Title of the subproject: Abscission management and managing abscission agent repository.

Participants: Jackie Burns (PI), Sunny Liao, Igor Kostenyuk, Bob Ebel, Fritz Roka, Jim Syvertsen

Progress: Distribution of viable Candidatus Liberibacter asiaticus (CaLas) in sweet orange fruit and leaves (‘Hamlin’ and ‘Valencia’) and transcriptomic changes associated with huanglongbing (HLB) infection in fruit tissues are reported. Viable CaLas was present in most fruit tissues tested in HLB trees, with the highest titer detected in vascular tissue near the calyx abscission zone. This likely contributes to premature fruit drop measured in HLB-infected fruit. Transcriptomic changes associated with HLB infection were analyzed in flavedo (FF), vascular tissue (VT), and juice vesicles (JV) from symptomatic (SY), asymptomatic (AS), and healthy (H) fruit. In SY ‘Hamlin’, HLB altered the expression of more genes in FF and VT than in JV, whereas in SY ‘Valencia’, the number of genes whose expression was changed by HLB was similar in these tissues. The expression of more genes was altered in SY ‘Valencia’ JV than in SY ‘Hamlin’ JV. More genes were also affected in AS ‘Valencia’ FF and VT than in AS ‘Valencia’ JV. Most genes whose expression was changed by HLB were classified as transporters or involved in carbohydrate metabolism. Physiological characteristics of HLB-infected and girdled fruit were compared to differentiate between HLB-specific and carbohydrate metabolism-related symptoms. SY and girdled fruit were smaller than H and ungirdled fruit, respectively, with poor juice quality. However, girdling did not cause misshapen fruit or differential peel coloration. Quantitative PCR analysis indicated that many elected genes changed their expression significantly in SY flavedo but not in girdled flavedo. Mechanisms regulating development of HLB symptoms may lie in the host disease response rather than being a direct consequence of carbohydrate starvation.

Dr. Igor Kostenyuk resigned his position, and with this, the management of the CMNP repository was handed over to the FDOC under Dr. Dan King’s supervision. Included in the transfer was the technical and formulated CMNP materials managed by us for over 6 years. Before Dr. Kostenyuk resigned, we returned the radiolabelled CMNP materials to vendors as directed by AgroSource, Inc., our private partner in registration of the CMNP material.

Impact: We showed that although reduced carbohydrate accumulation in HLB fruit could be a consequence of dysfunctional sieve elements in the phloem, disruption of cellular carbohydrate metabolic regulation and transport could be another contributing factor to carbohydrate imbalance. Carbohydrate imbalance and the presence of CLas in the fruit abscission zone contribute to premature fruit abscission. Numerous genes involved in carbohydrate transport and metabolism changed expression in ‘Hamlin’ and ‘Valencia’. In fact, several genes involved in starch metabolism that changed expression after girdling were altered in HLB and girdled FF, supporting the hypothesis that in addition to disrupted carbohydrate transport in phloem, HLB and fruit stem girdling also induce major changes in the cellular metabolism of carbohydrates. Such changes can disrupt
fruit growth and lead to small fruit size typical of HLB-affected fruit and fruit from girdled stems. Since girdling did not result in misshapen fruit or irregular peel color typical of HLB-affected fruit and several representative genes for specific pathways were affected by HLB but not girdling, the mechanisms regulating the development of these symptoms may lie in the host disease response rather than being a direct consequence of carbohydrate starvation.

Publications:


Note: JK Burns will no longer be conducting active research in abscission and harvesting, but remains committed to successful implementation of the citrus mechanical harvesting system through administrative duties. It has been a pleasure working with our IFAS research and outreach group, and with the citrus industry growers and cooperators.

For further information please contact Jackie Burns (jku@ufl.edu) 863-956-1151
Objective(s) Pursued (Priority Topics):

Objective 1: Evaluate standard fruit and juice quality and yield following the application of CMNP application trials for Hamlin and Valencia varieties and storage of up to 7 days (continuation of 2010).

Objective 2: Evaluate the fate of coliforms and E. coli sprayed onto Hamlin and Valencia trees in the field until populations can no longer be detected.

Detailed Accomplishments in 2011-12:

Objective 1:

This study evaluates the standard juice quality and yield of fruit harvested following the application of CMNP and storage for up to 7 days to determine if CMNP application has any effect on these parameters. For each replicate (two Hamlin and two Valencia), harvested fruit were collected. Fruit were then divided into treatment groups and stored for up to 7 days. Treatment groups included storage at: 10, 20, 30°C and ambient conditions (with temperature and humidity monitors). Within each group of fruit, 5 non-defective fruit were randomly selected from each group at each sample point for analysis. Quality analysis, still underway and not reported here include °Brix, Acid, % oil, and color. Additional measurement of puncture and crush forces, and decay were also collected and are still being analyzed.

To enumerate microorganisms, 30 ml of buffer were added and the rub/shake/rub technique was used to remove microorganisms from the fruit surface. Microbial analysis included total aerobic plate count (APC) on plate count agar (PCA), and acidophilic organisms count (AOC) on orange serum agar (OSA). Results of trials completed are reported in Tables 1 (December, 2011 Hamlin), 2 (January, 2012 Hamlin), 3 (March, 2012 Valencia) and 4 (May, 2012 Valencia) as log colony forming units (CFU) per orange. In general, no differences were seen in total APC or AOC microflora on orange surfaces with or without CMPN application during storage at any temperature.

No Alicyclobacillus was isolated from any of the fruit.

Analysis of quality parameters, puncture and crush forces, and decay is ongoing.
Table 1. Fruit surface microflora in log colony forming units (CFU) per orange one trial of Hamlin fruit harvested in December with or without CMNP application (n = 5 oranges) during storage of up to 7 days at 10, 20, 30°C or under ambient conditions.

<table>
<thead>
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Table 2. Fruit surface microflora in log colony forming units (CFU) per orange one trial of Hamlin fruit harvested in January with or without CMNP application (n = 5 oranges) during storage of up to 7 days at 10, 20, 30°C or under ambient conditions.

<table>
<thead>
<tr>
<th>Temp (°C)</th>
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Table 3. Fruit surface microflora in log colony forming units (CFU) per orange one trial of Valencia fruit harvested in March with or without CMNP application (n = 5 oranges) during storage of up to 7 days at 10, 20, 30°C or under ambient conditions.

<table>
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Table 4. Fruit surface microflora in log colony forming units (CFU) per orange one trial of Valencia fruit harvested in May with or without CMNP application (n = 5 oranges) during storage of up to 7 days at 10, 20, 30°C or under ambient conditions.

<table>
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<tr>
<th>Temp (°C)</th>
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<th></th>
<th>CMNP</th>
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<td></td>
<td>APC</td>
<td>AOC</td>
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Objective 2:
To evaluate the fate of coliforms and E. coli that may be sprayed onto oranges close to harvest if low microbial quality water is used to apply the abscission agent, low microbial quality water (ca. 6 log CFU/ml coliforms) was applied to Valencia trees, in March, April, May, and June. Three replicates of 10 oranges each, from each of three trees (n =
90 fruit) were be removed immediately prior to and following spraying, and at 2 and 6 h following application, and approximately every other day until *E. coli* was no longer detectable by enrichment, or equivalent to control trees.

Results of trials completed are reported in Tables 5 (March, 2012), and 6 (April, 2012) as colony forming units (CFU) or most probable number (MPN) per orange. For the final two experimental dates (May and June, 2012) data collection and analysis is ongoing. Based on current data it appears *E. coli* populations can be detected on fruits between 12 and 17 days after application.

Table 5. Fruit surface coliform and *E. coli* populations in log colony forming units (CFU) or Most Probable Number per orange. Trial of Valencia fruit harvested in March with or without low microbial quality water application (n = 90 oranges; 3 x 10 fruit from each of 3 trees).

<table>
<thead>
<tr>
<th>Time (hour)</th>
<th>Coliforms</th>
<th><em>E. coli</em></th>
<th>Coliforms</th>
<th><em>E. coli</em></th>
</tr>
</thead>
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<tr>
<td>Pre Spray</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>0</td>
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<td>5.1 ± 0.1</td>
<td>3.2 ± 0.6</td>
<td>0.3 ± 0.6</td>
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<td>2</td>
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<td>6</td>
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<td>24</td>
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<tr>
<td>48</td>
<td>2.8 ± 0.3</td>
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<tr>
<td>72</td>
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<td>144 (6 d)</td>
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<td>1.4 ± 1.4</td>
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</table>

Table 6. Fruit surface coliform and *E. coli* populations in colony forming units (CFU) or Most Probable Number per orange. Trial of Valencia fruit harvested in April with or without low microbial quality water application (n = 90 oranges; 3 x 10 fruit from each of 3 trees).

