A DGPS Yield Monitoring System for Florida Citrus

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

Abstract. *A yield monitoring system was developed based on a differential global positioning system (DGPS) and three fruit weighing systems. The DGPS unit eliminated post processing of the data and provided accurate location of fruit containers used in conventional manual harvesting. Three DGPS units did not vary significantly when comparing position accuracy. The weighing systems consisted of a pressure transducer mounted in the pressure line of the truck bed lifting cylinder, a system with four load cells under the four corners of the truck bed, and a single load cell in the loader boom. On trailer loads of fruit, the most to least accurate system was the lift cylinder (~1% error), the loader boom (<2% error), and the load cells (~5% error). On individual pallet bin loads of fruit, however, the coefficients of variation for the lift cylinder, loader boom, and load cells were 15, 6, and 25%, respectively.*

Keywords. *DGPS, GIS, Instrumentation, Load cell, Precision agriculture.*

Even though there is at least one commercially available yield monitor for Florida citrus (Schueller et al., 1999), a need exists for improving the reliability and accuracy of citrus yield mapping. In conventional manual harvesting of Florida citrus, harvesters place the fruit in containers (tubs for processed, pallet bins for fresh) distributed along a row of trees. Filled fruit containers are loaded with a hydraulically actuated boom on a truck moving through the citrus grove. When the truck stops to load the filled fruit containers, the operator pushes a button to actuate event logging of the DGPS location of the filled container. The quantity of fruit in each container is tallied by the truck operator in "field boxes" which is a volume estimate. The most common size of fruit container is 10 field boxes (~ 0.7 m^3), and this nominal capacity is used to develop yield maps. When the fruit is sold at the packinghouse or processing plant, the grower is paid by "weight boxes" or the actual load of fruit measured on a certified scale at the plant. One weight box of oranges, e.g., is defined in Florida state statutes as 40.8 kg (90 lb). The difference between total field and weight boxes in 500 field box trailer loads of fruit delivered to the plant can be greater than 5% (unpublished data). An accurate method for measuring the fruit load in a full or partially filled fruit container in the field would improve the accuracy of data for yield mapping. It would also allow mapping of fruit characteristics related to the bulk density of fruit and tallying the fruit load being delivered to a trailer.

Several yield–monitoring systems are commercially available for grains and other crops (Birrell et al., 1995; Borgelt and Sudduth, 1992; Searcy et al., 1989; Thomas et al. 1999; Vansichen and Baerdemaeker, 1991). We have been evaluating methods for measuring fruit loads in citrus tubs and pallet bins in the field (Miller and Whitney, 1999; Whitney et al., 1999) as part of a yield monitoring system for citrus. During the 1997–98 harvest season, a prototype GPS (global positioning system) receiver (Geo–Focus, Inc. Gainesville, Fla.) and three scale units were integrated into a citrus loading truck and tested in field trials. GPS data were post–processed to obtain the location of the citrus containers. Yield contour maps were derived from the location maps and field box capacity (not fruit loads) of the containers. The accuracy of the three scale units was compared to a certified packinghouse truck scale. One of the scale units used load cells that were similar to those described for a peanut yield monitor (Thomas et al., 1999).

Based on the findings of the 1997–98 season, design modifications were undertaken to improve the prototype yield monitoring system for the 1998–99 season. To eliminate post–processing of GPS data, a real–time prototype DGPS (differential global positioning system) receiver (Geo–Focus, Inc., Gainesville, Fla.) and one RS232 port were added to the previous prototype GPS yield monitor so data from all scale units were recorded in a similar manner.

The objectives of this study were to determine the accuracy of the three scale units installed on the citrus loading truck as recorded by the yield monitor and to compare the relative position accuracy of the modified yield monitor to that of two other commercial DGPS systems.

