

# Considerations for Machine Harvesting Fresh-market Eastern Thornless Blackberries: Trellis Design, Cane Training Systems, and Mechanical Harvester Developments

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**SUMMARY.** There is increased interest in growing blackberries in the United States for the fresh fruit market. For fresh market blackberry production, >350 h/acre (900 h·ha<sup>-1</sup>) of work is required to hand pick blackberries over a season that lasts 5 weeks with harvest every 2 days. Existing bramble mechanical harvesters can detach fruit from plants trained on a vertically oriented I trellis and harvest more cheaply than when harvested by hand, but the harvested fruit does not have fresh-market quality. We developed a cane training and trellis system for semierect blackberries to orient canes horizontally with the fruit positioned below the canes. Also, we developed an over-the-row mechanical harvester that uses vibrating nylon rods on a drum to shake fruit from horizontally trained canes onto a moving fruit-catching surface directly under the canopy to minimize impact damage to fruit. A new trellis design, new cane training practices, and new harvesting technologies have allowed fruit to be removed efficiently and be acceptable for fresh-market sales. This production system has been evaluated economically and appears to be profitable. It could overcome the high cost of handpicking, which has limited the expansion of fresh-market blackberries.

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In the last 30 years, the U.S. Department of Agriculture (USDA) has released seven semierect, genetically thornless blackberry cultivars: 'Black Satin', 'Smoothstem', 'Thornfree', 'Dirksen Thornless', 'Hull Thornless', 'Chester Thornless', and 'Triple Crown'. These cultivars are characterized by vigorous, semierect, smooth canes, and high productivity (Moore and Skirvin, 1990). The latter two have large, firm fruit, improved fresh-market and processing qualities (Halat et al., 1997), and are now commercially grown in states along the mid-Atlantic coast, in the Midwest, and along the Pacific coast.

The expansion of blackberry production into colder areas has been limited because of a lack of cold hardiness in existing cultivars (Warmund et al., 1992). These blackberries are produced mainly on small-acreage farms and hand picked for fresh-pack and pick-your-own markets.

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Typically, the ripe fruit of semierect blackberries are harvested over a 5- to 6-week period at 2- to 4-d intervals and can require as much as 350 h/acre (900 h·ha<sup>-1</sup>) of work if hand harvested (Brown et al., 1983). Scarcity of workers and the high cost of harvest labor have prevented increased commercialization of semierect blackberries. The Lincoln canopy system (Dunn et al., 1976), Gjerde method (Oydvin, 1986), slanted trellises (Peterson et al., 1992; Takeda and Peterson, 1996), and the variations of the shift trellis (Stiles, 1995) have positioned the fruiting zone of raspberries and blackberries to enable the fruit to be picked faster and to facilitate mechanical harvest operation.

Mechanical harvesters have been developed to rapidly harvest large acreage of blackberries for processing (Martin and Lawrence, 1976). Machine-harvested blackberries are higher-quality fruit (larger fruit, higher percentage of total soluble solids, lower acidity, and superior color) than hand picked fruit (Morris et al., 1978). However, no blackberries have been machine harvested for fresh-market use (Moore and Skirvin, 1990), and harvesting by machine has been shown to reduce the amount of saleable fruit compared with hand picking (Kingston, 1991).

This paper presents research conducted at the Appalachian Fruit Research Station, Kearneysville, W.Va., to develop alternative cane-training practices, trellis designs, and a new mechanical harvesting concept for the semierect, eastern thornless blackberry cultivars. They could ultimately allow cheaper, highly mechanized operations to harvest fresh-market-quality fruit.

### Training and pruning for machine harvesting

Semierect blackberries are planted typically in rows spaced 10 to 12 ft (3 to 3.6 m) apart with plants set at 5 to 8 ft (1.5 to 2.4 m) apart in the row and maintained in a hill culture system. The plants have a semierect growth habit and must be supported by a trellis post-and-wire system. As the primocanes grow, lateral canes develop at the axils of leaves. To promote the growth of these lateral canes along the entire length of the cane, primocanes are tipped as they extend beyond the top trellis wire. The laterals that emerge at the base of primocanes are generally large and stiff and not amenable for hand manipulation. However, the few suckers that radiate from the crown parallel with the row direction may be left and trained to trellis wires for fruit production.

