A CITRUS HARVESTING LABOR TRACKING AND YIELD MAPPING SYSTEM

J. D. Whitney, Q. Ling, T. A. Wheaton, W. M. Miller

ABSTRACT. *A labor tracking and yield mapping system for manual citrus harvesting was developed and evaluated in two commercial harvesting operations in Florida. The system consisted of button recognition and barcode units, integrated with a differential global positioning system (DGPS) unit mounted on a truck, which was used to handle fruit collection containers (tub or bin) in the citrus grove. When the truck operator stopped to load each full tub or bin, the button and barcode of the harvester who filled the container was activated. This action recorded the number or name assigned to the harvester and the DGPS location of the container. The button unit was more reliable and was designed with an audible (alarm) and a visible (light) feedback to provide the truck operator verification of the recorded information. The system tallied the number of containers each harvester had harvested for the day and allowed the entry of other information pertinent to the harvesting operation. The DGPS data were used to map the yields with ArcView software. Field tests showed the labor tracking system was reliable and user friendly.*

Keywords. *Labor tracking, Button, Barcode, DGPS, Citrus, Precision agriculture.*

Florida citrus industry produced a 13.7 Mt (304 million boxes) citrus crop in 1997–98, which was approximately 82% of total national citrus production (USDA Agricultural Statistics Board, 1999). Even though there have been extensive efforts to mechanize the harvest of citrus (Whitney, 1995; 1999), approximately 99% of the crop is harvested manually.

In a typical Florida harvesting crew, 20 to 30 harvesters work in a citrus grove. Each harvester places the fruit in field containers that are bins (fresh) or tubs (processed) with a capacity of about 410 kg. Depending on the grove conditions, each harvester can fill 5 to 15 containers per day and is paid by piece rate based on the number of filled containers. The harvested fruit is moved from the grove with a fruit loading truck that handles the containers. The truck operator is responsible for recording or keeping track of the number of containers or quantity of fruit loaded for each harvester. At the end of each day, the operator turns in the number of containers for each harvester for payroll purposes.

Article was submitted for review in September 1999; approved for publication by the Power & Machinery Division of ASAE in October 2000. Presented at the 1999 ASAE Annual Meeting as Paper No. 99–3107.

This research was supported by the Florida Agricultural Experiment Station, and approved as Journal Series No. R–07154. Mention of a trade name or a proprietary product is for specific information only and does not constitute a guarantee or warranty of the product by the University of Florida and does not imply endorsement of the product over other products not mentioned.

The authors are **Jodie D. Whitney,** ***ASAE Member Engineer,*** Professor, Agricultural Engineer, **Qingyue Ling**, Former Research Associate, **Thomas A. Wheaton**, Professor, and **William M. Miller,** ***ASAE Member Engineer,*** Professor, University of Florida, IFAS, Citrus Research and Education Center, Lake Alfred, Florida. **Corresponding author:** J. D. Whitney, University of Florida, IFAS, Citrus Research and Education Center, 700 Experiment Station Road, Lake Alfred, FL 33850; phone: 863-956-1151; fax: 863-956-4631; e-mail jdw@lal.ufl.edu.

Currently there are at least two common methods for manually tracking the number of containers or quantity of fruit for each harvester. One method involves a paper card with the harvester's name on it. The card has a number of circles that correspond to different estimated quantities of fruit in the container. When the truck stops to load the harvester's container of fruit, the operator gives the harvester credit by punching his or her card. The operator is also required to keep track of the number of hours each harvester works to verify that he or she is earning minimum wage based on actual hours worked. Depending on the number of harvesters and the amount of time each one works, the paper card method can involve considerable bookkeeping for the truck operator and the payroll accounting office.

