Fresh–Market Quality Tree Fruit Harvester
Part I: Sweet Cherry

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Abstract. *A two–unit mechanical harvester was developed to harvest fresh–market quality sweet cherries (*Prunus avium *L.). Units were essentially mirror images. On each unit the harvester operator used joysticks to position and engage a rapid displacement actuator (RDA) on main scaffolds to effect fruit removal. Catching conveyors were designed to intercept falling fruit without damage and elevate the fruit to a collecting conveyor. Cushioned catcher pans on each unit were used to seal around the trunk and connect the two units. Main scaffolds were inclined to reduce damage as cherries fell to the catching surface. Ethrel (2–chloroethyl phosphonic acid) was used to reduce the fruit retention force of mature cherries to enable removal without stems or damage. The experimental harvester demonstrated potential for harvesting stemless sweet cherries with fresh–market fruit quality comparable to commercial hand–picked cherries. The catching/collecting system was effective with low damage inflicted to the cherries. About 90% of the cherries were remove from the tree and of those removed, 88% were collected and containerized. These levels are expected to increase with proper tree training and appropriate sized catching surfaces. Harvest rate down–the–row ranged from 85 to 158 trees/h with harvester capacity up to 1590 kg/h (3500 lb/h).*

Keywords. *Mechanical harvest, Cherry, Quality.*

The supply of a skilled, harvest workforce is a concern of the sweet cherry (*Prunus avium L.*) industry in the United States (Warner, 1997; Hansen, 1999a; Morgan, 2002). At present no fresh–market sweet cherries are mechanically harvested (Sarig et. al., 1999). Main problems preventing machine harvest of sweet cherries are: 1) difficulty in fruit removal; and 2) fruit damage caused during detachment, falling through the tree canopy, and from catching surfaces.

Traditionally the industry has dictated that sweet cherries sold on the fresh market must have stems. Innovative growers in the state of Washington (Hansen, 1999b) have developed a system of training and cultural practices designed to be compatible with mechanical harvesting and yield stemless sweet cherries for the fresh market. Test marketing of the stemless sweet cherries found very good consumer acceptance (Black, 1999). Certain cultivars of sweet cherries are routinely sold as stemless in the European markets (Long, 2001). The timely application of a fruit abscission compound to loosen the fruit–pedicel attachment is an essential cultural practice. Bukovac (Bukovac et al., 1971) working with sweet cherries in Michigan found that ethrel applied 7 to 14 days before harvest could reduce the fruit to pedicel removal force from greater than 500 g (17.6 oz) to less than 300 g (10.5 oz).

Peterson and Wolford (2001, 2002) demonstrated a promising harvesting concept for stemless sweet cherries that rapidly displaced scaffold limbs to effect fruit removal. Energy absorbing catching surfaces permitted machine–harvested fruit to have only 2 to 6% more damage than commercial hand harvesting. Since positioning of a trunk seal took considerable time, machine harvest rates were limited to 80 trees/h. The harvesting concept appeared promising, so they suggested development of a complete harvesting system and extensive testing to determine commercial potential.

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Objective

The objective of this research was to develop a mechanical harvesting system for stemless, fresh–market quality sweet cherries by: (1) developing an effective positioning system for the fruit removal actuator, (2) developing an effective trunk seal that minimized fruit damage and is quickly positioned, (3) refining compatible tree–training characteristics and cultural practices, and (4) testing the system under commercial field conditions to determine operating parameters and fruit quality.

