IFAS Citrus Initiative
Annual Research and Extension Progress Report 2012-13

Project Title: Fate of Indicator Organisms on Citrus in the Field.
Investigator: M.D. Danyluk
Objective(s) Pursued: Evaluate the fate of coliforms and *E. coli* sprayed onto Hamlin and Valencia trees in the field until *E. coli* populations can no longer be detected.
Progress on Objectives:
Detailed Accomplishments in 2012-13:

To evaluate the fate of coliforms and *E. coli* that may be sprayed onto oranges close to harvest if low quality water is used, low quality water (ca. 2.5 and 4 log CFU/ml *E. coli*; low count (l) and high count (h) water) was applied to three citrus trees the highest application rate that may be applied. Experiments were conducted at the Citrus Research and Education Center on Hamlin fruit in October, November, December, January, and February, and to Valencia fruit in March, April, and June (8 months). Oranges (3 x 10 fruit samples) from canopies of each of three trees (n=90) were removed before and immediately following spraying, at 2 and 6 h following application, and approximately every other day until *E. coli* was no longer detectable by enrichment in two subsequent samples or no fruit remained on the trees. Coliform/*E. coli* were enumerated initially by plating onto *E. coli*/coliform chromogenic agar, and then enriched for using the Coliert Quanti-tray/2000 MPN standard testing kit to allow for a limit of detection of 1 MPN/10 oranges. Temperature, rainfall, relative humidity and other environmental factors were obtained for trial periods from FAWN.

Results for the 2012-2013 trials are included below, including initial inoculum loads (Table 1), and survival of *E. coli* and coliforms on citrus trees, by month (Figures 1-7). A summary of E. coli survival on citrus, including March, April, May, and June 2012 are also included in Figure 8. In four months, March, June, and October 2012, rainfall close to inoculum application appears to have increased survival, or allowed for growth of organisms. Rainfall, and changes of relative humidity, especially within 48 hours of spraying are the major environmental factors contributing to the survival of organisms on fruit. In January, 2013 a slower than expected decline of E. coli could not be attributed to any environmental factors.

Table 1. Microbial counts in low quality microbial waters generated for use in field trials.

	High Count Water (log CFU/ml)		Low Count Water (log CFU/ml)	
Month	TPC	*E. coli*	TPC	*E. coli*
October	5.6	4.3	3.9	0.9
November	6.6	4.0	5.7	2.6
December	5.3	3.9	4.9	2.3
January	6.0	5.1	4.8	2.5
February	5.5	4.5	6.0	2.6
March	5.2	4.4	3.7	2.0
April	5.2	4.0	3.6	2.3

* At no point were *E. coli* or coliform populations detected in CREC well water used as the mixing water to establish the low microbial quality water.

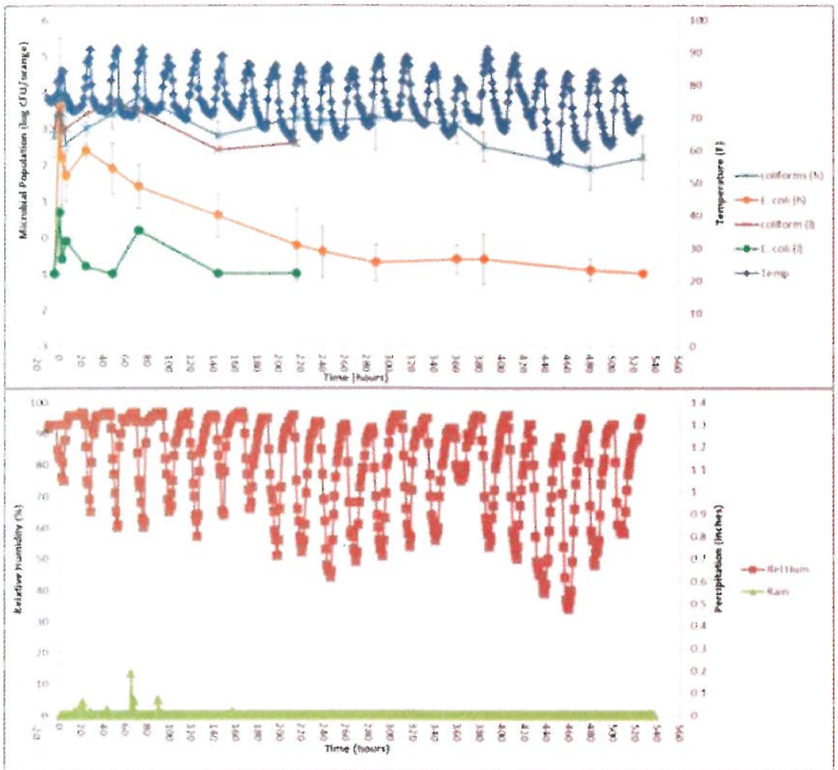

Figure 1. Fate of coliforms/E. coli on citrus in October, 2012

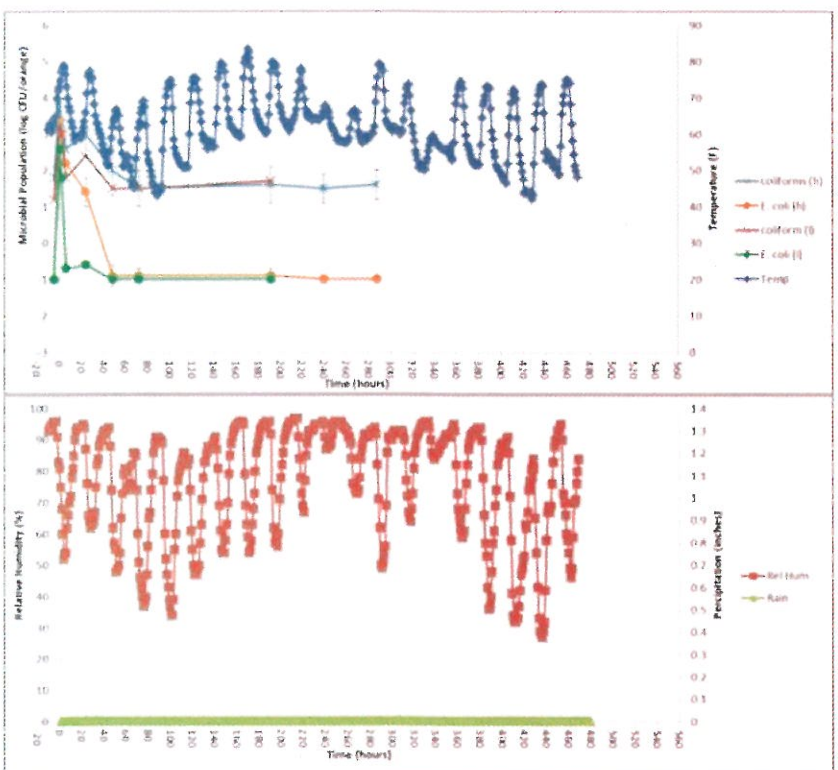

Figure 2. Fate of coliforms/E. coli on citrus in November, 2012

Areas where progress exceeded expectations:

The microbial modeling research group, led by Don Schaffner at Rutgers University has been engaged to help with microbial modeling of field survival to aid in the long term analysis of the data and the development of a model to help establish appropriate pre-harvest intervals on products.

Areas where progress didn't meet expectations:

Due to other commitments in May (cantaloupe packinghouse investigations by FDA), no trial was run in May, 2013. The June, 2013 spray trial is ongoing; the results of this trial are not reported here.

Impact of accomplishments towards overall goals of funding:

The overall goal of this funded project is to generate data on the survival of generic *E. coli* on citrus trees in the field over the course of the typical citrus harvest season. The data generated over the course of the

2012-2013 harvest season will be combined with data generated during the 2011-2012 harvest season to begin to set the framework for establishing a pre-harvest interval for the use of crop contact water that may not meet microbial water quality standards proposed in the Produce Safety Rule under the Food Safety Modernization Act.

<u>Presentations associated with 2012-13 efforts:</u>

Danyluk, M.D. and T.M. Spann. 2012. Fate of Indicator Organisms on Orange Trees in the Grove, Packinghouse Day and Indian River Postharvest Workshop, Lake Alfred and Fort Pierce, FL, 2012

Danyluk, M.D. 2012. Update on FSMA, Packing Line Studies and Field Indicator Survival Data. Indian River Citrus League, Vero Beach, FL, 2012