<table>
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<tr>
<th>Time (day)</th>
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<th><em>E. coli</em></th>
<th>Coliforms</th>
<th><em>E. coli</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Spray</td>
<td>1.7 ± 0.4</td>
<td>&lt; -0.1</td>
<td>1.5 ± 0.8</td>
<td>&lt; -0.1</td>
</tr>
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Areas where progress exceeded expectations:

In addition to the work discussed above, a hand harvesting CMNP trial was done at Lykes Camp Mack grove in late April. We sprayed 3 rows (~150 trees) at 300 ppm and 3 rows at 200 ppm on April 27 (1-2 pm). Three untreated rows served as controls. We used a standard air blast sprayer for the application.

Fruit detachment forces were:

- Control - 110.7 N
- 300 ppm - 69.9 N
- 200 ppm - 54.2 N.

This equals a 37% and 51% reduction in fruit detachment force for the 300 and 200 ppm treatments, respectively. We sampled 20 fruit from each treatment from 5-6 trees from the middle row of each plot.

We had a 15 person crew. The control plot was harvested first followed by the 300 ppm plot and then the 200 ppm plot. Fatigue was definitely an issue on the 200 ppm plot. The control and 300 ppm plots were complete by 1:30 pm. It took until nearly 5:30 pm to finish the 200 ppm plot.

The numbers work out to: Control - 2780 man minutes to harvest 340 boxes = 8.17 min/box; 300 ppm - 2328 man minutes to harvest 333 boxes = 6.99 min/box (a 14.5% increase in harvesting rate; 200 ppm - 2872 man minutes to harvest 330 boxes = 8.70 min/box.

Initial assessment of this trial is that it was a success. We demonstrated that CMNP can improve the efficiency of a harvest crew. However, there are issues to figure out for future trials, chief among them how to design the trial to NOT disrupt the natural work patterns of the crew and how to account for fatigue. The very modest (30 second) increase in time per box on the 200 ppm plot demonstrates that CMNP was effective. We estimate that the crew would have been at least 1 minute or more slower per box by the late afternoon if the fruit had not been sprayed.

Areas where progress didn’t meet expectations:

Initial plans included low quality water trials in the fall and winter. Due to timing issues these trials were not conducted. Additionally, due to extended survival of organisms on fruit surfaces, times between samplings needed to be expanded due to not enough fruit present on the trees.

Impact of accomplishments towards overall goals of funding:

There is practical importance to the surface microflora of oranges delivered to the processor. Contamination of raw materials is listed as the second most serious food safety problem in the food processing industry, after deficiencies in employee training. However, incoming fruit to citrus processing plants is typically washed and sanitized, and the vast majority (>98%) of Florida-processed orange juice is pasteurized or similarly treated to inactivate spoilage enzymes and to microbiologically stabilize the product. Wider adoption of mechanical harvest/pick up systems will be somewhat determined by the quality of fruit delivered to the processor. This quality includes potential microbiological contamination as well as the typical measures of machine yield and efficiency, and economics. For these reasons, it is important to collect fruit and juice
microbiological quality information for any harvest/collection system that promises commercial viability.

Presentations associated with 2011-12 efforts:
Results will be presented at the 2011 Florida State Horticultural Society.

Publications from 2011-12 efforts:

Next steps:
Objectives for the 2010/2011 season will involve continuing to evaluate fate of indicator organisms on fruit following the application of low microbial quality water at different levels over 9 months. A separate set of experiments led by Spann will be established to continue hand harvesting work.
IFAS Citrus Initiative
Research and/or Extension progress report 2011-12

Investigator(s):
PI – Robert C. Ebel
Co-PIs – Fritz Roka, Kelly Morgan

Priority area addressed: (Abscission management and harvester efficiency)

Objective 1: Develop best management practices for application of the abscission agent CMNP.

Objective 2: Develop best management practices for harvester settings utilizing the abscission agent CMNP to maximize harvest efficiency.

Objective 3: Enhance understanding of the mode of action of CMNP in promoting abscission.

1) Why this work is critical and needed

Labor shortages and cost have compelled the sweet orange industry to seek an alternative way to harvest the crop. Mechanical harvesters are currently being used, but must stop before the end of the season due to the newly developing crop. The abscission agent CMNP has proven effective at increasing fruit removal and as a result the industry is proceeding with its registration for use on citrus. Economic analysis estimate that CMNP will lower cost for mechanical harvesting. An Experimental Use Permit has been applied for with the EPA to spray 9,000 acres of sweet oranges. In preparation for commercial availability of CMNP, this research program is designed to understand the factors that interact with CMNP with the longterm goal of developing recommendations for its use on sweet oranges.

2) Objectives and accomplishments

Objective 1: Develop best management practices for application of the abscission agent CMNP. We have developed an empirical model to predict decline in fruit detachment force (FDF) and pre harvest fruit drop for sweet orange by CMNP based on air temperature. This data was presented at the ASHS meetings in September 2011.

Objective 2: Develop best management practices for harvester settings utilizing the abscission agent CMNP to maximize harvest efficiency. A major field study was initiated in 2011 to evaluate the use of CMNP on the late season Valencia harvest by self-propelled canopy shakers. The specific objectives are: 1) to determine the interaction of CMNP application and 2 canopy shaker frequency settings, the setting used by commercial operators, and a lower setting that was 40 cpm less than the higher setting, on fruit removal, fruit recovery, deck loss, and gleaning, 2) to determine the carry over effect on yield for each treatment in comparison to the controls.

This study was replicated 4 times beginning in early May, 2011 and conducted every 2 weeks. CMNP was applied at the maximum label rate (300 ppm and 300 gal/acre) and the trees harvested 4 days later. Approximately 130 trees per treatment were used. The machine settings varied for each harvest in consultation with the
commercial harvest managers, but the lower setting was always 40 cpm less than the higher setting. The tractors were run at 1.0 mph for all trials. There was also a hand-harvested control that was not treated with CMNP. Data collected included diameter of newly developing fruit and weights of preharvest fruit drop, fruit removed, fruit not captured by the deck during the harvesting process, and fruit left in the tree that had to be gleaned. This study is currently being repeated on the same set of trees.

2011 results: The immature fruit were slightly under 1 inch in diameter, the diameter commercial mechanical harvesting normally ends, for the first trial and have grown to 1.5 inch by the early June trial. A final trial is planned for June 11th (spray) and June 14th (harvest). Fruit drop in these trials has been small (less than 3% of the total yield). Fruit removal has ranged from 55-81% for unsprayed trees and 76-90% for trees treated with CMNP. Deck loss, that is fruit not captured by the catch frame of the harvesters, has been less than 8% in all trials, with no consistent results with respect to CMNP application. Removal of immature fruit was slightly higher for the higher canopy shaker frequencies, as would be expected, but was not affected by CMNP application. These results indicate that CMNP at lower canopy shaker frequency provides good removal that will allow later mechanical harvesting of Valencia, although the effect on yield loss will have to be determined next year.

2012 results: The immature fruit were much smaller than 1 inch in diameter for the first trial but were close to 1 inch in diameter by the second trial. The third trial has been completed but data not yet analyzed. The fourth trial will be conducted in less than two weeks. FDF was reduced in CMNP treated trees by almost 50% in the first trial and over 80% in the second trial. Fruit drop was low in the first trial but high in the second. Fruit removal of CMNP treated trees was higher than non-treated trees in both trials. Yields of mechanically harvested trees compared to hand harvested trees were variable. There appeared to be a slight yield reduction in the first trial, but no yield reduction by mechanical harvesting in the second trial.

Objective 3: Enhance understanding of the mode of action of CMNP in promoting abscission. This is a new project and is designed to increase our understanding of the mode of action of CMNP, which we believe may help in development of best management practices. In preliminary work we determined that CMNP treated fruit produce nitrous oxide (NO) and that exogenously applied NO to sweet oranges at concentrations similar to CMNP applied in the field produced similar reductions in FDF. It is our hypothesis that ADH in the flavedo tissues catabolizes CMNP to produce nitric oxide (NO), a known signal that induces an increase in production of jasmonic acid, which is transported to the abscission zone causing abscission. The PhD student working on this project at the FSHS meetings in June will present the results of this work.