A successful machine-harvesting system must include a trellis design to shape

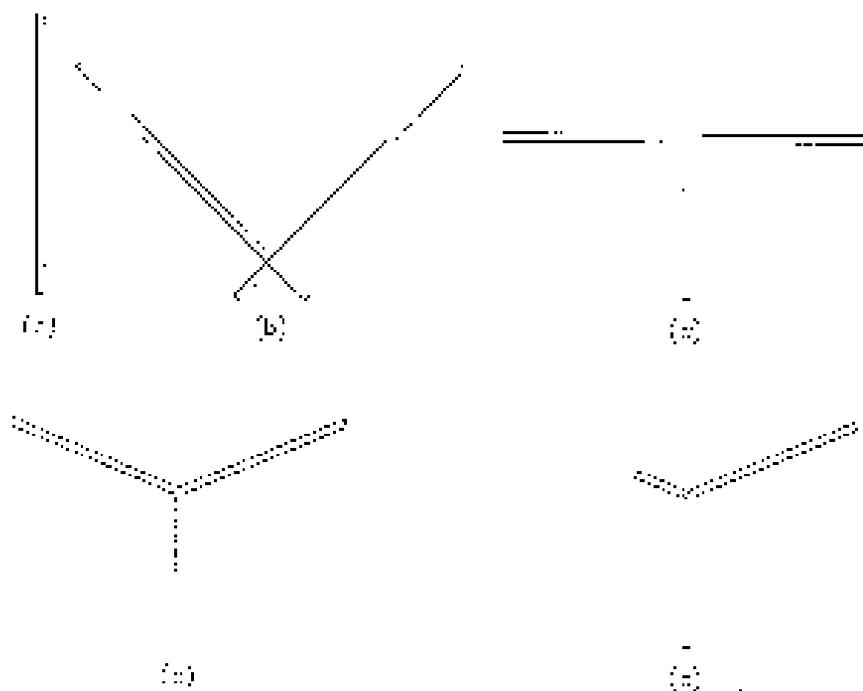
the plant into a narrow, unobstructed fruiting canopy. This allows the shaking mechanism to be positioned into the plant and the fruit-catching surface to be placed just below the fruiting canopy where fruit will be damaged least. The common support system for eastern thornless blackberries has been the standard I system (Fig. 1a) consisting of post or stake ≈6.5 ft (2-m) tall with two or more wires spaced evenly on the post. During the summer, as many as six strong primocanes are tied to these wires and tipped just above the top wire to promote lateral cane development. Additionally, all laterals originating near the ground and weak primocanes are removed. Following harvest, old floricanes are typically cut off at ground level. In the winter, the laterals in the fruiting zone are pruned to 20 inches (0.5 m) in length (Steiner et al., 1983).

Although the standard I system is relatively cheap, our early work indicated that the lateral canes were damaged considerably and fruit were bruised excessively during the harvest-and-catch operation (Takeda et al., 1989). Since the lateral canes were not tied to the trellis wires, the energy transmitted from the harvester rod action to individual fruit was not sufficient to detach many berries. Also, we observed that lateral cane and fruiting lateral numbers were low in the middle portion of the trellis because there was insufficient light for axillary bud development.

### Trellis designs

At the Appalachian Fruit Research Station, we evaluated several trellis designs that expanded the canopy surface to increase yield and make the fruit more accessible for picking (Takeda et al., 1989). In all of the trellis

**Fig. 1. Experimental blackberry trellis systems: (a) I, (b) V, (c) T, (d) Y, and (e) rotatable cross-arm Y.**



systems evaluated, supports were constructed with standard 1.5-inch (38-mm) welded black pipes for better stability. Galvanized high-tensile wire (12.5 gauge) was used in all the trellis systems. Other points considered in these trellis designs were the cost of materials and fabrication, cropping efficiency, and whether they would be compatible with cultural methods used and could be harvested mechanically. In the last ten years, modified trellis support designs such as T, V, Y, and modified Y with a rotatable cross-arm (RCA) have been investigated (Figs. 1 and 2). The details of fabrication and installation techniques for these trellis systems are discussed by Peterson et al. (1992) and Takeda and Peterson (1996).

