Mechanical Harvesting of Peaches— Limited Potential

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Abstract. This study evaluated the total and marketable yield of three peach cultivars [*Prunus persica* (L.) Batsch, ‘Autumnglo’, ‘Harvester’, and ‘Redhaven’] when mechanical pruning and harvesting systems were used and trees were grown under three irrigation regimes. All cultivars were trunk-shaken using an experimental inertial shaker on an over-the-row (OTR) shake-catch harvester. ‘Autumnglo’ also was hand-harvested at all irrigation regimes. Fruit damage was not significantly affected by irrigation. A significant source of fruit damage was pruning debris that remained in the canopy after hedging and became lodged in the fruit-conveying system, resulting in cultivar effects on fruit damage. Total yield of firm-ripe fruit was similar among cultivars in 1987 and 1988. However, ‘Autumnglo’ trees had a higher percentage of marketable fruit than ‘Redhaven’ or ‘Harvester’ in 1987 and 1991. Mechanical harvesting appeared to accelerate the decline of ‘Autumnglo’ as shown by tree deaths and greater symptom expression of *Prunus* necrotic ringspot virus. The potential for a single mechanical harvest of peaches is limited because of the difficulty in managing the ripening window, the high potential for fruit damage, and the possibility of accelerated tree decline for disease-susceptible cultivars.

Mechanical harvesting of fresh-market and processing peaches is not a practical way to reduce the high labor cost of peach harvesting (Peterson, 1988). Substantial research has addressed this problem, yet only 25% of the cling peaches used for processing are mechanically harvested, and many cling cultivars require one or two hand-harvests before mechanical harvesting (Peterson, 1988). Nonuniform ripening of peaches is the primary factor that limits mechanical harvesting, and according to Peterson (1985, 1988), three approaches have focused unsuccessfully on the problem: 1) development of shake-catch harvesters that remove only the mature fruit, 2) use of growth regulators to narrow the maturity range of peaches, and 3) breeding of new cultivars that ripen more uniformly than those now grown. In addition to nonuniform ripening, other cultural constraints limit efficient mechanical harvesting. Summarizing 20 years of experience, Fridley et al. (1971) recommended that the trees be trained with 1) the first scaffold branch ≥ 60 cm above the soil, 2) each limb radiating from the trunk in a separate vertical plane, 3) no long hanger shoots, 4) no branches in the lower part of the tree, and 5) flush pruning

cuts. Diener et al. (1976a, 1976b) based their tree design on Fridley et al. (1971), modifying the criteria so that scaffold limbs started 70 cm above the soil and there were no overlapping branches in the vertical planes. Chalmers et al. (1978) developed the V-shaped Tatura trellis system for mechanized peach production and further reduced the depth of the canopy to reduce fruit injury during harvest. Aldred et al. (1979) developed a Y-shape tree with a 60-cm-thick canopy to meet the criteria of Fridley et al. (1971). Similarly, Horton (1985) adapted the Y-shaped system for mechanization. The last three production systems used mechanized pruning, which left roughly cut stubs.

Peterson and Miller (1989) developed a mechanical harvesting system for apples (*Malus domestica* Borkh.) that removed 90% to 99% of the fruit with 80% to 92% fresh-market quality for ‘Delicious’. Our objectives were to integrate this over-the-row (OTR) shake-catch harvesting system with a mechanized peach pruning system and to evaluate the combined production system performance for ‘Redhaven’, ‘Harvester’, and ‘Autumnglo’ peaches. In addition, because Feldstein and Childers (1957) found that irrigation decreased the harvest period to a single picking, we wanted to examine the effect of irrigation on harvesting efficiency.

Materials and Methods

Peach trees were planted in Spring 1985 using a subsoil-type mechanical tree planter. Trees were spaced 2.5 m apart within the row, and row spacing was 4.5 m alternating with 6 m. The 6-m spacing was used to accommodate the bin-filling operation. Individual cultivars (‘Redhaven’, ‘Harvester’, and ‘Autumnglo’