Harvester Design

The harvester consisted of two separate units on opposite sides of the tree row (figs. 1, 2, and 3), which were essentially mirror images. Each unit was three–wheeled (front wheel steerable), all–wheel–hydraulic–drive with a driver, controlling all operations, positioned at the rear. Power was supplied by a 30–kW (40–hp) diesel engine that drove a 114–L/min. (30–gpm) pressure–compensated, variable–volume hydraulic pump. Peterson et al. (1999) described the rapid displacement actuator (RDA), a hydraulic cylinder that rapidly displaces scaffold–limbs for fruit removal. The RDA had a 2.9–cm (1.125–in.) bore and 5.08–cm (2–in.) stroke. A 10.16–cm (4–in.) diameter aluminum disk threaded to the end of the RDA cylinder rod partially housed a 7.62–cm (3–in.) diameter, 2.54–cm (1–in.) thick rubber disk. This rubber disk was positioned against a scaffold to transfer the rapid displacement of the RDA to the branch, but also to minimize tree damage. Each harvester operator used a pair of hydraulic joysticks to maneuver the RDA support system (fig. 4) to position the RDA against the branch. Four hydraulic actuators yield eight degrees–of–freedom. The RDA was attached to a slide tube that was journal bearing supported in a slide–support sleeve. The slide tube could rotate in the slide–support sleeve and be displaced through the slide–support sleeve by a slide cylinder [1.07–m (42–in.) stroke]. The rod of the slide cylinder was attached to one end of the slide tube. A split block bolted to a brass collar supported the slide cylinder (fig. 5). The inside diameter of the brass collar was sized to allow the slide tube to slide through it. A 9.5–mm (0.375–in.) keyway cut in the brass collar (105° from the center of the slide cylinder) supported a key (bolted to brass collar). A mating keyway in the slide tube (aligned with the bottom of the RDA) maintained the orientation between the RDA and slide cylinder. The end of the brass collar next to the slide–support sleeve had a 6.35–mm (0.25–in.) high × 12.7–mm (0.5–in.) wide lip machined in its outer circumference. A semi–circular rotation collar, the inside diameter of which matched the outside diameter of the slide–support sleeve, had a mating notch machined to its underside. This rotation collar bolted to the slide–support sleeve and captured the lip of the brass collar. This rotation collar also supported a hydraulic rotation

Figure 1. Front view of experimental sweet cherry harvester.

Figure 2. Rear view of experimental sweet cherry harvester.

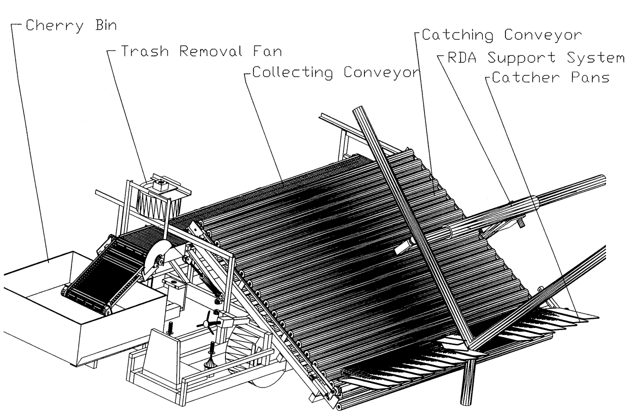

Figure 3. Schematic of the experimental sweet cherry harvester.

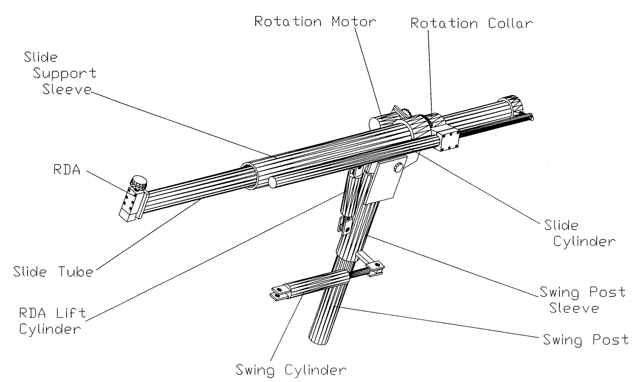

Figure 4. Schematic of RDA support system.

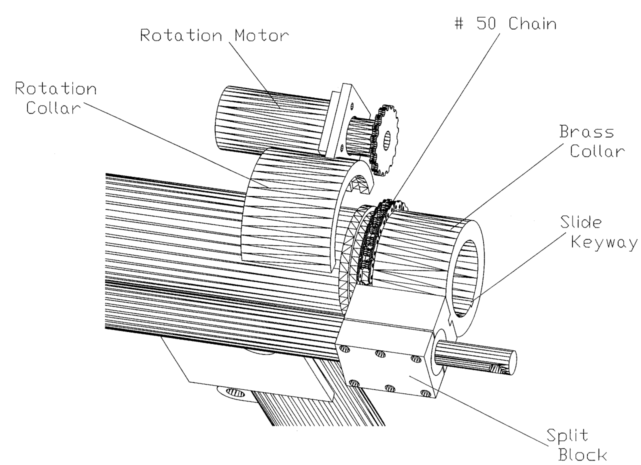

Figure 5. Close–up of RDA support parts.

