet with community and agriculture leaders and take on leadership roles. The Young Growers Alliance has infused new energy into the fruit-growing industry, as young growers are investing in new technologies, innovative production methods, and marketing strategies.

“We wanted to find a way to help these young people who grew up on farms come back to the orchard,” Baugher says, “and it really has rejuvenated the industry. Today's young growers aren't just growing apples and peaches—they're diversifying. And the latest trend has been young growers getting into the hard cider industry. It's our diversified markets that have made us so strong.”



Ribbon cutting for the new graduate student housing at FREC, January 28, 2016. From left to right: graduate students Tom Kon, Sarah Bardsley Capasso, Deonna Soergel, Sarah Shugrue and Professor Emeritus Larry Hull



The original FREC graduate housing trailers installed in 1980

CHAPTER 7: 1976-2017

Growers and Stakeholders

“The tree fruit industry is tough, It’s a perennial cropping system. It’s a chess game, and growers are making moves now that won’t pay off until eight or so years down the road. They’re sharp, they’re paying attention, and it’s a privilege to be here and working with a forward-thinking industry.”

Jim Schupp – FREC Director

The Importance of Research and Development

Growers recognize the importance of research and development, and they depend on FREC researchers to deliver the best information available. “We’ve had impacts because our industry recognizes things that need to change, and they look to us for solutions,” Schupp says. “Many of us here at FREC have split appointments between research and extension, which is an ideal model. We do the research, deliver it, and then get feedback, which informs our research going forward. It becomes a connected circle.”

Recent decades have brought dramatic changes to the commercial fruit industry—including changes in planting systems, equipment, and labor management. Sharing of information at the grower level has increased, along with support from state and local grower associations and extension.

The State Horticultural Association of Pennsylvania (SHAP) is a grower organization with a mission “to preserve and enhance the viability of the commercial fruit industry through educational outreach, research support, promotion, and proactive involvement with legislative affairs.” SHAP and FREC work closely together in a mutually beneficial relationship.

“There’s a significant group in our industry that is invested in research—in looking forward, envisioning how can we move our industry forward, and how can we solve problems, both old and new,” says Bruce Hollabaugh, production and field personnel manager at Hollabaugh Brothers Inc., in Biglerville, and chair of the SHAP research committee. “FREC personnel put their focus into research, and SHAP acts as an effective conduit between FREC and the fruit industry—we



Jim Lerew chaired the State Horticultural Association of Pennsylvania's Research Committee in its early years.

have excellent communication between the needs of the industry and the people with the expertise to do the work.”

The SHAP research committee provides funding to scientists who submit proposals for research grants, each year awarding grants to selected projects for the upcoming growing season. In this way, SHAP invests in research as a way to generate revenues that impact the industry. In some cases, FREC researchers use funding from SHAP as seed money for larger grants.

One project that received funding from SHAP—as well as a grant from the federal government—was the eradication of plum pox virus, which emerged in 1999. FREC scientists played a major role in collaborative efforts to eliminate the disease in North America. “I remember John Halbrendt and Ken Hickey were involved in that effort, and they brought in a team of pathologists from University Park to collaborate,” Hollabaugh says.

Another major project involving SHAP funding was a Conservation Innovation Grant awarded in 2008. FREC was selected for an experimental apple trellis planting, among a dozen or so plantings throughout the Mid-Atlantic region. The project, a collaboration of extension, research, and growers, “was a stepping stone for FREC,” Hollabaugh says. “There have been a lot of changes at FREC in the last ten years because of that work.”

Collaboration and communication, both within and beyond Pennsylvania's borders, are integral to making progress in research initiatives. Because of FREC, “We're not left with trying to see what other people have done outside Pennsylvania,” Hollabaugh says. “We have the benefit of work done at FREC, but also the work of others. The FREC researchers do a wonderful job of staying in touch with other scientists throughout the country. FREC is an excellent resource with great scientists and great communicators.”

SHAP also recently played a major role in funding new graduate housing on the grounds of FREC. Built in 2016 to replace outdated trailers, the new duplex features two four-bedroom apartments. “Our industry was ready to get behind that initiative,” says Phil Baugher, president of Adams County Nursery and chair of the graduate housing committee. It didn't take long for pledges to come in: \$50,000 from Knouse Foods; \$25,000 from Rice Fruit Company, in honor of Jim Lerew, an Adams County orchard co-owner who passed away in 2015; \$25,000 from Bob and Elizabeth Hodge; and \$25,000 from Mac and Carolyn Lott. “Other growers stepped up quickly,” Baugher says. “Now, we have a new house on the grounds, within walking distance for graduate students or visiting scientists. Residents love the comfort and convenience of the house—they can be here working in the labs in the evening, and they're just across the field from home.”

Baugher adds that growers appreciate another advantage FREC brings to the community and industry: providing opportunities for young people to experience agricultural academics. “I know of dozens of kids who worked at FREC when they were in high school or college—as technicians, counting bugs, measuring fruits, recording data—and went on to earn undergraduate graduate degrees in agriculture,” he says. “Their exposure to plant scientists who were mentors made them consider a career in agriculture, and that's had a significant impact on our industry.”

Hollabaugh echoes the sentiment that FREC has made a difference in the community and the commercial fruit industry. “I've been told that our industry has changed immensely in the last 75 years, in terms of how we, as growers, interact and work together,” he says. “They say we are much more open now, that we work together much more. When my grandfather was alive, and certainly today, my dad and his brothers talk regularly about Dr. Hickey and the openness and communication he fostered. He played a major role in encouraging that interaction.

“FREC is truly integral to the economy of Adams County and to keeping a healthy, vibrant industry,” Hollabaugh continues. “I think the strength of the presence of FREC in our industry, situated here in Adams County, is the diversity of the expertise, backgrounds, and perspectives that it brings to the grower community. From the grower perspective, it's wonderful to have as your neighbor such a complex and diverse knowledge base.”

Special Thanks

The Pennsylvania Fruit Research and Extension Center will be forever grateful to the many individuals, growers, industry organizations, and corporations that generously donated to the cost of building the graduate house duplex. Special thanks to the State Horticultural Association of Pennsylvania and the Endowment Committee, Robert and Elizabeth Hodge, Knouse Foods Cooperative, Inc., Mac & Carolyn Lott, Rice Fruit Company, Adams County Nursery, Inc., Ag Choice Farm Credit, Bear Mountain Orchards, and Bream Orchards, Inc.

Donor tree to recognize and show appreciation to all of those that made the Graduate House possible. This tree is located in FRECs Musselman building, just outside of the auditorium door.



The Graduate House is a duplex with units having a mirror image floor plan. Each unit consisting of 4 bedrooms and 2 bathrooms, full eat-in kitchen, living room, and full basement including a laundry room. The graduate house was ready for occupancy beginning with the Summer of 2016 and was at full occupancy starting this first summer.



Keith Nunamaker (left), graduate student Betsy Beers, and Gene Staub (right) planting apple trees for a mite stress study



Larry Hull and George Greene discussing the results of one of their collaborative projects

CHAPTER 8

Memories

Along with the many research and extension accomplishments at FREC over the last 40-some years come just as many memories—friendships formed, connections made, lessons learned, laughter shared. Here, a few faculty and staff members and former graduate students reminisce about their experiences during their time at FREC.

Jim Schupp

FREC Director (2004-present)

Ken Hickey and Larry Hull, two of my predecessors as director of FREC, were great mentors to me. I remember a time when we were going through a major budget upheaval. I was pulling my hair out, wondering how we were going to keep the door open and the lights on. Ken came in, and he was very sympathetic, and he listened while I wailed. Then he proceeded to tell me a story about a time when everything hung in the balance, but they pulled through okay. I came out of it thinking, “Well, what am I whining for? He had it worse than I did.” He had a very positive outlook on life. Ken was a close friend and contemporary of Tom Piper, and between the two of them—well, the only thing better than talking to one of them was talking with them together.

Over the years it’s been great to see a lot of our student workers go on to pursue careers in agriculture. We hire students in the summer, and they get a practical, hands-on education and first-hand experience with horticulture and related sciences. We’ve seen many of them change their major to horticulture or plant pathology or entomology. They get excited by agriculture and want to be part of it.

One recent example is Sarah Bardsley Capasso, who came here for a summer job as an undergraduate at Gettysburg College and then thought, “Hey, I think I like this.” She went on to get her master’s degree and then her Ph.D. Last year she worked as a postdoc with Kari Peter. Sarah was the first graduate student to live in the new graduate house.

For years we had two single-wide trailers for graduate student housing, and they were a great idea 30-some years ago, but they were getting to be in pretty bad shape. We approached the State Horticultural Association of Pennsylvania (SHAP) about building a new structure for graduate housing—a duplex at the edge of the property—and the fruit growers hit it out of the park for us. They stepped up and provided funding, and we now have an efficient, convenient, and affordable place for students to live. We're still smiling about that one—it was a great milestone, and it was thanks to the college, SHAP, and the growers.