We have also determined the effects of CMNP on oxidative metabolism and reactive oxygen species (ROS). CMNP promotes production of H₂O₂ and alters enzymes involved its metabolism. This work is continuing, especially with special reference to how temperature affects this important pathway that is known to produce signals that promote abscission.
3) Research gaps

Objective 1: The models we have developed to predict the decrease in FDF and fruit drop by CMNP and air temperature have been determined empirically and with data that does not span the entire temperature range that could be encountered commercially. We need to verify the models based on a mechanistic understanding of how CMNP promotes abscission as discussed in Objective 3. This work is continuing, however, in light of the probability that CMNP will be registered next Feb., we will publish the empirical model if we are not able to determine the mechanistic disruption of loosening by CMNP when air temperatures are low.

Objective 2: We need to continue the CMNP x canopy shaker frequency study of the late season Valencia’s to evaluate the carry over effect on yield, as well as to continue to build a database that allows us to determine how late in the Valencia season trees can be mechanically harvested using CMNP without affecting yield.

Objective 3: Understanding the mechanism of CMNP and especially how air temperature affects efficacy is vital to developing best management practices. We need to continue to determine if ADH produces NO with CMNP as a substrate, whether this reaction is temperature sensitive and if the temperature profile is similar to that of CMNP, and whether temperature affects uptake of CMNP. We also need to determine how temperature interacts with oxidative metabolism, especially in regards to the production of JA, and to determine if JA is the signal that stimulates formation of the abscission layer.

4) Employees being supported on CI funds and their roles in meeting objectives.

a) PhD student: her responsibility is to work on the aspects of the mechanism of CMNP, especially those related to NO and ADH activity (Objective 3)

b) Postdoc: his responsibility is to work on the aspects of the mechanism of CMNP, especially those related to oxidative metabolism (Objective 3)

c) Biological Scientist: This position is only partly funded by CI. His responsibilities include preparing equipment and materials and assisting in the field studies. Funding for his Teams position has been requested. He is vital support to the late season trials due to his organizing and leadership abilities in preparing and executing the study.

Publications and presentations related to this work

**S. Sharma, R.C. Ebel, and N. Kumar. 2012.** Production of nitrous oxide by the abscission agent CMNP and its impact on citrus fruit loosening. Florida State Horticulture Society, Delray Beach, FL, June 3-5.

**R.C. Ebel, F. Roka, and K. Morgan. 2012.** Field research with CMNP for loosening sweet oranges as an aid to mechanical harvesting. International Mechanical Harvesting Symposium, Lake Alfred, FL, April 2nd - 4th.


Title:
Machine Enhancement for Citrus Mechanical Harvesting Equipment

Investigator(s):
Reza Ehsani

Objective(s) Pursued:
Objective 1: Improve engineering solutions to reduce debris in mechanically harvested fruit

Detailed Accomplishments in 2011-2012:
Task 1- To make improvements to the pull-behind debris removal platform modified during 2010-2011.
Further improvements were made to the debris removal machine that was redeveloped and modified during 2010-11. Enhancements were made to improve the efficiency of the operation, such as: (i) Added output conveyor guard brackets (Fig. 1a) for quicker installation. (ii) Installed a raised solar panel mount (Fig. 1b) in order to capture more direct sunlight. (iii) Added a vertical hopper gate (Fig. 1c) in order to better regulate fruit flow. (iv) Added an permanent sensor box (Fig. 1d) to improve set-up time. (v) Added an output conveyor positioning cylinder (Fig. 1e) in order to ease conveyor setup movement, especially with various terrain inclination angle conditions. (vi) Added a debris conveyor and catch pan (Fig. 1f) in order to increase debris collection and test evaluation efficiencies.

Task 2- To conduct field experiments, in order to evaluate the pull-behind debris removal machine’s performance with respect to both fruit recovery and harvested load debris.
Field data collection began December 8th at the Lykes Fort Mach orchard in Lake Wales. Thirteen tests were performed on Parson Brown oranges which were machine-harvested using the Oxbo 3210 and subsequently picked up from the ground by hand. Nine tests were performed on Hamlin oranges on January 13th to 26th in the same manner. Nine more tests on the Midsweet citrus variety were performed on January 18th, however in this test the loads were entirely picked off the trees by hand. Eight additional Valencia tests (May 1 and 15th) were performed. Those tests, along with those from the 2011 season, add up to a total of 21 Valencia tests which was harvested using the Oxbo 3220. Since some of the mechanical harvesting tests were performed by the Oxbo 3210, emphasis was given toward categorizing the combination of leaves and wood (including stems, twigs and dead wood), bad fruit (immature, damaged and rotten) and sand. Sand is an issue when fruit is harvested and then picked up at a later period or date. Mean debris percentages were determined from each category, and then the overall potential total mean percentage of debris for each load was established. Machine-harvested loads produced up to approximately four-times more debris than hand-harvested loads, as shown in in Fig 3.
Fig. 1. Debris removal machine with added enhancements: (a) output conveyor bracket, (b) raised solar panel mount, (c) vertical hopper gate, (d) permanent sensor box, (e) output conveyor positioning cylinder, and (f) debris conveyor and catch pan.

The abscission compound was used on ten Valencia tests and on average, reduced the load debris by approximately 30 percent over the regular machine harvesting method (Fig. 3). The early May 2012 Valencia tests indicate an 82 (abscission) and 90 (non-abscission) percent total debris reduction, as compared to the 2011 tests value. Such a reduction could be due to variables as: 1) The winter months of 2011 endured a freeze period, which affected the trees. 2) There is less tree damage from the mechanical harvester when the tines are positioned within the canopy similar to the previous year’s harvesting. 3) Increased fruit size. 4) Possible change in machine operator.

Key findings can be summarized as:

- Results confirmed that mechanical harvested fruit produces more debris compared to hand-harvested loads and this amount was quantified.
- There is a significant amount of variability in the amount and type of debris created by different types of mechanical harvesting machines. Factors such as: type of machine, harvest time during growing season, fruit variety, frost damage, operator skills, and previous history of being mechanically harvested could significantly change the amount of debris.
- While overall, the Oxbo 3220 created slightly less debris compared to the Oxbo 3210, the types of debris were different. The Oxbo 3220 debris contained larger size branches and dead wood compared to the Oxbo 3210 hand-picked load. The amount of leaves and sand was higher in the Oxbo 3210 hand-picked loads.
Fig. 2. Categorized and total debris removed from 46 test loads of four different citrus varieties (Parson Brown, Hamlin, Midsweet and Valencia) with a mean weight of 4060 lbs.

Fig. 3. Mean debris removed comparison between the harvesting methods, including the abscission compound, from 21 Valencia test loads with a mean weight of 2924 lbs.

**Objective 2: Machine improvement and alternative design**

**TASK-1** To develop and study a citrus catch-frame attachment for the pull-behind mechanical harvester in order to reduce the quantity of fruit dropping to the ground during harvesting and reduce the associated labor with fruit collection.

The task was changed from developing a citrus catch-frame attachment as originally suggested to developing a fruit pick-up head for an Oxbo pick-up machine. The original and only Oxbo prototype pick-up machine is being modified and enhanced to increase fruit pick-up efficiencies (Fig 4a). A new system of collecting the fruit from the ground
was developed. It consists of wheels made of flexible rubber flaps capable of adjusting to the contour of the ground in conjunction with a new platform (Fig 4b). The system is able to float on the ground surface as opposed to digging into and beneath the ground surface. The preliminary tests in grass, sand and the CREC orchard resulted in 100 percent fruit pickup at a maximum of 1 mph ground speed. Further tests enhancing windrow techniques and an allowance for swell areas are yet to be incorporated and tested.

![Fig. 4. a) Oxbo pick-up machine during original testing. b) Modified machine at CREC.](image)

**TASK-2- To develop and study alternative harvesting technologies**

**Mobile mechanical harvester component and evaluation test station**

The donated MaQtec citrus harvesting machine was converted into a mobile mechanical harvester test station, as shown in Fig 5a. Most of the non-functional conveyors, elevators and shoots were removed (Fig 5b). The machine provides an adequate hydraulic power source and a rigid structure to mount and operate various components. The objective of the test station is to study and evaluate potential fruit removing devices, such as tine and air-induced systems in order to reduce tree damage and improve mechanical harvesting efficiencies. The test station provides a means to simulate component interaction within a given operating environment.