The second method uses tokens that are mainly used with tub containers in processed fruit harvesting. When the truck operator stops to dump a tub of fruit, a token is thrown in the empty tub. Each harvester collects the tokens from the empty tubs he or she had filled. At the end of day, each harvester gives his or her tokens to the operator who must tally the totals for payroll purposes. Compared to the card method, the token method reduces the bookkeeping work for the truck operator during harvesting. However, the operator must rely on the harvesters to return the proper number of dispensed tokens and the total number must agree with the quantity of fruit that was loaded. Bookkeeping requirements at the end of each day are similar to those of the card method.

To reduce the amount of bookkeeping work and provide an automated method of recording labor tracking information combined with other useful management information such as yield maps, a citrus labor tracking and DGPS system was developed and tested. This study was a cooperative effort between the Citrus Research and Education Center, University of Florida and Geofocus, Inc., Gainesville, Florida. The objective of this article is to describe the development of the system and report on its performance in a commercial harvesting operation.

Materials and Methods

Equipment and Instrumentation

A DGPS and labor tracking system was installed on a citrus loading truck. The system was assembled in a weatherproof instrumentation box that consisted of a button recognition unit, a barcode scanning unit, the receiver and antenna, a microprocessor, and a LCD display. The button recognition and barcode scanning units were selected to record the harvesters' identities and other harvesting information into the microprocessor. In addition, they functioned as the triggering devices (similar function to the push button described by Whitney et al., 1999b for system data logging. The DGPS unit was used to obtain the time and location of each fruit container loaded onto the truck. The microprocessor was used to control event data acquisition and store data for subsequent downloading. The LCD display showed the status of the signals and if the system was ready for data logging. The antenna was mounted at the top of an adjustable height (3–5 m aboveground) aluminum post mounted on an aluminum base with the weatherproof instrumentation box. Three round magnetic plates on the base secured it to the truck engine hood and allowed quick mounting and dismounting of the unit.

The button recognition unit consisted of a button touch probe and the metal buttons. The touch probe was a DYNASYS PC (Dynasys, Clearwater, Fla.) port probe P–1713. It had one cable DB9 female interface to the microprocessor. Thirty metal buttons (DYNASYS DS1990–F3 touch coins) were mounted on a rigid transparent plastic sheet with Velcro so that the buttons could be easily moved or changed. Each button was manufactured with a 16–digit ID number stamped on its surface. When the probe touched the button, the number was read by the probe and transferred to the microprocessor. The loader truck operator numbered the buttons from 1 to 30 with a permanent ink marker for identification. These numbers were assigned to the harvesters and other functions. One button was assigned the 'delete' function to erase an incorrect input. If the operator touched the wrong button, the 'delete' button was touched to erase the previous entry. Another button was designated as the "half or 0.5 container" button for recording half–full containers usually encountered near the completion of harvesting a grove. Other functions such as tallying the starting and ending work times (not used in our tests) could be assigned to other buttons. The truck operator also placed numbers assigned to the harvesters on plastic tags that the harvester left near the filled tubs for proper identification. Daily, the truck operator filled out a template paper sheet that was inserted behind the plastic button sheet. It included the harvester's names corresponding to the their button number, date, and number of filled tubs loaded.

The barcode scanning unit was composed of a barcode scanner and a barcode plate. The barcode scanner was a DYNASYS model 75 CCD with an internal RS–232C interface. Like the buttons, there were 30 barcodes on a sheet. The first 25 were designated for harvester's names, and the others were used for special functions. Unlike the buttons, the barcode could be easily edited using software to put desired information into the barcode. For example, the harvesters' names could be programmed on the barcode, and the computer could store the names in its memory.

The DGPS receiver utilized a Lassen–SK8 low–power GPS board (Trimble, Sunnyvale, Calif.) programmed to output Trimble 56–byte super–packet data, which included date and time, location (latitude, longitude, altitude), velocity (north, south, and vertical), and fix type (2D or 3D fixed, DGPS corrected or not corrected, etc.).