### Cane training and pruning techniques

All the trellis systems, except the I trellis, allowed the floricanes and primocanes to be separated into two canopies. To do this, canes needed to be trained weekly throughout the summer once they were high and strong enough to be pulled or bent. In the V trellis, primocanes were tied to the bottom wire on the side of trellis not occupied by floricanes. Up to five primocanes per hill were trained on the wire. When they grew 8 inches (20 cm) beyond the top wire, they were pruned back to the top wire. In late summer, the hanging lateral canes were mechanically hedged to prevent them from tip layering. Small primocanes that emerged later in the season were usually removed at ground level. In the winter, selected lateral canes, oriented along the row, were shortened to 15 nodes and tied to trellis wire. All other lateral canes were removed.

In the T and Y trellises, primocanes were trained up to a wire at the top of post. The primocane tips were then bent so that the subsequent growth would be horizontal ei-

ther along the wire or perpendicular to it. On plants where the primocanes were bent parallel to the wire, the canes were tipped when they reached the next plant. The lateral canes that developed on the horizontal portion of the primocanes were pulled down and tied to wires on the cross arm not occupied by floricanes. Lateral canes that could not be tied to the trellis were removed. On plants where the primocanes were trained to grow perpendicular to the row and to the side not occupied by floricanes, the shoots were tipped as they grew beyond the outermost wire to promote lateral cane growth. After harvest these lateral canes were pruned back to  $\approx 15$  nodes and tied to wire on the cross arm.

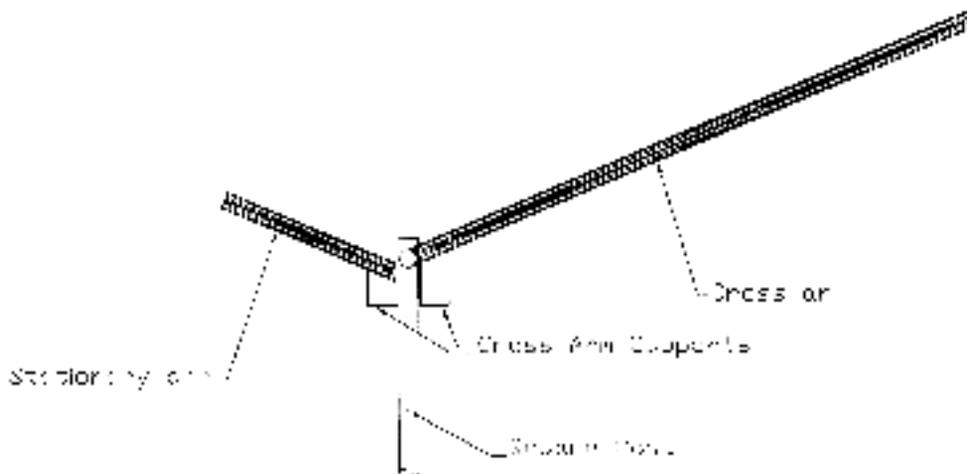
The permanent, wide cross-arms of the T and Y trellises made many primocanes inaccessible. So to make them more accessible, the RCA Y trellis system was developed. In the RCA Y system, primocanes  $>40$  inches (1 m) tall were tied to the training wire on the center post and bent to grow horizontally to the next plant where they were tipped. The lateral shoots on the horizontal portion of primocanes grew mostly upward and were confined between the main trellis cross arm and short stationary arm (Fig. 3a). Lateral canes that grew downward and could not be repositioned over the wires were pruned.