![Fig. 5 a) The MaQtec harvester 2011 before modification. b) The MaQtec harvester converted into a mobile mechanical harvester test station.](image)

Presently, the test station contains a hydraulic-actuated pivoting tine rig and a branch-bending stress and deflection evaluation system (Fig 6). The pivoting tine rig incorporates an adjustable clamping device in order to study various material diameters.
This system allows for real-time and full-scale tine material and related component development and evaluation. Most recent activities have been focused primarily on setting up the system, so no data has been produced. The present system involves a 1.63 OD, 0.65 wall thickness, 72 in. length 4130 DOM hardened steel tube from an Oxbo 3220 mechanical harvesting machine. The tube is secured at one end by an adjustable compression clamp in the pivoting tine rig, which helps avoid reduced tension stress. The setup simulates the cantilever beam principle for both theoretical purposes and actual mounting scenarios. The other end of the tube remains free to impact a nylon rod, which currently simulates a tree branch. The nylon has enough elasticity to aid with initial system set-up and the required instrumentation learning curves prior to using real tree branches.

**Small tine test rig**

A small test rig was also utilized to test and compare different tine materials Fig 7a. On the rig, a push rod moves up and down at a defined distance (stroke length approx. 1.5 in.) at various revolutions per minute (54, 141, 226 and 308 rpm). Three different tine tests were conducted. Tines were constructed from three different materials: rigid, nylon, and a combination of rigid and nylon. Results indicated the averaged percent difference between the fixed and free end acceleration (m/s²) values were: Rigid 46%, nylon 73% and the combination materials was 18%. The nylon dynamic bending displacement (+/-12 in.) from zero peaked at rpm values between 141 and 226. The material stabilized at values close to 308 rpm. Rigid materials offer greater stability, whereas more elasticity materials offer greater flexibility. The combination tine had more end weight, since the solid nylon was implemented into it, therefore it didn’t accelerate as dramatically.
Deflection and bending stress test rig

Theoretically, when a static force is applied to the free end of a cantilever beam the material properties define how far it deflects (in.) and how much bending stress (psi) it is subjected to. Table 1 indicates the typical material deflection and bending stress values for the following materials: Nylon rod (1.63 in. OD); steel and carbon fiber tubing (1.63 in. OD and 0.065 wall thickness); and wall steel square tubing (1.5 in. with a 0.1875 in.). All have lengths of 72 inches. These values help define material choices but additional criteria is needed to define what happens when materials are subjected to a dynamic load. The 1.5 in. square steel tubing was chosen to be incorporated into a test rig as the main impact push rod object, because it has the least deflection and bending stress value compared to the other materials at varying force values.

A boom-style deflection and bending stress test rig was developed and incorporated onto the front fork end of a Terex telehandler machine in order to rise to varying tree canopy heights. The test rig incorporates an Avery Weigh-Tronix weigh bar with a static capacity of 7,500 lbs. Structural grade square tubing (2.5, 2.0 and 1.5 inch) with 0.1875 inch wall thicknesses was used for the telescoping boom feature, in order to reach various canopy depths. The frame has an adjustable inclination angle of up to 90 degrees, in order to adapt to various tree branch growth angles. Five Naval variety orange trees were randomly chosen at the CREC facility test orchard. The test rig was operated either perpendicularly (Fig. 8a) or at a 45-degree angle (Fig. 8b) within the canopy. The maximum branch bending stress force range was between 110.6 to 556.7 lbs, with branch diameters reaching 4 inches. The branch deflection distance ranged from 12 to 56 inches, depending on the branch length and push rod position placement. The push rod was placed within the canopy to obtain the bending stress force. The force applied to various points on the rod was recorded. General observations indicate a rod placed perpendicular to the canopy will be subject to greater bending stresses. For both the tree and push rod, if the bending stress exceeds the materials yield strength it will be permanently deformed and not return to its original shape, which could lead to breakage.

Table 1. Material deflection and bending stress calculated values at various static force increments.
Material dimensions include:  1.63 in. OD Nylon rod; 1.63 in. OD and 0.065 in. wall thickness steel and carbon fiber tubing; 1.5 in. with a 0.1875 in. wall steel square tubing.

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Air induced systems

The concept of using high velocity air for shaking trees (air shaking) in combination with abscission compound has shown in the past some potential for fruit removal with little damage to the trees. A 90,000 cfm conical scan air shaker system (Fig 9b) that was available at the CREC was restored and its performance was compared to a smaller 1,600 cfm Billy Goat Force II blower (Fig 9a).

Field tests were conducted at different air volumes and wind velocities were measured at different locations around the canopy. Both units were used to determine throughput canopy air flow at the CREC experiment orchard, Lake Alfred Florida. The amount of fruit removal and tree damage were measured. The Billy Goat air velocity (mph) was reduced as much as 70 - 90 percent just past the first outer canopy layer. The turbulence caused by the actuating valve helped the throughput air flow, but the machine’s volume capacity proved too small to be very effective. The machine’s air volume was good at close proximities and at concentrated durations. It’s noted that none of the fruit was removed and no branches were damaged. The conical scan air shaker had a higher air volume, which by itself produced notable wind velocities similar to tornado or hurricane conditions. As the engine’s rpm increased the inlet air suction increased by 49%, the blowers output increased by 30% and the overall canopy throughput air velocity increased by 42%. More of the tree’s fruit was removed at the higher velocities and the canopy itself was shaking with limb displacement swaying reaching 4 and 5 ft. Some limbs were damaged and some were broken due to the concentrated turbulent shaking. This concept will be effective only with abscission compounds and will be incorporated in the future design if abscission compounds become commercially available.
Task 3- To study mechanical harvesting machine fruit-removal systems that can Enhance production efforts.

Fruit removal efficiency and tree damage are dependent on the amount of energy transferred to the tree branches. This energy is generated when the tines shake the canopy to remove the fruits. The Oxbo 3210/3220 slider crank mechanism in the canopy shaker harvester gives reciprocation motion to the hub-tine assembly which in turn shakes the tree canopy for fruit removal. A mathematical model was developed to predict acceleration at the end of tines without considering the inertia effects of component and friction(Fig 10). The machine enhancement objectives can be achieved by modifying the shaking tine configuration or hub and tine assembly configuration.

Canopy shaking tines are the main components of fruit removal systems on mechanical harvesting machines. Tines directly come in contact with the tree canopy and transfer vibrational energy to the tree which results in fruit removal. The goal of this task was to study alternative designs and enhance the performance of existing fruit removal systems used on the Oxbo canopy shaker. The following tine modification options have been proposed to achieve the desired goal.

**Option 1: Changing tine cross-section**

The current tines used on Oxbo canopy shakers consist of a circular tube with a 1.625 inch outside diameter with a 0.0625 inch wall thickness. The goal was to select the best cross-section which can increase fruit removal by transferring maximum vibrational energy to the tree canopy without significant damage to the tree canopy. It was found that increasing axial rigidity or stiffness increases the fruit removal and decreasing flexural rigidity or stiffness decreases the tree damage. The different cross-section dimensions have been studied to achieve desired objectives. The parameters of the cross-sections were optimized using a gradient-based constrained optimization algorithm. The tine with a rectangular cross-section provided the best results (1.85” x0.75”and 0.125(tickness)). However, further analysis must be performed before finally incorporating this design change into the current machine.

**Option 2: Composite tines**

The different composite tines were studied to minimize tree damage while keeping fruit removal as high as possible. The composite tines are made of different materials (nylon rod and steel pipe) and have cross-sections along the length of the tines. The various designs were optimized to reduce the overall cost of manufacturing. Some composite designs were optimized to meet the objectives of maximum fruit removal and minimum tree damage. However, further analysis and validation is required before incorporating them on the machine. Figure 11 shows a new design for a hub and tine assembly with deflectable tines that could potentially minimize tree damage.