David Biddinger

Associate Professor of Entomology (1996-present)

I was a graduate student of Larry Hull in the fall of 1989 and graduated in the spring of 1993. I've been an employee of Penn State since 1996.

When I was a Ph.D. student at FREC in the early 1990s, working with Larry, I survived living in one of the grad trailers for about three years. One summer it got really hot, and the air conditioner broke. The trailer got too hot, so I slept in the lab one night. I had some rubber waders in the closet at the trailer, and when I came back the waders had melted. I also remember being woken up at 6 every morning by the sprayers, and shooting woodchucks who hung around the trailers. One of my fellow students who lived in the trailer moved out when I left because he didn't feel safe without me around to shoot the woodchucks.

George Greene

Associate Professor Emeritus of Pomology (1971-2001)

FREC was a great place to do applied research on tree fruits and to have major interactions with the industry. I was active in the tree fruit extension program, and as an ex officio member of SHAP, I had the opportunity to be involved in grower education.

I organized several out-of-state major educational tours to help growers keep up to date with developing technologies. We conducted tours to Washington State, Maryland, New York, and Nova Scotia, among others.

I remember one adventure—when FREC began grape variety testing, Bob Peters (orchard technician) and I drove a flatbed truck to North East and picked up a load of vineyard posts. On the way back to Biglerville the load on the truck tried to push the truck faster and faster down the Allegheny Mountains on the Pennsylvania

turnpike. We had to be careful to maintain a safe speed, but we finally made it back to Biglerville.

Every fall, we would attend meetings at some of the regional experiment stations. On September 11, 2001, while at a meeting at the Virginia fruit experiment station, we were informed that an airplane had hit one of the Twin Towers in New York City. When the second tower was hit, it was decided to cancel the meeting after the noon meal. On the way home, while traveling east in Pennsylvania but near the Maryland border, we saw all kinds of security personnel near what was determined to be the “Alternate Pentagon.”

Rob Crassweller

Professor of Horticulture (1983-present)

I'm based at University Park but travel regularly to FREC to oversee projects. One time, I traveled to Biglerville using a Penn State fleet vehicle, and I had a flat tire. I did make it to Biglerville, and when I got there George Greene told me there was a tire repair place nearby, and that I should take his truck. So I'm there in the garage for about fifteen minutes, and in walks one of the fruit growers. He says to me, “What are you doing here? That's George's truck out there!” That's the community at Biglerville—they know your car, they know everyone.

When I was in graduate school at Ohio State, George Greene, Larry Hull, and Ken Hickey spent two or three days at our experiment station in Wooster, and that's when I met them. I was working on a project on pollinizers for crabapple trees, and I recommended that crabapple trees be planted at FREC. So I had a link with FREC before arriving at Penn State.

One other small thing that might be noteworthy is that I'm one of the few people not based at FREC to have a key to the facility!

John Halbrecht

Associate Professor Emeritus of Plant Pathology (1988-2014)

I met Ken Hickey when I was at Clemson University. I was on the faculty at Clemson, working with the nematologist on soybeans. Ken had come there on sabbatical. When the nematology position opened up here at FREC, I applied. I remember him telling me that the dean wanted a nematologist at University Park, but Ken pushed to have the position at Biglerville, because this is where the problems are. It would be difficult to run research programs from University Park. So that was the deciding factor, and I came to FREC in 1988.

I remember the early days—pre-PowerPoint—of preparing for extension meeting presentations. We would have to plan about two weeks ahead to get slides developed because you had to put each slide individually into the projector. Now you can put a talk together in a couple of hours.

Karen Weaver

Administrative Assistant (1985-present)

When I first started, Peg Shaffer, who hired me, gave me a steno pad and had me write down every single insect name alphabetically. That was in case I had to go back and reference it since I had never heard of these insects before. I enjoyed learning all the insect names and typing them out, but not always knowing how to pronounce them! After being here 33 years—although it doesn't seem that long because I love my job—I've learned some very interesting things.

When I first started, we had to create all the tables and letters on a typewriter, then run them off on a mimeograph machine with carbonized ink papers. We had to crank the machine, and the full-time secretary had to help me because it was a messy, two-person job.

Rodney Shaffer

Retired Technical Service Worker (1966-2004)

Every year at FREC we have a field day for the chemical company reps, when the researchers present the data they'd collected in the past year. In the late 1960s when the lab was at Arendtsville, one of the neighbors would, without fail, choose that day to clean out her shed. So we'd have all these visitors we wanted to present our best to, and there would be piles of junk stacked up next door. It drove the professors crazy, and they'd try their best to get the chemical reps away from the lab and out into the fields as quickly as they could!

Ken Mickley

Retired Technical Service Worker (1985-2016)

I kept a diary every day for almost all the years I worked at FREC. One day I wrote that I talked to George Greene about the condition of the trailer where we stored pesticides—the roof would leak when it rained, and the chemicals would get wet. I showed him the trailer and said, “Look what we have to work with here. Something needs to be done.” I wasn't sure what would happen, but Dr. Greene listened and before long we had a temporary roof over the trailer—and eventually we got a new pesticide building.

I also remember a lesson I learned when I first started



Eric Anderson (on planter) and Edwin Winzeler planting apple trees

at FREC. We had a small tractor that we called Shaky because the front end would shake really badly. One day we were picking apples, and when I put a full bin on the back of Shaky, the front end went up in the air, as it was known to do. Everyone had a good laugh about it. No one had said anything to warn me about it. I wrote in my diary that you learn the hard way sometimes. By the way, Shaky is still here and they still use it. It's practically an antique by now.

Eric Anderson

Technical Service Worker (2000-present)

I worked for 17 years on the commercial side of the fruit industry, and I thought I knew a few things about fruit growing. When I started at FREC, I came to find out they knew a lot more than I did. I was somewhat intimidated as a newbie. Jim May (retired technical service worker) was my boss when I started, and he had no problem letting me know if I made a mistake—having him for a boss was a great experience and I learned a lot from him.

One of my fondest memories is having the chance to visit research stations in other states. My first visit was to Virginia Tech with Dr. Hickey, and I remember having a long conversation with him in the car. We just started talking, and it was great to spend that time together. It was also interesting to see what they were doing at other stations and to get to know the technicians there. It was neat to see what results they got and compare with what we were doing.



New equipment is always a thrill. Freeman Showers takes delivery of a new orchard tractor

Freeman Showers

Technical Service Worker (2005-present)

Shortly after I started working at FREC, we were in Arendtsville helping Dr. Hull collect samples of insect pest injured fruit. I didn't know the professors would come out and help in the orchard, but Dr. Hull was there, up on a stepladder. All of a sudden I heard a big thud—someone had hit the ground and it was Dr. Hull. He was flat on his back. And I thought, my memory of this place is going to be Larry Hull breaking his back. But he just got up like nothing happened and went about his business.

The techniques for managing orchards are always changing. One time Jim Schupp took us out to the orchard to show us how he wanted the trees pruned, and Eric and I looked at each other and scratched our heads. It was a new technique that involved cutting off old limbs to let new ones grow, but to us it seemed like just chopping the hell out of the tree. We thought, there's no way this is going to work—it's going to kill the trees. But it turned out that the trees produced really well. I admitted to Dr. Schupp that we thought he was out of his mind—but that's research, and that's what the professors are here for.

Tim Baker

Farm Manager at FREC (1994-present; became farm manager in July 2017)

I remember one time when I wanted to talk to Larry Hull about using a certain kind of spray. I called him but I forgot he was at a conference in California. It

was four in the morning there, but Larry picked up the phone and answered my question. He said he was already up and working on his computer and it was okay. I did take some ribbing on that afterward, though. He would give me a hard time now and then, making sure I remembered my time zones. But Dr. Hull was always a perfectionist—he would rather take an early phone call and make sure things were done right.

Sarah Bardsley Capasso

Former Graduate Student Assistant Biosafety Officer University of Pennsylvania

At FREC, I studied bacterial spot of peach and nectarine. Specifically, I studied the epidemiology of bacterial spot and the development of antibiotic resistance in pathogenic and plant associated bacteria. Because some of my research was on commercial farms in the area, I was fortunate enough to interact with the tree fruit growers and gained a lot of on-farm experience.

I started at FREC as an undergraduate summer student in 2007. I went to Gettysburg College, which is less than ten miles away from FREC, so I was able to commute. I stayed on as lab tech during my senior year of college and started as an M.S. student in 2008. I completed that degree in 2010, then finished my Ph.D. in 2016.

I was one of the “privileged” ones to live in the trailers—I lived there during the summer from 2008 to 2014. I have lots of memories: the orange/brown shag carpeting, the faux brass fixtures in the bathroom that got really hot in the summer, the critters living under

the trailers, including mice and groundhogs. When the wind blew, the curtains fluttered inside—and that’s with the windows shut! We used to have bonfires between the two trailers, and I think it was the Schupps who started to replace the furniture after a while. We ceremoniously burned at least a couch and several chairs one summer.