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Materials and Methods

Equipment and Instrumentation

A prototype DGPS yield monitor, designed and fabricated specifically for this study through cooperation between Geo–Focus, Inc. (Gainesville, Fla.) and the Citrus Research and Education Center (IFAS, University of Florida), and three scale units were installed on a typical citrus loading truck (fig. 1). The DGPS antenna cable was installed inside a 5–cm diameter PVC pipe and the GPS antenna was attached to the top of the pipe on the truck at 3 m above ground level. The truck was used to pick up filled citrus containers (pallet bins) in the harvested grove and to transport the citrus onto the semi–trailer truck, which was then driven to the packinghouse. Two of the three scale units were used to measure the total load of fruit on the loading truck bed, one using a Barksdale model 423MI–12 (Barksdale, Inc., Los Angeles, Calif.) pressure transducer and the other using four Artech model 30310–10k (Artech Industries, Riverside, Calif.) load cells. The data from the two scale units were stored in the microcomputer through two A/D channels. The third scale unit used a single Artech model 20210–2.5k (Artech Industries, Riverside, Calif.) load cell in the loader boom to measure the load of each filled bin as it was loaded onto the truck. The three scale units were the same as those used in 1997–98 season, except for the method of recording the data for the third scale unit (see Miller and Whitney, 1999, for detailed information). With the previous yield monitor, the data were read with a digital voltmeter and recorded manually. With the new version, data from the loader boom scale were transmitted to the microcomputer through a serial communications port (RS232) and electronically recorded. Therefore, all data from the scales along with the DGPS data for the citrus container locations were recorded and stored in the memory of the yield monitor. Setup instructions and data were uploaded or downloaded, respectively, through a data key (Cybermem key, Dynasys, Clearwater, Fla.). The sequence of data recording was DGPS, A/D, and RS232.

Testing Procedures

The DGPS yield monitoring system was tested in a research plot and in a commercial harvesting operation with citrus trees spaced 7.6 m between rows and 3 to 4 m in row and canopy heights varying from 3 to 5 m. The performance of the three scale units installed on the citrus loading truck was tested in a four–day commercial fresh fruit harvesting operation in Haines City, Florida. In the research field tests, the accuracy of DGPS receiver of the yield monitor was compared with the other two commercial DGPS units.

Scale Units

The three scale units were rewired and re–calibrated. The units utilizing the four load cells and pressure transducer were calibrated using a certified scale at the Haines City

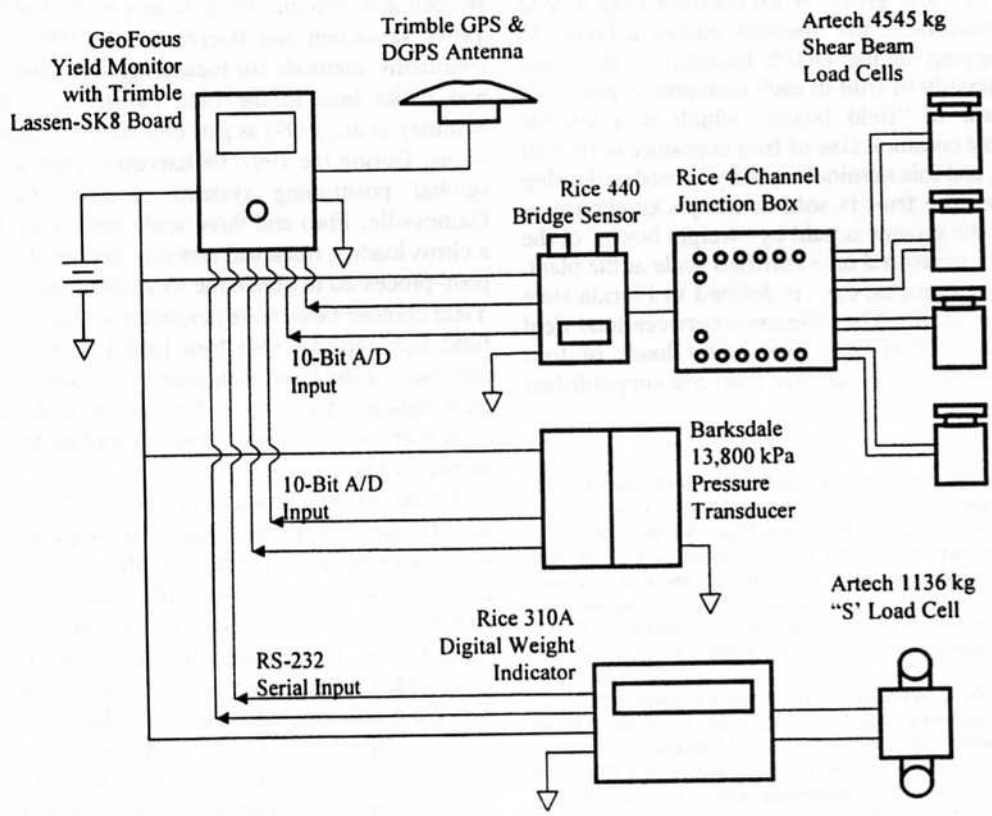

Figure 1. Schematic of instrumentation system for the DGPS yield monitor.