*Fig 10- variation of acceleration, velocity and displacement of tine with respect to time.*
Task 4- To enhance the functionality of tine control system for canopy shaker

The second version of tine control system was developed and a new enhanced feature was added to increase the functionality of the tine control system. The number of ultrasonic sensors used for canopy detection increased from two to four to cover a larger area of the tree canopy and to better estimate the canopy size and shape. The mast holding the sensors was also redesigned to facilitate the adjustment of the angles of the ultrasonic sensors with respect to the tree canopy. The new mast was made of extruded aluminum and sensors were installed on hinges so that their angles toward the tree canopy could be easily adjusted. Based on the knowledge learned from last year’s work, a new controller system was designed and developed. All important variables which were used for the automated control system could now be changed directly using the interactive user friendly software, thus, reprogramming the firmware is not needed when changing a control parameter. Different algorithms could be tested directly and activated by running the algorithm using the terminal services. The algorithm could also be configured to run on start up. This means that the driver did not need to connect the controller to the laptop every time he wanted to use the automated tine control system. Calibrated values for the updated variables, e.g., forward speed, canopy thickness, etc. could be stored even when the controller was powered off. The algorithm used in the new control system was also changed. In this algorithm, the ultrasonic sensors were installed perpendicular to the tree canopies. On the other hand, another algorithm was also tested in which the angle of the ultrasonic sensors toward the tree canopy was determined based on the row spacing, the canopy thickness and the time it took for the tines to move from their current position to their desired position. A delay was computed for the tines when they were moving forward based on the forward speed of the tractor and the canopy thickness.

Areas where progress exceeded expectations:

Objective 1: The debris removal machine enhancements decreased set-up time and reduced the number of people needed to perform the debris collection part of the operation. The continuous flow from the debris conveyor made it safer and easier to gather the debris, because it is primarily concentrated it to one central area, versus the previous stationary collection sheet method. Data was produced from two different test
sites, which allowed for four different citrus varieties and two different machine harvesting methods to be analyzed. This diversity of testing provided an opportunity to further examine the experimental test machines performance efficiencies.

**Objective 2, Task 1:** Since the preliminary pick-up tests were successful at picking up all the fruit, this allows future testing to be done at faster travel speeds. Further testing is required to provide support data and machine performance characteristics.

**Areas where progress didn’t meet expectations:**

**Objective 2, Task 1:** The machine operator must maintain operating the machine in the center of the rows, because sand dust reduces visibility; therefore, it is not advantageous for the operator to perform multiple tasks, i.e. raking the fruit and picking it up simultaneously.

**Objective 2, Task 2&3:** Due to multiple machine maintenance requirements, there wasn’t enough time to do more tests and progress was less than expected.

**Objective 2, Task 4:** The number of field tests was less than expected. We accomplished only two field tests on the system. More field tests are needed to better evaluate the system performance.

**Next steps:**

**Objective 1, Task 1&2:** This study was able to quantify and compare the type and amount of trash between mechanically-harvested and manually-harvested fruit loads. The debris removal machine has demonstrated that the concept is working and it is possible to clean the harvested load in the field. A provisional patent has been issued for the trash removal mechanisms used in the trash removal machine and the commercial version of this machine can be built. What was learned during the course of this study will be incorporated into systems and mechanisms for debris removal in future machine enhancement and improvement projects.

**Objective 2, Task 2:** The test bench developed during this year’s study will be used to test different tine materials and build the design concepts that were developed in this study.

**Objective 2, Task 3:** The proposed modification for the tine and hub assembly need to be built and tested.

**Objective 2, Task 4:** The automated tine control will be installed on an Oxbo 3220 and the performance of it will be evaluated and compared with the existing manual system.

**Impact of accomplishments towards overall goals of funding:**

The fruit removal system is one of the main components of mechanical harvesting machines. Improving the fruit removal system through a combination of theoretical and applied research can significantly improve the performance of existing and future mechanical harvesting machines. The results from this current research project in combination with other research projects such as the tree mapping system and the tine control system will allow development of a more precise fruit removal system with better fruit removal efficiency and reduced tree damage.
Presentations associated with 2011-12 efforts:


Publications from 2011-12 efforts:


Patents
Title: Postharvest Citrus Mass and Size Estimation using Machine Vision

Investigator(s): Wonsuk Lee, Reza Ehsani
Graduate Research Assistant: Junsu Shin

Objective(s) Pursued:
The objective of this research was to develop a real-time machine vision system for citrus mass and size estimation during postharvesting operation in the citrus debris cleaning machine. To achieve fruit detection, supervised learning algorithm was developed, and a modified version of the watershed algorithm was proposed. The fruit detection algorithms were developed such that they could form a basis for developing an advanced citrus yield mapping system in future research.

Detailed Accomplishments in FY2011-12:

Hardware system
The machine vision hardware system for the yield estimation consists of a CCD color camera (Bobcat GigE VGA, Imperx Inc., Boca Raton, FL), two of white Exolights (MetaWhite™, Metaphase Technologies Inc., Bensalem, PA), an incremental encoder, and a data acquisition card (DAQCard-6036E, National Instruments, Austin, TX). A camera with high frame rates (206 fps) feature has been chosen for the acquisition of high quality images. For synchronization considering the speed of conveyor belt, an incremental encoder was installed on the rotating axis of the conveyor.

During the late harvesting experiments on May 2, May 19, May 31, and June 14 in 2011 at the Lykes grove in Fort Basinger, the machine vision system acquired images of citrus fruit moving over the conveyor belt of the de-trasher in the cleaning machine. Since the vision system was located at the end of the de-trasher, the citrus debris was filtered by the de-trasher and was most unlikely included in the images captured by the system.

Software design and algorithms
An algorithm to estimate citrus mass based on machine vision was designed including image rectification, image segmentation based on logistic regression model, morphological operations, highly saturated area recovering (HSAR) and mass calibration algorithms. The block diagram representing the flow of the image processing algorithm is shown in Fig. 1.

The process of camera calibration has been completed to get a model of the camera’s geometry and a distortion model of the lens. Given the camera geometry and lens distortion model, the images were rectified.
Pixel classification using logistic regression model

Classifying pixels into fruit or non-fruit is regarded as the binary classification problem. For the binary classification, logistic regression model is utilized. Logistic regression is quick to train and easy to implement. In addition, the model runs fast, so it is suitable for real-time processing. The outcome of this pixel classification is in the form of a binary image. The value zero (0) indicates a black pixel, and the value one (1) represents a white pixel in the binary output image. The white pixel region denotes where fruit resides in an image, but the black pixel area denotes background (non-fruit). In order to find distinctive feature vectors for the classification, the training images were converted from red, green, and blue (RGB) color space to various types of color spaces. The histogram analysis was performed in each color space. Fruit and non-fruit pixels occupy separate places with little overlapping in the histogram of hue (H), saturation (S), chrominance in blue (Cb) and chrominance in red (Cr) color components. Hence, these four color components were chosen as the feature vector.

Highly saturated area recovering (HSAR)

Some part of the fruit image and the background (non-fruit) image were highly saturated due to the light emitted from the lamps. The highly saturated areas may cause an error in the classification process, and hence they were excluded from the training sample for the logistic regression model. This means that the classification model does not identify the very bright areas on fruit in an image as fruit. Therefore, a highly saturated area recovering (HSAR) algorithm was developed to detect and recover highly saturated areas surrounded only by fruit pixels. The steps involved in the HSAR algorithm were:

1) Find all highly saturated areas by thresholding operation.
2) Extract pixels in circumference around the areas found in step (1) by the combination of dilation and logical AND operation.
3) Look up the extracted pixels and see if they are part of fruit using the fruit color.
4) If they are fruit pixels, add the identified areas to the classification result by logical OR operation.

Fruit separation using H-minima transform based watershed transform

In order to count the number of fruit and to estimate the fruit diameter, neighboring fruit which joined together in the output binary image need to be separated. To separate the touching fruit into individual fruits, watershed transform was conducted on the inverse distance transform of the complement of the output binary images. However, it should be noted that the watershed separation yields over-segmentation because every local minimum forms its own catchment basin which comprises one segmented area after the transform. To minimize the over-segmentation effect, local minima that are too shallow are eliminated using H-minima transform. The H-minima transform is a powerful tool to suppress local minima whose depth is lower than a given threshold.
**Mass calibration and estimation**

While conducting each of the field experiments, a total of 40 fruit samples with varying sizes and masses were taken in order to calibrate the pixel area of fruit with respect to actual mass. The pixel area for each fruit sample was found out from the binary images obtained from manual cropping using an image editing software. The mass of the individual fruit sample was measured using a weighing scale. A regression analysis was conducted to find a relationship between pixel area and actual mass. A linear model was assumed in the analysis. Hence, the model has the form of Eq. 1.

\[
\text{Estimated mass (kg)} = p_1 \times \text{pixel area} + p_2 \tag{1}
\]

Table 1 lists the results of regression analysis on the three mass calibration sets, which include the constants \(p_1\) and \(p_2\) defined in Eq. 1.