At the end of the summer of 2014, a bad storm “did in” the trailers and they were condemned. As much as we complained, they did provide a cheap, convenient, local place to live. Members of FREC did their best to provide everything we needed.

In January 2016, the new grad student house was finally finished, and I was the first grad student to live there. I think the greatest thing about the new house was how much support came from the fruit grower community. They understood the importance of new graduate student housing in promoting growth and interest in FREC research. With the new housing, the FREC faculty no longer have to worry or scramble to house grad students during the summer, so they can take on more students or invite more visiting scholars, and more research gets done.

I always loved taking walks on the FREC property. I especially loved walking up to the entomology peach block. The view from up there is simply wonderful. It was always quiet and a great place to reflect.

FREC is full of amazing and caring people. The support and kindness I received from everyone really eased the stress of grad school.

Clayton Myers

Former Graduate Student

Senior Entomologist

EPA Office of Pesticide Programs

I worked at FREC as an undergrad with Greg Krawczyk and then decided to pursue a master’s degree (which later changed into a Ph.D.) in entomology, with Larry Hull as my major graduate adviser. Dr. Krawczyk was also on my graduate committee and we continued to have a great working relationship and friendship throughout my time as a grad student.

My Ph.D. research focused on host plant effects on the biology of the Oriental fruit moth—specifically, developmental differences of the pest on peaches vs. apples. Dr. Hull also delegated some aspects of his own research to grad students, to give us experience in study design and efficacy evaluation. He had chemical trials for tree fruit pests that were done under contract with chemical companies. This work gave me a real

appreciation for the insecticide research pipeline for eventual commercial development.

I lived in one of the trailers on site for my last three years as a grad student. Dr. Hull, who also lived close to the lab, used to tease that he expected to see my office light on late at night to ensure I was toiling away. I eventually got in the habit of leaving my light on periodically, even if I wasn’t in my office or lab! Despite our joking about the trailers—I had my share of problems, including skunks—the housing was quite adequate, and the cheap rent made it an excellent deal. Given the demands of field research and the occasional need to improvise on experiments in the orchards or at the lab at the last minute, it was a big benefit to live so close.

We always had a good rapport with the full-time farm staff at FREC. When I was there, each faculty member had their own hired hands to do plot set-ups, spraying, mowing, fruit sampling, harvesting, and station maintenance. These tended to be seasoned folks with lots of experience, and they provided real-world grounding to the exuberant grad students with pie-in-the-sky ideas. I think they enjoyed seeing the turnover of young students over the years, and we enjoyed their jokes and observations, and the way they would cut up with us and the FREC faculty. These were also the guys we always called if something was wrong with the trailers.

Morning coffee break was always a highlight too, bringing together the faculty, staff, grad students, and summer help. The social ties that were created were a cool part of working at FREC in the late 1990s and early 2000s—a lot of the grad students and summer students ended up hanging out together socially.

FREC was always well supported by the growers of PA. Grad students were encouraged to apply for SHAP grants over the years, and that bolstered our research efforts. I was always appreciative of SHAP’s support—it signaled that we had a very engaged, involved, and progressive industry community in Pennsylvania.

Gregory Clarke

Former Graduate Student

Field Market Development Specialist, Valent USA

Ken Hickey and Jim Travis were my advisors for both my master’s and Ph.D. studies (1988 and 1992). My master’s research—which I did in cooperating grower orchards near Arendtsville—was on the impact of tree canopy density on spray deposition in apple trees. My Ph.D. work, on the management of fire blight, involved



Greg Krawczyk and his graduate student, Deonna Soergel, presenting BMSB research at FREC Grower Field Day

studies evaluating the ability of aphids to spread disease, the use of copper compounds to reduce shoot blight, and the development of computer-aided decision making for control of the disease. Fire blight was not present in the FREC orchards at that time, so my research was done in cooperating orchards in Fairfield and Quincy.

Because Biglerville is my home town, FREC has had a significant impact on my life. I first became aware of FREC through my father's interaction with the faculty in his job as a pest management consultant for the agrochemical suppliers in town. My first visit to FREC was related to a Boy Scout merit badge. I met with George Greene one evening and he gave me a tour of the facility, told me about its work, and showed me European red mites under a microscope!

After my senior year at Biglerville High School, I got a summer job at FREC working on Dr. Hickey's summer crew. This was a fantastic experience and I recall being in awe of the graduate students there at the time: Lorraine Burkett, Norm Lalancette, Betsy Beers, and Debbie Breth. I worked on Dr. Hickey's summer crew for three summers, experiencing first-hand what it was to do field research, only to return to FREC as a graduate student beginning the summer of 1986.

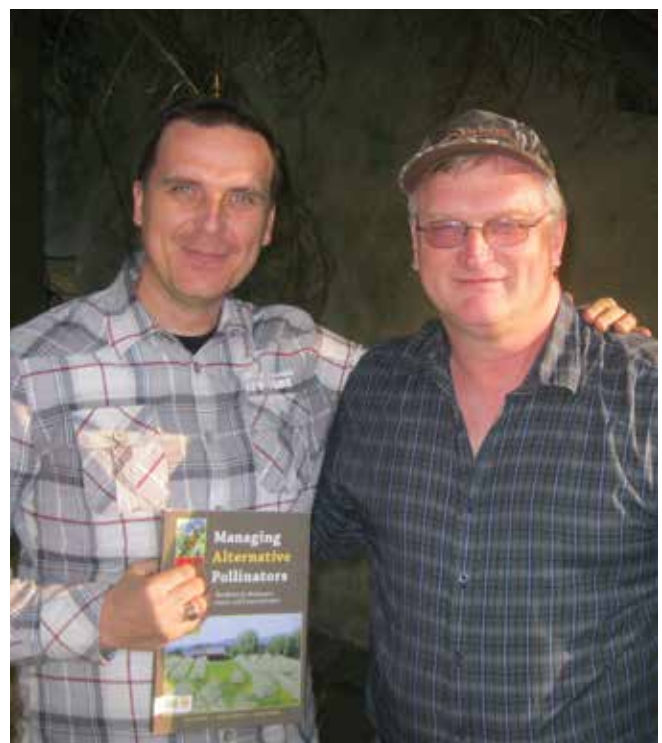
As both a summer crew member and then a grad student at FREC, I experienced the close and friendly relationships that are built there among the faculty, staff, grad students, and summer students. It's often difficult, tedious, hot work during the summer, but I have fond memories of the time there with everyone. The faculty

were good examples of folks who, though concerned with different disciplines, were genuinely interested in each other's work and had a common goal in solving problems for the fruit industry.

Thinking back to my time as a graduate student at FREC, I want to highlight the critical role that the permanent staff often plays in a student's work. The student, in cooperation with the faculty advisor, can devise, on paper, all sorts of innovative and creative research that then needs to translate into the real world of tractors, sprayers, trees, and plots. That's where orchard technicians become the teachers—patiently guiding a young scientist through the calibration of a sprayer or the safe use of a tractor or offering hard-earned guidance on when to trust a forecast and when to wait to apply treatment. Jim May and Marshall Garretson were incredibly helpful and patient in my early efforts. My guess is that all the graduate students that have passed through FREC have benefited from the experience, skill, and patience of these men and women.

Some of the impacts of FREC are intangible: the effect on lives in Adams County, the faculty and staff whose lives and livelihoods were centered there, the influence on summer students and their career or life decisions. I doubt those few people who first occupied that drafty building in Arendtsville could imagine what they were starting 100 years ago, but I think they would be pleased with what has been accomplished and amazed at how far-reaching the influence has been.

David Biddinger collaborates about mason bees for tree fruit pollination while on a USDA foreign agricultural service trip to Serbia





Long He, FREC Bio-Ag Engineer with his post doc Juan Feng



Alex McCoy, Research Technician with Long He, Frec Bio-Ag Engineer

CHAPTER 9

Future Directions: FREC scientists gaze into a crystal ball

From its inception, the mission of the Penn State Fruit Research and Extension Center has been to provide science-based solutions to fruit growers' most pressing problems. The previous chapters document the research and extension programs conducted, and the people who conducted them over the last 50 years. In this chapter, our scientists look into the future, both near-term and well beyond. Here are their responses.

Jim Schupp sees a bright future for the Mid-Atlantic fruit industry, and therefore the same is true for FREC. Consumer trends toward socially conscious spending (healthy, local, environmentally sound), and their growing willingness to spend disposable income on food experiences are here to stay.

Jim says that the current trend to intensive orchard systems will continue and accelerate, as a new generation of fruit growers contend with some well-known challenges: rising production costs and limited availability of skilled labor. Intensive orchard systems provide higher marketable yields, while increasing the efficiency of inputs, such as fertilizers, plant protectant chemicals, and labor. Irrigation will become increasingly important, and growers will be looking for better ways to monitor and manage ground water.

These systems will also be more adaptable to precision agriculture, mechanization, and automation. For the foreseeable future, horticulturists will continue to focus on key components of intensive orchards: tree size control, pruning and training, and crop load management for fruit quality. Jim sees an increasing role for horticulturists to assist scientists in other fields with integrating innovative plant materials, precision agriculture, and new plant protection/labor-saving technologies. This involvement will help speed grower adoption of these developments.