motor that had an 18 tooth No. 50 chain sprocket keyed to its shaft. This sprocket engaged a chain that was bolted (at the ends) to the brass collar. This arrangement permitted the slide tube to translate the slide–support sleeve while the rotation motor adjusted the angular orientation of the RDA (110° rotation). The slide–support sleeve had two parallel plates welded to it that were pin supported by two parallel plates that were welded to a swing post sleeve. An RDA lift cylinder was pin connected to both the slide–support sleeve and swing post sleeve. Activation of the RDA lift cylinder could rotate the slide tube 37° from the horizontal. A swing post supported the swing post sleeve. The swing post was positioned at a 45° angle (as viewed from the front of the harvester) and welded to the main harvester frame. A swing cylinder connected to the main harvester frame and the swing post sleeve permitted 90° of rotation (with the RDA slide tube fully extended, the RDA could reach from the bottom of the catching conveyor to the top).

An energy absorbing catching conveyor caught the fruit and elevated them to a collecting conveyor. The catching conveyors were 2.93 m wide × 2.29 m long (115 in. wide × 90 in. long) and angled 30° to the horizontal. The catching conveyors consisted of 28–mm id. × 19–mm thick (1.1–in. id. × 0.75–in. thick) Armaflex pipe insulation (Armstrong World Industries, Lancaster, Pa.) surrounding 27–mm (¾–in.) schedule 40 aluminum pipes. The pipes were 2.93 m (115 in.) long and were supported by B–1–1 attachments of 2050 roller chain spaced every 127 mm (5 in.). The pipe insulation was covered with a 0.56–mm (0.02–in.) thick polyurethane–coated nylon fabric that formed pockets to collect and transport the fruit. The design was such that the pockets were stretched at the outlet end of the conveyor to carefully discharge the fruit onto a transfer incline (Peterson and Wolford, 2001). This incline was covered with 12–mm (0.5–in.) thick Poron (Rogers Corp., East Woodstock, Conn.) and transferred the fruit to a 460–mm (18–in.) wide collecting conveyor. The collecting conveyor used a series 900 Flush Grid plastic perforated belt (Intralox, Harahan, La.) that transported the fruit to the rear and then declined to lower the fruit into a revolving bin for distribution. Before the conveyor declined, a fan pulled air through the conveyor to remove leaves and other light trash. An ultrasonic sensor was used to minimize fruit drop into the bin and ensure even fill. This sensor sensed the level of fruit in the bin and triggered a circuit to automatically raise the decline before the conveyor touched the fruit.

To seal around tree trunks and position the two halves together, each unit had a set of 19 catcher pans (part no. 500–1683D BEI, Inc. South Haven, Mich.) mounted on a rail above the lower edge of the inclined catching conveyor (fig. 3). The catcher pans pivot mounts were angled at 10° from the vertical instead of the normal 7°, to allow more space between overlapping catcher pans. This space permitted each catcher pan to be covered with 12.7–mm (0.5–in.) thick cushioning material (Armaflex insulation, Armstrong World Industries, Lancaster, Pa.) to minimize fruit damage. The catcher pans were angled about 14° from the horizontal.

All moving mechanisms were properly shielded to prevent accidents to the operators and onlookers whom may be in contact with the harvesters during field testing or demonstrations. Displaced components of the RDA were designed to maintain their integrity during rapid acceleration. During field evaluations, onlookers were advised to stand clear of the front of the harvesters, since the harvester's operators could often have restricted visibility.

Test Procedures

The harvester was tested in three orchards in 2002. At each orchard, one of the harvester operators was a first–time operator. Ethrel (2–chloroethyl phosphonic acid) was sprayed [3.5 L/ha (3 pt/acre) in 1870 L/ha (200 gal/acre)] on the trees 10 to 14 days before harvest. Before harvest, three replications of 20 cherries were detached from the pedicel with a digital force gauge (Imada DPS–11, Imada Co., LTD., Japan) to determine detachment force. For all tests, the drivers tried to position the outer edge of the catcher pans at or slightly beyond the center of the trunk. The drivers then used the joysticks to position the RDA perpendicular to a scaffold and activated the impulse. Each scaffold was impulsed two to three times at one to two locations. The drivers tried to keep the scaffold being harvested near the center of the inclined catching conveyor. When both drivers had harvested all scaffolds on a tree, they drove to the next tree. At random, the harvester down–the–row speed was timed.