The microprocessor was programmed to handle two RS–232 serial inputs (button and barcode) to store DGPS data, to drive a LCD display, and to allow all data to be downloaded through to a data key slot. A 0.5–MB data key (Cybermem key, Dynasys) was used to transfer the system data from the microprocessor to an office PC. A buzzer and three signal lamps were installed and programmed to provide both audio and visible signals or feedback to the operator when a button was touched and helped insure the operator that the data were successfully stored into the system.

Testing Procedures

Test 1

The purpose of this test was to compare the button and the barcode units and to determine which unit was more reliable and user friendly. The test was conducted in a 3–day, small commercial fresh fruit harvesting operation with Haines City Citrus Growers Association, Haines City, Florida. With a crew of five harvesters the first day and seven harvesters on the next two days, 85 bins of fresh fruit (net fruit load of 35,468 kg) were harvested. The citrus grove was typical of Central Florida with tree heights from 4 to 7 m and a drive middle width of 2.4 m between tree row canopies.

A button and barcode were assigned to each harvester. When the loading truck operator stopped by a filled bin, the operator punched the harvester's paper card to give him/her credit for the bin. Simultaneously, one of the authors (riding on the truck) input the same credit using both the button and barcode units. The data included DGPS data, i.e., the time and location of each loaded fruit bin, and who harvested the fruit. At the end of each day, data from the data key containing information from the buttons, barcodes, and 56–byte DGPS super–packet were downloaded to an office PC through a data key reader and the associated software. The number of bins for each harvester was determined from the file and compared to the record of the truck operator on the harvester's paper card.

Test 2

Based on the results from Test 1, the system was modified for Test 2. The purpose of Test 2 was to determine the accuracy and reliability of the labor tracking and DGPS data with the modified system. The modifications included 1) adding three visual lights in front of the instrumentation box, 2) replacing the original sound buzzer with a louder one, 3) only operating the button unit for data input, and 4) upgrading the firmware that controlled the DGPS receiver to obtain more reliable signals.

Test 2 was conducted as a cooperative effort between the Citrus Research and Education Center, University of Florida, and a commercial harvesting company (Dunson's Harvesting Inc., Winter Haven, Fla.). The system was used to track harvesters' working hours, the number of fruit containers they filled, and to produce a yield map for the test area using the DGPS data. Labor tracking results with the system were compared with the record from the company's accounting office.

Data were collected during the harvest of a 25–ha Hamlin orange grove typical of Central Florida. The trees were 3 to 7 m tall with an average between row spacing of 9 m. The harvesting crew consisted of 14 to 28 harvesters daily and an experienced loading truck operator. Labor was tracked manually with the token system. In the first three days of operation, similar to Test 1, one of the authors rode on the truck with the operator and instructed him on the use of the button system for data logging. After the operator felt comfortable with the system, he did data logging alone for both the token and button systems during the last 10 days of operation.

At the end of each day, data from the data key were transferred from the system to an office PC. A SAS (SAS Institute, Cary, N.C.) program and a C program were used to read, sort, and output the data from the data key file to two separate ASCII text files. One file contained the DGPS data that were organized mainly in five columns – date and time, latitude, longitude, altitude, and fix type. The DGPS data were used to create the yield map. The other file listed each harvester's ID number, name, number of field boxes (1 tub = 10 field boxes = 410 kg) of fruit harvested, and number of hours worked. Also listed were the total number of boxes harvested by the crew and the number of boxes of fruit loaded onto each semi–trailer. For comparison purposes, the record for each day with the button system was printed out and submitted to the company's accounting office along with the record created manually by the truck operator with the token system.

Results and Discussion

Test 1

Table 1 lists the number of bins recorded between the card system and two input devices of the labor tracking and DGPS system. The card system accurately recorded the number of bins of fruit harvested for each of the three days because its tally was identical to the number of bins delivered to the packinghouse. The operator had over 15 years of experience using the card system. He could remember each bin that he loaded each day and made the record complete at the end of the day even if he missed one or two bins during harvesting. With the button system, one bin was missed on the first day because a button was not touched with the probe for one of the bins. On the third day, one button was touched twice with the probe by mistake because of the difficulty in touching the button while the truck frame was moving during the bin loading operation.