In the long term, horticulturists will become increasingly involved with testing and adoption of new plant material. This will become important when plant breeders begin to release genetically modified tree fruit varieties with important traits, such as self-dwarfing, self-thinning, fire blight resistance, and uniform fruit maturity.

Long He joined FREC as an assistant professor of agricultural and biological engineering in 2018. In partnership with Dr. Dana Choi at Penn State University Park, Long's program is focused on providing Pennsylvania's specialty crop producers with engineering solutions.

Long sees the development of mechanization and automation to reduce labor dependency as one of the most important needs for the tree fruit industry. Major topics in this area include fruit harvesting, branch pruning, tree canopy training, and autonomous robotic orchard platforms. To accomplish these tasks, research will be required on intelligent sensing and machine vision systems, mechanical systems, mechatronic systems, robotic manipulators, robotic end-effectors, and automatic controllers.

Long says that precision agriculture and decision support is a second focus area of future engineering research at FREC. The goal here, he says, is to optimize production inputs, such as fertilizers and irrigation, so as to obtain optimal yield and fruit quality, while reducing both production inputs and the unintended environmental impacts of orchard systems. FREC faculty will continue to conduct research into developing relevant technologies including automated precision irrigation systems, sensor-based decision support for orchard operations, and in-orchard wireless sensor networks for crop stress and health management.

Long predicts that mechanization and automation for tree orchard management (including harvesting) will make significant progress in the next 10 years, with mechanical/robotic harvesting and pruning most likely to happen in the near term as well. The focus will be on how to adapt automated field operations into autonomous platforms to become a fully automated system. Sensing technologies, including remote sensing, will also be widely studied in agricultural applications in next 10 years.

In the more distant future (i.e., 30 years), Long envisions similar systems to those being used for large field crops (corn). Research may include machine design and improvement for imperfect systems (a better machine system is always essential); intelligent systems designed by integrating automation and crop phenotyping (crop health or any other interesting information); and orchard multi-robot collaboration to achieve highly efficient operations, including ground and aerial robotics. Long says finding "perfect" solutions will always be a challenge that requires interdisciplinary efforts.

Greg Krawczyk notes three challenges that will compel the development and adoption of novel and effective approaches to insect management. These include rapidly occurring changes in fruit production systems; combined with the persistent influx of new invasive pests, plus frequent resurgence of older common insect pests. Greg says that for the foreseeable future, the strength of the extension entomology program will be based on close cooperation with fruit growers. Collaboration with horticultural scientists will be necessary to reassess the usefulness of the older pest management practices to better reflect changes in canopy and microclimate in intensive fruit orchards.

Greg predicts that using new technologies such as unmanned aerial vehicles, high-definition photography, availability of species-specific management tools, and computing power of handheld devices should allow for immediate, on-site pest identification. These technologies will also provide a support system for assessing threats and provide directions for the best practical solutions, tailored for specific needs of diverse groups of growers.

Greg thinks the ongoing development and testing of environmentally friendly and sustainable methods to manage insect pests, such as pheromone mating disruption, mass trapping, or species-specific bio-rational tools, could eliminate or at least significantly reduce the reliance on synthetic pesticides. The long-term goal is to create self-regulating, adaptive fruit systems, based on natural resources present in the environment.

David Biddinger predicts that FREC will become an increasingly more regional fruit research station in the future as fruit programs, personnel, and sometimes acreages continue to decline in the surrounding mid-Atlantic states. He sees the station expanding its mission to include small fruits, wine grapes, and nut crops in the future.

David notes that collaborations with non-governmental - nonprofit organizations such as the Xerces Society for Invertebrate Conservation that are concerned about specific issues such as pollinator conservation are likely to increase. Socially conscious consumers will stimulate the certification of eco-labels that conserve a specific natural resource (i.e., pollinators) or want to ban a group of pesticides perceived by the public as being harmful (i.e., neonicotinoids). This will further the development of standards that affect market accessibility by fruit growers, and applied researchers

and fruit growers will need a voice in developing market standards. These future concerns will mostly be over the environmental impacts of pesticide use. Hence, IPM is evolving into a new paradigm called Integrated Pest and Pollinator Management (IPPM), reflecting the current environmental concern over pesticides and pollinators and safety to biological control organisms. This concept will become increasingly important as a way to reduce pesticide use.

David sees that precision agricultural promises to reduce pesticide use and increase efficacy by more effectively targeting sprays to the pest or by more closely monitoring pest levels remotely. Imaging technology on fruit packing lines that could reliably eliminate fruit damaged or blemished by insects or diseases could also change current economic thresholds and hence pesticide rates and frequencies. For example, tolerating just a slightly higher amount of fruit injury from codling moth in the field that could be reliably removed at the packing line, could result in significant reductions in the number of applications, rates, or choice of insecticides. It would also facilitate the substitution of environmentally better pesticide alternatives such as pheromone mating disruption with greatly reduced insecticide inputs.

Both Greg and David agree on one certainty for the future of tree fruit production in the mid-Atlantic region: The frequency of invasive species introductions is increasing, as are the subsequent disruptions of IPM programs. David notes that with products being shipped all over the world, the introduction of invasive pests has increased to the extent that at least seven invasive pests become established in the United States each year. Recent invasive pests, such as brown marmorated stink bug, spotted wing drosophila, and spotted lanternfly are examples of how a new pest disrupts well-established IPM programs, often in a way that disrupts biological control of secondary pests such as mites, scale, or aphids. For the foreseeable future, entomologists will be on the hunt for the right pathogen or biological control agent(s) to control invasive species, as was the case with the gypsy moth.

Kari Peter predicts that the biggest challenge for growers in the future will be the influence of climate change, which she says will impact the prevalence and severity of certain diseases. Diseases, such as fruit rots, which were once primarily relegated to southern parts of the country will become “the norm” in the mid-Atlantic and Northeastern states. Increasing severe weather events during the season will have the potential to increase the risk of disease epidemics, such as fire blight. More erratic weather patterns will also be a problem. Frequent warm and wet conditions will put further strain on fungicide usage to keep apple scab and fruit rots in check. Consequently, fungicide resistance will continue to be a threat. Drought conditions will lead to tree stress, which ultimately can be the tipping point for susceptibility to destructive insects (borers) and trees succumbing to minor pathogens. However, it is not all doom and gloom: there is hope.

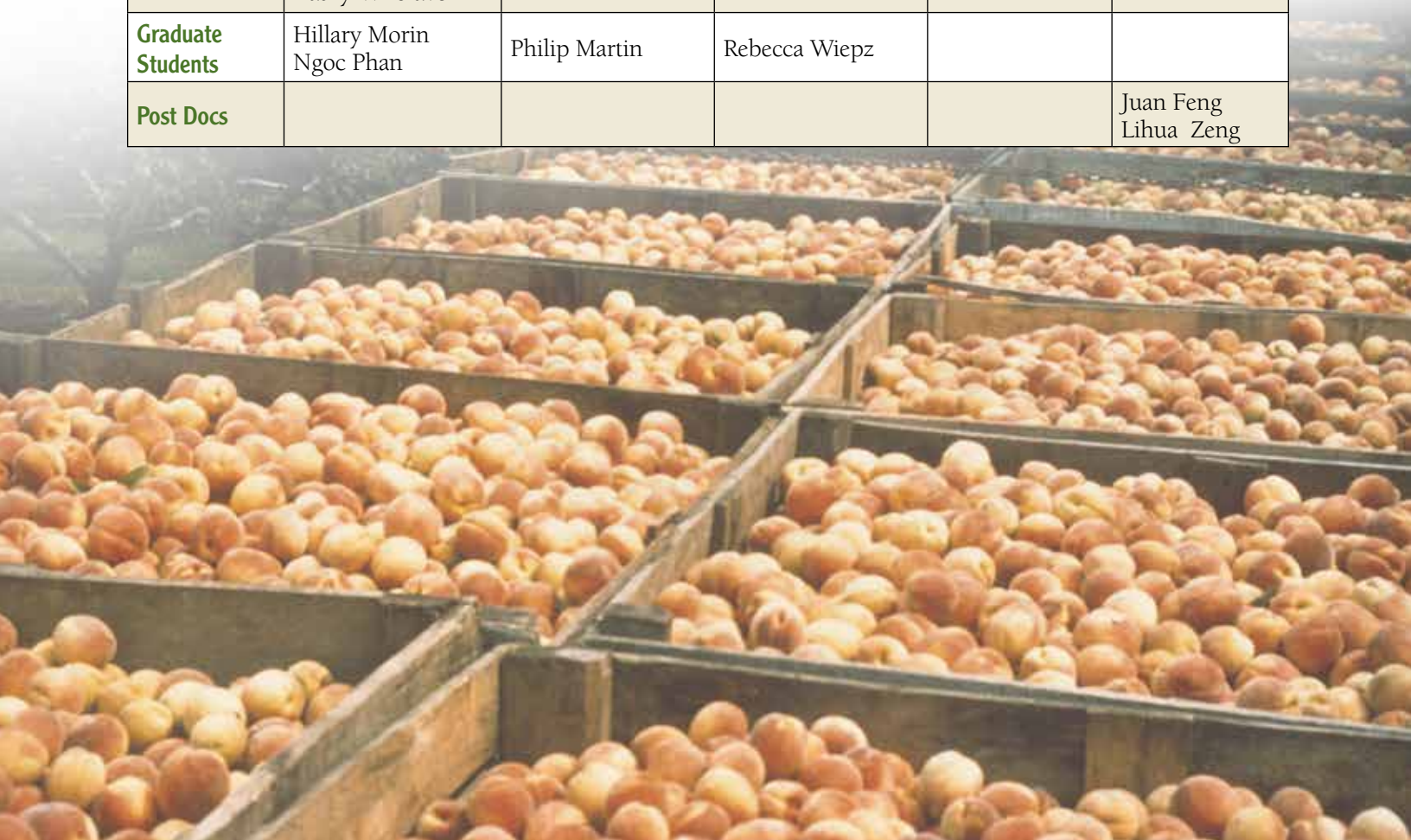
Kari believes challenges generate opportunities for creative sustainable solutions. The future of disease management will include enhanced disease diagnostic tools and control strategies. Sophisticated molecular tools, such as high throughput sequencing, quantitative and digital PCR, will become more affordable and commonplace. As a result, disease identification and mitigation measures will become timelier, especially for any potential emerging or invasive diseases. In addition, the use of unmanned aerial vehicles and specific imaging sensors will also have the potential to aid disease detection and diagnosis. Strategies for disease control will include optimizing disease resistance in cultivars and rootstocks through targeted breeding and gene editing; the use of nanotechnology for disease protection products; and the optimization of the phytobiome for tree health.

