

Evaluating Performance of Citrus Mechanical Harvesting Systems 2003/04 Season

Fritz Roka and Barbara Hyman
University of Florida – IFAS
Southwest Research and Education Center
Immokalee, FL

Report to the Citrus Harvesting Research Advisory Council
Lakeland, FL
August 2004

During the 2003-04 season, IFAS-SWFREC personnel collected data on machine performance for 73 sample periods. A sample period is defined as the time during which IFAS personnel follow one set of harvesting machines. Table 1 summarizes the sample periods by machine type and scion variety. The data summarized in this report represent more than 2,750 acres and nearly 1.25 million boxes of harvested oranges.

Data were collected to calculate average performance measures by machine type for each sample period. The performance measures included removal percentage, recovery percentage, harvest speed, machine productivity, labor productivity, and percent runtime. Removal percentage refers to the amount of available fruit pulled from the tree during the harvesting operation. Recovery percentage refers to the amount of fruit that the harvest system delivered to the bulk trailer for hauling to a processing plant. Recovery percentage *does not* include “gleaned” fruit. Harvest speed and machine productivity are based solely on active harvesting periods and include shake times, travel speeds, and minimum time requirements to change rows or off-load fruit to field goats. The percent runtime was determined for each sample period and reflects the amount of time engaged in active harvesting during the IFAS sample period. Reasons why runtime percentage is less than 100% include, repairs, crew breaks, and extra time waiting on field goats. Runtime percentage *does not* include time spent “engaged-to-wait.” Harvesting crews are “engaged-to-wait” because of scheduled maintenance, transportation and set-up between harvest sites, and bulk trailer availability.

Block and tree characteristics were recorded and included tree height, clear trunk height, skirt height, trunk circumference, tree spacing both down the row and across the bed, and the percentage of tree spaces that were blank or with young resets. Grove owners provided data on tree age, rootstock and scion varieties, and the total yield for the block observed during the sample period. These data are being further analyzed to determine effects of tree characteristics and grove conditions on mechanical harvesting performance.

Performance measures and data describing block characteristics are summarized in Tables 2-6. Tables 2 and 3 present data for the Coe-Collier and FMC Trunk-Shake-Catch

(TSC) systems, respectively. Tables 4 and 5 summarize performance data for the Oxbo and Korvan Continuous Canopy Shake-Catch (CCSC) systems. Table 6 presents data for the Oxbo Tractor-drawn canopy shaker. Please note that table values represent averages across sample periods and may not correspond to their respective functional relationships. For example, multiplying “Avg Tree Yield” by “Avg Tree Density” does not necessarily equal “Avg Block Yield.”

Tables 7 and 8 summarize average performance statistics for the past four seasons (2000-01 to 2003-04). These tables highlight how performance statistics for the TSC and CCSC systems have changed since the 2000-01 season.

The terms listed below provide addition information as to the data collected and how they were utilized in order to develop measures of performance for each sample period.

1. Available yield. The estimated boxes per tree that would have been harvested by a hand crew.

Available yield = Recovered fruit + broken fruit + missed ground & tree fruit + post-gleaning “shiners”.

2. Harvest yield. Boxes per tree harvested by both machine and hand-gleaning crew.

Harvest yield = Total net weight boxes / Estimated harvested tree spaces.

3. Gleaned harvest. Estimated boxes harvested by gleaning crews.

Gleaning harvest = Preharvest fruit drop + Post-harvest tree fruit + Post-harvest ground fruit – Post-gleaning shiners.

4. Machine harvest. Estimated boxes harvested by the mechanical system. (Note: this pertains only to those system that mechanically catch fruit.)

Machine harvest = Harvest yield – Gleaning harvest.

5. Removal %. The percentage of available fruit removed from the tree during the shaking action. Preharvest fruit drop is not available to the harvester, therefore is not counted in determining removal percentages.

Removal % = 1 – [post-harvest tree fruit / (Available Yield – Preharvest drop)].

6. Recovery %. The percentage of available fruit in the tree prior to harvest that is removed **and** delivered to the road trailer.

Recovery % = Machine harvest / (Available yield – Preharvest drop).

7. Machine speed (trees/hr) and productivity (boxes/hr) were estimated on the basis of a calculated value of machine hours observed during the sampling period. Machine hours reflect only time that the system was actively harvesting. Machine hours were based on average speeds recorded for shaking, moving between trees, goat dumps, and row repositioning. These speed observations were summed across the number of trees harvested during the trial period.

Machine speed = number of trees harvested / Machine hours.

Machine productivity = Machine harvest / Machine hours.

8. Runtime or System Efficiency. The percentage of time during the trial period that the system was actively harvesting.

System Efficiency = Machine hours / Duration of trial period.

9. Labor Productivity. These estimates refer only to the personnel involved with the operations of harvesting machines and goat trucks. Ground workers, gleaning crews, mechanics, and field supervisors are **not** included. Also, it is important to note that labor productivity was based on the entire duration of a trial and not on estimated machine hours.

*Labor Productivity = Machine harvest / (number of equipment operators * time duration of trial)*

OBSERVATIONS

1. Generally, yields were up from the 2002-03 season. Higher yields increase labor and machine productivity measures, which are dependent upon available boxes to be harvested.
2. 2003-04 was the second season of extended use for the FMC (TSC) and Korvan (CCSC) systems. These systems generally showed lower labor and machine productivity measures than observed by Coe-Collier and Oxbo systems, which reflect the average runtime percentage. As FMC and Korvan system gain additional field experience, runtime percentages are expected to increase along with the accompanying performance statistics.
3. The Tractor-Drawn (TD) canopy shaker (Oxbo equipment) operated in grove conditions significantly different from the conditions observed by TSC and CCSC systems. Generally, trees were older, less dense, and larger. Tree yield, especially in early-mid blocks, were smaller. Most trees in blocks harvested by the TD were skirted but lower than the typical trees in the TSC blocks. It was noted that most of the fruit not removed by the TD was located below the skirt line (36 inches).
4. Since the 2000-01 season, removal percentages have remained unchanged for both the TSC and CCSC systems. There has been a minor decrease in recovery percentages for both systems. This suggests that the technology for removing and catching fruit has not significantly changed. The major performance improvements have come in the way equipment operators have managed their crews and maintained the equipment. Increasing runtime percentage directly correlates to increasing harvest speed, machine and labor productivity.

**Table 1. Scope of citrus mechanical harvesting performance evaluation
2003/04 season**

| | Sample Periods | Net Tree Acres | Net Weight Boxes |
|------------------------------|---------------------------|---------------------------|-----------------------------|
| Total | 73 | 2,757 | 1,221,825 |
| Early/Mid | 60 | | |
| Late | 13 | | |
| TSC Coe-Collier | | | |
| <i>Total</i> | 14 | 589 | 342,585 |
| <i>Early/Mid</i> | 13 | 479 | 296,120 |
| <i>Late</i> | 1 | 111 | 46,465 |
| TSC FMC | | | |
| <i>Total</i> | 17 | 82 | 37,433 |
| <i>Early/Mid</i> | 15 | 69 | 30,056 |
| <i>Late</i> | 2 | 12 | 7,377 |
| Tractor-Drawn CS Oxbo | | | |
| <i>Total</i> | 3 | 220 | 71,890 |
| <i>Early/Mid</i> | 1 | 60 | 9,988 |
| <i>Late</i> | 2 | 160 | 61,902 |
| CCSC Oxbo | | | |
| <i>Total</i> | 29 | 1109 | 485,381 |
| <i>Early/Mid</i> | 22 | 962 | 373,277 |
| <i>Late</i> | 7 | 247 | 112,104 |
| CCSC Korvan | | | |
| <i>Total</i> | 10 | 657 | 284,536 |
| <i>Early/Mid</i> | 9 | 581 | 241,889 |
| <i>Late</i> | 1 | 76 | 42,647 |

Table 2. Average performance statistics of TSC -Coe-Collier and harvest block characteristics, 2003/04 season

| | | Early/Mids | Late Season |
|--|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Number of trial periods | <i>#</i> | 13 | 1 |
| Average trial duration | <i>Hrs</i> | 1.28 | 1.28 |
| Removal | <i>%</i> | 95% | 97% |
| Recovery (excluding preharvest drop) | <i>%</i> | 86% | 88% |
| Shake time | <i>Sec</i> | 10 | 6 |
| System Efficiency (% runtime) | <i>%</i> | 66% | 51% |
| Machine Speed (100% runtime) | <i>tree/hr</i> | 209 | 261 |
| Machine Productivity (100% runtime) | <i>boxes/hr</i> | 420 | 512 |
| Crew Size (not including gleaners) | | 2.7 | 2.6 |
| Labor Productivity (operators + goat drivers, no gleaners) | <i>boxes/hr</i> | 108 | 101 |

| Block Characteristics | | Early/Mids | Late Season |
|---|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Tree Density | <i>Tree/ac</i> | 175 | 151 |
| Tree age | <i>Years</i> | 11 | 10 |
| Avg. Block Yield | <i>Box/ac</i> | 634 | 420 |
| Avg. Tree Yield (Block) Avg. Tree Yield (Sample) | <i>Box/tree</i> | 3.69 3.17 | 2.96 3.09 |
| Tree height | <i>Ft</i> | 14 | 14 |
| Clear trunk height | <i>In</i> | 18 | 19 |
| Skirt height | <i>In</i> | 33 | 37 |
| Trunk circumference | <i>In</i> | 18 | 20 |

Table 3. Average performance statistics of TSC -FMC and harvest block characteristics, 2003/04 season

| | | Early/Mids | Late Season |
|--|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Number of trial periods | <i>#</i> | 9 | 1 |
| Average trial duration | <i>Hrs</i> | 3.92 | 3.25 |
| Removal | <i>%</i> | 93% | 92% |
| Recovery (excluding preharvest drop) | <i>%</i> | 73% | 69% |
| Shake time | <i>Sec</i> | 11 | 11 |
| System Efficiency (% runtime) | <i>%</i> | 38% | 39% |
| Machine Speed (100% runtime) | <i>tree/hr</i> | 111 | 117 |
| Machine Productivity (100% runtime) | <i>boxes/hr</i> | 317 | 326 |
| Crew Size | <i>#</i> | 3 | 3 |
| Labor Productivity (operators + goat drivers, no gleaners) | <i>boxes/hr</i> | 42 | 42 |

| Block Characteristics | | Early/Mids | Late Season |
|---|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Tree Density | <i>Tree/ac</i> | 165 | 158 |
| Tree age | <i>Years</i> | 15 | 14 |
| Avg. Block Yield | <i>Box/ac</i> | 509 | 596 |
| Avg. Tree Yield (Block) Avg. Tree Yield (Sample) | <i>Box/tree</i> | 3.10 3.25 | 3.18 3.26 |
| Tree height | <i>Ft</i> | 15 | 14 |
| Clear trunk height | <i>In</i> | 17 | 18 |
| Skirt height | <i>In</i> | 24 | 24 |
| Trunk circumference | <i>In</i> | 21 | 19 |

Table 4. Average performance statistics of CCSC-Oxbo and harvested block characteristics, 2003/04 season

| | | Early/Mids | Late Season |
|---|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Number of trial periods | <i>#</i> | 12 | 31 |
| Average trial duration | <i>hrs</i> | 3.59 | 3.50 |
| Removal | <i>%</i> | 94% | 95% |
| Recovery (excluding preharvest drop) | <i>%</i> | 88% | 91% |
| Travel Speed | <i>mph</i> | 1.03 | 1.08 |
| Machine Speed (100% runtime) | <i>tree/hr</i> | 481 | 527 |
| Machine Productivity (100% runtime) | <i>boxes/hr</i> | 968 | 1223 |
| System Efficiency (% runtime) | <i>%</i> | 60% | 78% |
| Crew Size (no gleaners) | <i>#</i> | 6 | 6 |
| Labor Productivity (operators + goat drivers) | <i>boxes/hr</i> | 100 | 169 |

| Block Characteristics | | Early/Mids | Late Season |
|---|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Tree Density | <i>Tree/ac</i> | 155 | 177 |
| Tree age | <i>Years</i> | 20 | 13 |
| Avg. Block Yield | <i>Box/ac</i> | 535 | 454 |
| Avg. Tree Yield (Block) Avg. Tree Yield (Sample) | <i>Box/tree</i> | 3.68 3.42 | 2.66 3.28 |
| Tree height | <i>ft</i> | 15 | 14 |
| Clear trunk height | <i>in</i> | 16 | 16 |
| Skirt height | <i>in</i> | 9 | 16 |
| Trunk circumference | <i>in</i> | 21 | 20 |

Table 5. Average performance statistics of CCSC-Korvan and harvested block characteristics, 2003/04 season

| | | Early/Mids | Late Season |
|--|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Number of trial periods | <i>#</i> | 7 | 1 |
| Average trial duration | <i>hrs</i> | 3.56 | 3.38 |
| Removal | <i>%</i> | 96% | 95% |
| Recovery (excluding preharvest drop) | <i>%</i> | 89% | 92% |
| Travel Speed | <i>mph</i> | .80 | 1.09 |
| Machine Speed (100% runtime) | <i>tree/hr</i> | 368 | 462 |
| Machine Productivity (100% runtime) | <i>boxes/hr</i> | 1110 | 1810 |
| System Efficiency (% runtime) | <i>%</i> | 48% | 50% |
| Crew Size (no gleaners) | <i>#</i> | 6 | 6 |
| Labor Productivity (operators + goat drivers) | <i>boxes/hr</i> | 89 | 150 |

| Block Characteristics | | Early/Mids | Late Season |
|---------------------------------|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Tree Density | <i>Tree/ac</i> | 126 | 145 |
| Tree age | <i>Years</i> | 15 | 11 |
| Avg. Block Yield | <i>Box/ac</i> | 461 | 561 |
| Avg. Tree Yield (Block) | <i>Box/tree</i> | 5.61 | 3.85 |
| Avg. Tree Yield (Sample) | | 3.92 | 4.87 |
| Tree height | <i>ft</i> | 14 | 13 |
| Clear trunk height | <i>in</i> | 15 | 17 |
| Skirt height | <i>in</i> | 14 | 22 |
| Trunk circumference | <i>in</i> | 21 | 19 |

Table 6. Average performance statistics of Tractor-Drawn canopy shaker (Oxbo) and harvested block characteristics, 2003/04 season

| | | Early/Mids | Late Season |
|---|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Number of trial periods | <i>#</i> | 1 | 2 |
| Average trial duration | <i>hrs</i> | 2.6 | 3.2 |
| Removal | <i>%</i> | 91% | 94% |
| Recovery (excluding preharvest drop) | <i>%</i> | 99.5% | 99% |
| Machine Speed (100% runtime) | <i>tree/hr</i> | 200 | 450 |
| Size of Pick-up crew | <i>#</i> | 23 | 27 |
| Labor Productivity (pick-up crew) | <i>boxes/hr</i> | 7 | 12 |

| Block Characteristics | | Early/Mids | Late Season |
|---------------------------------|-----------------|-------------------|--------------------|
| | Units | Average | Average |
| Tree Density | <i>Tree/ac</i> | 62 | 165 |
| Tree age | <i>Years</i> | unknown | 13 |
| Avg. Tree Yield (Block) | <i>Box/ac</i> | 166 | 367 |
| Avg. Tree Yield (Block) | <i>Box/tree</i> | 1.9 | 2.4 |
| Avg. Tree Yield (Sample) | <i>Box/tree</i> | 4.3 | 2.3 |
| Tree height | <i>ft</i> | 16 | 13 |
| Clear trunk height | <i>in</i> | 9 | 16 |
| Skirt height | <i>in</i> | 12 | 16 |
| Trunk circumference | <i>in</i> | 39 | 19 |

Table 7. Average performance statistics of TSC (Coe-Collier) on early-mid oranges from 2000/01 to 2003/04

| | | 2000-01 | 2001-02 | 2002-03 | 2003-04 |
|----------------------|------------------|----------------|----------------|----------------|----------------|
| Yield | Bx/acre | 561 | 512 | 492 | 634 |
| Removal | % | 95 | 95 | 94 | 95 |
| Recovery | % | 87 | 89 | 87 | 86 |
| Harvest speed | Tree/hr | 107 | 174 | 187 | 209 |
| Runtime | % | 53 | 67 | 54 | 66 |
| Productivity | Bx/man-hr | 53 | 98 | 82 | 108 |

Table 8. Average performance statistics of CCSC (Oxbo) on early-mid oranges from 2000/01 to 2003/04

| | | 2000-01 | 2001-02 | 2002-03 | 2003-04 |
|----------------------|------------------|----------------|----------------|----------------|----------------|
| Yield | Bx/acre | 463 | 429 | 415 | 535 |
| Removal | % | 95 | 95 | 96 | 94 |
| Recovery | % | 90 | 90 | 91 | 88 |
| Harvest speed | Tree/hr | 235 | 288 | 313 | 481 |
| Runtime | % | 51 | 67 | 66 | 60 |
| Productivity | Bx/man-hr | 70 | 98 | 110 | 100 |