With the barcode system, three bins were missed on both the first and second day, and one bin was missed on the third day. Sometimes over 10 s were required to scan a barcode and sometimes the barcode could not be successfully scanned at all because of the sunlight. If the barcode scanner could be modified to cover the barcode from sunlight or the barcode could be changed so it was not exposed under sunlight, the barcode unit could work more reliably. Also, the alert beep sound (feedback) from the system when a barcode was scanned was not always audible over the truck engine noise.

Table 1. Comparison of the number of bins of fruit recorded using three input systems.

	Card			Button			Barcode		
Input System	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
Total Bins	28	30	27	27	30	28	25	27	26
No. of Bins Entered Incorrectly[a]	0	0	0	-1	0	+1	-3	-3	-1

[a] Positive and negative numbers indicates the number of bins recorded greater than and less than, respectively, compared to the card system.

The button unit proved to be more reliable and for this reason was selected for use in Test 2. It worked every time as long as the probe touched the button whether the touch was of short or long duration. Other considerations were the harsh conditions in which the loader truck was operated. Without a cab, the operator work area was exposed to dust, trash, hydraulic oil, rain, and dew and other elements that would reduce the reliability of the barcode unit more than the button unit.

Test 2

During the 13–day period of this commercial harvesting test, the labor tracking and DGPS system with the button units was extensively tested.

Labor Tracking

A total of 1040 t (2548.5 tubs of oranges) was harvested with the tracking system. Table 2 summarizes the number of tubs obtained day by day from the tracking system and recorded at the commercial harvester's office. There was only a four tub difference in the total number of tubs of fruit tallied by the commercial harvester and the tracking system record. However, within the 13–day harvest, 56 tubs of fruit were not matched between the two records. But only four of the 56–tub mismatches were caused by the tracking system. Because of distractions in the field, the truck operator forgot to enter two of the tubs, one each on 8 and 17 February. The remaining two tubs were not entered into the tracking system on 20 February because the DGPS signal was temporarily lost at the moment the button was touched. No tub location was recorded if the DGPS signal was not available. Most of the other 56 tubs were either mistakes by the truck operator or mistakes by the accounting personnel in processing the data. Sometimes a harvester was incorrectly credited with a tub. That is why there were still a mismatched number of tubs when the difference between Dunson's record and that of the tracking system was zero. For example, on 16 February there were eight mismatched tubs while the difference between the total number of tubs recorded was zero. On four occasions Dunson's record gave four harvesters one more credit each and four other occasions it gave four other harvesters one less credit each. These eight occasions may have been caused by several situations. First, harvesting personnel can change daily. Second, most of the harvesters in this crew had Spanish names and proper identification of the names was sometimes difficult for the authors who were not fluent in Spanish. Finally, sometimes several harvesters worked under one harvester's name and created difficulties in properly crediting all harvesters.

Table 2. Tubs recorded daily by two different systems.

		No. of Tubs Recorded				
					No. of Tubs Not Matched	
Date	No. of Harvesters	Dunson's Record	Tracking System	Difference	Miss-Recorded[a]	Missed by Tracking System[b]
02/08/99	14	143	142	1	1	1
02/09/99	14	125	125	0	2	0
02/10/99	14	157	157	0	2	0
02/11/99	15	156	157	-1	4	0
02/12/99	21	200	199	1	2	0
02/13/99	18	174	177	-3	4	0
02/15/99	18	269	267	2	2	0
02/16/99	19	243	243	0	8	0
02/17/99	21	253	252	1	4	1
02/18/99	16	209	209	0	2	0
02/19/99	23	241	240	1	7	0
02/20/99	28	325	323	2	12	2
02/21/99	14	53.5	53.5	0	6	0
Total	235	2548.5[c]	2544.5	4	56	0

[a] Number of tubs miss-recorded between the accounting personnel and the truck operator.
[b] Number of tubs missed by the tracking system.
[c] The total number of tubs from the Dunson's record matches with the actual record by the truck operator.