Fruit Research and Extension Center Personnel - 2018

Administrative Members	Tech Service Members	Administrative Assistant	Statistician
James R. Schupp Center Director Tim Baker Facilities and Farm Manager Deanne P. Bailey Administrative Support Coordinator	Eric Anderson Carl Bower S. Bashar Jarjour William Peters Freeman Showers Jody Stine Custodian - Part-time	Karen Weaver	Milton Loyer

Faculty and Staff by Home Department

	Entomology	Plant Pathology	Plant Science	Agr. Economics	Agr. Engineering
Faculty	David Biddinger Greg Krawczyk	Kari Peter	James Schupp		Long He
Staff	Claire Hirt Lot Miller Sharon Scamack Kathy Wholaver	Teresa Krawczyk Brian Lehman	Melanie Schupp Edwin Winzeler	Lynn Kime	
Graduate Students	Hillary Morin Ngoc Phan	Philip Martin	Rebecca Wiepz		
Post Docs					Juan Feng Lihua Zeng



FREC Timeline

- **1917** Penn State entomologist J. R. Eyer conducts studies in Flora Dale, then returns to State College
- **1918** Fruit Research Lab (FRL) opens in former Arendtsville Hotel
- **1922** College purchases old school house and relocates Drs Frost and Walton, with financial assistance from grower Chester Tyson.
- **1927** Dr. Walton's untimely death leaves Dr Frost the sole scientist at the Lab
- **1936** College closes Lab and recalls Dr. Frost. Growers appeal.
- **1937** College reopens FRL and expands it to four scientists.
- **1948** Lab relocates to Sheeley property in Arendtsville. 14.5 acres leased to Agricultural Experiment Station.
- **1953** University purchases the outstanding bonds, and takes ownership of the property.
- **1955** University purchases 70 acres in Biglerville.
- **1961-65** Growers work with Musselman foundation to provide \$350,000 matching grant. Additional land acquired by Penn State.
- **1963** Dr. Fred Lewis appointed Scientist-in-Charge
- **1966** Construction of Musselman Building begins
- **1971** Musselman Building officially opens
- **1972** Peg Marks appointed secretary
- **1974** FRL office in Arendtsville sold. Penn State purchases additional 39 acres of land near Arendtsville with proceeds.
- **1976** Dr. Ken Hickey appointed Scientist-in-Charge
- **1981** Trailers installed to house graduate students
- **1989** Controlled atmosphere storage building built with support from PDA
- **1998** Dr. Larry Hull appointed Scientist-in-Charge
- **2004** FREC administrative structure reorganized to be composed as:
Mr. Terry Salada appointed Farm Manager
Mrs Jean Morris, Admin Coordinator
Scientist-in-Charge, Dr. Larry Hull appointed Center Director
- **2005** Greenhouses replaced
- **2006** Dr. Jim Travis appointed Center Director
- **2010** Dr. Jim Schupp appointed Center Director
- **2011** Adjacent 45 acre farm in Biglerville acquired by CAS
- **2012** Mrs. Deanne Bailey appointed Administrative Coordinator
- **2016** New Graduate house opens; donated by the SHAP Endowment Committee
- **2017** Mr. Tim Baker appointed Farm Manager
- **2018** Dr. Long He joins Penn State as the first Ag Engineer to be located at FREC

Faculty Time Line

ENTOMOLOGY		
Dean Asquith	Professor	1948-1977
David Biddinger	Research Associate	2002-2008
	Associate Research Professor	2009-2017
	Research Professor	2018-Present
William Bode	Assistant Professor	1970-1983
Larry Hull	Professor	1977-2011
	Scientist-In-Charge	1998-2003
	Center Director	2004-2006
Greg Krawczyk	Post-Doctoral Scholar	1998-2000
	Research Associate	2000-2008
	Associate Research Professor	2009-2017
	Research Professor	2018-Present
PLANT PATHOLOGY		
John Halbrendt	Associate Professor	1988-2014
Kenneth Hickey	Professor	1976-2000
	Scientist-In-Charge	1976-1998
Bruce Jaffee	Assistant Professor	1984-1986
Henry Ngugi	Assistant Professor	2005-2011
Kari Peter	Assistant Professor	2013-Present
Richard Stouffer	Professor	1966-1983
James Travis	Professor	2002-2010
	Center Director	2006-2010
HORTICULTURE		
George Greene	Associate Professor	1970-2001
Laura Lehman	Senior Research Associate	1990-1996
Nathan Reed	Assistant Professor	2001-2004
Jim Schupp	Associate Professor	2004-2010
	Center Director	2010-Present
	Professor	2017-Present
Cynthia Barden	Post-Doctoral Scholar	1994-1999
	Assistant Professor	1999-2001
Agricultural Bio Engineering		
Long He	Assistant Professor	2018-Present