![Table 1](image)

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Error sum of squares (SSE, kg)</th>
<th>Coefficient of determination ((R^2))</th>
<th>Root mean square error (kg)</th>
<th>(P_1)</th>
<th>(P_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0055</td>
<td>0.982</td>
<td>0.0121</td>
<td>0.0000636</td>
<td>-0.0892</td>
</tr>
<tr>
<td>2</td>
<td>0.0322</td>
<td>0.924</td>
<td>0.0291</td>
<td>0.0000686</td>
<td>-0.0273</td>
</tr>
<tr>
<td>3</td>
<td>0.0303</td>
<td>0.929</td>
<td>0.0282</td>
<td>0.0000718</td>
<td>-0.0659</td>
</tr>
</tbody>
</table>

**Results**

The main finding of this work is the development of an image processing algorithm to perform the detection of citrus fruit in an image to estimate fruit mass. Pixel area corresponding to fruit was computed based on the binary image obtained from the image processing algorithm. The core part of the image processing algorithm is the logistic regression model based image segmentation, designed for classifying pixels as fruit or non-fruit. Figure 2 summarizes the whole process for the fruit identification.

The image processing algorithm was applied to all images acquired from the field experiments, and binary images were generated. Then, the entire pixel area corresponding to citrus fruit in the experiment set was computed. The sum of pixel area was then mapped to estimated fruit mass using Eq. 1. Table 2 summarizes the estimation results. Regression analysis was conducted on the estimated fruit mass with respect to the measured mass obtained from the entire experiment sets. The highest \(R^2\) between the measured fruit mass and the estimated fruit mass was 0.945. A root mean square error (RMSE) was 116.2 kg.

After only fruit regions were extracted from the image processing algorithm, the watershed transform was applied to separate joined fruit into individual fruits. The acquisition of individual fruit images enabled the number of fruit to be counted and the diameter of fruit to be estimated. The watershed transformation generated incorrect separation which led to over-segmentation since the regional minima were utilized directly for separating the touching fruit. The excessive over-segmentation in the watershed separation was prevented using H-minima transform. The appropriate constant \(h\) value was chosen empirically for the best segmentation. Figure 3 shows the results of the watershed separation with and without H-minima transform. Table 3 summarizes the potential distribution of the fruit size and counting. As shown in the table, a majority of fruit had diameter between 6 cm and 8 cm. The average fruit size ranged from 6.4 cm to 7.0 cm.
Fig. 2 – Example of the image processing results: (a) original image, (b) rectified image, (c) segmented image using logistic regression model, (d) after performing morphological operations and filtering, (e) after HSAR, and (f) H-minima transform based watershed separation.

Table 2 - Summary of the field experiment results.

<table>
<thead>
<tr>
<th>Set number</th>
<th>Measured fruit mass (kg)</th>
<th>Fruit pixel area (pixels)</th>
<th>Estimated fruit mass (kg)</th>
<th>Measured mass - Estimated mass (kg)</th>
<th>*Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st experiment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1,721.4</td>
<td>25,105,593</td>
<td>1,597.6</td>
<td>123.8</td>
<td>7.2</td>
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<tr>
<td>2</td>
<td>587.4</td>
<td>10,317,474</td>
<td>656.5</td>
<td>-69.1</td>
<td>-11.8</td>
</tr>
<tr>
<td>3</td>
<td>739.4</td>
<td>12,053,362</td>
<td>767.0</td>
<td>-27.6</td>
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<tr>
<td>4</td>
<td>1,984.5</td>
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<td>1,853.7</td>
<td>130.8</td>
<td>6.6</td>
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<tr>
<td>1</td>
<td>1,492.3</td>
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<td>-4.0</td>
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<td>848.9</td>
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<td>1,510.5</td>
<td>19,927,113</td>
<td>1,589.1</td>
<td>-78.6</td>
<td>-5.2</td>
</tr>
<tr>
<td>3rd experiment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2,004.9</td>
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<td>2,168.1</td>
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<td>1,217.9</td>
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<td>-24.2</td>
<td>-2.0</td>
</tr>
<tr>
<td>3</td>
<td>1,510.5</td>
<td>22,118,519</td>
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<td>-78.6</td>
<td>-5.2</td>
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<td>4</td>
<td>1,614.8</td>
<td>19,927,113</td>
<td>1,431.7</td>
<td>183.1</td>
<td>11.3</td>
</tr>
</tbody>
</table>

*Error(%) = \frac{\text{Measured fruit mass} - \text{Estimated fruit mass}}{\text{Measured fruit mass}} \times 100

Fig. 3 - Fruit separation result with watershed transform: (a) original image, (b) segmented binary image, (c) after watershed transform without H-minima transform, and (d) after watershed transform with H-minima transform.
### Table 3 - Potential fruit counting and diameter distribution.

<table>
<thead>
<tr>
<th>Set number</th>
<th>Number of fruit</th>
<th>Average (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5~6 cm</td>
<td>6~7 cm</td>
</tr>
<tr>
<td>2nd experiment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>544</td>
<td>2016</td>
</tr>
<tr>
<td>2</td>
<td>605</td>
<td>1419</td>
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<tr>
<td>3</td>
<td>1059</td>
<td>3347</td>
</tr>
<tr>
<td>3rd experiment</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>994</td>
<td>3257</td>
</tr>
<tr>
<td>2</td>
<td>680</td>
<td>2199</td>
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<tr>
<td>3</td>
<td>962</td>
<td>3226</td>
</tr>
<tr>
<td>4</td>
<td>1325</td>
<td>2943</td>
</tr>
</tbody>
</table>

**Areas where progress exceeded expectations:** The following three algorithms contributed to the performance of the system by increasing the fruit detection and size estimation.

- Image segmentation algorithm using logistic regression model to perform the detection of citrus fruit in an image.
- HSAR (highly saturated area recovering) algorithm to increase the segmentation accuracy.
- H-minima transform based watershed algorithm to separate neighboring fruit that is joined together in the binary output image.

**Areas where progress didn’t meet expectations:** There was an issue of synchronization between the moving speed of conveyor belt of the cleaning machine and the speed of image acquisition, however the developed system yielded good results.

**Impact of accomplishments towards overall goals of funding:** This research was conducted as a preliminary step towards implementing an advanced citrus yield mapping system on the citrus debris cleaning machine. The developed system showed great potential to be used in a grove in real-time, which allows citrus growers to monitor fruit yield in the grove.

**Presentations associated with 2011-12 efforts:** A poster, titled “Machine vision based citrus mass estimation during post-harvesting using supervised learning algorithms”, was presented at the International Symposium on Mechanical Harvesting & Handling Systems of Fruits & Nuts held in Lake Alfred, FL on April 3, 2012.

**Publications from 2011-12 efforts:**

**Refereed:**


**Non-refereed:**


**Next steps:** During FY 2012-13, a machine vision system will be developed that can estimate the number of fruit drop on the ground. The proposed system will help other research projects in the Citrus Initiative.
IFAS Citrus Initiative
Annual Research and Extension Progress Report 2011-12

EFFECT OF INITIAL TREE HEALTH and IRRIGATION TIMING ON SHORT AND LONG TERM IMPACTS of MECHANICAL HARVESTING

Investigator:
PI – Kelly T. Morgan
Co-PIs – Robert C. Ebel

Objective Pursued (Priority Topics):
Priority topic studied in this project is effect of mechanical harvesting on tree health. The objectives of this project are to determine the effect of tree condition prior to harvest and harvest method on measures of short-term and long-term tree health. The goal of the research will be the documentation of short-term and long-term impacts of mechanical harvesting on trees of selected levels of initial tree health compared with hand harvested trees over a three year period.