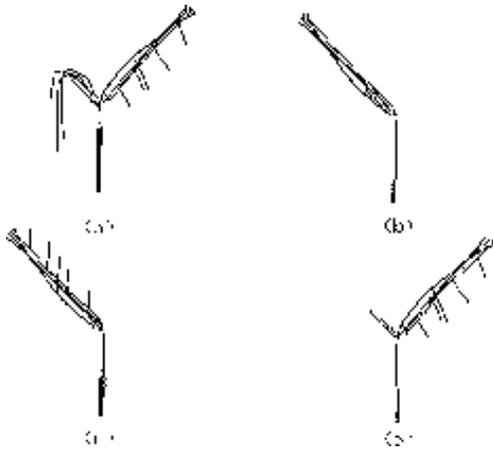
In the fall, the main trellis cross-arm was swung over to the side with the short stationary arm (Fig. 3b). The lateral canes were then tied to the top or outermost wire on the main trellis cross arm and trimmed back. During this period, ties that held the lateral portion of primocanes to the training wire were removed. The cross-arm was left in this position or  $\approx 22.5$  degrees above the horizontal. In late spring when most of the primary flowers had opened (Fig. 3c), the cross-arm was again swung back to the other side for harvest operation (Fig. 3d). When most of the secondary flowers had bloomed, a crew of three workers rotated the

entire row of trellis cross-arms with the lateral canes attached to the outer wire by rotating each cross-arm 135 degrees about the pivot point at the top of post to the other side of the post. The rotation of trellis cross-arms resulted in the fruiting laterals that were previously upright to hang now right to hang from the lateral canes. The rotation of cross arms occurred without any loss of floricanes or fruiting laterals. The leaves on the fruiting laterals reoriented themselves within 2 weeks. After harvest the floricanes were removed from the main cross-arm.

The angle at which the

**Fig. 2. Schematic of rotatable cross-arm Y trellis.**





**Fig. 3. Rotatable cross-arm Y trellis (a) in July with the rotatable cross-arm for machine harvest and the short, stationary arm catching lateral canes, (b) after harvest, with the cross-arm rotated for lateral cane tying, (c) at peak bloom in early June, showing the orientation of flower clusters, and (d) postbloom with the cross-arm now pivoted to the other side of trellis post for harvest. Note that now the fruiting laterals are positioned below the canopy.**

cross-arm was positioned during the period from budbreak to full bloom affected the distribution of flowering shoots on the trellis. The relationship between the orientation of lateral canes achieved with the cross-arm of Y trellis system set at different angles and the amount of flowering shoots that developed above the cross-arms is shown in Fig. 4. In summary, the results indicated that the closer the trellis cross-arm was held parallel to the ground the greater the proportion of flowering shoots that emerged above the cross arm. Orientation of lateral canes to <30 degrees above the horizontal during the period following budbreak until an onset of bloom maximized the numbers of fruiting laterals developing above the trellis cross-arms (Fig 3c). The rotation of the cross-arms to the harvest position placed these fruiting laterals now under the canopy (Fig. 3d). The distribution of flowering shoots in a vertically oriented trellis was ≈55% and 45%, with greater numbers of flowering shoots emerging to the east side of a north-south oriented row (Fig. 4).

### Advantages and disadvantages of trellis systems

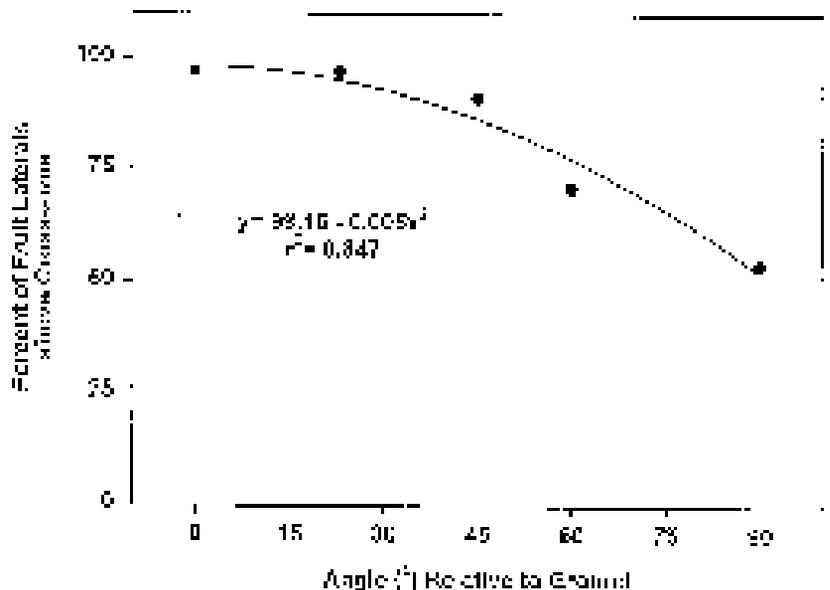
The V trellis provided a narrow, unobstructed hedge-like structure and separation of floricanes and primocanes. The angle between the two posts was set sufficiently wide to allow the shaking heads of the USDA experimental bramble harvester inside the V to shake the fruit from the top and detach fruit onto a catching