Appendix 1: Selected Publications of the Center, 1977-2018

Entomology: Research

- Agnello, A. M. A. Attanassov, **D. J. Biddinger**, L. J. Gut, J. K. Harper, M. J. Haas, W. M. Hogmire, **L. A. Hull**, L. F. Kime, **G. Krawczyk**, P. S. McGhee, J. P. Nyrop, W. H. Reissig, P. W. Shearer, R. W. Straub, R. T. Villanueva, and J. F. Walgenbach. 2009. Reduced-risk pest management programs for eastern U.S. apple and peach orchards: A 4-year regional project. *American Entomologist* 55(3): 184-197.
- Biddinger, D. J.**, N. K. Joshi, E. G. Rajotte, N. O. Halbrendt, C. Pulig, K. J. Naithani, and M. Vaughn. 2013. An immunomarking method to determine the foraging patterns of *Osmia cornifrons* and resulting fruit set in a cherry orchard. *Apidologie*, 44 (6): 738-749.
- Biddinger, D.**, T. Leslie, and N. K. Joshi. 2014. Reduced-risk pest management programs for Eastern U.S. peach orchards: Impacts on non-target arthropod parasitoids, predators and some select pests. *Journal of Economic Entomology*, 107(3): 1084-1091.
- Biddinger, D. J.** and E. G. Rajotte. 2015. Integrated pest and pollinator management – adding a new dimension to an accepted paradigm. *Current Opinion in Insect Science*, 10: 204-209.
- Biddinger, D. J.** and **L. A. Hull**. 1995. Effects of several types of insecticides on the mite predator, *Stethorus punctum* (Coleoptera: Coccinellidae), including insect growth regulators and abamectin. *Journal of Economic Entomology*. 88: 358-366.
- Biddinger, D. J.**, C. M. Felland, and **L. A. Hull**. 1994. Parasitism of tufted apple bud moth (Lepidoptera: Tortricidae) in conventional insecticide and pheromone-treated Pennsylvania apple orchards. *Environmental Entomology*. 23: 1568-1579.
- Biddinger, D. J.**, D. C. Weber, and **L. A. Hull**. 2009. Coccinellidae as predators of mites (Acarina), with emphasis on *Stethorini*. *Biological Control* 51(2): 268-283.
- Biddinger, D. J.**, E. G. Rajotte, J. Robertson, C. Mullin, J. Frazier, N. Joshi, M. Vaughn, and S. Ashcraft. 2013. Comparative toxicities and synergism of orchard pesticides to *Apis mellifera* (L.) and *Osmia cornifrons* (Radoszkowski). *PloS One* 8(9): e72587. doi:10.1371/journal.pone.0072587.
- Biddinger, D. J.**, **L. A. Hull**, and B. A. McPheron. 1996. Cross-resistance and synergism of azinphosmethyl resistant and susceptible strains of tufted apple bud moth (Lepidoptera: Tortricidae) to various insect growth regulators and abamectin. *Journal of Economic Entomology*. 89: 274-287.
- Bohnenblust, E.**, **L. A. Hull**, **G. Krawczyk**, and N. K. Joshi. 2011. Capture of two moth species in traps placed at different heights in sex pheromone treated apple orchards. *J. Entomol. Sci.* 46(3): 223-231.
- Code, A., J. Hopwood, M. Vaughn, M. Shepherd, **D. Biddinger**, E. Mader, S. Black, and C. Mazzacano. 2016. How neonicotinoids can kill bees: The science behind the role these insecticides play in harming bees. The Xerces Society for Invertebrate Conservation, Portland, OR. 88 p. <http://www.xerces.org/neonicotinoids-and-bees/>.
- Hull, L. A.** and **E. H. Beers**. 1990. Validation of injury thresholds for European red mite (Acari: Tetranychidae) on 'Yorking' and 'Delicious' apple. *J. Econ. Entomol.* 83(5): 2026-2031.
- Hull, L. A.** and **E. H. Beers**. 1985. Ecological selectivity: Modifying chemical control practices to preserve natural enemies. Chap 8 in *Biological Control in Agricultural IPM Systems*. pp. 103-122. Edited by M. A. Hoy and D. C. Herzog. Academic Press.
- Hull, L. A.** and **G. Krawczyk**. 2011. Long term effects of the area-wide pheromone mating disruption program on the control of two major fruit pests in Pennsylvania orchards. *Pennsylvania Fruit News* 91(2): 39-48.
- Hull, L. A.**, B. A. McPheron, and **A. M. Lake**. 1997. Insecticide resistance management and integrated mite management in orchards: Can they coexist? *Pestic. Sci.* 51: 359-366.
- Hull, L. A.**, **D. Asquith**, and **P. D. Mowery**. 1977. The mite searching ability of *Stethorus punctum* within an apple orchard. *Environ. Entomol.* 6(5): 684-88.
- Hull, L. A.**, **K. D. Hickey**, and **W. W. Kanour**. 1983. Pesticide usage patterns and associated pest damage in commercial apple orchards of Pennsylvania. *J. Econ. Entomol.* 76: 577-583.

- Joshi, N. K., E. G. Rajotte, K. J. Naithani, G. Krawczyk, and L. A. Hull. 2016. Population dynamics and flight phenology model of codling moth differ between commercial and abandoned apple orchards ecosystems. *Front. Physiol.* 7:408. doi: 10.3389/fphys.2016.00408.
- Joshi, N. K., T. Leslie, E. Rajotte, M. Kammerer, M. Otieno, and D. Biddinger. 2015. Comparative trapping efficiency to characterize bee abundance, diversity, and community composition in apple orchards. *Ann. Entomol. Soc. Am.* 1–15 (2015); DOI: 10.1093/aesa/sav057.
- Kammerer, M. A., D. J. Biddinger, E. G. Rajotte, and D. Mortensen. 2016. Local plant diversity across multiple habitats supports a diverse wild bee community in Pennsylvania apple orchards. *Environ. Ent.* 45(1): 32-38.
- Knight, A. L. and L. A. Hull. 1988. Area-wide population dynamics of *Platynota idaeusalis* (Lepidoptera: Tortricidae) in south-central Pennsylvania pome and stone fruits. *Environ. Entomol.* 17(6): 1000-1008.
- Krawczyk, G. and L. Shaak. 2017. Field experience with monitoring *Grapholita molesta* (Busck) in peach and apple orchards treated with mating disruption. IOBC-WPRS Bulletin 126: 79-81.
- Krawczyk, G., M. Zanelato Nunes, H. Morin, and L. Shaak. 2017. New endeavors in monitoring and management of brown marmorated stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae) in eastern United States. IOBC-WPRS Bulletin. 123: 50-56.
- Leskey, T. C., A. Agnello, J. C. Bergh, G. P. Dively, G. C. Hamilton, P. Jentsch, A. Khrimian, G. Krawczyk, T. P. Kuhar, D. Lee, W. R. Morrison III, D. F. Polk, C. Rodriguez-Saona, P. W. Shearer, B. D. Short, P. M. Shrewsbury, J. F. Walgenbach, D. C. Weber, C. Welty, J. Whalen, N. Wiman, and F. Zaman. 2015. Attraction of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) to traps baited with semiochemicals stimuli across the United States. *Environ. Ent.* 44(3): 746-756 <http://www.bioone.org/doi/abs/10.1093/ee/nvv049>.
- Myers, C. T., L. A. Hull, and G. Krawczyk. 2006. Comparative survival rates of Oriental fruit moth (Lepidoptera: Tortricidae) larvae on shoots and fruit of apple and peach. *J. Econ Entomol.* 99(4): 1299-1309.
- Myers, C. T., L. A. Hull, and G. Krawczyk. 2006. Seasonal and cultivar associated variation in the oviposition behavior of the Oriental fruit moth, (Lepidoptera: Tortricidae) adults and feeding behavior of neonate larvae in apples. *J. Econ Entomol.* 99(2): 349-358.
- Rice, K. B., C. Bergh, E. Bergman, D. Biddinger, C. Dieckhoff, G. Dively, H. Fraser, T. Garipey, G. Hamilton, T. Haye, A. Herbert, K. Hoelmer, C. Hooks, A. Jones, G. Krawczyk, T. Kuhar, W. Mitchell, A. Nielsen, D. Pfeiffer, M. Raup, C. Rodriguez-Saona, P. Shearer, P. Shrewsbury, D. Vengugopal, J. Whalen, N. Wiman, T. Leskey, and J. Tooker. 2014. Biology, ecology, and management of brown marmorated stink bug (*Halyomorpha halys*). *Journal of Pest Management.* Vol. 5 (3): DOI: <http://dx.doi.org/10.1603/IPM14002>.
- Soergel, D. C., N. Ostiguy, S. J. Fleisher, R. R. Troyer, E. G. Rajotte, and G. Krawczyk. 2015. Sunflower as a potential trap crop of *Halyomorpha halys* (Hemiptera: Pentatomidae) in pepper fields. *Environ. Entomol.* 44(6): 1581-1589 DOI: <http://dx.doi.org/10.1093/ee/nvv136>.

Entomology: Extension

Chaney, D., D. Cooley, G. Krawczyk, T. Leskey, and A. Tuttle. 2015. Ecological management of key arthropod pests in Northeast apple orchards. SARE Ag Innovation Series. Technical Bulletin. 20 pages. <http://www.sare.org/Learning-Center/Fact-Sheets/Ecological-Management-of-Key-Arthropod-Pests-in-Northeast-Apple-Orchards>.

Horticulture: Research

Baughner, T., J. Schupp, K. Lesser, R. M. Harsh, C. Seavert, K. Lewis, and T. Auvil. 2009. Mobile platforms increase orchard management efficiency and profitability. *Acta Horticulturae* 824: 361-364.

Crassweller, R., R. McNew, D. Greene, S. Miller, J. Cline, A. Azarenko, B. Barritt, L. Berkett, S. Brown, W. Cowgill, E. Fallahi, B. Fallahi, E. Garcia, C. Hampson, T. Lindstrom, I. Merwin, J. D. Obermiller, M. Stasiak, and G. M. Greene. 2007. Performance of apple cultivars in the 1999 NE-183 regional project planting. I. Growth and yield characteristics. *Journal of the American Pomological Society* 61(2): 84-96.

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Haeseler, C. W. and G. M. Greene. 1991. Response of Vidal 256 grapevines to the Geneva double curtain and six-cane Kniffin systems of training as grown in Southcentral Pennsylvania. *Journal of the American Pomological Society*. 45(1).