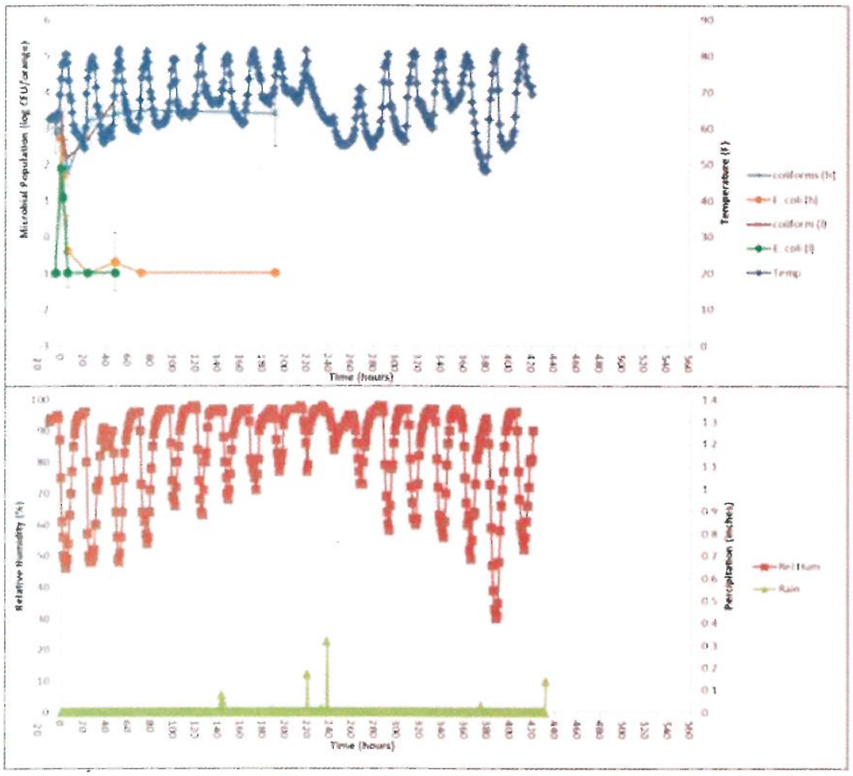

Figure 3. Fate of coliforms/E. coli on citrus in December, 2012

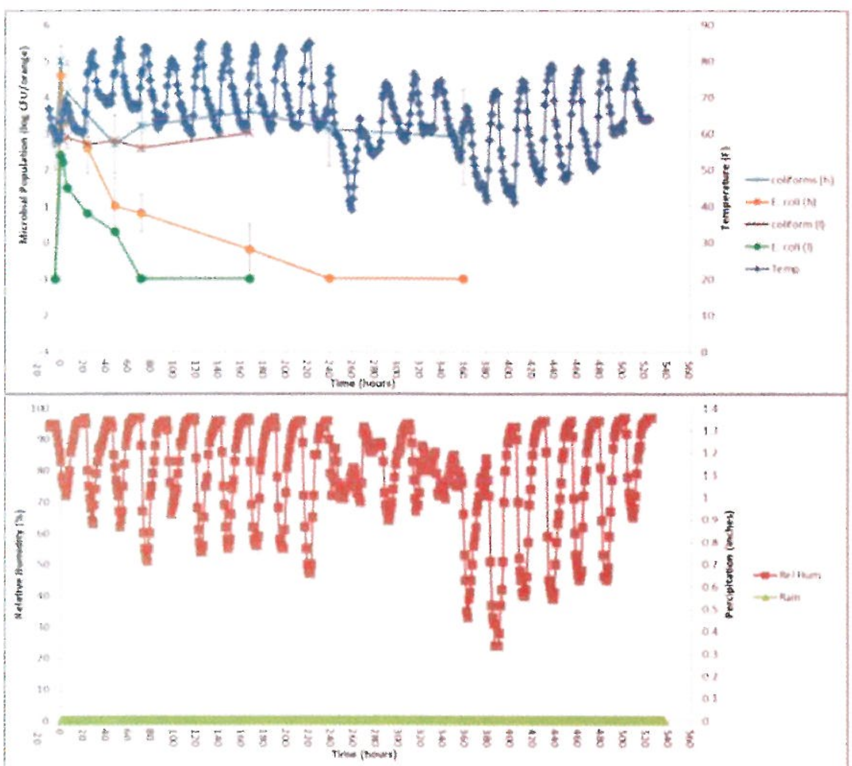

Figure 4. Fate of coliforms/E. coli on citrus in January, 2013

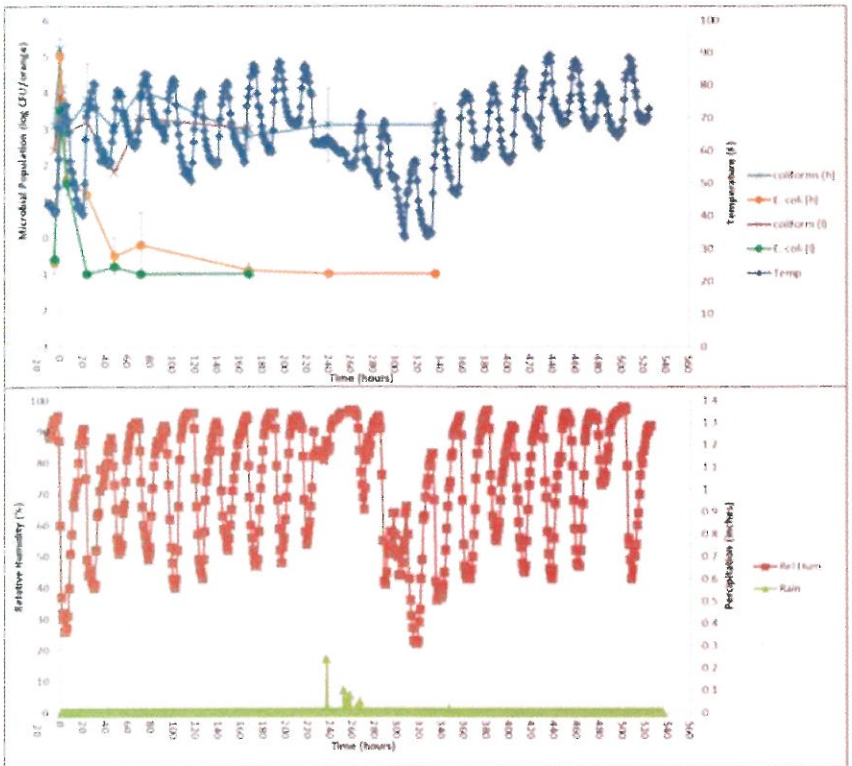

Figure 5. Fate of coliforms/E. coli on citrus in February, 2013

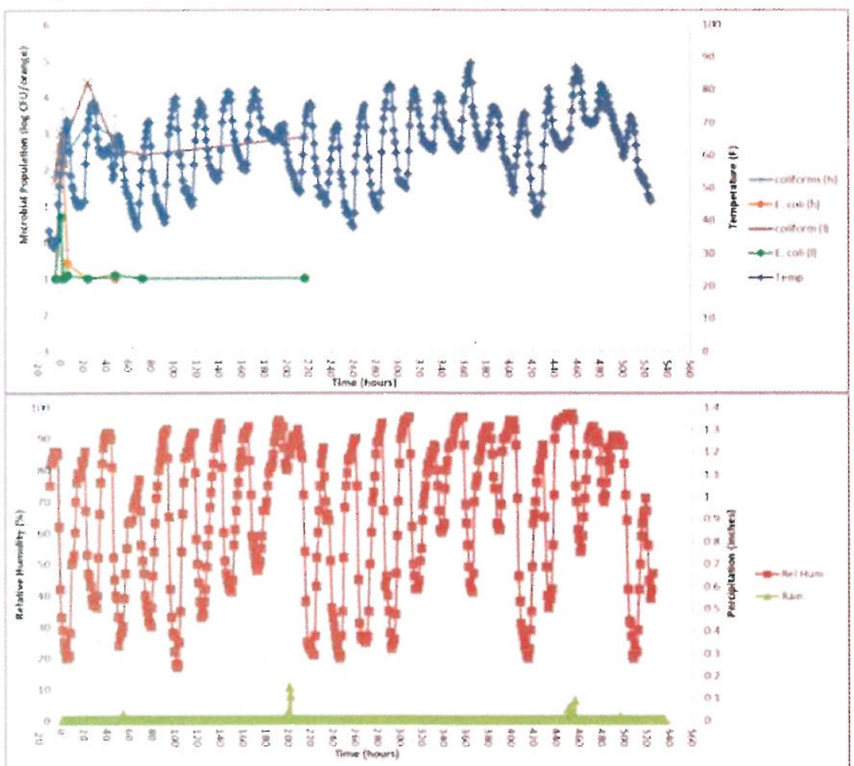

Figure 6. Fate of coliforms/E. coli on citrus in March, 2013

Mootain, G.K., L.M. Friedrich, T.M. Spann, D.W. Schaffner and M.D. Danyluk. 2013 Fate of indicator organisms on oranges following the application of contaminated foliar sprays. Florida State Horticultural Society, Sarasota, FL, 2013.

Mootian, G.K., L.M. Friedrich, T.M. Spann, D.W. Schaffner, and M.D. Danyluk Fate of Indicator microorganisms on oranges following application of low microbial quality water in foliar sprays. To be presented at the 2013 International Association for Food Protection Annual Meeting in Charlotte, NC.

Refereed and non – refereed publications from 2012-13 efforts:
None in 2012.