Detailed Accomplishments in 2011-12:
Two sets of plots were established with one of two irrigation treatments prior to harvest. Each plot consisted of six adjacent trees in the planted row and was replicated four times for a total of 16 plots per tree category. Trees received the same irrigation prior to start of the irrigation treatment. Irrigation treatments were; no water stress prior to harvest with irrigation applied up to date of harvest or water stress prior to harvest with no irrigation at least five days prior to harvest. One set of plots with all irrigation treatments were hand harvested and the other set of plots were machine harvested. A pull behind canopy shaker was used to harvest the plots mechanically. After harvest each plot was split into two-three tree plots with one sub-plot receiving irrigation (no stress) or no irrigation for eight days after harvest (stress). Leaf area index (LAI) was used to quantify initial tree condition prior to harvest and to determine effect of harvest method on tree canopy density. Stem water potential was measured using three leaves per tree, randomly selected from the 2\textsuperscript{nd} and 5\textsuperscript{th} tree of each plot. Sap flow sensors were used in one of the four replications of each tree category. Because the 2\textsuperscript{nd} and the 5\textsuperscript{th} tree of a plot represent two different irrigation treatments. On the day of harvesting, 5 fruit were randomly selected from the 2\textsuperscript{nd} and the 5\textsuperscript{th} tree of each plot (10 fruits/plot). The pull behind harvesters deposit harvested fruit on the ground thus fruit for both hand and machine harvested plots were picked off the trees or from the ground and placed into one or more designated 10-40.8 kg box tub(s). J: The leaves, twigs, small stems, blooms, and immature fruits that fall from the tree while harvesting were referred to as the harvesting debris.

Areas where progress exceeded expectations:
Stem water potential of trees with water stress was significantly higher than non-stressed trees prior to harvest in 2011 and 2012. In third year of the study, the highest sap flows, as expected, were observed in the non-stressed irrigated trees in all categories. Under low
density category, trees subjected to water stress nine days before or after harvest did not show much change in sap flow despite lack of water. Irrigated trees with no stress showed sap flow as high as 612 and 547 g/d while trees water-stressed nine days before harvesting peaked to 401 and 585 g/d, and water stressed after harvesting peaked to 175 and 383 g/d under hand and mechanical harvesting, respectively. A similar trend was observed in the trees under moderate and high density.

In 2012, fruit yields declined by 4% and 23% for hand and mechanically harvested low density trees, and 17% for hand harvested moderate density trees. However, the fruit yields for high density trees increased by 14 and 53% for hand and mechanically harvested tree categories, respectively over 2011 harvest.

Areas where progress didn’t meet expectations:

After harvest, stem water potential increased for the water stressed trees in all tree densities but high density owing to rainfall totaling 42 mm on April 20 through 22, 2012, just a few days before taking the water potential measurements.

Impact of accomplishments towards overall goals of funding:

After three years, mechanical harvesting does not appear to affect short or long term tree health and yield of well maintained trees of high canopy densities. These data would support previous findings and suggest low impact of mechanical harvest on long-term yields. However, both hand and mechanical harvest trees with moderate or low density prior to harvest declined in yield in 2012.

Presentations associated with 2011-12 efforts:

Presentation to the CPI board of directors on June 8, 2011

Publications from 2011-12 efforts:
Refereed: None (plained publications after third year)

Next steps:

Adequate data has been compiled to produce a referred journal article with repeated years of data and long-term effects tabulated.
IFAS Citrus Initiative
Mechanical Harvesting and Abscission
Progress Report
June 8, 2012

Program: Education and Outreach Program
Investigator: Fritz Roka

Why work is important: Grower education was given a “high” priority by a southwest Florida grower advisory committee during a meeting on September 2, 2005. If mechanical harvesting is to realize its full economic potential of harvest cost reduction, all aspects of the Florida citrus industry will be affected.

Objectives:

- Organize, develop, and deliver multi-media extension materials for convenient and ready use by citrus industry clientele, university personnel, and the general public.
- Organize workshops, field days, and grower meetings for the purpose of direct communication with citrus industry clientele.

Research Gaps:

- Better understanding of growers’ underlying concern over tree health and cost savings threshold before they adopt MH.
- Value of existing equipment significantly improving debris removal as measured by processors allocating sufficient trailers to MH sites.

Employees supported with CI funds:

- Barbara Hyman, .33 FTE of TEAMS position as coordinator of the citrus MH outreach program.

Accomplishments in July 2011 - June 2011:

Publications during 2011-12:

- Refereed Articles

- Trade Journal Articles


“What’s Shakin.” Monthly column in *Citrus Industry Magazine*. Hyman, BR and FM Roka. Titles by month 2011-12:

- July 11- Abscission and Unwanted Fruitlet, Flower and Leaf Drop
- Aug 11- Announcement of 1st Intl. Symposium
- Sept 11- 2010-2011 Progress Report
- Oct 11- New Mechanical Harvesters Being TRIaled
- Nov 11- Abscission and Effect of Microorganisms on Surface of Fruit
- Dec 11- Announcement of Intl. Symposium Registration and topics
- Jan 12- Announcement of Intl. Symposium Keynote Speakers
- Feb 12- Abscission Update
- Mar 12- Oleocellosis in Late Season Fruitlets
- Apr 12- Update of Citrus MH Website Search Engine
- May 12- Final Numbers of Mechanically Harvested Acres and Boxes
- Jun 12- Intl. Symposium Post Report

Posters for the International Symposium on Mechanical Harvesting and Handling Systems of Fruit and Nuts.

- Citrus Mechanical Harvesting and Abscission Agent Application- R.C. Ebel and F.M. Roka
- Effect of Tree Health and Drought Stress on Short and Long Term Impacts Due to Mechanical Harvesting- S. Barkataky, K.T. Morgan, R.C. Ebel and F.M. Roka
- The Past, Present & Future of Citrus Mechanical Harvesting- J.D. Whitney, B.R. Hyman, and F.M. Roka
- Mechanical Harvesting of Sweet Oranges for Juice Processing- F.M. Roka and B.R. Hyman
- Cost of Handling Debris and Implications for Mechanical Harvesting – F.M. Roka, T. Spann, R. Ehsani, and B.R Hyman

Proposals submitted:


Presentations on citrus mechanical harvesting:


International Symposium of Mechanical Harvesting and Handling System of Fruit and Nuts:
- The annual MH field day and workshop at SWFREC was not scheduled due to the International Symposium of Mechanical Harvesting and Handling System of Fruit and Nuts held in Lake Alfred. There were 150 in attendance for the two day workshop and 70 for the field trip to a phosphate mine and orange grove to observe a CCSC. Duties performed by Citrus MH/IFAS team:
  - F. Roka, member of the program committee. Collected and organized abstracts for 30 selected papers and 25(?) posters.
  - B. Hyman, member of Publicity committee for the International Symposium on MH.
  - B. Hyman prepared and sent ~600 emails (~300 two times) to prospective attendees and presenters.
  - B. Hyman prepared publication materials to be dispersed at trade shows and citrus meetings
  - B. Hyman formatted paper and poster abstracts for International Symposium and printed the abstract compendium.
  - F. Roka served as moderator for 2 of 7 sessions of oral presentations.
- The IFAS Citrus Mechanical Harvesting booth was displayed at four meetings that featured growers and allied trade representatives:
  - EPAF Mtg., Orlando – Aug. 29-30, 2011
  - EXPO, Fort Myers, FL Aug. 17-18, 2011
  - Florida State Hort. Society, Delray Beach, FL, June 5-6, 2012

Citrus MH websites visits through May 2012.

<table>
<thead>
<tr>
<th>Month</th>
<th>Visits</th>
<th>Hits</th>
<th>Downloads</th>
</tr>
</thead>
<tbody>
<tr>
<td>June07-May08</td>
<td>32,751</td>
<td>191,424</td>
<td>32,297</td>
</tr>
<tr>
<td>June08-May09</td>
<td>48,491</td>
<td>291,962</td>
<td>107,716</td>
</tr>
</tbody>
</table>

*Citrus Initiative – Mechanical Harvesting and Abscission FY 2011-12 annual progress reports*  
*June 2012*
Number of “visits” and “hits” to the Citrus MH/IFAS website declined by 1% and 13%, respectively, from 2010-11 totals. Website activity has declined for the second straight year and in my opinion, reflects a sagging general interest in mechanical harvesting within the Florida citrus industry.

Other activities/accomplishments:

1. Collected fruit count data at the Lykes Ft. Basinger grove from Sep 10-17. These data were presented at the Nov FDOC Harvest Council meeting and attempted to estimate yield effects from 2011 late season harvest trial.
2. Participated and assisted Dr. Bob Ebel in organizing the 2012 late season harvest trial at Lykes Bros. Harvest dates: May 1, May 15, May 29, and Jun 12. This is a significant trial that will, hopefully be repeated for the next several years to collect data on how next year’s crop will be affected by mechanical harvesting with and without CMNP.
3. Updated an ongoing yield study in Southwest Florida by collecting yield data from from selected commercial blocks. Data being currently analyzed to provide a representative tree age-yield plot for Hamlin and Valencia sweet oranges on Swingle and Carrizo rootstocks. With 2010-11 data, the study can track avg commercial yields blocks for trees up to 25 years old.
5. Traveled to Tulare, CA, (Feb 12-15, 2012) to observe Oxbo vacuum assist harvester working in a Naval orange orchard outside of Deland, CA. Unfortunately, rainy weather prevented the equipment from operating during the 3-day visit. The visit was timed to attend the World Ag Expo in Tulare, CA. Met with several MH vendors, including Coe and Oxbo.