Citrus Grower's Association (Haines City, Fla.). Individual bins filled with citrus were loaded on the truck bed to generate 18 data points covering 90% of full scale capacity. For the four load cells, a linear regression curve yielded a slope of 1131.3 kg/[ΔV] (2494.6 lb/[ΔV]) with $r^2 = 0.999$. For the pressure transducer, a linear regression curve yielded a slope of 1180.3 kg/[ΔV] (2602.5 lb/[ΔV]) with $r^2 = 1.000$. At the end of the harvest season, the scale units were re–calibrated. A maximum difference of –3.7% was observed at 90% full scale, while the average absolute variation between the calibration curves was 1.9%. The third scale unit (boom scale) was calibrated with known loads of 101 and 302 kg (222 and 664 lb), which were approximately 22 and 66% of the load of a bin filled with citrus. Periodic readings taken throughout the test season indicated a maximum variation of ±3% between the load cell module's display and known loads.

During the commercial harvesting tests, a semi–trailer load of citrus was loaded each of the four days with the citrus loading truck. First, the loading boom of the truck picked up the full pallet bin of citrus. Next the load of the full pallet bin as indicated by the boom scale and the load of the empty truck bed, as well as the bin location, were read into the computer memory by a push button on the yield monitor display. For each button push, readings from the boom scale and the other scales were sampled at 10 Hz for 1s, and the average of the 10 readings was recorded. After the pallet bin was loaded onto the truck, the load on the truck bed as sensed by the four load cells installed at the four corners was obtained by a button push. When the truck bed was lifted 3 cm (1.2 in) off the truck frame (and load cells) with an integrated hydraulic cylinder, the hydraulic pressure was recorded. This procedure completed the cycle of loading and measuring the load of one full citrus pallet bin with all three scale units, after which the truck bed was lowered onto the truck frame (and load cells). The loading truck was then moved to the next full pallet bin location and the cycle was repeated until the truck was fully loaded with six fruit bins. It then transported the six full pallet bins and unloaded them onto a semi–trailer truck parked adjacent to the citrus grove. (The loading truck used in the study had a shorter loading boom than some of those used in fresh fruit harvesting, limiting its loading capacity to six bins. A typical fresh fruit loading truck with a longer loading boom has a capacity for nine bins.)

At the end of each day, the total load of all full pallet bins on the semi–trailer truck was obtained from a certified packinghouse scale (±9 kg accuracy). The scale data collected on the citrus loading truck, as well as the DGPS data, were downloaded from the yield monitor using a data key to a personal computer. The output sequence on downloading was A/D, RS232, and DGPS.

DGPS Receivers

Relative position accuracy of the DGPS receiver used in the Goat yield monitor and two commercial DGPS receivers were tested in a two–ha citrus grove at the Citrus Research and Education Center, University of Florida in Lake Alfred, Florida. The sources of the differential correction signal were two Coast Guard Beacon Stations 018 and 024 at Cape Canaveral and Egmont Key, Fla., respectively. Two types of tests, fixed position and field operation, were conducted. The former was used to examine the temporal variation of the DGPS data while the latter was used to determine the relative accuracy of the Goat DGPS receiver as compared to two other commercial DGPS receivers. In the fixed position test, the citrus loading truck was parked in one fixed position with three DGPS receivers installed on it: (1) a Goat DGPS 8–channel receiver (Geo–Focus, Inc., Gainesville, Fla.), (2) a Garmin GPS 12Xl (12 channels) with a GPR 21 differential correction unit (Garmin Co., Olathe, Kans.), and (3) a Rockwell Vision System (12 channels, WAG Corp. Tupelo, Miss.). DGPS data were collected at 1–min intervals for 6 h between 9 a.m. and 4:30 p.m. In the field operation test, DGPS position data from all three receivers were recorded when the citrus loading truck was stopped every 18 to 24 m through the citrus grove. The data from the DGPS receivers were in degrees and were converted to metric distances on the ground using the Albers Projection (ArcView 3.1 software).