Next steps:

An additional year of funding is being requested to replicate field trials during the 2013-2014 harvest season. A recently published framework document

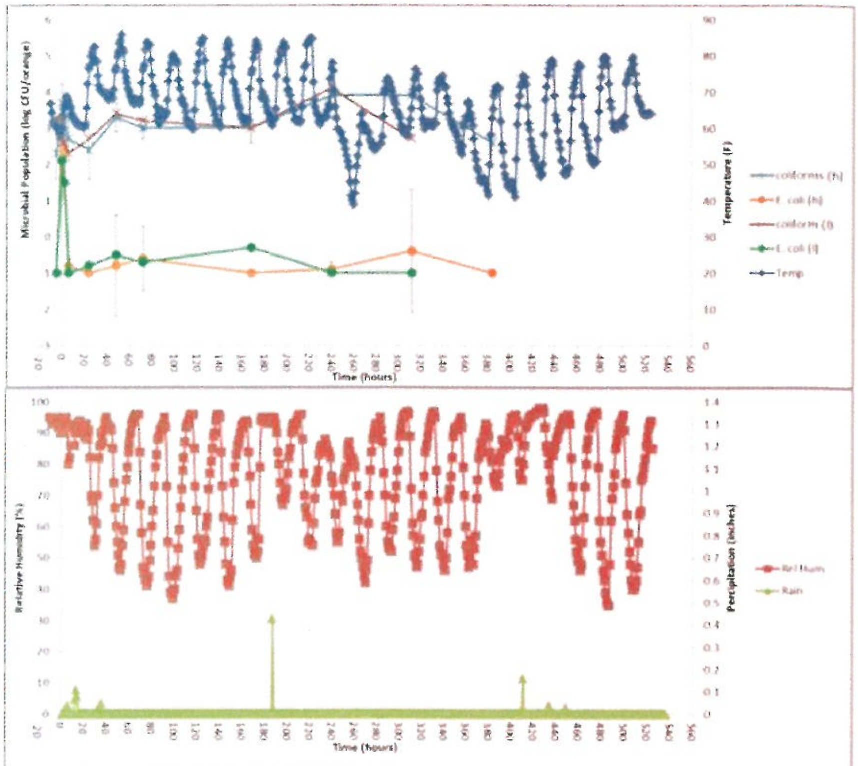

Figure 7. Fate of coliforms/E. coli on citrus in April, 2013

to evaluate research related to low microbial quality agricultural waters recommends multiple years of field trials to establish recommendations for pre-harvest intervals.

Additional funding in 2013-2014 is requested to hold a 1 day workshop for Florida growers, packers and Extension Agents, discussing available technologies to improve the microbial quality of agricultural waters.

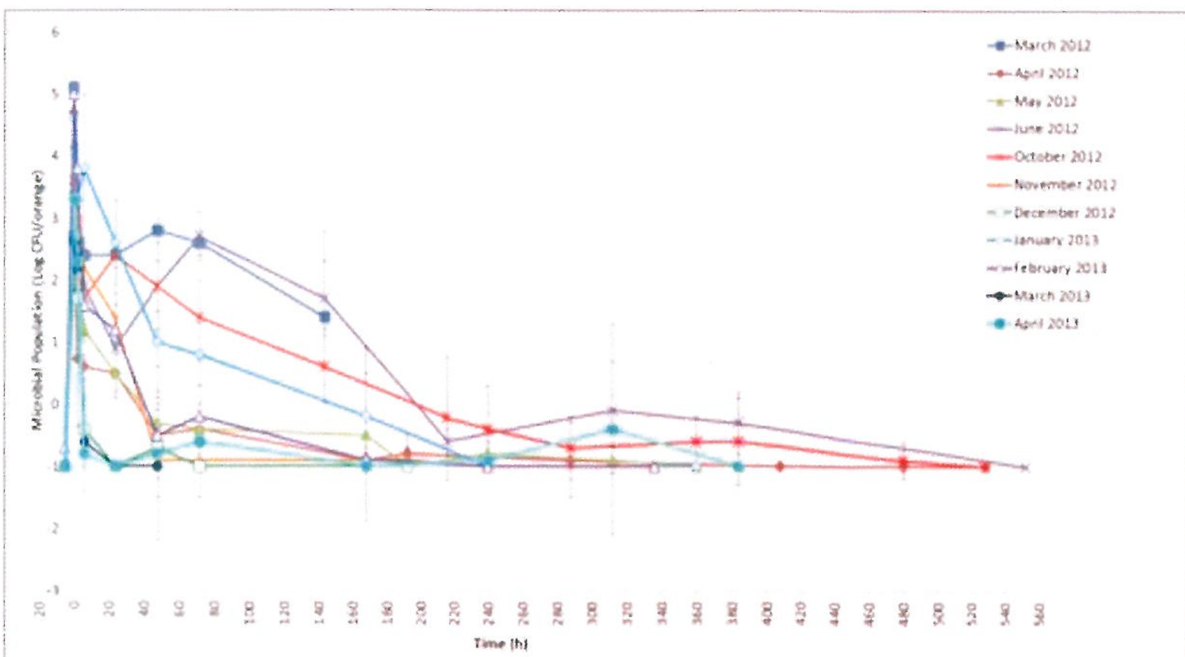

Figure 7. Summary of E. coli decline on citrus trees in March – June, and October – December, 2012 and January – April, 2013.

IFAS Citrus Initiative
Research and/or Extension progress report 2012-13

Investigator(s):

PI – Robert C. Ebel

Co-PIs – Fritz Roka, Kelly Morgan

Objective(s) Pursued: (Abscission management and harvester efficiency)

Objective 1: Develop best management practices for harvester settings utilizing the abscission agent CMNP to maximize harvest efficiency.

Objective 2: Effect of CMNP on hand harvesting of sweet oranges.

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

Progress on Objectives:

Detailed Accomplishments in 2012-13:

Objective 1: 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 2012 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 was in its second year in 2012. Yield data was collected in 2013 to determine carry over effect.

Objective 2: Effect of CMNP on hand harvesting of sweet oranges. This work was under the leadership of Fritz Roka. In the event a suitable method of mechanical harvesting cannot be developed for late season 'Valencia', the question was posed as to whether CMNP can improve worker efficiency sufficiently to economically justify its use. Two trials were initiated using workers that first harvested trees not treated with CMNP and then harvested trees that were sprayed with CMNP. The trials were conducted in April and May in two commercial groves. CMNP was sprayed at the maximum label rate and 3 days after application the trees were harvested. Throughout the day, the amount of fruit picked by each worker was recorded.

Objective 3: Enhance understanding of the mode of action of CMNP in promoting abscission and based on the results develop a mechanistic model that describes loosening as influenced by temperature. This 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. Our original hypothesis was that CMNP promoted high levels of nitrous oxide (NO) which was then a signal that promoted abscission. However, after careful studies of the amount of NO being produced in the flavedo and abscission zone tissues, the amount of NO is not high enough to promote abscission. Alternatively, low levels of NO can promote healing and the levels we found are in that range. After CMNP application, loosening increases up to 5 days after which the pedicel retightens. NO may be involved in the healing process in the abscission zone.

We have also determined the effects of CMNP on oxidative metabolism and reactive oxygen species (ROS) in flavedo and the abscission zone. CMNP promotes production of H_2O_2 and alters enzymes involved its metabolism. An interesting outcome from this work is a differential response of oxidative metabolism in the abscission zone and flavedo tissues. Oxidative metabolism is substantially altered in flavedo tissue however there is little effect in the abscission zone. These results may indicate that CMNP does not readily traverse to the abscission zone after application. Thus, loosening would be caused by a signal produced in flavedo tissues and transported to the abscission.

Areas where progress didn't meet expectations:

Objective 1: The late season trial with 'Valencia' and CMNP indicates that canopy shakers will have to be terminated in most years due to excessive yield reduction the following year. Different methods of mechanical harvesting will have to be developed to mechanically remove this fruit.

Objective 2: This data needs to be analyzed before gaps can be identified.

Objective 3: Understanding the mechanism of CMNP and especially how air temperature affects efficacy is vital to developing best management practices. We have concluded based on the oxidative metabolism work that the most likely mode of action of CMNP is that it produces a signal in the flavedo tissue and that this signal moves to the abscission zone to promote abscission. We are currently testing a hypothesis of the identity of this signal.

Presentations associated with 2012-13 efforts:

1. S. Sharma, **R. Ebel**, and N. Kumar. **2012**. Role of nitric oxide in promoting abscission in citrus by the abscission agent CMNP. Amer. Soc. Hort. Sci., Miami, FL, July 31st – Aug. 3rd. (Abstr.)

2. **R.C. Ebel. 2012.** Update on the late season 'Valencia' trials: Preliminary results. Southwest Florida Research Advisory Meeting, SWFREC, Immokalee, FL, June 22nd. (25 participants).

3. N. Kumar and **R.C. Ebel**. **2013**. CMNP induced oxidative changes in Valencia: I. Flavedo tissue. Florida State Horticulture Society, Sarasota, FL, June 2-4. (Abstr.)

4. N. Kumar and **R.C. Ebel**. **2013**. CMNP induced oxidative changes in Valencia: II. Abscission tissue. Florida State Horticulture Society, Sarasota, FL, June 2-4. (Abstr.)

5. N. Kumar and **R.C. Ebel**. **2013**. Canker control using commercially available compounds. Florida State Horticulture Society, Sarasota, FL, June 2-4. (Abstr.)

Refereed and non–refereed publications from 2012-13 efforts:

1. S. Sharma, **R.C. Ebel**, and N. Kumar. **2012**. Production of nitric oxide by the abscission agent CMNP and its impact on citrus fruit loosening. Proc. Fla. State Hort. Soc., in press.

2. U. Handique, **R.C. Ebel**, and K.T. Morgan. **2012**. Influence of soil-applied fertilizer on greening development in new growth flushes of sweet orange. Proc. Fla. State Hort. Soc., in press.

3. N. Kumar, **R.C. Ebel**, and P.D. Roberts. **2012**. Effect of high temperature on different genotypes of citrus and kumquat. Proc. Fla. State Hort. Soc., in press.

4. N. Kumar, **R.C. Ebel**, and P.D. Roberts. **2012.** Responses of Chinese citron during *Xanthomonas citri* pv. *citri* invasion. Proc. Fla. State Hort. Soc., in press.

5. N. Kumar and **R.C. Ebel**. Changes in oxidative metabolism in sweet orange 'Valencia' flavedo tissue by the abscission agent 5-chloro-3-methyl-4-nitro-1H-pyrazole (CMNP). Environmental and experimental botany, submitted.

Next steps:
Objective 1: Develop best management practices for harvester settings utilizing the abscission agent CMNP to maximize harvest efficiency. I plan to work with Fritz Roka to analyze the data from the late season trial conducted at Lykes.

Objective 2: Effect of CMNP on hand harvesting of sweet oranges. I plan to work with Fritz Roka on analyzing the data for the hand harvesting trials

Objective 3: Enhance understanding of the mode of action of CMNP in promoting abscission. We have one paper submitted and are working on a second on the effect of CMNP on oxidative metabolism of the flavedo and abscission zone tissues. I am also working with the PhD student Sunehali Sharma on preparing a manuscript for the nitric oxide work and we are conducting studies on a new hypothesis we believe is the signal for CMNP. This work will also be published. I don't think we'll have time to determine the impact of temperature on this process, thus the model we have developed empirically will be published.

IFAS Citrus Initiative
Annual Research and Extension Progress Report 2012-13

Title: Machine Enhancement for Citrus Mechanical Harvesting Equipment
Investigator(s): Reza Ehsani

Objective(s) Pursued:

Objective 1: Machine improvement and alternative design to reduce tree structural damage

A- Improving the design of fruit removal tines
- Determining mechanical and physical properties of citrus wood
- Statistical modeling of tree limbs
- Formulation of mechanistic tree damage and fruit detachment model
- Perform optimization based on numerical techniques

B- Developing alternative fruit removal systems

Objective 2: Improved automated tine control system

Objective 3: Enhancing the application efficiency of an abscission compound using a smart sprayer

- To test the potential of the variable rate axial-fan airblast sprayer retrofit for increasing the abscission-inducing chemical application efficiency in different size citrus canopies
- Evaluating the targeted delivery, coverage, droplet deposition density, and uniformity of chemical applications

Detailed Accomplishments in FY2012-13:

Objective 1-A: Improving the design of fruit removal tines:

- *Mechanical and physical properties of citrus wood:* The mechanical and physical properties of fresh citrus wood were determined. The average values of the mechanical properties such as flexural modulus, modulus of rupture, stress at proportional limit, work to maximum load in bending, and physical properties such as specific gravity, moisture content, and damping ratio were used to define the parameters of a numerical model of tree limbs.
- *Statistical modeling of limbs:* The tree was classified into three zones: top, middle, and bottom. The tines corresponding to each zone were designed based on the probability of the tines hitting a main structural branch or small branches with fruit. These probabilities were different in each zone. A methodology was developed to model sets of tree limb prototypes having similar spatial distribution and vibrational characteristics. This methodology was used to model the limb as a truncated conical elastic beam with secondary branches and fruit masses added onto the main limb at their point of attachment.
- *Formulation of mechanistic tree damage and fruit detachment model:* The physical phenomenon of tree injury and fruit removal was quantified in terms of mathematical quantity such as stress and acceleration using mechanistic models. A tree damage and fruit detachment model was formulated based on the results from the numerical methods. A finite element method was used to find the transient response of the tree limbs considering mass proportional damping. The transient response of the tree limbs under impact from sinusoidal vibrating tines (shaking member) of the harvesting machine was used to calculate mechanistic fruit detachment and the tree damage index. These mechanistic models were used in optimization formulations to predict the optimum tine design and the operating parameters of the shaker for each zone.

- *Optimization based on numerical models:* A two-part optimization strategy was used. The first part optimized the shaker based on structural variables such as stiffness and lengths of the metal and plastic segments of the tines. The second part optimized the shaking parameters such as frequency and amplitude of the tines.

The results from objective 1-A are summarized below:

- Mechanical properties of fresh citrus wood were determined: elastic modulus (8.5 GPa), the modulus of rupture (67.3 MPa), specific gravity (1.4508 g/cc), and damping ratio (10.78%). Samples were taken from primary branches with diameter greater than 3 inches.
- An analytical model was developed which describes the physical characteristics of tree limbs in three different zones of the tree canopy, top, middle, bottom.
- A methodology was developed which used finite element analysis to optimize the current fruit removal system.
- A combination of low (nylon) and high stiffness (steel tube) tines in the ratio of approximately 3:1 works best for primary limbs that curve down sharply, which are typically located in the bottom and middle zones. For the top zone, which consists of limbs that are long and point upwards, low stiffness tines worked best.
- High frequency and low amplitude vibrations showed good results for most of the proposed two-piece designs.
- Structural optimization of the canopy shaker resulted in a 15-20% reduction in tree damage simulations.

Objective 1-B: Development of an alternative fruit removal system
A four-stage harvesting management technique to increase harvesting efficiency was established. The four stages are: ground preparation, mechanical harvesting, fruit sweeping, and fruit pick-up. A material-sweeping unit and a modified pick-up head for the Oxbo 3200 were developed, and a utility vehicle (Bobcat Toolcat 5610) with a surface conditioning attachment (flail cutter) was obtained. Preliminary tests involved: i. Ground preparation to condition the fruit drop area. ii. Machine harvesting by the Oxbo 3210. iii. Fruit sweeping from underneath the tree canopy toward the center aisle. iv. Fruit pick-up by the Oxbo 3200. The main focus was put on modifying the Oxbo 3200 to create a more simplistic and efficient fruit pick-up machine system (Fig. 1). The machine was evaluated at the CREC facility, Lykes Brighton orchard, and Lykes Lake Placid orchard.
The most challenging feat for the modified pick-up machine was adapting to the worst-case scenarios in an orchard: very loose sand or swale areas. Also, 38 soil compaction tests were performed. The measurement differences taken from underneath the canopy varied as much as 105 percent compared with measurements taken from the vehicle wheel paths. On average, the difference between underneath the canopy and the center of the row aisle was 47 percent. This data proves useful when determining mechanical system spring tension and hydraulic motor torque requirements. The present development period improvements include:

- Automating the hydraulic cylinders, thus eliminating the need for the operator to predict ground clearance heights and gap areas while traveling. Mechanical devices, such as wheels and nylon arrows, have been incorporated to actuate limit switches. Soft sand has been problematic for predicting system mechanism heights.
- After testing sandy soil, it was determined that the floating mechanism needed to be modified. Several modifications were developed and tested, including both resistant and non-resistant methodologies, which included: lower mounted and longer floating rods,

rubber folds, a combination nylon brush and flap wheel, counteracting flap wheels and independent spring plungers. The later mechanisms have been the most successful.

- New conveyor belt risers were developed and incorporated in order to hold the fruit while increasing both 55 and 35 degree inclination angles.

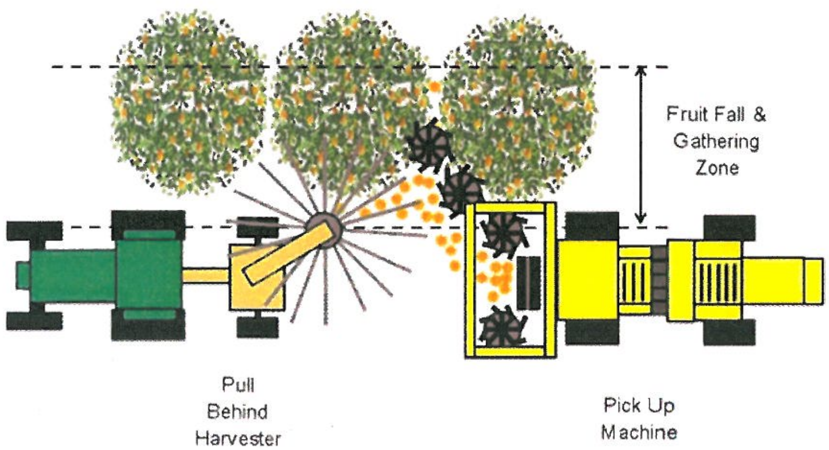

Fig. 1. Concept drawing of a simplistic fruit ground drop and pick up harvesting system.

The modified pick-up head for the Oxbo 3200 consisted of two subsystems; a fruit sweeper system and a fruit pick-up system. For the fruit pick-up subsystem, a combination of a center flap wheel and push rod float bars were used. Four different versions of the fruit sweeper were developed (Fig. 2) as described below:

1) Two flap wheel wings with a utility vehicle material-sweeping unit for underneath the canopy.
    - It was determined that the utility vehicle was not necessary
2) Two centipede wings with one centipede underneath the canopy.
    - Soil conditions posed a challenge, which stopped the machine from moving.
    - Soil surface depth variances required a device that can adapt more easily.
    - The hydraulic system was divided into two valves.
3) Two modified centipede wings with two wheel-sweeps for underneath the canopy.
    - The wheel-sweeps outperformed the modified centipede.
    - The hydraulic system bogged down, mostly with the center flap wheel and wings.
4) Two wheel-sweeps and two additional wheel-sweeps for underneath the canopy.
    - Hydraulic motor torques were increased by 185 N-m for the wheel-sweeps underneath the canopy, 126 N-m for the two wing wheel-sweep, and 45 N-m for the center flap wheel.
    - Due to lack of hydraulic flow rate and motor torque as well as gaps in the sweeping system, a low percentage of fruit were swept and picked up.

The pick-up system has evolved and is in the process of overcoming hydraulic supply and motor torque deficiencies, vulnerable system device gap areas, and operator dependency versus automation. The biggest challenge is creating a machine that can function in the worst-case scenarios, i.e. soft sand and swell areas.

Fig. 2. The modified Oxbo 3200: 1. flap-wheel. 2. centipede. 3. combination centipede and wheel-sweep. 4. wheel-sweep.

