Mechanical Thinning of Peach and Apple Trees Reduces Labor Input and Increases Fruit Size

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SUMMARY. Hand thinning is a necessary but costly management practice in peach (*Prunus persica*) production. Organic apple (*Malus × domestica*) production also may require hand thinning to adjust crop load. Mechanical devices to aid in thinning have been developed, but none has proven highly efficient and capable of completely replacing hand thinning. Narrow canopy training systems and novel peach tree growth habits offer new opportunities to examine mechanical methods for thinning peach and apple trees. Our studies evaluated mechanical thinning devices on peach and organically grown apple trees. In 2005 and 2006, a U.S. Department of Agriculture-designed spiked-drum shaker was used to thin pillar (columnar) peach trees at 52 to 55 days after full bloom. The drum shaker, driven at two different speeds in the orchard, reduced crop load an average of 58% and follow-up hand thinning time by 50%, and increased fruit size by 9% at harvest compared with conventional hand-thinned or nonthinned control trees in 2005. In 2006, the shaker was driven at one speed but operated at two different frequencies. At 260 cycles/minute, the drum shaker removed more fruit and reduced crop load to a greater extent than when operated at 180 cycles/minute, however, fruit size at harvest did not differ between the two operating frequencies. The drum shaker reduced follow-up hand thinning time between 54% and 81%. Horticultural and economic evaluations of the drum shaker and/or a German-designed blossom string thinner were conducted in 2007 in four commercial peach orchards trained to a perpendicular V or quad V system and an organic apple block trained to a narrow vertical axis system. Mechanical thinners reduced peach crop load by an average of 36%, decreased follow-up hand thinning time by 20% to 42%, and increased fruit in higher market value size categories by 35%. The net economic impact of mechanical thinning versus hand thinning alone ranged from \$175/ha to \$1966/ha. Mechanical thinning at 20% full bloom resulted in more fruit in the large size categories (2.75 inches in diameter and larger) than thinning at 80% full bloom. Detailed counts of flowers on branches with different orientations indicated that pruning may be adjusted to improve thinner performance. The string thinner effectively thinned dwarf apple trees trained to a vertical axis system in a certified organic orchard, resulting in a reduction in hand thinning time and an increase in fruit size. Based on our tests, mechanical thinning appears to be a promising technique for supplementing hand thinning in apple and peach trees.

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Growers are finding it increasingly difficult to find a workforce to manually thin fruit crops, and the cost of farm labor is increasing. Glozer and Hasey (2006) estimated that hand thinning labor represented 31% of all cultural costs associated with cling peach production. The availability and efficacy of chemical thinning programs varies by crop, orchard, and season, therefore hand thinning is often required to adjust crop load for optimal fruit size and quality, and to promote return bloom. This is particularly true for stone fruit and organic apple production, where chemical thinning options are limited. Various surfactants and fertilizer salts have been evaluated as blossom thinners for peach (Byers, 1999; Fallahi et al., 2006; Klein and Cohen, 2000; Osborne et al., 2005; Wilkins et al., 2004), however, chemical thinning is considered a growth regulator application, regulated in the United States under the Federal Insecticide, Fungicide, and Rodenticide Act, and presently, none of these chemicals are registered for use as thinners. Likewise, several studies have shown that a tank mix of various crop oils and liquid lime sulfur is an effective thinner for organically grown apples (McArtney, et al., 2006; McFerson, 2003; Noordijk and Schupp, 2003), but this use is not labeled, except in Washington state (Hansen, 2004).

Various mechanical thinning devices have been tested over the years for peach trees, including trunk shakers (Berlage and Langmo, 1982), low-frequency electrodynamic limb shakers (Diezma and Rosa, 2005; Glozer and Hasey, 2006), high-pressure water streams (Byers, 1990),

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
0.4536	lb	kg	2.2046
1.6093	mph	km·h ⁻¹	0.6214
28.3495	oz	g	0.0353

and rotating rope curtains (Baugher et al., 1991). As growers modify training systems for automation by maintaining narrow canopy widths, mechanical thinning options are more attainable (Glenn et al., 1994). The objectives of this research were to evaluate the effect of a mechanical spiked-drum canopy shaker operated at two different ground speeds, or at two drum rotation speeds on green peach fruit thinning in pillar growth habit peach trees; to compare the effect of a mechanical string blossom thinner at two bloom stages with a mechanical spiked-drum canopy shaker for green peach fruit thinning, and three chemical blossom thinners for thinning peach trees and nectarine (*Prunus persica*) trees trained to perpendicular V or quad V systems; and to compare the effect of a mechanical string blossom thinner at the tight cluster to first pink stage of bud development with an organically acceptable chemical thinner and hand thinning for thinning apple trees in a certified organic orchard.

Materials and methods

MECHANICAL THINNING DEVICES. Two mechanical thinners were evaluated in this study. The first machine was a rotating string thinner (Darwin 300; Fruit-Tec, Deggenhausertal, Germany; Fig. 1A) designed by H. Gessler, a German grower, to remove apple blossoms in organic orchards. A description of the string thinner (Bertschinger et al., 1998) and details of its application can be found in Bertschinger and Stadler (1998). The string thinner consisted of a tractor-mounted frame with a 3.0-m-tall vertical spindle in the center of the frame. Attached to the spindle were 36 steel plates securing a total of 648 plastic cords each measuring 50 cm long. The speed of the clockwise rotating spindle was adjusted with a hydraulic motor. The height and angle of the frame was adjustable to conform to the vertical inclination of the tree canopy, and the intensity of thinning was adjustable by changing the number of strings and the rotation speed.

The second machine was a vibrating direct drive double spiked-drum shaker (Fig. 1B), designed for harvesting citrus (*Citrus* spp.) fruit (Peterson, 1998) that was slightly modified for our tests. The shaker was mounted on

Fig. 1. Mechanical peach thinning equipment evaluated for bloom or green fruit thinning in peach, nectarine, and apple trees with narrow canopies: (A) Darwin 300 string thinner (Fruit-Tec, Deggenhausertal, Germany), (B) U.S. Department of Agriculture spiked-drum shaker. The string thinner was tested at the 20% and 80% full bloom stages, and the drum shaker was tested at 35 d after full bloom.

a tractor-towed trailer and consisted of two rotating drums each measuring 8 ft in diameter and 5 ft in height. Each drum was composed of six whorls of nylon rods spaced 12 inches apart on a central axis. Each whorl was made up of 16 individual rods measuring 1.25 inches in diameter by 44 inches long. The rods were radially spaced at equal angles around the axis of the drum. The first whorl of rods was 30 inches above the ground. The drums could rotate freely on their axis

or resistance could be applied with a hydraulic brake. Movement of the drums in a horizontal plane was controlled by a hydraulic motor with an adjustable flow regulator to set the frequency of displacement. Thinning with the string thinner was conducted during bloom and thinning with the spiked-drum shaker was conducted before pit hardening when fruit ranged from 20 to 30 mm diameter (the green fruit stage when peaches are normally hand thinned).

2005 AND 2006 DRUM SHAKER TRIALS. The trees used in these studies were developed through the Appalachian Fruit Research Station (AFRS) breeding program, were of the pillar (columnar) growth habit, and were planted at the AFRS orchards, Kearneysville, WV. The trees were a selection designated KV93479 on 'Lovell' rootstock and were beginning their seventh growing season at the time of treatment. Fruit size on this selection is generally medium to somewhat smaller than average. Trees were planted in a north-south direction and were spaced 1.5 or 2.0 m apart in rows spaced 6.0 m apart. Tree height averaged 8.5 ft with an average canopy width of 4.9 ft. Individual trees had been trained to a multiple leader or central leader system at random in the row.

Green fruit were mechanically thinned 52 d after full bloom (DAFB). The spiked drums were allowed to rotate freely on their axis as they passed through the canopy. The rods were set to oscillate at 200 cycles/min with a maximum displacement of about 8 inches at the tip. Forward travel speeds of 2 and 3 km·h⁻¹, set by the tractor's tachometer dial, were evaluated. Treatments were applied to five (2 km·h⁻¹) or four (3 km·h⁻¹) 10-tree plots. Follow-up hand thinning was performed on mechanically thinned trees 54 DAFB to adjust fruit spacing (about 2–3 inches apart) and to eliminate double fruit on a node. The total number of fruit removed from each tree was recorded. Nine nonthinned control trees and a like number of hand-thinned control trees were tagged at random throughout the block. The hand-thinned control trees were thinned 59 DAFB. Three trees from each 10-tree plot were selected at random and harvested as an once-over harvest when the first mature fruit were observed to have dropped to the ground. Control trees were harvested on the same dates. The total weight of fruit harvested was recorded and fruit diameter was taken on a random sample of 50 fruit/tree. Data were averaged for the three-tree subsamples for the mechanical thinning treatments; the nonthinned and hand-thinned control trees were treated as individual replications for analysis.

Tests of the spiked-drum shaker were repeated in the AFRS pillar

peach block in 2006. Conditions were similar to those previously described for 2005, except that the shaker drums were evaluated at two different frequencies, 180 and 260 cycles/min, and the forward speed of the thinner machine was held constant at 3 km·h⁻¹. Fruit were mechanically thinned $\approx$ 55 DAFB. Fruit were harvested on two dates, the first at 124 DAFB and the second 7 d later. Only firm ripe (based on ground color) fruit were harvested at the first picking. All remaining fruit were harvested at the second picking. Data were collected as in 2005 except that fruit weight was measured and recorded for trees in all treatments. Data on fruit size, weight, and yield were combined from the two pickings for analysis. The experimental design for all drum shaker trials was randomized complete block.

2007 COMMERCIAL PEACH ORCHARD TRIALS. Mechanical thinning trials were conducted in four Pennsylvania orchards on 'Redhaven', 'White Lady', and 'Babygold 5' peach trees, and 'Arctic Sweet' nectarine trees trained to a perpendicular V or a quad V system—both narrow canopy architectures. The string thinner was evaluated in all plots, and the drum shaker was tested in the 'Redhaven' and 'Babygold 5' orchards. The string thinner configuration for thinning peach blossoms used 18 plates and 162 cords. The string thinner spindle was operated at 180 rpm for thinning peach blossoms. The drum shaker rods oscillated at 220 cycles/min. Both mechanical thinners were powered by tractors and driven through orchard rows at 4.0 km·h⁻¹. The experimental design in each trial was randomized complete block, with four multiple tree replicates. Data were collected from two center trees in each replicate (with the exception of 'White Lady', where three center trees were used). The mechanical treatments were compared with hand thinning at 40 to 50 DAFB. In the 'Babygold' trial, the mechanical thinners also were compared with the following chemical treatments: two surfactants [1% (v/v) Silwet 408 (Crompton Corp., Greenwich, CT) or 1.5% (v/v) Tergitol TMN-6 (Union Carbide Corp., Danbury, CT)] and a fertilizer [4% (v/v) ammonium thiosulfate (Ag Com, Inc.,

Gettysburg, PA)]. Chemical thinner solutions were applied at 80% open bloom with an airblast sprayer at 100 gal/acre.

The string thinner was evaluated at the 80% full bloom (FB) stage in the 'White Lady', 'Babygold 5', and 'Arctic Sweet' experiments and at 20% and 80% FB in the 'Redhaven' trial. The drum shaker was tested at 35 to 40 DAFB. The 'Arctic Sweet' crop load was reduced by freezing temperatures before thinning, and only the top portion of the canopy was thinned. This was accomplished by removing all the plates of cords on the lower half of the string thinner. The 'Arctic Sweet' crop was further reduced by low temperatures following thinning; therefore, only fruit set measurements were collected.

Crop load, follow-up hand thinning requirement, and fruit size were determined on one pretagged scaffold on each of the test trees per replicate. Blossom (string thinner) or fruit (drum shaker) removal with mechanical thinners was evaluated by counting all of the blossoms or fruit in the upper and lower canopy regions of the tagged scaffold immediately before and after thinning. Reduction in fruit set was evaluated the day of thinning and again following physiological drop by calculating number of blossoms or fruit per limb cross-sectional area in the upper canopy, the lower canopy, and the total tagged scaffold. All trees were hand-thinned to a uniform crop load, during which follow-up hand thinning time was recorded. At harvest, a sample of 50 fruit was evaluated for mean fruit diameter and fruit size distribution. In the 'Redhaven' and 'White Lady' trials, preharvest data on mature fruit diameter and fruit per scaffold also were collected.

Economic cost-benefit analyses were performed to evaluate the potential impact of each thinning method on fruit returns. Mechanical thinning costs, based on a 15-year useful life of equipment and 8% interest rate averaged \$41.26/ha for the string thinner and \$119.33/ha for the drum shaker, including tractor cost (\$12.00/h) and labor (\$12.00/h). Realized economic savings were calculated from follow-up hand thinning time and fruit size distribution experimental comparisons and from average yields reported by grower cooperators. Prices for the various size categories for each cultivar were obtained from the *USDA Agricultural*

Marketing Service Report, Appalachian District (U.S. Department of Agriculture, 2007).

The influence of branch position on string thinner efficacy was assessed by counting blossoms before and after thinning on two branches in each of three positions: interior, exterior, or parallel to the row (Fig. 2A), per scaffold. These trials were conducted in the 'Redhaven' and 'White Lady' orchards.

The size of fruit removed by the drum shaker was assessed in a commercial-scale trial conducted in a 'John Boy' peach orchard trained to a perpendicular V. Fifty fruit were collected from under each of 20 mechanically thinned and 20 hand-thinned trees following thinning, and fruit were immediately weighed and then sorted by diameter.

2007 ORGANIC APPLE BLOCK TRIALS. A test of the mechanical string thinner was conducted in a certified organic orchard of 4-year-old 'Gold-Rush'/'Malling 26' apple trees trained to a vertical axis system that were pruned to maintain a narrow cone

canopy architecture. Tree height averaged 9.5 ft with an average canopy width of 5.0 ft at the base of the cone. The string thinner configuration for apple orchards used 36 plates securing 648 plastic cords. The string thinner spindle was operated at 245 rpm for thinning apple blossoms. The mechanical thinner was driven through orchard rows at 4.0 km·h⁻¹ at the tight cluster to first pink stage of bud development. The experimental design was a randomized complete block, with four multiple tree replicates. Data were collected from two center trees in each replicate. The mechanical blossom thinner was compared with a chemical blossom thinning treatment: 2% (v/v) Organic Stylet Oil (JMS Flower Farms, Vero Beach, FL) tank mixed with 2.5% (v/v) liquid lime sulfur (Miller Chemical, Hanover, PA), and to hand thinning at 40 to 50 DAFB. The chemical thinner solution was applied at 80% FB with an airblast sprayer at 100 gal/acre. Fruit set and time requirement for hand thinning were evaluated as previously described. Yield per tree was recorded

at harvest, and fruit size distribution was determined from all the fruit from the two data trees in each plot.

STATISTICAL ANALYSES. All data in the 2005 and 2006 studies were analyzed using analysis of variance procedures (Proc MIXED SAS system for mixed models; SAS Institute, Cary, NC). Mean separations were performed on least square means (LS means) at $P \leq 0.05$. Data in the 2007 studies were subjected to an analysis of variance and treatments separated using Fisher's protected least significant difference test.

Results and discussion

2005 DRUM SHAKER TRIALS. The number of fruit removed by the spiked-drum mechanical shaker at 2 km·h⁻¹ was not significantly different from the number of fruit removed at 3 km·h⁻¹ (Table 1). Mechanical thinning reduced follow-up hand thinning $\approx 50\%$ compared with the hand-thinned control trees. The hand-thinned control and drum shaker treatments at both travel speeds reduced crop load and improved fruit diameter compared with the nonthinned control trees (Table 1). All treatments reduced crop load below that for the nonthinned control trees. Fruit size was increased on the hand-thinned control trees; however, fruit size was less than that achieved with the drum shaker plus follow-up hand thinning. Consumers are increasingly demanding larger size peaches, and fruit brokers consider a peach below 2.75 inches in diameter as one of lower value than those that are larger. Hand or mechanical thinning resulted in average fruit sizes within the desired size range.

While mechanical thinning generated the largest size fruit, the overall level of crop load reduction as well as the distribution of crop load reduction were concerns. Average yields for pillar peach trees at similar planting densities in the fifth through eighth leaf have been slightly above 700 bushels (1 bushel = 48 lb) per acre (S. Miller and R. Scorza, unpublished data). Comparable yields have also been reported for standard growth habit peaches planted in high-density systems (Grossman and DeJong, 1998; Hoying et al., 2007). Mechanical thinning reduced the crop load an average of 51% compared with the hand-thinned control trees and by 63% over the nonthinned control

Fig. 2. Influence of branch position on efficacy of the string thinner for removing blossoms from two peach cultivars: (A) diagram of branch positions, (B) percentage of blossom removal in two peach cultivars on branches at different positions in the canopy. Mean separation within cultivar and bloom stage by Fisher's protected least significant difference at $P \leq 0.05$ ('Redhaven') or $P \leq 0.15$ ('White Lady'); FB = full bloom.

trees. Based on observations at the time of mechanical thinning and during follow-up hand thinning, it was evident that the drum shaker removed fruit disproportionately over the canopy. Some shoots and areas in the canopy were completely defruited, while other areas showed little or no fruit removal. In general, it was felt that the drum shaker resulted in a larger portion of the tree canopy being defruited than desirable. Detailed data based on fruit counts and limb orientation were not recorded in this study as in a previous study by Glenn et al. (1994) using a similar spiked-drum canopy shaker. In their study, more fruit were removed from horizontal branches than from vertical branches. The subsequent hand thinning of the mechanically thinned trees in the current study to eliminate “doubles” (two fruit/node) and space the fruit on the branches probably contributed to additional overthinning and thus the significant reduction in crop load compared with the hand-thinned control trees. The speed of travel of the shaker, the frequency of the

shaker rods, and tree training are variables that could be altered to reduce the number of fruit removed and to obtain a more uniform distribution of crop over the canopy.

The spiked-drum mechanical shaker broke some small shoots and twigs (generally ≤ 0.5 -inch diameter), but the damage was considered minimal. At the $3 \text{ km}\cdot\text{h}^{-1}$ travel speed, a few larger branches (1-inch diameter or larger) were broken, but the number was not significantly different from the $2 \text{ km}\cdot\text{h}^{-1}$ treatment where no larger branches were broken (data not shown). During the mechanical thinning treatment, it was observed that rods on the drum shaker could become temporarily lodged between a primary scaffold limb and a leader especially if the crotch angle was narrow and the limbs were rigid and of a large diameter (≥ 1 inch). While none of these limbs were broken when the rod “released” and continued rotating, the opportunity for limb breakage was apparent. Bark damage generally occurred when rods became temporarily lodged in branches. Tree training has long been

considered critical in attempting to adapt mechanized equipment to fruit tree culture operations (Glenn et al., 1994; Peterson, 1985). Preliminary tests of the spiked-drum shaker for thinning suggest that pruning and training techniques should be developed to maintain no more than a single major upright scaffold in pillar trees for best adaptation of mechanized thinning equipment. In addition, large permanent lateral branches should be avoided in favor of smaller diameter 1- and 2-year-old shoots that would serve as the bearing surface and be renewed on a regular basis.

2006 DRUM SHAKER TRIALS. The drum shaker operating at 260 cycles/min removed an average of 518 fruit/tree (Table 2). Significantly fewer peaches were removed when the shaker was operated at 180 cycles/min. On average, 508 fruit were removed from the hand-thinned control trees. Mechanical thinning at 260 cycles/min plus follow-up hand thinning removed more fruit than mechanical thinning at 180 cycles/min plus follow-up hand thinning (Table 2). The total number of fruit

Table 1. Effect of a mechanical spiked-drum canopy shaker on green peach fruit thinning, follow-up hand thinning, fruit size, and crop load in pillar growth habit peach trees, 2005.

Treatment	Fruit removed (no./tree)		Hand thinning time (s/tree)	Fruit diameter (cm) ^z	Yield (kg/tree) ^y	Projected yield (bushels/acre) ^x
	Spiked-drum	Hand				
Nonthinned control	—	—	—	6.45 c ^v	54.3 a	1,132
Hand-thinned control	—	455 a	774 a	7.19 b	40.6 b	847
Drum shaker, $2 \text{ km}\cdot\text{h}^{-1}$ ^w	275 a	175 b	354 b	7.47 a	17.6 c	367
Drum shaker, $3 \text{ km}\cdot\text{h}^{-1}$	234 a	222 b	432 b	7.44 a	22.4 c	467

^z1 cm = 0.3937 inch.

^y1 kg = 2.2046 lb.

^xYield based on 454 trees/acre (1121.9 trees/ha) and weight of 48 lb per bushel; 1 bushel/acre = 53.8009 kg·ha⁻¹.

^wForward travel speed of mechanical spiked-drum shaker down the tree row. Drum shaker operated at a frequency of 200 cycles/min; $1 \text{ km}\cdot\text{h}^{-1}$ = 0.6214 mph.

^vMean separation within columns by Proc Mixed SAS system for mixed models (SAS Institute, Cary, NC) at $P \leq 0.05$.

Table 2. Effect of a mechanical spiked-drum canopy shaker on green peach fruit thinning, follow-up hand thinning, fruit size, and crop load in pillar growth habit peach trees, 2006.

Treatment	Fruit removed (no./tree)			Hand thinning time (s/tree)	Fruit size		Yield (kg/tree) ^x	Projected yield (bushels/acre) ^w
	Spiked-drum	Hand	Total		Diameter (cm) ^z	Weight (g) ^y		
Nonthinned control	—	—	—	—	6.45 b ^u	126 c	76.6 a	874
Hand-thinned control	—	508 a	508 ab	911 a	7.47 a	206 a	63.0 a	716
Drum shaker, 180 cycles/min ^v	263 b	208 b	471 b	420 b	7.32 a	180 b	23.1 b	483
Drum shaker, 260 cycles/min	518 a	55 c	573 a	173 c	7.47 a	199 a	8.2 c	168

^z1 cm = 0.3937 inch.

^y1 g = 0.0353 oz.

^w1 kg = 2.2046 lb.

^xYield based on 454 trees/acre (1121.9 trees/ha) and weight of 48 lb per bushel. Yield adjusted for control trees based on canopy volumes equivalent to mechanically thinned trees; 1 bushel/acre = 53.8009 kg·ha⁻¹.

^vSet frequency for spiked-drum shaker rods. Forward travel speed of mechanical shaker down the tree row was $3 \text{ km}\cdot\text{h}^{-1}$ (1.9 mph).

^uMean separation within columns by Proc MIXED SAS system for mixed models (SAS Institute, Cary, NC) at $P \leq 0.05$.

removed from the hand-thinned control trees did not differ from the total number of fruit removed on the mechanically thinned trees. Mechanical thinning reduced the time required for follow-up hand thinning by 54% to 81% compared with the time needed to thin the hand-thinned control trees. Fruit size (diameter and weight) at harvest was increased by hand thinning alone and mechanical thinning plus follow-up hand thinning (Table 2). There was no difference in fruit diameter between thinning treatments, but mean fruit weight of peaches from trees mechanically thinned at 180 cycles/min was less than fruit from trees in the hand-thinned control treatment and trees mechanically thinned at 260 cycles/min. Yield per tree was reduced by mechanical thinning compared with the hand-thinned control and the nonthinned control trees. Yield on trees that were mechanically thinned at 260 cycles/min plus follow-up hand-thinned was reduced by 87% compared with trees that were only hand-thinned. Mechanical thinning at 180 cycles/min plus follow-up hand thinning reduced mean crop load by 63% over the hand-thinned control trees and by 70% compared with the nonthinned control trees. Mechanical thinning at 260 cycles/min resulted in a substantial reduction in the projected yield per acre compared with trees that were only hand-thinned or trees that were mechanically thinned at 180 cycles/min (Table 2).

Many factors affect fruit size at harvest and in these spiked-drum thinning trials, differences in canopy size between control trees and mechanically thinned trees, later timing for thinning treatments, crop load, and the once-over harvest in 2005 may have impacted final fruit size. Fruit size is negatively related to the number of fruit per tree (Johnson and Handley, 1989) and the longer thinning is delayed after bloom (Havis, 1962). Also, some fruit that have not matured and fully sized will generally be harvested in an once-over harvest. The higher yields per tree and projected yields per acre (Tables 1 and 2) for control trees were likely influenced (inflated) by differences in canopy size in the 2005–06 trials.

Tests conducted in 2006 confirmed results obtained in 2005 and

demonstrated the potential for mechanically thinning peach fruit with the spiked-drum shaker and thus reducing the time needed for follow-up hand thinning.

2007 COMMERCIAL PEACH ORCHARD TRIALS. Blossom removal with the string thinner for ‘Redhaven’ and ‘White Lady’ peaches ranged from 30% to 46% (Fig. 3A). Blossom removal in ‘Arctic Sweet’ and ‘Babygold 5’ trees was similar to that for ‘Redhaven’ and ‘White Lady’ (data not shown). Differences among cultivars, canopy position, and bloom stages were not significant. Percentage of fruit removal with the drum shaker ranged from 49 to 68 (Fig. 3B). Differences among cultivars and canopy position were not significant.

The string thinner effectively reduced flower density (flowers per

square centimeter of limb cross-sectional area) in the upper canopy in all cultivars compared with the hand-thinned control trees (Table 3). In contrast, only ‘Babygold 5’ exhibited a significant reduction in flower density in the lower canopy. Crop load (fruit per square centimeter of limb cross-sectional area), measured at 35 to 40 DAFB, and before follow-up hand thinning, was reduced in the upper and lower canopy by string thinning at 80% FB in all cultivars (except ‘Arctic Sweet’), but not at 20% FB (‘Redhaven’) (Table 3). Crop load was reduced on the tagged scaffold limb by all string thinning treatments except in the ‘Arctic Sweet’ nectarine trees. The drum shaker reduced crop load in both cultivars tested (Table 3). In the ‘Babygold 5’ trees, the drum shaker reduced crop

Fig. 3. Blossom or fruit removal from the lower and upper canopy of mature peach trees with two mechanical thinning devices: (A) percentage of blossom removal with string thinner (cultivar, canopy position, and bloom stage not significant at $P \leq 0.05$), (B) percentage of fruit removal with drum shaker (cultivar and canopy position not significant at $P \leq 0.05$); FB = full bloom, DAFB = days after full bloom.

Table 3. Peach and nectarine blossom thinning and fruit set response to mechanical and hand thinning treatments in commercial orchard trials, 2007.

Thinning treatment	Flower density after thinning (flowers/cm ² limb-cross-sectional area) ^z			Crop load (density) 35 DAFB ^y (fruit/cm ² limb-cross-sectional area)		
	Upper canopy	Lower canopy	Scaffold	Upper canopy	Lower canopy	Scaffold
‘Redhaven’						
String thinner 20% FB ^x	10.0 a ^w	5.1 a	11.4 a	4.0 ab	2.2 ab	4.6 a
String thinner 80% FB	11.0 a	3.5 a	10.5 a	3.6 a	1.5 a	3.8 a
Drum shaker 35 DAFB	—	—	—	2.4 a	1.4 a	3.2 a
Hand-thinned control	17.4 b	5.6 a	17.4 b	5.9 b	2.9 b	6.9 b
‘White Lady’						
String thinner 80% FB	9.5 a	3.1 a	7.0 a	2.6 a	0.9 a	1.4 a
Hand-thinned control	19.1 b	6.4 a	14.8 b	6.4 b	1.8 a	3.2 b
‘Babygold 5’						
String thinner 80% FB	10.0 a	3.6 a	6.8 a	2.9 b	1.5 b	2.2 a
Drum shaker 35 DAFB	—	—	—	0.2 a	0.5 a	0.4 a
Hand-thinned control	19.7 b	14.1 b	16.9 b	6.2 c	4.9 c	5.5 b
‘Arctic Sweet’ ^v						
String thinner 80% FB	3.4 a	—	4.2 a	0.6 a	—	0.9 a
Hand-thinned control	5.5 b	—	6.4 a	0.7 a	—	1.3 a

^z1 flower or fruit/cm² = 6.4516 flowers or fruit/inch².

^yDAFB = days after full bloom, before follow-up hand thinning.

^xFB = full bloom.

^wMean separation within columns and cultivars by Fisher’s protected least significant difference at $P \leq 0.05$ (‘Redhaven’ and ‘Babygold’ peach) or $P \leq 0.10$ (‘White Lady’ peach and ‘Arctic Sweet’ nectarine).

^vCrop reduced by low temperatures; thinned upper canopy only.

load in the upper and lower canopy to a greater extent than string thinning at 80% FB and in comparison with the hand-thinned control trees. The degree of crop load reduction in these studies was similar to that in the 2005 and 2006 trials on pillar peach. Despite some crop loss due to low temperature injury in the ‘Arctic Sweet’ trees, the string thinner applied at 80% FB did not further reduce crop load compared with the hand-thinned control trees in this treatment (Table 3).

The lower canopy of the trees used in these studies had fewer blossoms to begin with than the upper canopy (Table 3). This could be due to low temperature injury or to shading, resulting in poorer bearing wood in that area. Observations during our trials indicated that to obtain a consistent response between upper and lower canopy with the string thinner, it is necessary to adjust the machine spindle so that it is parallel to the vertical plane of the canopy (Fig. 1A). The drum shaker operates on the principle of horizontal displacement of the branches contacted by the shaker’s rods to dislodge fruit. While it was not measured in this study, horizontal displacement is likely to be much greater in the upper canopy that is furthest removed from the fixed point of the tree’s trunk at the ground than in the lower canopy.

Blossom removal by the string thinner was much greater on branches that were parallel to, or extended out into, the drive row than on interior branches (Fig. 2, A and B). Blossom removal from interior branches ranged from 2% to 28%, depending on cultivar and bloom stage, whereas blossom removal from exterior and parallel branches ranged from 41% to 65%. Even in a narrow canopy system, access to interior branches and blossoms was limited. Limited access could be due in part to the grower’s dormant pruning practices on the trees used in these trials. Our study with the string thinner demonstrates that branch position is an important consideration to maximize thinning efficacy of the mechanical string thinner. Limb position, orientation, and pruning practices have been associated with efficacy of mechanical thinners (Baughner et al., 1991; Glenn et al., 1994). While our results were generally positive and encouraging, the initial findings illustrate that refinements in machinery and canopy design are needed to obtain maximum efficacy with the mechanical string thinner and drum shaker.

The spiked-drum shaker resulted in more large-sized fruit removed than with hand thinning at 35 DAFB (Fig. 4A). Forty-three percent of the

‘John Boy’ peaches removed by the drum shaker were >3.0 cm diameter compared with only 29% of the hand-thinned fruit in this size category (Fig. 4B). Both mechanical thinners tested were nonselective with regard to the fruit removed, a disadvantage that must be weighed against the relative speed with which the thinning task can be completed. However, while larger fruit may be removed by a mechanical thinner, the speed of the technique may allow the grower to improve final fruit size by earlier thinning than is practical by hand.

Follow-up hand thinning time was reduced by both mechanical thinning devices in all cultivars evaluated (Table 4; Fig. 5A). The labor savings in the ‘Redhaven’ trial was 24%, 42%, and 19% for the string thinner at 20% FB, 80% FB, and the drum shaker treatments, respectively. The string thinner at 80% FB reduced follow-up hand thinning time in the ‘White Lady’ trial by 24%. Reductions in follow-up hand thinning time in the ‘Babygold’ trial were 48% for the string thinner at 80% FB and 64% for the drum shaker. Savings in follow-up hand thinning labor on ‘Babygold 5’ peaches were greater for the mechanical thinning treatments compared with the chemical bloom thinning treatments except for

Fig. 4. Size of fruit removed by the U.S. Department of Agriculture drum shaker or by hand thinning in a commercial ‘John Boy’ peach orchard trained to a perpendicular V system when thinned at 35 d after full bloom. Fifty fruit collected from under each of 20 mechanically or hand thinned trees. (A) Mean weight of fruit removed by drum shaker or by hand. (B) Size (fruit diameter) distribution of thinned fruit. Mean separation by Fisher’s protected least significant difference at $P \leq 0.05$; 1 g = 0.0353 oz, 1 cm = 0.3937 inch.

Table 4. Follow-up hand thinning time required in two mechanically thinned peach cultivars compared with conventional hand thinning only.

Thinning treatment	Hand thinning at 35 to 40 DAFB ^z (h·ha ⁻¹) ^y
‘Redhaven’	
String thinner 20% FB ^x	77 a ^w
String thinner 80% FB	59 a
Drum shaker 35 DAFB	82 a
Hand-thinned control	101 b
‘White Lady’	
String thinner 80% FB	37 a
Hand-thinned control	49 b

^zDAFB = days after full bloom.

^y1 h·ha⁻¹ = 0.4047 h/acre.

^xFB = full bloom.

^wMean separation within columns and cultivars by Fisher’s protected least significant difference at $P \leq 0.05$.

Silwet and the string thinner, which produced similar savings (Fig. 5B).

Both mechanical thinning devices reduced total yield of ‘Redhaven’ peaches, but yield of high-value large

fruit was increased by the string thinner at 20% FB and by the spiked-drum shaker used at 35 DAFB compared with hand-thinned controls (Table 5). Yield of larger, high-market-value

‘White Lady’ peaches was also increased compared with fruit from conventional hand-thinned trees. Fruit diameter was increased by the string thinner in the upper and lower sections of the canopy when measured the day before harvest. Pre-harvest fruit size was not different from the hand-thinned controls where the drum shaker was used (Table 5). Mean fruit size at harvest for ‘Redhaven’ peaches thinned with the string thinner at 20% FB, 80% FB, or the drum shaker at 35 DAFB did not differ from hand-thinned fruit. However, the string-thinned at 20% FB and the drum shaker-thinned trees produced a higher percentage of large, high-market-value peaches than the conventional hand-thinned trees (Table 5). Fruit size was increased in ‘Babygold 5’ peaches with the mechanical thinning devices, but results with chemical thinners were variable (Fig. 5B). When separated into size categories, the 20% string-thinned and drum shaker-thinned ‘Redhaven’ trees had more fruit in the 2.75 inches or larger size classes than conventional hand-thinned trees, and the string-thinned ‘White Lady’ peach trees had more fruit in the 3.0 inches or larger size classes than conventional hand-thinned trees (Fig. 6).

The savings in hand thinning time and increases in fruit size realized with mechanical thinners increased the economic value of the peach crop beyond hand thinning alone (Fig. 7). Net economic impact (cost-benefit beyond hand thinning alone) in ‘Redhaven’ was \$1963/ha for the string thinner at 20% FB, \$931/ha for the string thinner at 80% FB, and \$116/ha for the drum shaker treatment. Net economic impact in the ‘Babygold 5’ peaches was \$496/ha for the string thinner at 80% FB and \$602/ha for the drum shaker treatment, and in ‘White Lady’, the net economic impact was \$1350/ha for the 80% FB treatment. For ‘Redhaven’, the greatest increase in crop value was realized with the string thinner treatments, while for ‘Babygold 5’, the drum shaker produced the greatest value. Mechanically thinning ‘Redhaven’ with the string thinner at 20% FB produced the largest fruit size increase and the greatest economic value, although this treatment was only 3 d earlier than the same treatment at 80% FB. The results suggest

Fig. 5. (A) Follow-up hand thinning time and (B) mean fruit size at harvest of mechanical or chemical thinned 'Babygold 5' peach trees trained to a perpendicular V system. Mean separation by Fisher's protected least significant difference at $P \leq 0.05$. Tergitol (Tergitol TMN-6; Union Carbide, Danbury, CT) and Silwet (Silwet 408; Crompton Corp., Greenwich, CT) are surfactants; ATS = ammonium thiosulfate, $1 \text{ h} \cdot \text{ha}^{-1} = 0.4047 \text{ h/acre}$, $1 \text{ cm} = 0.3937 \text{ inch}$.

that early timing is critical in obtaining the optimal fruit size response to mechanical blossom thinning. Additional studies focused on timing for mechanical thinning of peach seem warranted.