Results and Discussion

Scale Units

Table 1 shows the total citrus load harvested on each trailer, the errors produced by each of the three scale units compared to the load at the certified scale, and the average of the standard deviations of individual pallet bin loads recorded by each scale unit on each fruit loading truck. Certified scale loads were obtained from the scale house for each semi–trailer truck at the end of each day and varied from 13,950 to 19,405 kg. The total loads for each scale were determined by adding the individual pallet bin loads on each fruit loading truck.

Table 1. Results with the three scale units.

	Trailer No. 1			Trailer No. 2			Trailer No. 3			Trailer No. 4				
Scale Unit	Citrus Load (kg)	Error[a] (%)	SD[b] (kg)	Citrus Load (kg)	Error[a] (%)	SD[b] (kg)	Citrus Load (kg)	Error[a] (%)	SD[b] (kg)	Citrus Load (kg)	Error[a] (%)	SD[b] (kg)	Average Absolute Value of Error (%)	Average SD (kg)
Lift Cylinder	16,420	2.13	55	19,420	0.08	57	13,876	0.53	70	18,188	1.37	60	1.03	61
Load Cells	15,606	2.93	114	18,045	7.05	122	13,120	5.95	83	17,219	4.04	79	4.99	100
Boom Loader	16,420	2.13	14	19,000	2.08	14	13,865	0.61	46	18,229	1.59	17	1.60	23
Certified Scale	16,077			19,405			13,950			17,943				

[a] Absolute Value of Error = [| Certified scale load - Load of scale unit | / Certified scale load] × 100.

[b] Average of standard deviations of individual pallet bin loads on each truck that made up trailer load.

Hereafter, the three scale units will be referred to as (a) "lift cylinder" utilizing the pressure transducer, (b) "load cells" mounted on truck frame, and (c) "loader boom." The lift cylinder scale unit produced the lowest errors ranging from 0.08 to 2.13% with an average absolute error value of 1.03% while the load cells scale unit generated the highest errors ranging from 2.93 to 7.05% with an average absolute error value of 4.99%. The loads with the load cells scale units were always less than those with the certified scale indicating a possible calibration error. The errors produced by the load boom scale unit were between the two other units, with an average absolute error value of 1.60%.

The average standard deviation values shown in table 1 were calculated as follows. For each truckload on the trailer, a standard deviation of individual pallet loads was calculated. Then standard deviations for all truckloads on the trailer were averaged. The values were similar to the standard deviation of the individual pallet loads on the trailer. They indicated the loader boom and load cells scale units resulted in the lowest and highest variabilities between individual pallet bin loads, respectively. On average, the load cells and lift cylinder scale units' variabilities were, respectively, ca. 4 and 3 times those of the loader boom scale unit. The coefficients of variation for the lift cylinder, load cells, and loader boom scale units on individual pallet bin loads were 15, 25, and 6%, respectively, assuming a mean pallet by load of ca 400 kg. Certified individual pallet bin loads were not available but it was surmised the load variabilities were closer to those indicated by the boom scale, and thus it would be most accurate for measuring individual pallet bin loads.

Some large errors produced in the load cells scale unit may be due to the effects of the fruit container location on the load truck since the load cells were more sensitive to it than the lift cylinder scale unit (Miller and Whitney, 1999). It was difficult to control the pallet bin location on the truck bed in commercial harvest operations but they were usually stacked two deep and centered laterally on the bed. Although the bed lifting height may affect the accuracy of the lift cylinder scale unit, it was controlled consistently at 3 cm (1.2 in.) throughout the field tests. Likewise, the loading position of the loader boom scale unit was controlled so that each pallet bin was loaded at approximately the same relative position to the truck bed. These procedures may have helped reduce the errors produced by the lift cylinder and the loader boom scale units.

Accuracies of measuring citrus loads on the truck bed agreed with the results of the previous study (Miller and Whitney, 1999). Therefore, it was concluded that the lift cylinder scale unit provided more accurate load information than load cells scale unit, but measuring individual pallet bin loads can probably be measured most accurately with the loader boom scale unit.