on Lovell rootstock) were planted in 40-tree rows as a randomized complete-block design with four replications. Each cultivar was represented once in each row and each block, except ‘Autumnglo’, which had duplicate rows. Each cultivar was mechanically harvested; an additional row of ‘Autumnglo’ was used as a hand-harvested control. Within each 40-tree row, subplots of 10 trees were randomly assigned irrigation treatments of 1) none, 2) full season, and 3) irrigation beginning 4 weeks before harvest and continuing 2 weeks after harvest. Subplot 3 was randomly duplicated within the tree row as a measure of within-plot variability. Data for the mechanically harvested cultivars and irrigation treatments were analyzed by year, using a split-plot design with cultivars (tree row) as the mainplot and irrigation as the subplot. Data for the method of harvesting ‘Autumnglo’ (hand vs. mechanical) were analyzed using a split-plot design with harvesting method (tree row) as the mainplot and irrigation as the subplot each year. The duplicate of subplot 3 was analyzed as a separate subplot treatment (subplot 4); because it did not differ from subplot 3, the means of subplots 3 and 4 were pooled. There were no significant cultivar $\times$ irrigation interactions, so the main and subplot effects are described separately. Percentage data were log-arc-sin-transformed before analysis of variance (ANOVA) and are presented as percentage means of the transformed data.

The trees were trained to a free-standing Y (Horton, 1985), with the lower scaffolds 60 cm above the soil and a 60° angle between the arms of the Y. Tree height was limited to 2.5 m by mechanical topping and the arms of the Y were dormant-season sheared, leaving a 45-cm canopy depth. Pruning by hand involved up to six cuts per tree per year to remove overlapping branches. Crop load was adjusted by hand-thinning 40 to 60 days after full bloom, leaving a fruit spacing of 10 to 15 cm.

All peaches were harvested with an experimental OTR, a continuously moving shake-catch harvester (Peterson and Miller, 1989), in 1987, 1988, and 1991. Spring frost damage to floral buds eliminated fruit in 1989, 1990, and 1992. Fruit was removed from each tree using a multidirectional inertial trunk shaker operating at 17 Hz for 4 sec. The trunk shaker used a C-clamp with Kilby pads (60 Durometer; Grildley Manufacturing, Calif.). The clamping force did not exceed 19,000 N. Nitrile-covered belts (3.7 mm thick) (Polymate 135 Nitrile COS; Globe International, Buffalo, N.Y.) were used to support the trunk shaker pads and were lubricated every 40 trees with a silicone spray. Catching surfaces and conveyors were padded to minimize fruit damage. Peaches were placed in 0.7-m³ bulk bins and transported ≈ 1 km by forklift to a grading facility.

A commercial grader (OMNISORT; Durand-Wayland, La Grange, Ga.) was used for sorting. A sample of ≈ 50 kg of fruit from each subplot was inspected visually within 6 h of harvest and manually separated into three maturity ranges: marketable firm-ripe, green, and over-ripe. Firm-ripe fruit with a skin break

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or a distinguishable bruised area were identified further as damaged culls. After the peaches were separated into those four categories, they continued through the electronic weight-sizer, where the size distribution (based on the weight of each fruit in each category) was determined and recorded. After this subsample was sorted, the remaining fruit from each subplot was passed through the electronic weight-sizer. The final distribution of grades in each subplot was based on percentages from the 50-kg subsample.

Irrigation was provided by two 4-liters/min emitters per tree. The emitters were spaced 60 and 100 cm from the tree. Water application began in early May for full-season irrigation (subplot 2) and continued through September for all cultivars. The application rate was nominally 240 liters/week. Subplot 3 received the same application rate 4 weeks before projected harvest and for 2 weeks after harvest. Tree diameter was measured using an ultrasonic tree tape (Upchurch et al., 1993) 30 cm above the soil surface. At the conclusion of the study in Fall 1992, dead trees were counted.

The presence of *Prunus* necrotic ringspot virus (PNRSV) symptoms was determined in Mar. 1993 for all 'Autumnnglo' trees. The key visual indicators of PNRSV, as described by Barrat and Otto (1984), were the presence of fissures and "bubble bark" on the trunk. The percentage of infection was calculated, and ANOVA was performed on log-arc-sin-transformed data. Yield data were not collected in 1989, 1990, and 1992 because of spring frost damage to floral buds.

Results and Discussion

Peach cultivars had similar total yield of firm-ripe fruit in 1987 and 1988; however, in 1991, 'Autumnnglo' had higher yield and marketable percentage than 'Redhaven' or 'Harvester'. The percentage of marketable firm-ripe fruit mechanically harvested with a single pass ranged from 62.4% to 95.7% (Table 1) for the three cultivars. In two of the three years, 'Autumnnglo' had a higher percentage of marketable firm-ripe fruit than 'Harvester' and 'Redhaven'. Irrigation treatments had no effect on the percentage of marketable firm-ripe fruit mechanically harvested in any year. In 1991, full-season irrigation resulted in a lower total harvest percentage than irrigation during the ripening period. In all years, the non-irrigated trees tended to produce the highest percentage of marketable firm-ripe fruit, although none of the differences were significant.