- Hampson, C., R. McNew, R. Crassweller, D. Greene, S. Miller, **L. Berkett**, M. E. Garcia, A. Azarenko, T. Lindstrom, M. Stasiak, W. Cowgill, and **G. M. Greene**. 2007. Performance of apple cultivars in the 1999 NE-183 regional project planting. III. Fruit sensory characteristics. *Journal of the American Pomological Society* 61(2): 115-126.
- Johnson, S., R. Anderson, W. Autio, B. Black, P. Byers, J. A. Cline, W. Cowgill, C. Chavex-Gonzales, W. Cowgill, R. Godin, **G. Greene**, M. Kaps, H. Larsen, T. Lindstrom, D. Miller, M. Newell, D. Ophardt, D. Ouellette, R. Parra-Quezada, R. Pokharel, G. Reighard, T. Robinson, **J. Schupp**, L. Stein, K. Taylor, C. Walsh, D. Ward, M. Warmund, and M. Whiting. 2011. Performance of the 2002 NC-140 cooperative peach rootstock planting. *Journal of the American Pomological Society* 65(1): 17-25.
- Kon, T. M., J. R. Schupp, H. E. Winzeler**, and R. P. Marini. 2013. Influence of mechanical string thinning treatments on vegetative and reproductive tissues, fruit set, yield, and fruit quality of apple. *HortScience* 48: 40-46.
- Krawczyk, G.** and **G. M. Greene**. 2002. The impact of plant growth regulator Apogee on insect pest populations and fruit quality. *Pennsylvania Fruit News* 82(2): 18-24.
- Marini, R. P., J. L. Anderson, W. R. Autio, B. H. Barritt, J. Cline, W. P. Cowgill, Jr., R. C. Crassweller, R. M. Garner, **A. Gaus**, R. Godin, **G. M. Greene**, C. Hampson, P. Hirst, M. M. Kushad, J. Masabni, E. Mielke, R. Moran, C. A. Mullins, M. Parker, R. L. Perry, J. P. Privé, G. L. Reighard, T. Robinson, C. R. Rom, T. Roper, **J. R. Schupp**, E. Stover, and C. Unrath. 2006. Performance of 'Gala' apple trees on 18 dwarfing rootstocks: ten-year summary of the 1994 NC-140 rootstock trial. *Journal of the American Pomological Society* 60(2): 69-83.
- Miller, S., R. McNew, R. Crassweller, D. Greene, C. Hampson, A. Azarenko, **L. Berkett**, W. Cowgill, E. Garcia, T. Lindstrom, M. Stasiak, J. Cline, B. Fallahi, E. Fallahi, and **G. Greene II**. 2007. Performance of apple cultivars in the 1999 NE-183 regional project planting. II. Fruit quality characteristics. *Journal of the American Pomological Society* 61(2): 97-114.
- Ngugi, H.** and **J. R. Schupp**. 2009. Evaluation of the risk of spreading fire blight in apple orchards with a mechanical string blossom thinner. *HortScience* 44: 862-865.
- Robinson, T. L., L. Anderson, A. Azarenko, B. H. Barritt, G. Brown, J. Cline, R. Crassweller, P. Domoto, C. Embree, A. Fennell, D. Ferree, E. Garcia, **A. Gaus, G. Greene**, C. Hampson, P. Hirst, E. Hoover, S. Johnson, M. Kushad, R.E. Marini, R. Moran, C. Mullins, M. Parker, R. Perry, J. P. Prive, G. Reighard, C. R. Rom, T. Roper, **J. R. Schupp**, M. Warmund, W. Autio, W. Cowgill, K. Taylor, and D. Wolfe. 2004. Performance of Cornell-Geneva rootstocks across North America in multi-location NC-140 rootstock trials. *Acta Hort.* 658: 241-245.
- Schupp, J. R., H. E. Winzeler, T. M. Kon**, R. P. Marini, **T. A. Baugher, L. F. Kime**, and **M. A. Schupp**. 2017. A Method for quantifying whole-tree pruning severity in mature tall spindle apple plantings. *HortScience* 52: 1233-1240.
- Schupp, J. R., T. M. Kon**, and **H. E. Winzeler**. 2012. 1-Aminocyclopropane carboxylic acid shows promise as a chemical thinner for apple. *HortScience* 47: 1308-1311.
- Schupp, J. R., T. A. Baugher**, S. S. Miller, R. M. Harsh, and K. M. Lesser. 2008. Mechanical thinning of peach and apple trees reduces labor inputs and increases fruit size. *HortTechnology* 18: 660-670.

Horticulture: Extension

Crassweller, R. M. and **G. M. Greene**. Part I, Cultural Information. In: *Pennsylvania Tree Fruit Production Guide 2002-2003*, College of Agricultural Sciences, The Pennsylvania State University State University, University Park, PA.

Schupp, J. R. and **T. Baugher**. 2017. Peach systems: Trials, tribulations, and looking to the future. <https://extension.psu.edu/peach-tree-pruning-trials-tribulations-and-looking-to-the-future>.

Schupp, J. R., T. A. Baugher, P. Heinemann, J. Liu, **E. Winzeler, T. Kon**, and **M. Schupp**. 2013. Labor efficient apple and peach production. *Compact Fruit Tree* 42(2): 17-19.

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Nematology: Research

Brown, D. J. F., **J. M. Halbrendt**, A. T. Jones, T. C. Vrain, and R. T. Robbins. 1994. Transmission of three North American nepoviruses by populations of four distinct species of the *Xiphinema americanum* group. *Phytopathology* 84: 646-649.

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Plant Pathology: Research

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Appendix 2: Graduate Student Published Thesis 1942 - Present

Year	Student Name	Degree	Thesis Title	Advisor Name	Discipline
1942	Tompkins, John	MS	Preliminary Studies on the Nutrition of the Peach. The Interrelation between Potassium, Nitrogen, and Phosphorous Composition of the Foliage and Other Growth Indices		Horticulture
1960	Hickey, Kenneth	PhD	The Sooty Blotch and Flyspeck Diseases of Apple with Emphasis on Variation within <i>Gloeodes pomigena</i> (Schw.) Colby	Lewis, Fred	Plant Pathology
1966	Smith, Donald	PhD	A Study of Certain Aspects of the Black Knot Disease of Plum and its Causal Agent, <i>Dibotryon morbosum</i> (Schw.) Theiss and Syd.	Lewis, Fred	Plant Pathology
1966	Greene, George M.	MS	The Effect of Several Factors on the Foliar Absorption and Translocation of Tris-(2-Diethylamino Ethyl) Phosphate, Trihydrochloride by Peaches, <i>Prunus persica</i> (L.) Botsch	Tukey, Loren	Horticulture
1968	Horsburgh, Robert	MS	A Survey of Arthropod Predators of Spider Mites on Deciduous Fruit Trees in South Central Pennsylvania	Asquith, D. Snetsinger, Robert	Entomology
1968	Wainwright, Robert	MS	The Development Morphology of <i>Dibotryon morbosum</i> (Schw.) Theiss. Et Syd. On Plum	Lewis, Fred	Plant Pathology
1969	Horsburgh, Robert	PhD	The Predaceous Mirid <i>Hyaliodes vitripennus</i> (Hemiptera) and its Role in the Control of <i>Panonychus ulmi</i> (Acarina: Tetranychidae)	Asquith, D. Snetsinger, Robert	Entomology
1971	Greene, George M.	PhD	The Influence of Harvest Maturity and Storage Environment on Several Characteristics of 'Delicious' Applesauce	Ritter, Marshall	Horticulture
1971	Colburn, Richard	PhD	The Predator <i>Stethorus punctum</i> (Coleoptera: Coccinellidae) and its Relationship to <i>Panonychus ulmi</i> (Acarina: Tetranychidae)	Asquith, D. Snetsinger, Robert	Entomology
1971	Wainwright, Stephen	PhD	Comparative Histopathology of the Resistant and Susceptible Response of <i>Pelargonium</i> spp. to Infection by <i>Xanthomonas pilargonii</i>	Nelson, P. E.	Plant Pathology
1976	Smith, Roger	MS	The Effects of Preharvest Growth Regulator Applications on the Quality of 'Delicious' Apples after Storage	Ritter, Marshall	Horticulture
1977	Hull, Larry	PhD	The Functional and Numerical Responses of <i>Stethorus punctum</i> (Coleoptera: Coccinellidae) to Densities of <i>Panonychus ulmi</i> (Acarina: Tetranychidae)	Asquith, Dean	Entomology
1977	Travis, Jim	MS	A Bioassay Study of Commercial Formulations of Several Insecticides on <i>Platynota idaeusalis</i>	Asquith, Dean	Entomology
1978	Royse, Daniel	PhD	Epidemiology and Control of Perennial Canker of Peach	Ries, Stephen	Plant Pathology
1979	Davis, Alice	MS	An Evaluation of Leaf Trap and Soil Dilution and Plating Techniques as Detectors of <i>Cylindrocladium scoparium</i> and <i>Rhizoctonia</i> spp. In Soils	Hickey, Kenneth	Plant Pathology
1979	Scalza, Janice	MS	The Effect of <i>Agrobacterium radiobacter</i> var. <i>Radiobacter</i> Strain 84 and Soil Fumigation on the Incidence of Crown Gall Induced by Strains of <i>A. Radiobacter</i> var. <i>Tumefaciens</i> in PA	Hickey, Kenneth	Plant Pathology
1980	Houck, Marilyn	PhD	Predatory Behavior of <i>Stethorus punctum</i> (Coleoptera: coccinellidae) in Response to the Prey <i>Panonychus ulmi</i> and <i>Tetranychus urticae</i> (Acarina: Tetranychidae)	Williams, Frederick	Ecology
1981	Starner, Van	MS	Seasonal Life History and Distribution of <i>Dysaphis plantaginina</i> within Apple Trees (Homoptera: Aphididae)	Hull, Larry	Entomology