Relative Accuracy of the DGPS Data of the Yield Monitor

Fixed Position Tests

A total of 317 points was collected for each of the DGPS receivers, and table 2 summarizes the DGPS data statistically. In the north/south direction, the farthest distance between two points was 16.6 m for the Goat DGPS receiver, 12 m for the Garmin receiver, and 16.9 m for Rockwell DGPS receiver. In the east/west direction, the farthest distance was 11.6 m for the Goat, 9.0 m for the Garmin, and 8.9 m for the Rockwell Vision receiver. Thus, the DGPS data varied quite noticeably at a fixed point within the 6–h time frame. The Garmin receiver seemed to produce the least data dispersion while the center of data points for the Rockwell receiver was approximately 3 to 4 m to the east of the center of data points from the other two receivers. Most of the DGPS data from the Goat receiver clustered around the center of Garmin data points, indicating reasonable agreement with the Garmin DGPS data. Table 2 shows the two standard deviation values that included 95% of the recorded points.

Field Operation Test

In most locations, the DGPS data from Goat DGPS receiver were very close to those from the other two commercial DGPS units, although there were a few locations where the distance between Goat and the two commercial units was greater than 3.5 m. The distances between the locations of the Goat DGPS receiver and those of the other two DGPS receivers were also calculated and summarized in table 3. Further statistical analysis showed no significant difference in the distance between locations among the three DGPS receivers. This analysis implied that the accuracy of the Goat DGPS receiver was similar to that of the Garmin and Rockwell units.

Table 2. Relative position accuracy of the three DGPS receivers in the fixed position test using the Albers projection.[a]

	Rockwell Vision		Goat		Garmin	
	North (m)	East (m)	North (m)	East (m)	North (m)	East (m)
Mean	457,531.0	624,030.8	457,529.9	624,027.3	457,530.4	624,028.0
2 Std. Dev.[b]	6.4	4.2	4.0	3.6	3.2	2.4
Min.	457,520.7	624,026.6	457,522.2	624,022.1	457,523.8	624,022.6
Max.	457,537.6	624,035.5	457,538.8	624,033.7	457,535.8	624,031.6

[a] Parameters and values were:

		Parameters:			
Datum	HPGN	24	0	0.0	1st standard parallel
Zunits	No	31	30	0.0	2nd standard parallel
Units	Meters	-84	0	0.0	Central meridian
Spheroid	GRS 1980	24	0	0.0	Latitude of projection's origin
Xshift	0.0	400,000	0	0.0	False easting (m)
Yshift	0.0			0.0	False northing (m)

[b] In a normal distribution, the mean value plus or minus 2 standard deviations includes approximately 95% of the values.

Table 3. Summary of the distance among the three DGPS units in the field operation test using the Albers projection. [a]

	Distance Between Goat and Garmin (m)	Distance Between Goat and Rockwell (m)	Distance Between Garmin and Rockwell (m)
Mean	1.3	1.7	1.5
2 Std Dev.[b]	1.6	1.8	1.6
Min.	0.2	0.2	0.1
Max.	4.3	4.9	5.0

[a] See footnote in table 2.

[b] In a normal distribution, the mean value plus or minus 2 standard deviations includes approximately 95% of the values.

Observations

During the four–day commercial harvest tests, there were several occasions when the yield monitor malfunctioned apparently due to the unavailability of GPS signals. The yield monitor was designed to not record signals from the scale units if no GPS signal was available at the time when the button was pushed, and this design caused several data points to be missed. It was based on the assumption that the fruit load data were meaningless if the container location data were not known. However, in a practical commercial harvest operation, the load of every container is useful and vital information used to tally the total amount of fruit harvested at the end of day. Therefore, the yield monitor should be reprogrammed to record the data from the scale units with and without availability of the GPS signals. When the GPS signal was unavailable, the only way found to resume operation with the yield monitor was to reboot it. No obvious causes were found for the disappearance of GPS signal. It could have been affected by satellite signals, poor connections, height of surrounding tree canopies, and other field conditions. A sound and/or light alarm would be useful to alert the operator when a GPS signal is unavailable so that some necessary adjustment of the yield monitoring system may be made or a self–diagnostic program could be initiated.

CONCLUSIONS

The Goat DGPS yield monitoring system eliminated post–processing of GPS data and generally provided information accurate enough to determine citrus pallet bin loads and to plot their location. Based on the test results of the three scale units on four trailer loads of fruit, the lift cylinder scale unit produced the least average error of 1.03% while the load cells scale unit generated the largest average error of 4.99%. The loader boom scale unit produced an average error of 1.66%. However, the loader boom scale unit indicated the lowest variability between individual pallet bin loads and would probably be the most accurate scale unit for measuring these loads. Improvements still need to be made in the yield monitoring system as far as system accuracy both in scale units and reliability of the DGPS receiver.

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