Fruit damage to the firm-ripe fruit ranged from 5.4% to 38.3% for the three cultivars. No single cultivar had consistently higher or lower damage (Table 1). Similarly, irrigation did not affect fruit damage. Chalmers et al. (1978) reported 34% to 43% bruising and cuts, Fridley et al. (1971) reported 35% bruising, and Diener et al. (1976b) reported 15% to 31% damaged and soft fruit losses using mechanized harvests. In our tests, most damage was caused by punctures. Mechanized hedging produces short, roughly cut shoots that can puncture

fruit as it passes through the tree. Hedging also can leave cut shoots in the canopy. These dead shoots occasionally fall into the harvester, become lodged in the conveying system, and puncture each fruit that passes. This situation was shown clearly in 1991 when loose dead branches were carefully removed from the 'Autumnnglo' trees before harvest, following the high damage levels in harvesting 'Redhaven' and 'Harvester'; the careful removal of such branches from 'Autumnnglo' trees reduced the damage level by about two-thirds (Redhaven and Harvester, respectively) to 12.4% for 'Autumnnglo' (Table 1).

Our experience indicates that mechanized pruning systems must remove all cut shoots

from the canopy completely to avoid fruit damage when using mechanical harvest systems. A goal of <10% cut or bruised fruit is generally accepted in hand-harvesting commercial fresh-market peaches. Studies have documented losses due to bruises and cuts at 5% and 19% for hand-harvested, fresh-market peaches (Diener et al., 1976) and at 29% (Fridley et al., 1971) and 46% (Chalmers et al., 1978) for mechanically harvested cling peaches. The percentage of bruises and cuts in cling peaches does not always reduce the percentage of choice peach slices, so an elevated damage level is acceptable. We obtained <10% damage (Table 1) in our first year of harvest, when yield per tree was low. Commercial

Table 1. Effect of cultivar and irrigation on fruit damage and yield components in a mechanically pruned and harvested "Y" peach production system.

Year and variable	Yield		Damage fruit (%) ^z	Firm-ripe yield >64 mm in diam (kg/tree)
	Total (kg/tree)	Marketable (%) ^z		
1987				
Cultivar				
Autumnnglo	4.0 ^{ns,y}	89.6 a	8.1 a	4.0 a
Redhaven	3.7	77.4 b	5.4 c	2.5 b
Harvester	2.6	75.8 b	6.7 b	2.2 b
Irrigation				
None	2.8 ^{ns}	81.8 ^{ns}	5.8 ^{ns}	2.1 b
Full season	3.7	80.0	6.8	3.1 a
Ripening period	3.6	80.0	7.0	3.1 a
1988				
Cultivar				
Autumnnglo	10.3 ^{ns}	63.7 b	24.4 b	10.2 a
Redhaven	12.5	68.1 ab	29.0 a	6.5 b
Harvester	11.0	73.3 a	26.9 ab	7.8 ab
Irrigation				
None	10.8 ^{ns}	70.7 ^{ns}	26.0 ^{ns}	7.0 b
Full season	11.6	68.8	24.2	8.6 a
Ripening period	11.4	67.0	28.4	8.5 a
1991				
Cultivar				
Autumnnglo	11.2 a	95.7 a	12.4 b	10.9 a
Redhaven	7.0 b	64.1 b	31.8 a	1.5 b
Harvester	6.6 b	62.4 b	38.3 a	1.8 b
Irrigation				
None	7.8 ab	76.9 ^{ns}	23.4 ^{ns}	3.9 b
Full season	7.0 b	72.0	29.5	3.9 b
Ripening period	9.1 a	73.7	28.4	5.5 a

^zData transformed to log arcsin for analysis and mean separation.

^yMean separation within cultivar or irrigation treatment by Ryan-Einot-Gabriel-Welsch multiple F test at $P \leq 0.05$; ns = nonsignificant.

Table 2. Effect of harvest method and irrigation treatments on total yield components of 'Autumnnglo' peach.