A total of 32 harvesters were utilized over the 13 days of harvest for a total of 248 harvester worker days (data not shown, see Whitney et al., 1999b). Twenty–six of the 32 harvesters were wrongly credited with tubs with one harvester being wrongly credited with the highest number of tubs (six). To reduce these errors, which mostly happened in the process of manually recording data, the labor tracking system provided a possible solution.

DGPS Data

Out of 2549 tub locations, the labor tracking system only lost four. Two tubs were missed because of no button input and the other two were lost because of the unavailability of DGPS signals. From the DGPS data, the latitude and longitude of each location were imported to ArcView 3.1 software, and the location map of 2545 tubs was created. Then it was overlaid with a geo–referenced aerial photographic image of the 25–ha grove. The result was a tub density map (fig. 1). Only a few of the tub locations were outside the grove and corresponded to those not differentially corrected. A total of 2443 data points (96%) were differentially corrected while 102 (4%) were not corrected. From the tub density map, a yield contour map in t/ha (fig. 2) was developed. The procedure and parameters for developing the contour map have been described byWhitney et al. (1999a) using a search radius of 18.85 m. The contour map was "ground truthed" from the tub density map information in figure 1 and the results are shown in table 3. There was a considerable range in the ground truth yields and the correlation between ground truth and contour yields was fairly good ($r = 0.69$, $p = 0.0001$). The regression of yield per ha on percent canopy ground cover demonstrated an association between canopy size and fruit production ($r = 0.37$, $p = 0.0001$) similar to that reported by Whitney et al. (1999a).

Based on the performance of the labor tracking and DGPS system and authors' experience in testing the system, a few observations on the system were made:

1. Two of the missed tubs by the tracking system were due to the fact that both token and button tracking systems were used at the same time, which caused some distraction in data logging process. They may not have been missed if only one system had been used.

Figure 1. Location of tubs of harvested fruit (white dots) overlaid on an aerial image of the 25–ha grove. Each tub is designed to contain 0.408 t of oranges. Exploded view of portion of grove shown at upper right.