Objective 2: Improved automated tine control system
The controller board that was developed last year was redesigned to address the issues that were found in the previous design (Fig. 3). The control algorithm used in the new board is the same as the one used last year thus, the response time of the system is still the same. The penetration settings of the tine system were not changed, but several functionalities were added to the new system; for instance, the tine position change can be recorded. Also, all the settings can now be accessed by the operator/driver directly in the control box, as compared to the previous design where the operator needed to run a hyperterminal program to change the settings. The connector board provides a quick connect capability for all the sensors (ultrasonic and asm) and also for the Tine Control Connection from the Oxbo System. Also new is a joystick for controlling the tine manually and the same joystick is also used for changing the configurations of the system. The board also translates the TTL Serial from the main controller to RS232 signal for GPS. The LCD connector on this board uses the same pin configuration as found on the main controller. The new system is now enclosed. The ultrasonic sensors are now protected with aluminum enclosures.

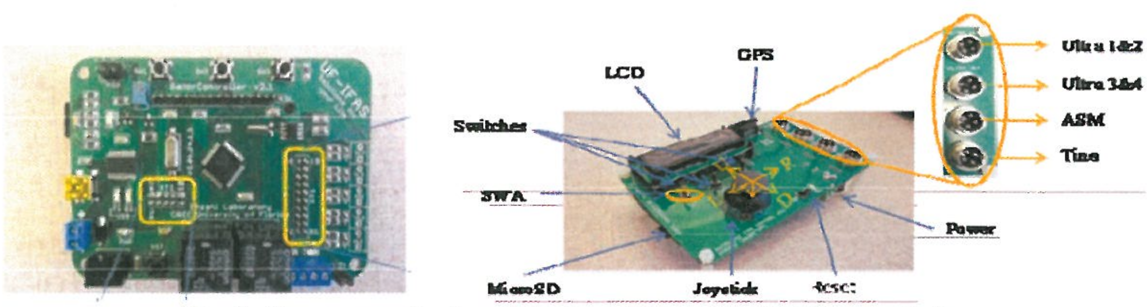

Fig. 3. New connector board designed for automated tine control.

Objective 3: Enhancing the application efficiency of an abscission compound using smart sprayer
This study evaluated an air-assisted sprayer retrofit, i.e. smart sprayer, that was developed through a USDA-SCRI grant, and two other sprayers commonly used in citrus production for their application efficiency in spraying the abscission chemical (simulated using water as spray with tracer dye as spray mix). Three sprayers: a) an air-assisted sprayer retrofit, b) a conventional

airblast sprayer and b) a multifan vertical airblast sprayer (Oxbo) were tested in this study. A series of field tests were conducted to measure spray deposition and coverage for each sprayer.

Data analysis results revealed that:

- For all three sprayers, deposition and coverage on the canopy surface was higher than at 0.6 m inside the canopies.
- The smart sprayer resulted in the same amount of spray deposition as the other two sprayers, while using 30% less spray volume for medium canopies and 70% less spray volume for small canopies. The WSP results confirmed the above trends.
- Multifan vertical airblast sprayer treatments resulted in relatively less deposition and coverage at lower sections of small (both canopy surface and 0.6 m inside) and 0.6 m inside of large canopies. Thus, the above sprayer is more suited for applications in commercial orchards with medium sized, less dense, and hedged canopies; whereas the air-assisted sprayer retrofit may be well suited for all types of canopies as it adjusts air-assist and liquid rates based on canopy size.

Areas where progress exceeded expectations:

Objective 1-A: The results for the properties of fresh citrus wood can also be used for other research involving fresh citrus wood.

Objective 1-B: All proposed objectives were met.

Objective 2: The addition of new capabilities such GPS logging and a new interactive display were beyond the proposed scope of work for this year.

Objective 3: All proposed quarterly objectives were accomplished. In addition to using WSPs, the study also used a reliable fluorometry technique which was beyond the proposed scope of work for this year to confirm results.

Areas where progress did not meet expectations:

Objective 1-A: Did not have time to validate the numerical model.

Objective 1-B: Most tests were performed at the CREC with little or no fruit loads. We found that running the machine under field conditions was more challenging than at the CREC grove.

Objective 2: The new control board was not ready for installation and testing on the Oxbo 3220.

Objective 3: All objectives were met.

Impact of accomplishments towards overall goals of funding:

Objective 1-A: Until now, the design and development of citrus canopy shakers has been mainly based on trial and error. This study developed a modeling approach to simulate the tree canopy and canopy shaker interaction and proposed an optimization approach that maximizes fruit removal while reducing tree structural damage. The result proposed an adaptive shaking system which is an advancement over the existing uniform shaking system. This methodology can also be applied to optimize harvesting systems for other fruits. The results of the simulation study suggest the need for design changes which can be incorporated into either the exiting machine or a new machine.

Objective 1-B: Developing an efficient fruit pick-up system can increase the efficiency of harvesting of citrus fruit, which reduces harvesting costs. In particular, it can help in cases of excessive fruit drop.

Objective 2: An automated tine control system can increase the efficiency of the operator by reducing the number of tasks required to operate the harvester during driving. Correct positioning of the tine system in the canopy can potentially increase fruit removal while reducing tree damage.

Objective 3: The effectiveness of the abscission compound is heavily dependent on the uniformity and accurate deposition during spraying throughout the canopy. The results of this study show that smart sprayer was a better choice for application of the abscission compound.

Presentations associated with 2012-13 efforts:

Khot, L. R., R. Ehsani, J. M. Maja, J. Campoy, and C. Wellington. 2013. An enhanced variable rate axial-fan airblast sprayer for citrus. Poster no. 27, Posters and Pastries Research Gallery, March 1st, 2013, Organized by Citrus Research and Education Center, Lake Alfred, FL.

Publications from 2012-13 efforts:

Refereed:

1. Yamakawa, M., L. R. Khot, R. Ehsani, N. Kondo. 2012. Real-time nondestructive citrus fruit quality monitoring system: development and laboratory testing. Agricultural Engineering International: CIGR Journal, 14(3):117-124.
2. Shamshiri, R., R. Ehsani, J.M. Maja, and F. Roka. 2013. Determining machine efficiency parameters for a citrus canopy shaker using yield monitor data. Applied Engineering in Agriculture. 29(1): 33-41.
3. Jadhav, U., L. R. Khot, R. Ehsani, J. K. Schueller. 2013. Volumetric mass flow sensor for citrus mechanical harvesting machines. 17 pages. Journal of Computers and Electronics. (submitted)
4. Khot, L. R., R. Ehsani, J. M. Maja, J. Campoy, and C. Wellington. 2013. Evaluation of an air-assisted sprayer retrofit and two airblast sprayers deposition and coverage in citrus orchards. (Under internal review)
5. Gupta, S.K., R. Ehsani, N.H. Kim, 2013.Statistical modeling of limb prototypes using response surface methodology. (in progress)
6. Gupta, S.K., R. Ehsani, N.H. Kim. 2013. Optimizing citrus harvesting system based mechanistic tree damage and fruit detachment models. (in progress)

Non- Refereed

1. Khot, L.R., R. Ehsani, G. Albrigo, W. Swen, J. C. Neto, J. Campoy and C. Wellington. 2012. Validation of variable rate spray decision rules in intricate micro-metrological conditions. Paper No. 1314. 11th International Conference on Precision Agriculture (ICPA), July 15-18, 2012, Indianapolis, IN, USA.
2. Gupta, S. K. 2013. Optimization of citrus harvesting system based on mechanistic tree damage and fruit detachment models. MS thesis. University of Florida.

Next steps:

Objective 1-A: Based on the simulation study, a modified fruit removal system needs to be built to validate the simulation results by field tests.

Objective 1-B: The latest design of the fruit pick-up head has showed promise; however, there are several issues that need to be addressed. The next step is to address all the existing issues and conduct more field trials.

Objective 2: The automated tine control system can be a part of the future mechanical harvesting design where controlling the distance between the shaking head and tree canopy is important. It can also be used in other applications for other tree crops such as blossom thinning systems used in apples and peaches.

Objective 3: Since the registration of abscission compound is not clear at this point, no further work is proposed.

Final Report of 2012-13 Citrus Initiative Program

Title: Estimation of citrus fruit drop on the ground using machine vision

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Co-PI: Reza Ehsani, Citrus Research and Education Center, University of Florida
Graduate Research Assistant: Daeun Choi, Agricultural and Bio. Engr., Univ. of Florida

In this project, a machine vision system for detecting and counting citrus fruit on the ground was developed and tested in order to aid other research projects in the Citrus Initiative program. Specific objectives were to:

1. Complete a hardware system for image acquisition using multiple cameras,
2. Acquire images of citrus fruit drops on the ground in a grove, and develop a software system to identify citrus fruit, and
3. Test the citrus fruit drop estimation system in a citrus grove where other citrus initiative projects are conducted.

A sophisticated classification algorithm was developed to detect dropped citrus fruit from images using logistic classifiers trained by feature information of each object in images. After detecting the citrus fruit using the classifier, a least square circle fitting was applied in order to get the position and the diameter of each citrus fruit individually. Field experiments were conducted in a commercial citrus grove to evaluate the performance of the prototype system.

MATERIALS AND METHODS

Hardware for Image Acquisition: The hardware for image acquisition consisted of two parts: image acquisition equipment and a camera-triggering device, which are shown in Figure 1. To acquire images, the machine vision system had two color CCD cameras with a microprocessor (1772C smart camera, National Instruments Corp., Austin, TX), two VGA monitors, metal mounting frames to a vehicle, and an encoder (CI20, Stegmann Inc., Dayton, OH).