The first location, near Pasco, Washington, had lightly–cropped 'Bing' trees planted in the spring of 1999 at 3.35 m (11 ft.) in–the–row and 4.6 m (15 ft) between rows. These trees had two to three main scaffolds on each side of the tree row. The training scheme had each scaffold inclined 50° to 80° from the horizontal. Since the operators could not see most scaffolds, a considerable amount of pruning was required before harvest. Approximately 120 trees were harvested and 3.5 bins of cherries collected [476 kg (1050 lb)]. Fruit removal was estimated. After harvest 18 random samples of at least 50 cherries were collected from the bins of both machine harvested and commercially hand–harvested cherries. Half of the samples were sent to two independent sources for evaluation (experienced sweet cherry buyer Doug Fields, Excel Fruit Brokerage, Yakima, Wash., or Allie Bradley of Allan Brothers Fruits, Naches, Wash.). The samples were kept at 1°C (33°F) for five days, and then held for 36 h at 22°C (72°F) before grading. The fruit were graded as marketable (no damage), natural culls, pitting (indentations of 3 mm (0.125 in.) or smaller), bruises [indentations larger than 3 mm (0.125 in.) or soft areas], and major damage (stem tears, smashed fruits, and cuts).

The second harvest location was in two 'Bing' orchards at Washington State University's Roza Farm, Irrigated Agriculture Research and Extension Center, Prosser, Washington. Each orchard was planted at 2.44 m (8 ft) in–the–row and 4.27 m (14 ft) between rows. Crop set was normal. The east block had 43 trees/row and was planted in the spring of 1997. Trees were trained to a "Y" trellis with main scaffolds varying from 45° to 60° from the horizontal. The trees were not trained for machine harvesting; thus they had 6 to 8 scaffolds/tree and many long thin limbs. The lowest scaffolds were about 50 cm (20 in.) above the soil. On one row, fruit left on the tree, lost to the ground, and collected in bins were collected and weighted.

In the west block, a row trained as central leaders and a row trained to a Spanish bush (a multiple–leader vase shaped architecture) were machined harvested and portions of the row timed. Trees were planted in the spring of 1995. None of the rows were ideally trained for machine harvesting, but we felt that we could gain some insight on the adaptability of the different systems to this machine–harvesting concept. In this orchard a row of 'Bing' was not sprayed with ethrel, and the detachment force samples, as explained above, were collected to provide a comparison with ethrel treated trees. Machine and hand harvested fruit samples were collected, but unfortunately were not graded properly. Approximately 310 trees were harvested and 22 bins of cherries collected [2994 kg (6600 lb)].

The third harvest location was an orchard near Roosevelt, Washington that had been used in previous harvest trials (Peterson and Wolford, 2001, 2002). These trees were planted in 1995, spaced at 2.14 m (7 ft) in–the–row and 4.6 m (15 ft.) between rows, and had a 'Van' tree every fifth tree (all other trees were 'Bing'). Crop load was light. Each tree had three main scaffold branches approximately 120° apart with one scaffold perpendicular to the tree row (looking from above). The next tree in the row had the scaffold perpendicular to the row on the opposite side of the preceding tree and this pattern alternated the entire row. The training scheme had each scaffold inclined 55° to 85° to the horizontal. Only the 'Van' trees were harvested to test machine reliability and harvest rates. Fruit removal was estimated. After harvest, four random samples of at least 50 cherries were collected from the bins of both machine harvested and commercially hand harvested cherries. Cherries were held at room temperature for 24 h and then sorted (Tory Schmidt, Washington Tree Fruit Research Commission, Wenatchee, Wash.) into fresh–market (no damage) and damage (fruit with pitting, cuts, tears, and bruising). At the same time, fruit firmness was also measured for both machine and hand harvested cherries using a FirmTech1 (BioWorks, Stillwater, Okla.). About 450 'Van' trees were harvested yielding 14 bins [1905 kg (4200 lb)].

Results and Discussion

Fruit detachment force averaged 210 g (7.4 oz), 150 g (5.3 oz) (east orchard), and 157 g (5.5 oz) for the first, second, and third orchards, respectively. These values were considerably less than previously reported (Peterson and Wolford, 2002). Weather conditions in the two weeks before harvest were normal with minimal rainfall. In the two previous pre–harvest seasons, weather had been cooler and wetter than normal which required application of calcium chloride to prevent fruit cracking. We think that the calcium chloride interfered with the ethrel response to fruit loosing. In the second orchard, fruit detachment force in the west orchard on ethrel treated trees averaged 234 g (8.3 oz) and was significantly different (P = 0.05, df = 6) from the 467–g (16.5–oz) average fruit detachment force from untreated trees. Fruit drop before harvest was not a problem in any orchard.