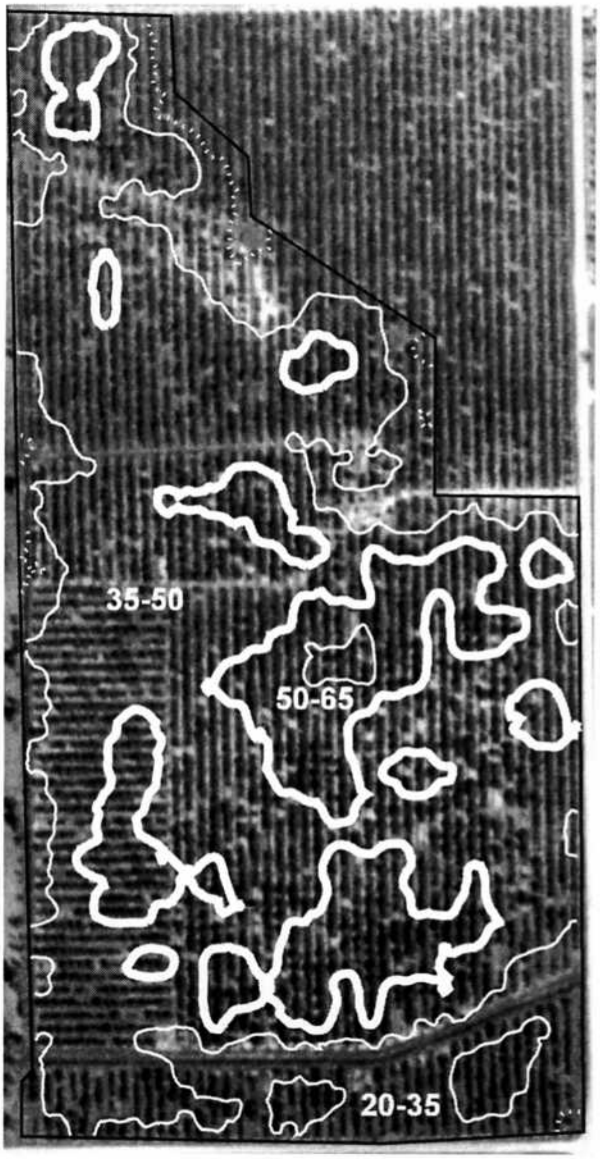

Figure 2. Yield contour lines (t/ha) overlaid on an aerial image of the 25–ha grove.

2. The labor tracking and DGPS system could be more reliable if an extra audio feedback was added to the system so that the operator would be warned if there was no DGPS signal available at the moment the button was touched.
3. The system would be more user friendly if the DGPS antenna was separated from the system box and installed independently on the loading truck since less effort would be involved installing and uninstalling the system on the truck every day.

Table 3. Yield (t/ha) range and standard deviation (S.D.) for ground truth and corresponding estimate from yield contour map.

			Yield (t/ha)		
	N	Mean	Min.	Max.	S.D.
Ground truth	685	42.1	11.4	102.5	18.3
Interpolated surface	685	42.0	8.6	65.3	10.1

4. The system would be more useful to the truck operator if a printer was installed to print a ticket for each harvester showing the number of tubs harvested each day. To realize this function, the system would have to be reprogrammed.
5. The button sheet could be larger to contain more buttons programmed for special functions. For example, starting and ending time buttons might be added to the sheet to accurately record the time that each harvester worked each day. Currently, only the time between the first tub and the last tub being loaded was used to estimate the working time for each harvester.

Conclusions

From the results of the two tests, the following conclusions can be made regarding to the labor tracking and DGPS system:

- With minimum modification on the two input devices, the button recognition unit was more reliable and user friendly than the barcode scanning unit.
- The labor tracking system worked reasonably well to provide the information for the number of tubs that each harvester filled each day. It is more reliable and more efficient than the existing token or paper card system.
- It can also be used as a yield–mapping device.
- Further studies with other commercial harvesters are needed to develop a general system that is efficient and reliable.

Acknowledgements

The authors would like to acknowledge the technical support of Mr. Greg Drouillard, Mr. David Noxel, and Ms. Mary Beth Freeman, technicians at the University of Florida, Citrus Research and Education Center, Lake Alfred, Florida, the cooperation of Haines City Citrus Growers Association and Dunson Harvesting Inc. in evaluating the equipment, and funding support in part of the Florida Citrus Production Research Advisory Council, IFAS, and the Florida Department of Agriculture and Consumer Services.

References

USDA Agricultural Statistics Board. 1999. Citrus production, 1 May 1999, forecasts by varieties and states, with comparisons. http://www.nass.usda.gov/fl/citrus/cit/199899/cit0599.htm.

Whitney, J. D. 1995. A review of citrus harvesting in Florida. *Trans. Citrus Eng. Conf., Florida Sect., ASME* 41: 33–59.

——. 1999. Field test results with mechanical harvesting equipment in Florida citrus. *Applied Engineering in Agriculture* 15(3): 205–210.

Whitney, J. D., W. M. Miller, T. A. Wheaton, M. Salyani, and J. K. Schueller. 1999a. Precision farming applications in Florida citrus. *Applied Engineering in Agriculture* 15(5): 399–403.

Whitney, J. D., Q. Ling, T. A. Wheaton, and W. M. Miller. 1999b. A citrus harvesting labor tracking and yield monitoring system. ASAE Paper No. 99–3107. St. Joseph, Mich.: ASAE.