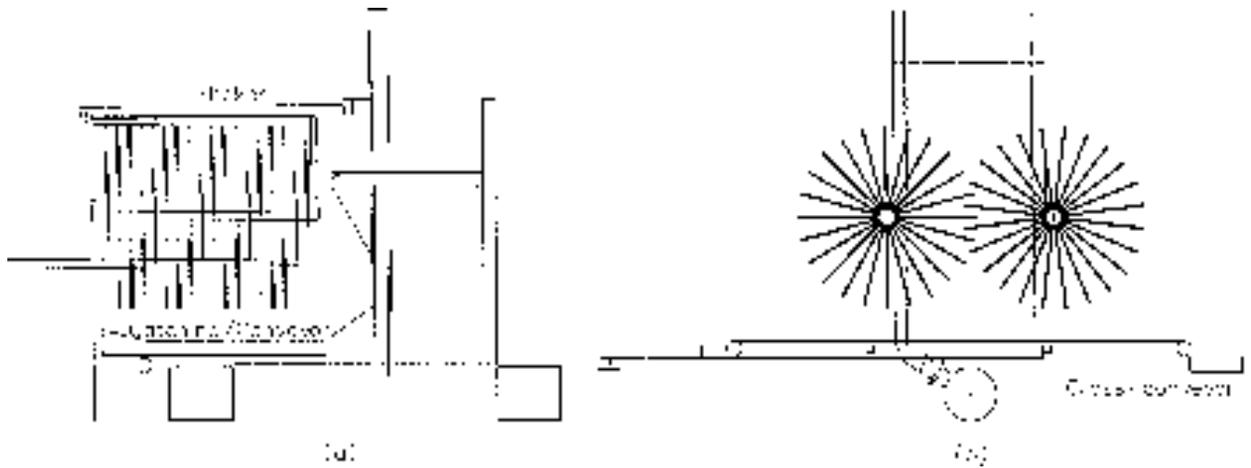
surface located to the outside and below the fruiting canopy. The V trellis had a span between the two posts at their apex of ≈10 ft (3 m) and required a row spacing of at least 22 ft (6.5 m), which makes it impractical for commercial blackberry operation.

In the T and Y trellis systems, the shaking mechanism could be positioned above the fruiting canopy and the fruit-catching surface just below the canopy. The distance the fruit fell was rather short, thus minimizing fruit damage. However, there were some disadvantages to these two trellises. Fruiting laterals developed upward above the tied canes and fruit were exposed to the sun, resulting in higher incidences of sun scorched fruit. Field observations indicated that insects, such as the Japanese beetle, preferred feeding on fruit on the upper canopy surface than in the canopy interior or lower canopy surface (unpublished data). Also, direct contacts on the fruiting laterals by the shaking rods caused more breakage of fruit clusters and severely bruised some fruit.

The RCA trellis system simplified the primocane training procedure and reduced labor required for summer cane training (Harper et al., 1998). In this system, which permitted the reorientation of the established canopy, the fruiting laterals could be oriented downward below the trellis cross-arm. The fruit was thus shaded by the foliage and exposure to direct sunlight was decreased. During machine harvest, the shaking rods mainly vibrated the lattice of lateral canes on the trellis wires and direct impact of the fruit was minimized. The harvester's catching surface could be positioned directly underneath the fruit clusters, minimizing the distance the detached fruit fell. Another advantage of this system is that rows could be established using the conventional, commercial row spacing of

**Fig. 4. Relationship between the angle of cross-arm for training lateral canes and percentage of flowering shoots developing upward above the tied canes.**





**Fig. 5. Schematic of trailer-mounted USDA blackberry harvester showing (a) front view and (b) side view.**

11 ft (3.3 m). It also has the flexibility of permitting an efficient hand harvest of fruit when the cross-arm is positioned at 60 degrees from the horizontal. In contrast, other trellis systems evaluated for split canopy development and machine harvestability required much wider, commercially unacceptable row spacings. The major disadvantage of this system was the significantly higher cost of fabricating the rotatable cross-arm system.