Variable	Total peach yield (kg/tree)					
	1987		1988		1991	
	All fruit	Fruit >64 mm in diam	All fruit	Fruit >64 mm in diam	All fruit	Fruit >64 mm in diam
Harvest method						
Hand	4.8 ^{ns,z}	4.7 ^{ns}	21.9 ^{ns}	21.8 ^{ns}	21.4 a	20.7 a
Mechanical	4.3	4.2	22.0	21.8	13.3 b	12.9 b
Irrigation						
None	3.6 ^{ns}	3.5 ^{ns}	20.6 ab	20.5 ab	17.3 ab	16.2 ab
Full season	4.5	4.4	18.9 b	18.7 b	14.7 b	14.5 b
Ripening period	5.1	5.0	24.1 a	23.9 a	18.7 a	18.3 a

^zMean separation within harvest method or irrigation treatment by Ryan-Einot-Gabriel-Welsch multiple F test at $P \leq 0.05$; ns = nonsignificant.

peach operations, however, plan for $\geq 80\%$ pack-out. We never consistently achieved this level because of a combination of damage losses and losses from green or soft fruit removed by the single harvest.

The late-season cultivar *Autumnnglo* produced the highest yield of large fruit (>64 mm in diameter) relative to 'Redhaven' and 'Harvester' (Table 1) in 1987 and 1991. Lack of irrigation (subplot 1) reduced the yield of large fruit relative to irrigation during the ripening period (subplot 3). Full-season irrigation (subplot 2) did not increase total or large-fruit yield over that of subplot 3, and in 1991, full-season irrigation reduced the yield of large fruit, probably because of excessive vegetative growth.

In 1987 and 1988, the yields for 'Autumnnglo' harvest methods (Table 2) were similar. In 1991, however, the total and large fruit yield of the mechanically harvested trees was $\approx 60\%$ that of the hand-harvested trees because of a fruit loss during the 'June-drop'. This yield reduction suggested a decline in the trees that had been subjected to mechanical harvesting. Tree diameter data indicated no effect of harvest method (data not presented), although trees with full-season irrigation (subplot 2) were generally the largest trees, and trees with no irrigation (subplot 1) were generally the smallest. Evidence supporting a decline in mechanically harvested 'Autumnnglo' was the number of dead trees in 1992, 6 years after the first mechanical harvest. Mechanically harvested 'Redhaven' and 'Harvester' and hand-harvested 'Autumnnglo' each had one dead tree out of 160; mechanically harvested 'Autumnnglo' had five dead trees out of 160 trees, which was significantly higher ($t = 3.23$, $P \leq 0.05$) than for the hand-harvested 'Autumnnglo'. Symptoms of PNRSV appeared in 'Autumnnglo' in 1991 and in Fall 1992 when 50% of the mechanically harvested trees and 31% of the hand-harvested trees exhibited symptoms ($t = 7.43$; $P \leq 0.01$). The action of

mechanical harvesting slightly discolored the bark at the point of shaker attachment because of compression and abrasion, but the OTR harvester did not visually break the bark. The fissures and bubble bark associated with PNRSV in mechanically harvested trees were located throughout the trunk and were not restricted to the area of shaker attachment. We are assuming that all trees came from the nursery with a similar (although unknown) incidence of PNRSV infection. Mechanical harvesting apparently accelerated the development of PNRSV in 'Autumnnglo', reduced yield potential in 1991, and accelerated tree death by 1993. We did not establish a hand-harvest control for 'Harvester' and 'Redhaven'; thus, we cannot state that they were not in decline. However, the number of dead trees in 'Harvester' and 'Redhaven' were the same as in the hand-harvested 'Autumnnglo', which does not suggest such a decline. Symptoms of PNRSV were not evident in these cultivars, although 'Redhaven' is cited as a susceptible cultivar (Barrat and Otto, 1984). 'Autumnnglo' is harvested ≈ 30 days after 'Redhaven', when air temperatures are dropping. Leaf drop occurs within 30 days of 'Autumnnglo' harvest. Thus, it is possible that 'Redhaven' had an additional 30 days following harvest to recover from the stress of trunk shaking.

From this study, we conclude that the potential for mechanical harvesting of fresh-market peaches is limited with an OTR harvester and mechanized pruning system. Although there is interest in mechanical harvesting, the limitations outlined by earlier researchers still exist. Furthermore, two additional factors that limit a mechanical peach pruning and harvesting system have been identified: 1) mechanical harvesting may accelerate the decline of disease-susceptible peach cultivars, as physical trunk stress interacts with disease, and 2) canopy debris may cause damage in mechanically harvested peaches.

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