Since ethrel was effective in reducing the detachment force, fruit removal averaged 90% or better in all orchards. In the second orchard where actual weights were recorded, 90% of the fruit were removed. Fruit that remained in the tree were generally on long thin limbs that did not transmit the impulse force effectively. More extensive tree training studies need to be conducted to determine the most compatible training system. Also on the recorded row, of the fruit removed, 88% were caught and collected in the bins. The majority of the fruit loss to the ground fell beyond the front or rear of the catching conveyor. The catching conveyor should be about 2 m (6 ft) longer to minimize this loss. However, some fruit loss occurred because low scaffolds or wide trellis posts displaced the catcher pans farther than desired, causing gaps in the catching area.

Harvest rate down–the–row ranged from 85 to 158 trees/h on trees with inclined scaffolds. Harvest rate was highest when there were only two scaffolds/side/tree and the scaffolds were visible so the operators could quickly position the RDA. Down–the–row harvest rates for Spanish bush and central leader trained trees were 45 and 43 trees/h, respectively. At least 25% of the branches on a central leader tree were not accessible by the RDA. Many of the main scaffolds on the Spanish bush trees were in the tree line and prevented efficient positioning of the RDA. These results reinforce the importance of a compatible tree design for efficient harvester operation.

'Bing' fruit quality showed no significant differences between commercial hand harvest and machine harvest for both independent graders (table 1). Although the two graders had slightly different packout values, both showed that the fresh–market quality machine harvested fruit was comparable to that of hand harvested fruit. 'Van' packout of the harvested fruit (table 2) also showed no significant differences in fruit quality and firmness between machine and hand harvested fruit. Although there was no difference in firmness between machine and hand harvested fruit (both sprayed with ethrel), it has been reported (Elfving, 2003) that ethrel can reduce fruit firmness when applied before harvest. The effect of ethrel on fruit firmness and market acceptability will require additional investigation.

Table 1. Packout[a] of 'Bing' sweet cherry comparing hand and machine harvesting.

Grader	Harvest Technique	Fresh Market (%)[b]	Pitting (%)	Bruising (%)	Major Damage (%)	Natural Culls (%)
A	Hand	61.5	5.4	7.2	3.5	22.4
A	Machine	57.5	8.2	9.0	3.8	21.5
B	Hand	68.0	9.1	8.0	0.0	14.9
B	Machine	63.8	10.2	10.4	1.6	14.0

[a] Fresh Market = firm fruit with no damage
Pitting = fruit with indentations or soft spots ≤ 3.2 mm (0.125 in.)
Bruising = fruit with indentations or soft spots > 3.2 mm (0.125 in.)
Major Damage = fruit that are cut, smashed, or have tears
Natural Culls = fruit that have wind damage, rain splits, or frost marks
[b] Comparisons are between hand and machine harvest for each grader. There were no significant differences in any of the grade categories, mean separation by Duncan's multiple range test, P = 0.05, df = 16.

Table 2. Average grade[a] of 'Van' sweet cherry

Harvest Technique	Fresh Market (%)[b]	Damage (%)	Firmness (g)
Hand	88.0	12.0	266
Machine	86.5	13.5	270

[a] Fresh Market = firm fruit with no damage
Damage = fruit with pitting, cuts, tears, and bruising
[b] Comparisons are between hand and machine harvest. There were no significant differences in any of the grade categories, mean separation by Duncan's multiple range test, P = 0.05,df = 6.

Generally, all machine components operated reliably and as designed. The catcher pans facilitated positioning of the harvesters along the tree row. After practice, the drivers easily controlled the positioning of the RDA and had problems only when scaffold visibility was obstructed. The RDA rubber disk caused no visible bark damage on the scaffolds. Conveyors and bin fillers were very effective, durable, and capacity was never a problem in these harvest trials.

CONCLUSIONS

The experimental harvesting system demonstrated potential for harvesting stemless sweet cherries with fresh–market quality comparable with commercial hand harvest. Ethrel was effective in reducing fruit detachment force to the range of 150 to 234 g (5.3 to 8.3 oz) which is essential for system success. With compatible trees, harvest rate down–the–row ranged from 85 to 158 trees/h with harvester capacity up to 1590 kg/h (3500 lb/h). The RDA positioning and control system was reliable and easy to operate. The cushioned catcher pans were an effective trunk seal that was easily positioned. The catching/collecting system was effective with little damage inflicted on the cherries. A compatible tree–training system is critical for efficient machine operation and optimum fruit quality.

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