## Machine harvesting developments

Traditional mechanical blackberry harvesters use three types of shaking mechanisms. The first consists of one or more pairs of oscillating horizontal beater bars that provide a slapping action to remove the fruit (Booster et al., 1983). The second uses a spiked drum that is oscillating in horizontal plane relative to the rotation of the drum, activated by either an inertia drive (Weygandt, Inc., Canby, Ore.) or an eccentric cam mechanism (Blueberry Equipment, Inc., South Haven, Mich.). The third uses a spiked drum that is oscillated vertically (Korvan, Inc., Lynden, Wash., and Littau, Inc., Stayton, Ore.).

In 1988, we began blackberry harvest mechanization research. A prototype harvester with positive-displacement spike drums imparted nearly uniform displacement and acceleration within the fruiting canopy (Peterson et al., 1989, 1992). It was relatively simple in design and initially all harvesting components were mounted on a two-wheeled trailer that could be towed by a tractor (Fig. 5).

This trailer-mounted prototype harvester was used to harvest 'Chester Thornless', 'Hull Thornless', and 'Thornfree' blackberries trained to T, V, and Y trellis systems every 2 d throughout the harvest season in 1990, 1991, and 1992 (Peterson et al., 1992). Very few fruit fell to the ground because, in these trellis systems, the fruiting laterals were located away from the plant crown. Fruit removal from V trellis was acceptable. More than 90% of ripe fruit was detached while limiting the detachment of immature fruit to <10% of the total harvested. In the T and Y trellises the harvester removed 85% and 88% of the ripe fruit, respectively.

Harvested fruit was acceptable for processing, with total soluble solids of 9.1%, titratable acids of 0.8%, and a pH of 3.5 (Halat et al., 1997). Alternate-day harvest schedules minimized the amount of overripe fruit. These early field tests indicated that 'Chester Thornless' fruit were firm enough to be harvested mechanically and retain their fresh-market quality. 'Hull Thornless' and 'Thornfree' fruit were too soft. Fruit on canes hanging below the trellis or on long fruiting laterals could not be shaken vigorously enough to be detached. Fruit from the T and Y trellises had better quality as they had shorter distances to fall to the catching surface than those from the V trellis.

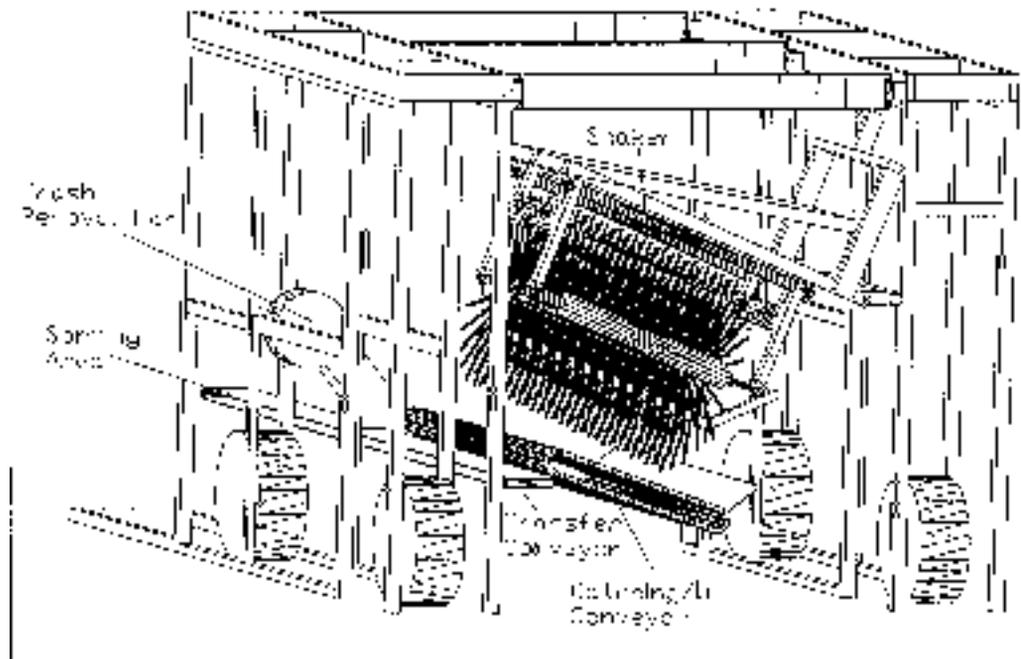
In 1995, 'Chester Thornless' blackberries trained to T and Y trellises were machine harvested on alternate days. The harvesting machine had a cushioned, horizontal conveyor installed to catch the fruit. The conveyor carried fruit to the rear of the harvester where it was transferred laterally by another conveyor belt into containers. Hand sorting of fresh-market-quality fruit was done on the cross conveyor belt. As much as 70% of the machine