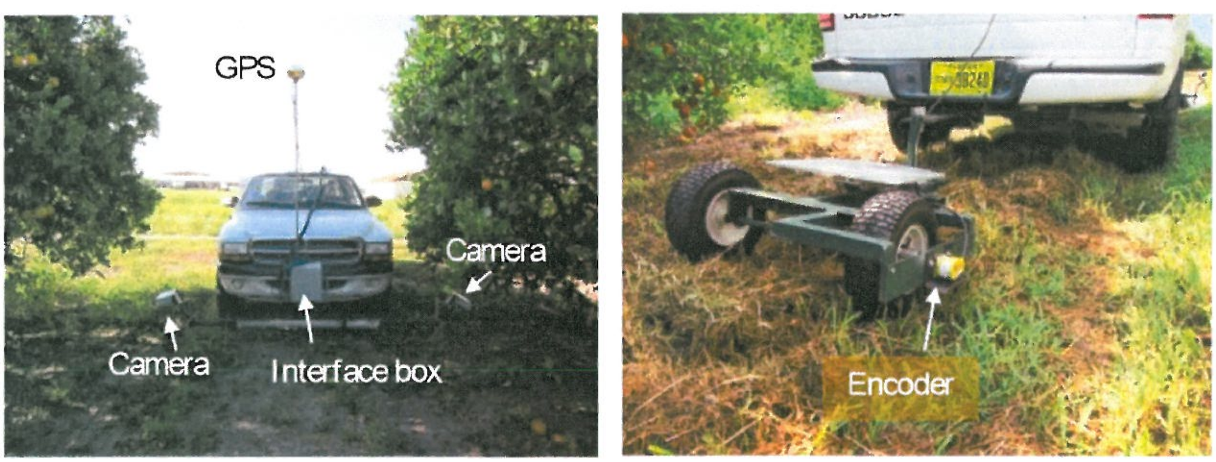

Figure 1. Prototype system for detecting and counting fruit drop on the ground: front view (left), and rear view (right).

The camera had an Intel 1.6 GHz Atom processor and real-time operating system which enabled the camera to acquire digital color images and other information in a simpler way, as opposed to the traditional way of passing data to a computer and then transmitting a trigger signal to the camera. Data from the encoder and a differential GPS receiver (AgGPS 132, Trimble, Sunnyvale, CA) were sent to the camera through a terminal block installed inside an interface box. The encoder was used as an external triggering device for the camera, which helped avoid an overlapped area between images. The DGPS receiver was also triggered to save the position information where images were acquired.

Image Acquisition Software: An executable software to acquire images and GPS coordinate was developed using LabVIEW 2012 (National Instruments Corp., Austin, Texas). This image acquisition software had three main purposes, i.e., displaying images, reading digital input from the encoder, and reading position information in a serial port transmitted from the DGPS receiver.

Field Experiment: The detection and counting algorithm of dropped citrus fruit was developed using images acquired from three field experiments in Duda & Sons grove (Immokalee, FL), Silver strand grove (Immokalee, FL), and Lykes Bros. Inc. grove (Ft. Basinger, FL). The average row spacing for these citrus groves was 24 ft and the tree spacing was 15 ft. Since dropped citrus fruit on the ground were most important in the experiments, images covered a wide area of the ground, especially under the canopy. The clearance between the ground and lowest canopy for hand harvested rows at the Duda grove was less than one foot. While this would be OK for hand harvesting, it turned out to be troublesome for acquiring images by the developed prototype system. For the mechanically harvested rows at the Lykes grove, the canopy was skirted in order to make it accessible by a mechanical harvester, and so the lowest canopy was about 18 inches above the ground.

Machine Vision Algorithm: In total, 1470 images were acquired during the field experiment. Each image had a resolution of 480□640 pixels to make process time faster. Among those, 10% of the images were randomly chosen to be used as a training set and the rest of 90% were designated as a validation set. The image pixels were classified into two classes: citrus fruit and background (non-citrus objects). Direct classification was difficult due to the similarity in the color of the objects and the varying illumination conditions between the images and within an image. This was because the images covered a wide area (3 ft horizontal field of view and 7 ft vertical field of view), which included ground under the canopy and the ground without canopy. The ground had a lot of shadows in some areas, which made the color of objects darker. In contrast, some areas without the shadow resulted in the soil having an excessive amount of white color due to the high sunlight intensity. Therefore, illumination conditions were normalized to diminish the drastic change in intensity level, as defined as Equation 1. After that, multiplying with 255 made citrus fruit more distinguishable among other objects by increasing the difference of the color value.

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where I is intensity component of an image; R, G, and B are red, green and blue components, respectively; and □□ □□□□□□ □ □□□□□□ □ □□□□□□.

The normalized images were converted into the hue, saturation and value (HSV) color space and the luminance, blue-difference and red-difference chroma components (YCbCr) color space. These color information was used to train a logistic classifier. Then, an entropy filter was applied to analyze the texture of the image to find boundaries of citrus fruit. After detecting the citrus in the image, the number of citrus fruit and the mass estimation were performed using least square circle fitting. The circle fitting provided the information needed to estimate the mass of the citrus fruit. Based on the calibration data of the size and mass of the citrus, interpolation and extrapolation were performed to estimate the actual mass of the citrus in the image. Figure 2 illustrates an example fruit detection steps.

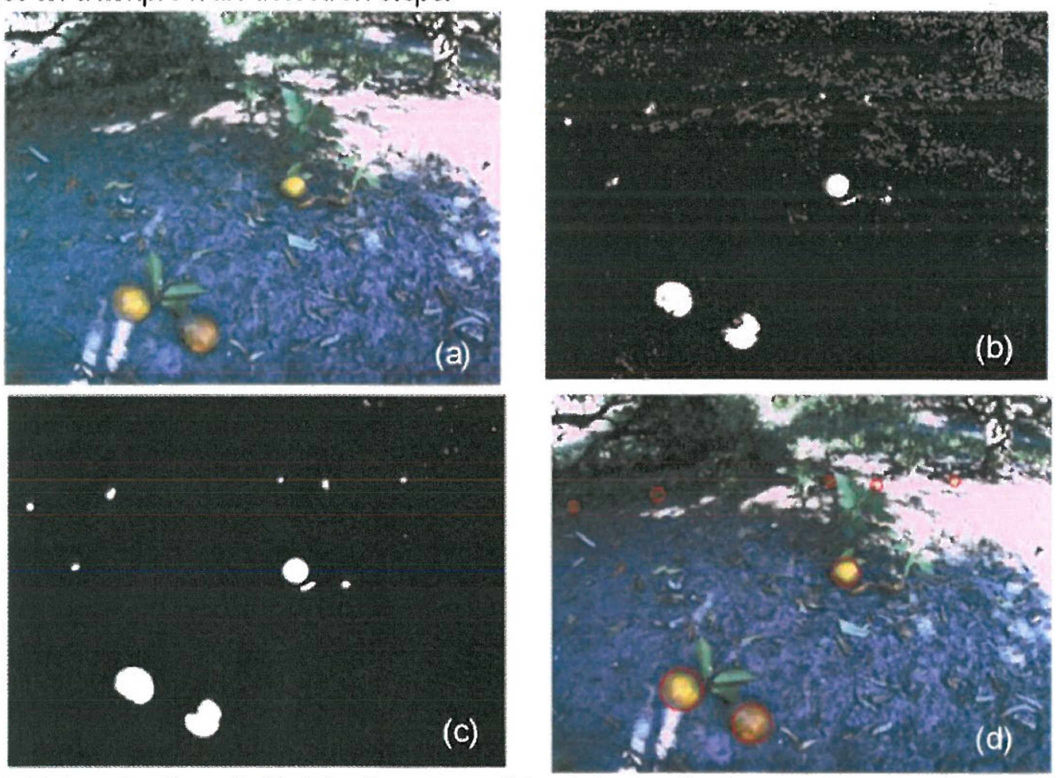

Figure 2. Example citrus fruit detection steps: (a) original color image, (b) after the classification using a logistic regression, (c) morphological operations after entropy filter, and (d) final fruit recognition result with red circles.

FINAL RESULT AND DISCUSSION

The developed citrus fruit algorithm was evaluated by comparing the number of fruit counted by the algorithm and the number of fruit counted manually in the images. Also, weight of dropped fruit on the ground was estimated. These results are summarized in Table 1.

A total of seven trials was validated by comparing manual fruit counting and the number of fruit counted by the algorithm. In manual counting, the actual number of fruit was counted in all of 1,470 images. Additionally, the number of correct count, missing fruit, and false positives (other objects incorrectly identified as citrus) by the algorithm were examined. Trial 1 yielded the most fruit drop (1,650 dropped citrus fruit with an estimated weight of 697 lb) among the seven trials, while Trial 3 showed the least number of dropped fruit. An average number of actual dropped fruit was found to be 1,018 for the seven trials. The percentage of correctly counted fruit by the algorithm was also calculated in every trial. The highest accuracy was in Trial 6 which was 89.5%.

Table 1. Image analysis results of the number of fruit correctly identified by the algorithm, missed fruit, counted by the developed algorithm and false positives, along with the number of actual fruit by manual counting. Estimated weight of dropped fruit is also listed in pound.

Trial number	Number of acquired images	Number of actual fruit by manual counting	Number of fruit correctly identified by the developed algorithm (%)	Number of missed fruit (%)	Number of fruit counted by the algorithm	Number of false positives (%)	Estimated fruit mass in pound
1	220	1650	1322 (80.1)	328 (19.9)	1466	144 (9.8)	697.5
2	222	1448	859 (59.3)	589 (40.7)	881	23 (2.6)	622.1
3	224	430	330 (76.7)	100 (23.3)	473	144 (30.4)	312.8
4	210	1102	784 (71.1)	318 (28.9)	815	31 (3.8)	394.4
5	192	885	707 (80.0)	178 (20.1)	766	59 (7.7)	444.2
6	191	618	553 (89.5)	65 (10.5)	652	99 (15.2)	346.3
7	211	999	782 (78.4)	217 (21.8)	932	150 (16.1)	495.4
Sum	1470	7132	5337 (74.8)	1795 (25.2)	5985	650 (10.9)	3313.0

In Trial 6, only 65 fruit (10.5%) were not counted (missed) by the algorithm. This was because the images in Trial 6 were clear and had better contrast compared to the images in other trials. However, Trial 2 had the least accuracy of 59.3%. The missed fruit in Trial 2 was 40.7% which is relatively high. The reason of this high error in Trial 2 was that the images were dark and unclear, which caused the low contrast in color between citrus and background objects. Also, the citrus in the images were located farther than in the other images, and so the size of the citrus were too small to be detected. The mean accuracy of the seven trials was 74.8%.

In addition, false positive counts by the algorithm were evaluated. Most of false positive errors were from the highly saturated area in soil and leaf pixels. They had bright yellowish color which was similar to the citrus pixels. The highest error was in Trial 3. This was because it was unclear to compare the colors between rotten or unhealthy citrus, and healthy fruits under the canopy. While the developed algorithm was counted them as healthy fruit, they were considered as unhealthy fruit by the manual counting.

For the result of the mass estimation, Trial 1 had the highest weight which was 697.5 lb and Trial 3 has the least which was 312.8 lb. The total weight of dropped fruit was estimated to be 3,313 lb, and each trial showed different weight of dropped fruit. This result corresponds to the number of fruit counted by the algorithm, which also showed the highest value in Trial 1 and the lowest value in Trial 3. However, the estimated weight in Trial 4 was less than Trial 5, although the number of fruit count by the algorithm was higher in Trial 4. This error might be because the size of the fruit were different in images between the two trials. The images in Trial 4 were taken in farther distance than in Trial 5, and so the size of the citrus were smaller.

Based on the analysis result, each trial had different number of fruit drop. The possible reason of the variation in trials is that each area had different spatial variability factors such as canopy size, nutrient level, soil pH, and disease infection. However, the impact of the CMNP which was sprayed during the past couple of years was not shown specifically. Trial 6 was sprayed with CMNP, however the number of fruit drop was relatively low compared to other non-sprayed area in the past.

Figure 3 shows spatial distribution of dropped fruit weight at four selected rows in the Lykes grove trial. Total weight of the dropped fruit was 3,313 lb with an average of 2.5 lb estimated from 1,470 images. Spatial variability of fruit weight can be clearly observed. This information can be used to identify potential causes of fruit drop along with other factors, such as degree of disease infection, soil type, tree age, rootstock, and citrus variety.

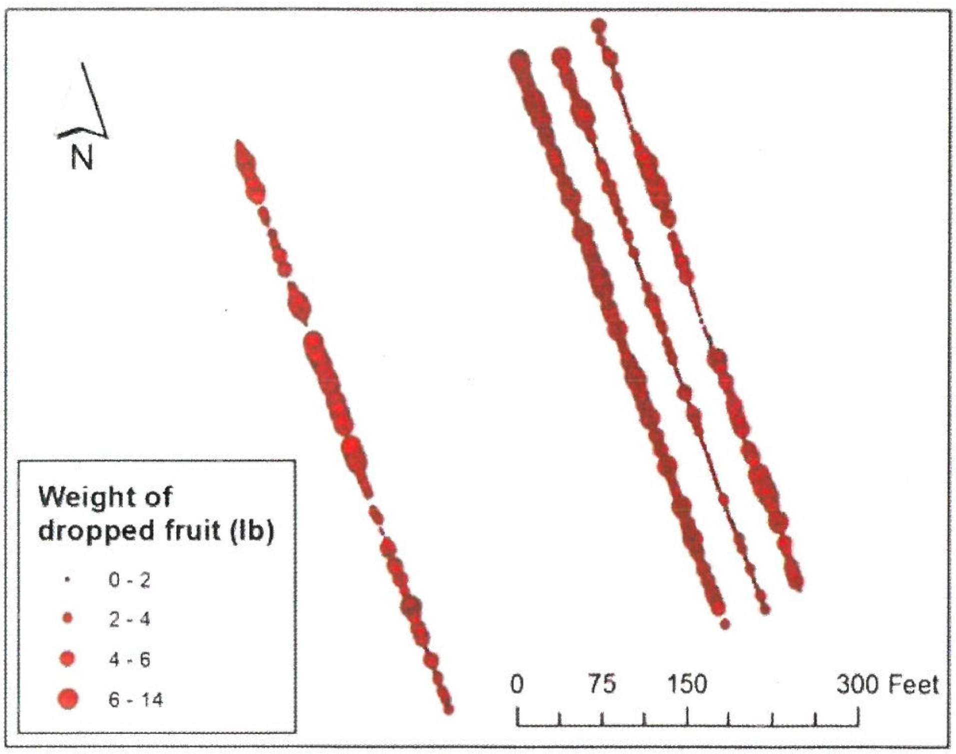

Figure 3. Estimated weight of dropped fruit at four selected rows in Lykes grove.

Output from this project: A master student, Daeun Choi, will graduate at the end of Summer 2013 who were supported by this project. A conference meeting paper and a journal manuscript will be written in the near future.

22-Jun-13

IFAS Citrus Initiative
Annual Research and Extension Progress Report 2012-13

Investigator: Fritz Roka, Mechanical Harvesting and Abscission

Objective(s) Pursued:

1. Organize, develop, and deliver multi-media extension materials as well as organize workshops, field days, and grower meetings for the purpose of encouraging adoption of citrus mechanical harvesting.
2. Organize and complete field trials evaluating effect of CMNP on machine efficiency and hand harvester productivity.
3. Encourage commercial equipment manufactures to develop harvesting equipment.

Detailed Accomplishments in 2012-13:

1. Participated as a speaker in 3 events that drew more than 300 Florida citrus growers. Contributed to two sessions during the 2012 International Citrus Congress held in Valencia, Spain. The UF/IFAS Citrus Mechanical Harvesting and Abscission display traveled to five grower events during the year and the Citrus Mechanical Harvesting website attracted more than 45,576 visitors who collectively downloaded 165,682 pages.

2. Three field trials were completed during the Valencia harvesting season. One trial collected yield data from the Late Season Valencia that was conducted on the Lykes Citrus Fort Basinger grove. These data completed two full years of CMNP x harvester speed treatments. The 2013 data were collected using Oxbo 3220 equipment, which allowed us to collect fruit removal data as well as the yield effects from the 2012 treatments. Two other field trials were conducted to assess the effect of CMNP on performance of hand harvesters. One trial was conducted on the Duda Grove just north of Felda, FL and the second trial was held on the Ranch One grove south of Immokalee. Both trials were conducted during May and collected hourly worker productivity data from two sets of 12 harvesters. As of June 10, 2013, data analysis of the hand x CMNP trials was not yet completed. Preliminary results, however, suggest that no benefit was realized during the Duda trial, but more than a 25% increase in productivity was achieved during the Ranch One trial. This result is contrary to initial expectations and may be explained by the fact that both harvesting crews preferred harvesting directly into pick-sacks and a rain event during the second trial limited fruit loosening and pre-harvest fruit drop.

3. Extensive conversations were held with BEI, Oxbo, and New Holland about bringing new harvesting equipment to Florida. None of these discussions yielded any substantive action during the 2012-13 season. BEI requested significant funds (>$150,000) to build a prototype harvester. The UF Citrus Initiative cannot allocate such funds to a commercial equipment manufacturer and an attempt to organize a grower private fund did not materialize. Oxbo proposed to modify an existing olive harvester by exchanging the current "bow" rods with "beater" rods. This proposal was not accepted because no provision was made to expand the machine's tunnel width, which was not sufficient to handle 4+ year old trees. New Holland Platform Manager for Grapes and Olive Harvesters, Thierry LeBriquer, visited Florida in October of 2012. After visiting several grove sites, Mr LeBriquer informed Drs Ehsani and Roka that New Holland's five year

plan did not include Florida citrus. If, however, a trial planned for Sao Paulo, Brazil went better than expected, New Holland could advance its timeline for bringing a harvester to Florida. Unfortunately, the New Holland trial, conducted in February 2013, could not adequately harvest over 6+year old trees.

A fourth equipment manufacturer, DRB Conveyor Systems was contacted and one of the company's owners, Chuck Dietrich, visited SWFREC in early December. DRB builds a vacuum assist machine currently being developed for fresh apple harvest. The current machine does not have a sufficient wheel base to accommodate Florida's Flatwoods beds and swales. Mr. Dietrich promised more discussion and perhaps explore the opportunity to test a machine in Florida during the 2013-14 season.

Areas where progress exceeded expectations:
Prior to the hand harvesting trials with CMNP, our expectation was that harvester productivity could only be improved if the loosened fruit could be easily knocked to the ground where harvesters could more quickly collect them. During the Duda trial, an estimated 20% of the crop was already on the ground before the harvesters actually started. Despite good fruit loosening, the Duda harvest crew did NOT enjoy an increase in overall productivity. During the Ranch One trial, rainfall 6 hours after CMNP application limited fruit loosening to only a 16% FDF reduction. When the Ranch One harvest crew started, very little fruit drop had occurred and more than a 25% increase in overall harvest productivity was measured. In post-harvest conversations with the workers, both the Duda and Ranch One crews preferred to harvest oranges directly into their pick-sacks. The Duda crew complained about having to "work twice" – once to remove fruit and second to pick up fruit off the ground. The fact that pre-harvest fruit drop did not occur during the Ranch One trial, may have provided a valuable insight into generating CMNP value with respect to hand harvester productivity, especially when the harvesters prefer to harvest directly into their pick-sacks.

Areas where progress didn't meet expectations:
The EPA CMNP registration process was not completed by Feb 2013, as originally hoped. The UF/IFAS MH team was planning to follow commercial harvesters and refine the CMNP applications requirements, as well as organizing at least one grower workshop on CMNP management. With the registration process interrupted, we decided not to hold a grower workshop on CMNP and furthermore, we scaled back our CMNP research efforts to just focus on the hand harvester productivity.

We were not able to complete a CMNP trial with a trunk shaker. Only two shaker units remain in southwest Florida and they have not operated since the 2010 season. We were not able to confirm that at least one of the two remaining shakers units could functionally operate for the purposes of a small trial.

Our ability to attract commercial equipment manufacturers was compromised by the delay in CMNP registration. Oxbo, in particular, believed that CMNP registration could spur renewed interest in citrus mechanical harvesting. As a result of the registration delay, Oxbo announced that it was closing its LaBelle service center effective July 2013.

Impact of accomplishments towards overall goals of funding:
The delay and overall uncertainty with respect to CMNP registration should focus our efforts in the next season on machine improvements and developing additional values associated with

CMNP. The results of the Ranch One hand harvester trial encourages us to repeat this experiment during the 2013-14 season and confirm the effect of CMNP loosening on harvester productivity.

Publications during 2012-13:

- Refereed publications:
  - Shamshiri, R, R Ehsani, JM Maja, and FM Roka. 2013. Determining machine efficiency parameters for a citrus canopy shaker using yield monitor data. Applied Engineering in Agriculture 29(1):33-41 (Jan 2013).
  - Roka, FM and BR Hyman. 2013. Gleaner Productivity, Implied Piece Rates, and Implications For Citrus Mechanical Harvesting. Proceedings of the Fla Stat Hort Soc 125:130-136, 2012. Refereed Section.
- Refereed abstracts
  - Searcy, J, FM Roka, and TH Thomas. 2012. The Impact of Mechanical Citrus Harvester Adoption on Florida Orange Juice Growers. Poster. Agricultural and Applied Economics Association Annual Meeting, Seattle, WA, Aug 12-14, 2012.
- EDIS publications:
  - Roka, FM and BR Hyman. 2013. Measuring Productivity of Citrus Hand Harvesters and Assessing Implications on Harvest Costs and Mechanical Harvesting. EDIS 933, June 2013
  - Submitted for EDIS publication:
    - Roka, FM. 2013. Outlook on Agricultural Labor and Mechanical Harvesting in Florida, 2012-13. EDIS. Submitted Dec 2012
    - Ehsani, RJ, L. Khot, and FM Roka. 2013. A new path for citrus mechanical harvesting. EDIS. Submitted Dec 2012
    - Roka, FM, BR Hyman, and RJ Ehsani. Field Performance Data on Citrus Mechanical Harvesting Equipment. More data needed on current performance measures.
- Conference Proceedings:
  Syversten, JP editor. 2012. International Symposium on Mechanical Harvesting and Handling Systems of Fruits and Nuts. Actae Horticulturae 965:
  - Barkataky, S., KT Morgan, RC Ebel, and FM Roka. 2012. Effects of Short-Term Drought Stress and Mechanical Harvesting on Sweet Orange Tree Health, Water Uptake and Yield: 73-82.
  - Ebel, RC, FM Roka, and KT Morgan. 2012. Field Research with the Abscission Agent CMNP as an Aid to Mechanical Harvesting of Sweet Orange: 97-100.
  - Roka, FM, RJ Ehsani, and T Spann. 2012. Harvest Debris and Cost Implications for Mechanical Harvesting: 159-162.
  - Whitney, JD, BR Hyman, and FM Roka. 2012. The Past, Present and Future of Citrus Mechanical Harvesting: 183-188.
  - Iwai, N., RD Emerson, and FM Roka. 2012. Immigration Reform and Citrus Harvest Mechanization in a World of Uncertainty: 233-240.
  - Roka, FM and BR Hyman. 2012. Mechanical Harvesting of Sweet Oranges for Juice Processing: 241-243.
- Trade Journal Articles:
  - What's Shakin. Monthly column in Citrus Industry Magazine. Hyman, BR and FM Roka. Titles by month 2012-13:
    - July 12- Pull Behind Trash Remover and Other Agric. Eng. Projects
    - August 12- Gleaning Crew Productivity
    - September 12- Vacuum Assist Picking Aid in Fresh Apples
    - October 12- Robotic Mass Removal of Citrus Fruit

- November 12- Bill Barber, Lykes Bros, And Future of Mechanical Harvesting
- December 12- Use of Abscission with Mandarins in Spain
- January 13- Benefits of Achieving Adoption of an Abscission Agent
- February 13- High Density Plantings in Spain (with Mireia Bordas)
- March 13- Machine Vision Devices (with Won Suk Lee)
- April 13 – Short Term Effects of Mechanical Harvesting on Crop Yield and Tree Health
- May 13 – CHRAC Members Visit California to Observe Olive Mechanical Harvesting (Dave Crumbly)
- June 13 – How to Use the Citrus Mechanical Harvesting Website Effectively
- July 13 – Abscission and Hand Harvesting Trials Being Conducted Summer 2013

- Roka, FM. 2012. True Costs of Hand Harvesters. Citrus Industry Magazine 93(8):14-16.
- Hyman, BR and FM Roka. 2012. Citrus Mechanical Harvesting Website. http://swfrec.ifas.ufl.edu/docs/pdf/econ_021313.pdf.

Presentations on citrus mechanical harvesting:

- 2012 Citrus Expo. Moderator. Harvesting and Economics Session. Fort Myers, FL, August 15, 2012 (250 attending).
- UF/IFAS MH program. DOC Harvest Research Advisory Council, Lake Alfred, FL, Sep 10, 2012 (27 attending).
- Evolution of Citrus Mechanical Harvesting in Florida. International Citrus Congress, Valencia, Spain, Nov 20, 2012 (150 attending).
- Mechanical Harvesting Workshop. International Citrus Congress, Valencia, Spain, Nov 20, 2012 (75 attending).
- CMNP Spring Field Trials. DOC Harvest Research Advisory Council, Bartow, FL, Jan 10, 2013 (32 attending).
- Mechanical Harvesting Update. SWFREC Citrus Advisory Committee, Immokalee, FL, Jan 25, 2013 (25 attending).
- Citrus Mechanical Harvesting Summary. Brazilian citrus growers and consultant tour, Immokalee, FL, Mar 8, 2013 (15 attending).

- Venues where UF/IFAS Citrus Mechanical Harvesting Booth displayed:

EPAF Mtg., Orlando	Aug. 29-30, 2012
Ag Expo, Balm	Nov 7, 2012
Citrus Expo, Ft. Myers	Aug. 15-16, 2012
The Citrus Show, Ft. Pierce	Jan. 23-24, 2013
Fla Stat Hort Soc, Sarasota, FL	June 2-4, 2013

22-Jun-13

Citrus MH websites visits through May 2013.

Month	Visits	Hits	Downloads
June07-May08	32,751	191,424	32,297
June08–May09	48,491	291,962	107,716
June09-May10	58,742	594,921	379,118
June10- May11	48,111	581,049	352,810
June11- May12	47,563	506,836	274,536
June 2012	4,292	56,669	25,961
July	4,783	121,024	27,053
August	4,972	40,746	25,289
September	4,406	39,346	21,947
October	4,292	35,526	18,494
November	4,359	33,371	15,584
December	3,576	25,112	11,658
January 2013	1,595	12,263	5,027
February	740	2,499	621
March	4,230	16,357	3,696
April	4,230	17,227	4,922
May	4,101	17,707	5,430
June12- May13	45,576	417,847	165,682

Next steps:

1. Repeat CMNP x hand harvester productivity to include a harvesting crew that explicitly seeks to put fruit on the ground as part of their harvesting preference.
2. Attempt to resurrect a trunk shaker to repeat previous harvesting results and demonstrate to wary growers that with CMNP a significantly gentler shake can be achieved with good fruit removal.
3. Follow commercial Oxbo 3220 systems and utilize imaging equipment being developed by Dr. Lee to document the overall change in fruit removal and recovery percentages.
4. Work with Drs. Ehsani and Burks to provide economic outcomes to the systems they are developing – ground pick-up and over-the-row harvesters.
5. Document the effect (or no effect) mechanical harvesting has on the spread of Citrus HLB. Work with selected growers who have both a mechanical harvesting history and data on HLB spread by block.
6. Visit the Michigan offices of DRB Conveyor Systems and observe their vacuum assist equipment during apple harvest in Michigan and Washington State. Determine whether a vacuum assist system could bring value to Florida citrus harvesting.