Year	Student Name	Degree	Thesis Title	Advisor Name	Discipline
1982	LaLancette, Norman	MS	Comparison of Management Strategies by Quantification of Apple Powdery Mildew Epidemics	Hickey, Kenneth	Plant Pathology
1982	Parish, Priscilla	MS	Assessment of Secondary Infection of Apple Powdery Mildew in Experimental Plots	Hickey, Kenneth	Plant Pathology
1985	Beers, Elizabeth	PhD	The Effect of Cultivar and Crop Load on the Injury Caused by European Red Mite, <i>Panonychus ulmi</i> (Koch), to Apple	Hull, Larry	Entomology
1985	Berkett, Lorraine	PhD	Apple Powdery Mildew: Relation of Time of Application to Efficacy of a Sterol-Inhibiting Fungicide, the Effect of Late Season Secondary Mildew on Apical Bud Survival, and an Evaluation of a Management Tactic Against Late Season Secondary Mildew	Hickey, Kenneth	Plant Pathology
1985	LaLancette, Norman	PhD	Selection and Fitness of Benomyl-Sensitive and Benomyl-Resistant Subpopulations of <i>Venturia inaequalis</i> on Apple	Hickey, Kenneth	Plant Pathology
1985	Meagher, Robert	PhD	Spatial Patterns, Predictive Sampling, and Techniques to Measure Azinphosmethyl Resistance to <i>Platynota idaeusalis</i> (Walker) (Lepidoptera: Tortricidae)	Hull, Larry	Entomology
1986	Breth, Deborah	MS	The Effect of the Lesser Peach Tree Borer on the Expansion of Cytospora Canker on Peach Tree	Travis, Jim Hull, Larry	Plant Path
1986	Li, Shu Fang	MS	The Influence of Mineral Composition of Apple Tissue on Postharvest Storage Life and Quality of Canned Products of 'York Imperial' Apples	Beelman, Robert	Food Science
1988	Clarke, Gregory	MS	Canopy Density and Spray Deposition in Apple Trees	Hickey, Kenneth	Plant Pathology
1988	Kleiner, William	MS	Evaluation of Fungicides for the Management of Orange Rust on Black Raspberry	Travis, Jim	Plant Pathology
1990	Gaus, Alvan	PhD	The Influence of Growing Season Water Stress on the Physiology and Cold Hardiness of 'Redhaven' Peach Trees	Greene, George	Horticulture
1992	Carlini, Edward	MS	Enzymatic Profiles of Azinphosmethyl-Resistant and - Susceptible Tufted Apple Bud Moth, <i>Platynota idaeusalis</i> (Lepidoptera: Tortricidae)	McPheron, Bruce	Entomology
1992	Clarke, Gregory	PhD	Development of an Expert System for the Fire Blight Management in Pennsylvania, and the Role of Aphids and Copper in Blight Management	Hickey, Kenneth	Plant Pathology
1992	Truxall, David	PhD	The Requirements for Infection of <i>Arthuriomyces peckianus</i> on Black Raspberry	Travis, Jim	Plant Pathology
1993	Biddinger, David	PhD	Toxicity, Stage Specificity, and Sublethal Effects of Abamectin and Several Classes of Insect Growth Regulators to <i>Platynota idaeusalis</i> (Lepidoptera: Tortricidae) and <i>Stethorus punctum</i> (Coleoptera: Coccinellidae)	Hull, Larry Rajotte, Ed	Entomology
1994	Dominguex-Gill, Oscar	PhD	Diet Effects in Development, Azinphosmethyl Susceptibility, and Detoxification Enzyme Activity in the Tufted Apple Bud Moth <i>Platynota idaeusalis</i> (Walker) (Lepidoptera: Tortricidae)	McPheron, Bruce	Entomology
1995	Truxall, David	PhD	An Environmentally Driven Model for Grape Black Rot Scouting and the Impact of Environmental Data Differences on Disease Control Decision Making	Travis, Jim	Plant Path
1997	Ibbotson, Holly	MS	Susceptibility of Peach and Nectarine Fruit of <i>Monilinia fructicola</i> at Different Developmental Stages	Hickey, Kenneth	Plant Pathology
1997	Lake, Amy	MS	Searching for Resistance-Associated Fitness Costs in a Field Population of the Tufted Apple Bud Moth, <i>Platynota idaeusalis</i> (Walker) (Lepidoptera: Tortricidae)	Hull, Larry McPheron, Bruce	Entomology

Year	Student Name	Degree	Thesis Title	Advisor Name	Discipline
1998	Carlini, Edward	PhD	In Vivo and In Vitro Effects of Plant Allelochemicals on Glutathione Transferase Expression and Function	McPheron, Bruce	Entomology
1998	Northover, Philip	MS	The Relationship of the Number of Wetting Periods and Accumulated Degree-Days to Sporulation of <i>Guignardia bidwellii</i> (Ellis) Viola and Ravoz in Vineyards	Travis, Jim	Plant Pathology
2000	Gugino, Beth	MS	Identification of Soil-Borne Pathogens Associated with Grapevine Decline in Six Vineyards from Central, Southcentral, and Southeastern Pennsylvania	Travis, Jim	Plant Pathology
2001	Robertson, Shawn	PhD	The Role of Pheromones and Larval Behavior in the Management of Tufted Apple Bud Moth, <i>Platynota idaeusalis</i> (Lepidoptera: Tortricidae) in Apples	Hull, Larry	Entomology
2001	Chen, Hong	PhD	Population Dynamics of Apple Maggot and Flowering Dogwood Flies (Diptera: Tephretidae) in Southcentral Pennsylvania and their Population Genetic Structure Across the Northeastern United States	McPheron, Bruce	Entomology
2002	Ellis, Nicholas	MS	Efficacy and Integration of Two Novel Mating Disruption Technologies and Biorational Insecticides for the Oriental Fruit Moth [<i>Grapholita molesta</i> (Busck)] and Leafrollers in Apples and the Response of Oriental Fruit Moth to Delayed Mating	Hull, Larry	Entomology
2004	Gugino, Beth	PhD	The Pathogenicity of <i>Cylenrocarpon dittractans</i> , a Factor in Grapevine Decline and its Potential Management Using Composted Soil Amendments	Travis, Jim	Plant Pathology
2005	Myers, Clayton	PhD	Orchard Host Plant Effects on the Survival, Development, Reproduction, and Behavior of the Oriental Fruit Moth, <i>Grapholita molesta</i> (Busck)	Hull, Larry	Entomology
2006	Ellis, Nicholas	PhD	Flight Phenology and Dispersal of <i>Grapholita molesta</i> (Busck) as Affected by Rubidium Enrichment and Orchard Hosts	Hull, Larry	Entomology
2009	Bohnenblust, Eric	MS	Mating Disruption and Monitoring of Codling Moth (<i>Cydia pomonella</i> L.) and Oriental Fruit Moth (<i>Grapholita molesta</i> Busck) in Pennsylvania Apple Orchards	Hull, Larry	Entomology
2010	Pfeufer, Emily	MS	Status of Resistance to Sterol-Demethylation Inhibiting Fungicides in Populations of <i>Venturia inaequalis</i> from Pennsylvania Apple Orchards	Ngugi, Henry	Plant Pathology
2010	Bardsley, Sarah	MS	Studies on the Epidemiology and Management of Bacterial Spot of Peach and Nectarine in Pennsylvania	Ngugi, Henry	Plant Pathology
2011	Joshi, Neelendra	PhD	Codling Moth, <i>Cydia pomonella</i> (L.) Edology and Phenology Model Development for Pennsylvania Apple Orchards	Hull, Larry Rajotte, Ed	Entomology
2012	Kon, Thomas	MS	Influence of a Mechanical String Thinner on the Physiology of Apple	Schupp, James	Horticulture
2014	Soergel, Deonna	MS	Daily Behavior and Trap Cropping of the Brown Marmorated Stink Bug (<i>Halyomorpha halys</i>) in Pennsylvania Agricultural Systems	Krawczyk, Greg	Entomology
2016	Shugrue, Sarah	MS	Pesticide Use, Habitat Manipulation, and Management Changes as Factors in Pollinator Sustainability in Pennsylvania Apple Orchards	Biddinger, David	Entomology
2016	Kon, Thomas	PhD	Evaluation of Chemical and Thermal Blossom Thinning Strategies for Apple	Schupp, James	Horticulture
2016	Bardsley Capasso, Sarah	PhD	Antibiotic Resistance in Pennsylvania Stone Fruit Orchards	Ngugi, Henry Jimenez-Gasco, Maria del Mar	Plant Pathology

History and Accomplishments of the Penn State Fruit Research and Extension Center, 1977-2018

*This publication is dedicated to the many wonderful staff and students
who have served at the FREC during its first century.*

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Associate Dean Gary Thompson, Tara Baugher and summer student Ryan Hilton at Grower Field Day





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