detached fruit was fresh-market quality. Quality evaluations of fresh-market-quality fruit stored for 7 d at 45 °F (7 °C) indicated that the fruits were free of molds and still relatively firm. Juice did not leak from the fruit. The results suggested that the USDA experimental blackberry harvester can effectively machine harvest thornless blackberry cultivars such as 'Chester Thornless' with fresh-market quality.

In 1997, a new harvester, designed specifically to machine harvest blackberries on the RCA trellis system, was field tested (Fig. 6). The inside tunnel of the harvester was 9 ft wide × 10 ft high (2.7 m wide × 3.0 m high) and the overall width of the machine was 13.7 ft (4.1 m). A single spiked-drum shaker was installed inside the tunnel. The 4 ft × 8-ft (1.2 × 2.4-m) cushioned and moving catching surface was located under the shaker unit and inclined 18 degrees from the horizontal. The moving catching surface conveyed the fruit to a transfer conveyor on one side of the harvester where leaves and trash were separated and immature, bruised, and overripe fruit were hand sorted. Fresh-market-quality fruit dropped into half-pint (0.25-L) plastic tills.

'Chester Thornless' blackberries on the RCA trellis system were machine harvested every other day throughout the harvest season with the prototype over-the-row harvester. The harvester was operated at 5 to 6 Hz with maximum displacement at the tips of the rods set at 7 inches (175 mm) and at a 0.6-mph (1 km·h<sup>-1</sup>) ground speed. The spike-drum shaker was lowered to a height above the canopy to achieve maximum insertion of nylon rods into the fruiting canopy. A crew of five sorted and packed the fruit. The shaking unit easily moved through the slanted fruit canopy. How-

**Fig. 6. Schematic of USDA fresh blackberry harvester.**



ever, some breakage of fruiting laterals and excessive removal of immature fruit occurred during the initial two harvests. Between 40% and 70% of the machine-harvested fruit was in the fresh-market category and the rest was in the overripe, bruised, leaky, or immature categories. An economic evaluation of machine harvesting blackberries for fresh market indicated that the rotatable cross arm trellis system would need a packout of 71% to equal the fresh market return of a conventional I trellis system that is hand harvested (Harper et al., 1998).

### Conclusions

The ultimate goal of machine harvesting eastern thornless blackberries with a high percentage of fruit with fresh-market quality now appears attainable. We now have developed a blackberry harvester that can remove 90% of the ripe fruit without removing immature fruit. New trellis designs and cane-training procedures have contributed to high machine harvestability of semierect blackberry. These improvements in the management of blackberry plants have increased the quality of machine harvested fruit and reduced the work needed to train and tie primocanes without sacrificing blackberry productivity.

A new over-the-row, single-spiked-drum shaker, which can effectively detach ripe fruit from a horizontally oriented canopy, was developed. Its size and maneuverability are similar to conventional shakers designed for harvesting vertically oriented canopies. Its moving fruit-catching surface positioned just underneath the fruiting clusters will reduce fruit bruising and damage. In the next several years, additional field work will be done to evaluate different shaker oscillating frequencies and stroking span to improve fruit removal and quality. After the harvester has been developed further and canopy management strategies refined, the best way to mechanically harvest blackberries will be determined.

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