Graduate students with MH topic,
Completed:
1. Jacob Searcy, Ph.D. Co-Chair. Food & Resource Economics, Aug 2011
2. Farangis, Khosro Anjom, M.S. Member. Agricultural & Biological Engineering (Dr. Ehsani, chair), Dec 2011.

In-progress:
1. Aldosary, Naji Mordi, Ph.D. Member. Agricultural & Biological Engineering (Dr. Burks, chair), est: May 2013.
IFAS Citrus Initiative  
Mechanical Harvesting and Abscission  
Progress Report

Program: Economic Studies  
Investigator: Fritz Roka

A southwest Florida grower advisory committee rated Economic studies a “medium” priority.

Why work is important: Economic studies attempt to address questions related to machine and worker productivity, crop yields, harvesting costs, and valuing the costs and benefits of incorporating abscission as part of the overall harvesting system.

Objectives:
Three field studies were planned for the 2011-12 season:

1. (S1) Distribute and analyze a grower survey to determine the threshold cost savings before which they will adopt MH despite lingering concerns with tree health.
   
   Status: A draft of a grower survey was completed and a preliminary list of grower contacts was organized. Discussions with various growers, however, convinced UF/IFAS researchers that the premise of the study had changed. HLB and limiting the amount of additional stress to trees was, and remains, an overriding concern to growers. Therefore, until growers can restore their trees to a suitable horticultural health, no amount of tree damage from mechanical harvesting will be tolerated.

2. (S2) Determine to what extent grove conditions and operator speeds influence fruit recovery percentages of the self-propelled equipment.
   
   Status: This study did not take place during the 2011-12 season. Preliminary work had been done during the 2010-11 season at the CCLP Summerland Grove near Immokalee and during the late-season trial at Lykes Ft Basinger Grove.

3. (S3) Work with Oxbo and BEI to modify existing “over-the-row” equipment for citrus mechanical harvesting.
   
   Status: A December meeting was arranged by Dr. Ehsani with two large growers and representatives of BEI to discuss how the BEI blueberry harvester could be modified to harvest young and/or small citrus trees. A BEI proposal, which asked for grower financial contributions, was rejected by the growers. BEI made no other attempts to pursue harvesting interest. Another effort was made in conjunction with Oxbo Corp. Oxbo engineers attempted to harvest young (4-yrs, ~4 ft high) trees with an olive harvester. The trial block was managed by CPI near SWFREC. After 15 minutes of operation and significant damage to 3 out of 4 trees, the trial
was stopped. While there was some discussion of modifying the harvesting head, Oxbo did not pursue any more work on its olive harvester.

Note: $30,000 of the allocated $41,733 was returned in large part because a graduate student designated for (S1) was not funded and the OE-materials budgeted for study (S2) were not incurred since the study did not move forward.

**Research Gaps:**

- 10 ac/yr CMNP constraint limiting the sufficient collection of data to confirm existing economic models as to the value of CMNP to mechanical harvesting systems.

**Employees supported** with CI funds:

- Barbara Hyman, .33 FTE of TEAMS position. Ms Hyman serves as the coordinator of the citrus MH education and outreach program. She works to collect and analyze economic data relevant to citrus mechanical harvesting.

**Accomplishments in July 2011 - June 2011:**

**Publications during 2011-12:**

1. Published refereed articles:

2. Manuscripts prepared for refereed journals:

**Proposals submitted related to citrus mechanical harvesting:**


Facing the US Citrus Industry. Submitted to the USDA SCRI 2012. 5-yr. Request: ~$10M.
Pending.

Graduate students with a citrus mechanical harvesting topic,
Completed:

In-progress:
2. Aldosary, Naji Mordi, Ph.D. Member. Agricultural & Biological Engineering (Dr. Burks, chair), est: May 2013.

Other activities/accomplishments:
6. Collected fruit count data at the Lykes Ft. Basinger grove from Sep 10-17. These data were presented at the Nov FDOC Harvest Council meeting and attempted to estimate yield effects from 2011 late season harvest trial.
7. Participated and assisted Dr. Bob Ebel in organizing the 2012 late season harvest trial at Lykes Bros. Harvest dates: May 1, May 15, May 29, and Jun 12. This is a significant trial that will, hopefully be repeated for the next several years to collect data on how next year’s crop will be affected by mechanical harvesting with and without CMNP.
8. Updated an ongoing yield study in Southwest Florida by collecting yield data from selected commercial blocks. Data being currently analyzed to provide a representative tree age-yield plot for Hamlin and Valencia sweet oranges on Swingle and Carrizo rootstocks. With 2010-11 data, the study can track average commercial yields blocks for trees up to 25 years old.
10. Traveled to Tulare, CA, (Feb 12-15, 2012) to observe Oxbo vacuum assist harvester working in a Naval orange orchard outside of Deland, CA. Unfortunately, rainy weather prevented the equipment from operating during the 3-day visit. The visit was timed to attend the World Ag Expo in Tulare, CA. Met with several MH vendors, including Coe and Oxbo.
IFAS Citrus Initiative
Annual Research and Extension Progress Report 2011-12
Mechanical Harvesting and Abscission

Investigator(s): J.P. Syvertsen
Collaborator(s): J.K. Burns, B. Hyman

2011-12 Priority areas addressed: Horticultural Concerns, Tree Health and The International Symposium on Mechanical Harvesting

Objective 3. The principle objective for 2011-12 was to lead the extension effort by developing and hosting The International Symposium on Mechanical Harvesting and Handling Systems of Fruits and Nuts. April 1-4, 2012, in Lake Alfred, FL. Plans were made in conjunction with the Intl. Soc. Hort. Sci. (ISHS) for symposium development, advertising and for publishing the proceedings in Acta Hort. The UF/IFAS Office of Conferences and Institutes developed the Mechanical harvesting (MH) web page (http://conference.ifas.ufl.edu/harvest/) for advertising the program and to accomplish on-line registration. Symposium topics included canopy and trunk shakers, past history of MH, tree design, orchard design, fruit retention force, abscission aids, harvesting efficiency, unwanted debris, economics of manual vs. MH, labor concerns and the future of MH. Nine guest speakers, who have expertise in mechanical harvesting and handling of olives, citrus and apples along with experts in abscission chemicals and harvesting aids, were invited to serve as key note speakers. The Symposium included 31 oral presentations, 31 poster presentations, 2 lunches, a dinner with speaker, and many opportunities for interactions over posters and social hours. Additional support came from Florida Citrus Mutual, ISHS and IFAS. In the end, there were 152 registrants that exceeded our expectations. About 70 participants and some of their families were accommodated at the Hyatt Universal hotel in Orlando. We could have accommodated more but the hotel became totally booked out. The Symposium also included a very successful, optional one day tour of phosphate operations and citrus mechanical harvesting in central Florida that was attended by 66 participants.

All presented Abstracts, power point presentations of oral talks and copies of posters are now available at http://conference.ifas.ufl.edu/harvest/. About 40 of the 60 presentations have been submitted and edited for publication in the proceedings as a volume of Acta Hort.

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<th>Objective 3. Symposium, 2-4 April 2011</th>
<th>OE Travel, Material, Supplies</th>
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Budget Justification. Within Objective 3, we requested $35,000 total. $22,000 is budgeted for 10 invited speakers (@ $2200) for airfare, lodging, meals and a bus for local transportation and the all day tour. An additional $3000 is budgeted for 2x100 participant lunches during the symposium and $10,000 for Symposium Materials. The symposium should end up making a profit.

1. Develop and post webpage and agenda for International Symposium on MH.

October 1st – December 20
1. Invite and confirm Symposium guest speakers.
2. Symposium Registration and local arrangements.

2012.
January 1st – March 31st
1. Symposium Registration and local arrangements.

April 1st to June.
2. Post oral presentations and abstracts from all presentations including posters on the CREC webpage http://www.crec.ifas.ufl.edu/
3. Edit and publish Symposium proceedings through ISHS in Acta Hort.

Presentations associated with 2011-12 M.H. efforts:

Manuscripts published and in press: