limited trees with buffer trees between treatments. These results are not intended to suggest that such uses are not appropriate, but rather that there is no inherent advantage to use of multi-tree blocks to buffer treatment variability.

A survey of the ecological literature revealed that a large proportion of the published studies used pseudoreplication (reviewed in Heffner et al., 1996). It is possible that some horticultural researchers who routinely use multi-tree experimental units in field trials have found that such designs are more likely to successfully distinguish treatment differences because each tree is treated as a pseudoreplicate. The analyses presented here underscore that such practices are contrary to sound statistical analysis and may result in misleading and unfounded conclusions.

Literature Cited

Heffner, R. A., M. J. Butler IV, and C. K. Reilly. 1996. Pseudoreplication revisited. Ecology 77:2558-2562.

Lin, C. S., M. R. Binns, H. D. Voldeng, and R. Guillemette. 1993. Performance of randomized block designs in field experiments. Agron. J. 85:168-171.

Schabenberger, O. 2001. The difference between the GRBD and the RCBD with subsampling. 15 June 2004. <http://www.stat.vt.edu/~oliver/stat 5616/handouts/GRBDvsRCBDSS.pdf>.

Proc. Fla. State Hort. Soc. 117:117-119. 2004.

TREE SHAPING AND GROVE DESIGN TO ENHANCE PERFORMANCE OF CITRUS MECHANICAL HARVESTING

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Abstract. **UF/IFAS personnel have been collecting performance data on citrus mechanical harvesting systems since the 1999-00 season. In addition, data were collected on tree characteristics including skirt and clear trunk heights. Working in typical southwest Florida grove conditions, trunk shakers and continuous canopy shakers with catch frames remove 95% and recover 90% of the on-tree fruit. Removal and recovery rates are dependent upon adequate tree preparation. Current recommendations for citrus mechanical harvesting systems with catch frames suggest that trees be skirted to a height of 36 inches at the drip line and lower scaffold limbs pruned for at least 18 inches of clear trunk height. This paper presents data that indicate how removal and recovery percentages are affected by skirt and clear trunk heights.**

Citrus mechanical harvesting systems offer the potential to dramatically reduce the harvesting costs for Florida growers of processed citrus. Currently, a Florida grower pays between $1.40 and $1.80 per box to pick and roadside fruit for processed juice. It is projected that when mechanical is adopted through out Florida's processed citrus industry, harvesting costs could be reduced by more than 50%. However, incumbent upon success of mechanical harvesting is a significant change in the horticultural focus for a Florida grower. The flexibility of a hand harvesting system allows a grower to freely design and maintain a grove in any configuration that meets his or her production goals. While a harvesting crew will likely adjust picking charges to tree height, tree height can be managed to any level that maximizes boxes per acre. A grower can decide to skirt trees as part of his or her irrigation and disease management programs, and not for reasons of harvesting convenience. With mechanical systems, however, changes in tree and grove design may be necessary solely to promote harvesting efficiency.

This paper presents data and analysis of how tree characteristics affect removal and recovery performance of citrus mechanical harvesting systems. The harvesting systems that will achieve the most dramatic reduction in harvest costs will be those systems that remove and deliver fruit to the bulk trailer. Harvesting systems that operate with catch frames will have the most profound effect on labor productivity because human hands will not be required to touch every piece of fruit.

Trunk-shake-catch (TSC) and continuous-canopy-shake-catch (CCSC) systems are achieving commercial success, particularly in southwest Florida (FDOC, 2004). During the 2002-03 season, these two systems combined to mechanically harvest more than 16,000 acres. Since the 1999-00 season, UF/IFAS personnel have been observing and collecting performance data on TSC and CCSC systems. Performance measures include removal, recovery, harvesting speed, and harvest labor productivity. Removal indicates the percentage of fruit detached from the tree. Both systems operate with catch frames that direct fruit into trailing carts or goats. Hence, recovery measures the percentage of on-tree fruit that the harvesting system delivers to the bulk-hauling trailers. Speed measures how many trees a system can handle during an hour of "active" harvesting. "Active" harvesting does not include any downtime for equipment repairs, transport between grove sites, and downtime due to limited trailer allocation. Labor productivity measures the number of boxes the "core" team delivers to the bulk trailer during an hour of active harvesting. The "core" team includes equipment operators and goat drivers. For a TSC system, between 2.5 and 3 people make up the core team, two equipment drivers and one goat driver. If the goat driver can service two harvesting units, then one-half of a

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person is allocated for each unit. A CCSC core team requires up to six people, two equipment operators and four goat drivers. Since a CCSC system can harvest continuously, one pair of goats can be collecting fruit while the second pair delivers fruit to the bulk trailer. Members of the "gleaning" crew, mechanics, and supervisory staff are not included in the core team.

Removal and recovery rates are dependent upon adequate tree preparation. Current recommendations for citrus mechanical harvesting systems with catch frames suggest that trees be skirted to a height of 36 inches at the drip line and lower scaffold limbs pruned for at least 18 inches for clear trunk height. In addition, commercial harvesters are recommending that tree height be maintained between 16 and 18 ft to avoid splitting fruit as it falls onto the catch frame. A grower has to balance between production goals and performance efficiency of the harvesting equipment. Increasing skirt height and limiting tree height may reduce overall canopy volume, and subsequently, yield potential. On the other hand, inadequate skirt and clear trunk heights may adversely affect fruit removal of low hanging fruit. Further, inadequate skirt and clear trunk heights could impair operator visibility that, at best, slows down harvest speed, and at worst, increases the risk of damaging or snapping low hanging scaffold limbs. The purpose of this paper is to test the hypotheses that tree characteristics and grove preparation make a difference on removal and recovery percentages of mechanical harvesting systems.

Materials and Methods

Since the 1999/00 season, UF/IFAS personnel have traveled to commercial harvesting sites and "passively" collected data on mechanical harvesting systems. An important criterion of the data collection effort was not to interfere with ongoing harvesting operations and record data that reflected operational conditions typical for the specific grove and day of harvest. A single observation lasted between 2 and 4 h depending on the harvester's schedule and machine downtime. Stopwatches recorded tree shaking durations, ground speed, and fruit off-loading times on at least ten separate occasions during the course of a single observation. Two, three-tree samples were marked to collect data on tree removal and fruit losses to the ground. Boxes harvested by the machines were estimated by measuring the volume of fruit in the field goats as they delivered fruit to the bulk trailers. All data were converted to a per-tree basis. Data representing tree characteristics included measurements on tree height (ft), clear trunk height (inches), skirt height (inches), trunk circumference (inches), and tree spacing both in-row and across beds (ft).

A summary of performance statistics is presented in Table 1. Performance data were based on individual observations, which include all data collected for one harvesting unit over a given period of time. Field data were organized into Excel spreadsheets where performance statistics could be summarized. SAS data sets were configured to conduct multivariate analysis on how tree and grove characteristics affected removal and recovery performance. Linear models were analyzed by OLS techniques (SAS, 1987).

Results and Discussion

Table 1 presents summary statistics for the performance measures on TSC and CCSC systems during the 2002-03 season. Working in typical southwest Florida grove conditions,

Table 1. Average performance statistics for Trunk-shake-catch (TSC) and Continuous-canopy-shake-catch (CCSC) systems during the 2002-03 season.

		2002-03 Early-Mid Season	
		TSC	CCSC
Removal	%	94	95
Recovery	%	89	91
Harvest Speed	trees/hr	185	310
Labor Productivity	boxes/hr	100	100
Number of observations[z]	#	28	28

[z]One observation represents between 2 and 4 hours of time during which data were collected from a single harvesting unit.

trunk shakers and continuous canopy shakers with catch frames remove 95% and recover 90% of the on-tree fruit. A TSC system harvests trees individually with actual shaking time varying between 4 and 13 s. Including time to reposition, a TSC unit can harvest an average of three trees per minute. CCSC systems can harvest much faster. Traveling between 0.5 and 1.25 miles per hour and in groves with between 150 and 175 trees per acre, a CCSC system can harvest more than 300 trees per hour. Labor productivity is similar between the two systems. While the CCSC system is faster, its "core" team is twice as large as a TSC system. Overall, labor productivity for either system improves by 10-fold over harvesting productivity of typical hand crews.

Characteristics of trees harvested by either TSC or CCSC systems were similar (Table 2). Tree height, trunk circumference, and clear trunk height averaged 14 ft, 20 inches, and 17 inches, respectively. Sufficient clear trunk height is important for the clamping mechanism on TSC systems. Clear trunk height was measured from the ground to the first scaffold limbs and average clear trunk height was close to the recommended height of 18 inches. Sufficient skirt heights are necessary for efficient function of the catch frames. Average skirt heights for trees harvested by TSC and CCSC systems were 25 and 15 inches, respectively. This average height was more than a foot less than the recommended height of 36 inches. CCSC systems tended to operate in more variable skirt height situations, ranging from nothing (i.e., 0 inches) to nearly 3 ft. CCSC systems also operated in lower yielding blocks. Average yield in blocks harvested by CCSC systems were 2.5 boxes per tree while TSC harvested trees average 3.2 boxes.

Table 2. Average (low-high) statistics describing tree characteristics of trees harvested by trunk-shake-catch (TSC) and continuous-canopy-shake-catch (CCSC) systems during the 2002/03 season.

Variable	Unit	TSC	CCSC
Tree density	tree/acre	157 (120-180)	156 (116-223)
Tree height	feet	14 (7-23)	14 (10-18)
Clear trunk height	inches	17 (11-26)	17 (14-22)
Circumference	inches	20 (15-29)	20 (14-26)
Skirt height	inches	25 (4-41)	15 (0-35)
Yield	box/tree	3.2 (1.5-5.0)	2.5 (0.9-5.7)

Tables 3 and 4 present results from multivariate analysis on removal and recovery, respectively. For TSC systems, skirt height and tree yield had a significant and positive effect on removal percentages. Based on the parameter estimate for skirt height listed in Table 3, removal percentage could be increased to 98% if skirt heights increased from 25 to 36[z] inches. Increasing skirt heights had no apparent effects on improving overall removal percentage for CCSC systems. The parameter estimate was close to zero both in magnitude and statistical significance.

Skirt height had a positive and statistical significant effect on recovery percentage for both TSC and CCSC systems. A one percent increase in skirt height was predicted to increase overall recovery by nearly 0.2%. If the effect is, as assumed, linear, TSC and CCSC could achieve nearly 98% recovery if skirt heights were increased to 36 inches. The linearity assumption is quite strong and more analysis is required to better understand the extent recovery percentages improve with skirt height.

It is interesting to note that "harvest duration," as measured by shake time for TSC systems and ground speed for CCSC systems, did not have a significant influence on either removal or recovery percentages. Data scatter plots of shake times on removal for TSC systems indicated most, if not all, fruit was detached within the first four seconds of trunk shaking. While not significantly different from zero, the parameter estimate of "ground speed" for CCSC systems is negative, indicating some chance that removal and recovery percentages decrease with increasing speed.

Table 3. Parameter estimates and significance of tree and grove characteristics on **removal** percentage of trunk-shake-catch (TSC) and continuous-canopy-shake-catch (CCSC) systems during the 2002/03 season.

Variable	Unit	TSC	CCSC
Intercept		0.730	1.022
Tree density	tree/ac	0.0001	**-0.0003***
Tree height	feet	-0.003	-0.006
Clear trunk height	inches	0.004	-0.0002
Circumference	inches	0.002	0.003
Skirt height	inches	**0.001****	0.0006
Yield	box/tree	**0.021*****	0.002
Shake time	seconds	0.019	—
Ground speed	mph	—	-0.014
Observations	N	28	28
Adj. R^2		0.26	0.10

*Parameter estimate significant at the 10% level.
**Parameter estimate significant at the 5% level.
***Parameter estimate significant at the 1% level.

[z]An increase from 25 to 36 inches is a 44% increase.

Table 4. Parameter estimates and significance of tree and grove characteristics on **recovery** percentage of trunk-shake-catch (TSC) and continuous-canopy-shake-catch (CCSC) systems during the 2002/03 season.

Variable	Unit	TSC	CCSC
Intercept		0.639	0.976
Tree density	tree/ac	0.0002	-0.0004
Tree height	feet	-0.003	-0.007
Clear trunk height	inches	0.005	0.004
Circumference	inches	0.0008	-0.002
Skirt height	inches	**0.002****	**0.002*****
Yield	box/tree	**0.026****	0.011
Shake time	seconds	0.104	—
Ground speed	mph	—	-0.007
Observations	N	28	28
Adj. R^2		0.26	0.20

*Parameter estimate significant at the 10% level.
**Parameter estimate significant at the 5% level.
***Parameter estimate significant at the 1% level.

Conclusions

Data collected from field observations of citrus mechanical harvesting systems and analyzed through multivariate analysis suggest that fruit recovery percentages could be improved with adequate tree skirt height. Increasing recovery percentages to more than 95% would lessen, if not eliminate, the need for hand crews to glean fruit not captured by the mechanical units. Assuming that the per box of harvesting from a mechanical system would be less than from a hand crew, improvements in recovery percentage would translate into a direct benefit of harvesting more boxes at a lower price. Further, if improvements to harvesting performance encourage new growers to adopt mechanical harvesting systems, the cost structure for owning and operating mechanical units would change. More acreage per machine system would lower the unit costs of equipment ownership. With increased competition among mechanical harvesting companies, a lower cost structure of equipment ownership would be passed on the grower through lower citrus harvesting costs.

Literature Cited

FDOC. 2004. Commercial Mechanical Harvesting for Processed Fruit. Florida Dept. of Citrus, Lakeland. 11 pp.
SAS Institute, Inc. 1987. SAS/STAT™ Guide for Personal Computers, Version 6 Edition. Cary, NC. 1,028 pp.