2007 ORGANIC APPLE BLOCK TRIAL. The mechanical string blossom thinner reduced fruit set, follow-up hand thinning time, and yield of 'GoldRush' apple trees, and increased the proportion of fruit in the two largest size categories (Table 6). The string thinner removed flowers within clusters and entire clusters. Fruit set of trees thinned with the string thinner was a little less than half the fruit set of hand-thinned or oil- and lime sulfur-treated trees. The string thinner reduced follow-up hand thinning time by 31% compared with conventional hand thinning. Yield was reduced by 28%, but the percentage of large ($\geq 2.75 \text{ inch}$) fruit was increased. The oil and lime sulfur spray had no effect on fruit set, thinning time, and yield or fruit size. Although oil and lime sulfur in combination can be an effective chemical thinner (McArtney, et al., 2006; Schupp, et al., 2007), the efficacy of chemical thinners is strongly influenced by environmental factors, and results can be unpredictable (Stover and Greene, 2005).

The narrow canopy form of the apple trees in our study was ideal for mechanical thinning. Bertschinger et al. (1998) observed that the string

Table 5. Peach fruit size, total yield, and calculated high market value yield as affected by two mechanical thinning devices and conventional hand thinning treatments.

Thinning treatment	Total yield (kg·ha ⁻¹) ^z	Yield of high market value size fruit (kg·ha ⁻¹) ^y	Fruit diameter (cm) ^x			Fruit in high market value size categories (%)
			Preharvest ^w		Harvest ^v	≥2.75 inches
			Upper canopy	Lower canopy	50-fruit sample	(‘Redhaven’) or 3.0 inches
						(‘White Lady’)
‘Redhaven’						
String thinner 20% FB ^u	20,424 b ^s	18,053 a	6.8 a	6.5 a	7.1 a	84 a
String thinner 80% FB	19,293 b	14,012 b	6.9 a	6.4 a	7.0 a	65 b
Drum shaker 35 DAFB ^t	21,017 b	17,784 a	6.4 ab	5.8 ab	7.0 a	80 a
Hand-thinned control	25,652 a	14,766 b	5.6 b	5.2 b	6.9 a	56 b
‘White Lady’						
String thinner 80% FB	13,096 a	10,185 a	7.3 a	7.0 a	7.5 a	71 a
Hand-thinned control	17,137 a	8,676 b	6.6 b	6.5 b	7.2 b	44 b

^aYield calculated from fruit counts per scaffold and percentage of size distribution at harvest.

^bHigh market value fruit are all fruit $\geq 2.75 \text{ inches}$ or 3.0 inches diameter for ‘Redhaven’ and ‘White Lady’, respectively; $1 \text{ kg} \cdot \text{ha}^{-1} = 0.8922 \text{ lb/acre}$.

^c $1 \text{ inch} = 2.54 \text{ cm}$.

^dFruit diameter determined 1 d before harvest on 10 fruit per scaffold.

^eFruit diameter determined on 50 fruit harvested per treatment from each of four replicates.

^fFB = full bloom.

^gDAFB = days after full bloom.

^hMean separation within columns and cultivars by Fisher's protected least significant difference at $P \leq 0.05$.

Fig. 6. Peach fruit size distribution response to two mechanical thinning techniques and conventional hand thinning: (A) 'Redhaven' and (B) 'White Lady' peach trees trained to a quad V system; FB = full bloom, DAFB = days after full bloom, 1 inch = 2.54 cm.

Fig. 7. Economic comparison of mechanical and hand thinning treatments in three peach orchard trials. Net economic impact is cost benefit beyond hand thinning alone and includes machine cost, follow-up hand thinning time, and fruit size distribution. Prices for various fruit sizes are based on data obtained from the USDA Agricultural Marketing Service Report, Appalachian District (U.S. Department of Agriculture, 2007); FB = full bloom, \$1.00/ha = \$0.4047/acre.

thinner was less effective on trees with branches longer than 70 cm. Cultivar growth habit may also affect the response to the blossom thinner. Bertschinger et al. (1998) reported fruit set between 31% and 65% across several cultivars following string thinning at the pink stage, and noted that string thinning at bud swell severely damaged shoots and spurs of 'Jonica'. They reported that the best results were obtained between the tight cluster and pink stages, as later timing resulted in deformed fruit and increased the possibility of spreading disease, especially fire blight (*Erwinia amylovora*).

IMPLICATIONS FOR GROWERS. Mechanical thinning, being a physical removal technique, has greater predictability than chemical thinning. Because the effects of physical removal are immediately visible, the level of crop removal can be determined by comparing pre- and post-thinning flower or fruit counts. Therefore, a grower can assess the level of crop removal and adjust the machinery to increase or reduce thinning as needed. Likewise, the string thinner enables the grower to selectively thin only portions of the canopy, leaving sectors with low blossom density nonthinned. However, the ability to determine the optimal crop load level and thus obtain the optimal balance of yield and fruit size distribution is still required. Because the potential negative economic consequence of overthinning high-value crops such as stone fruit and organic apples is great, it may be a safer strategy to use nonselective mechanical thinners to reduce but not entirely replace hand thinning.

In the current trials, the level of crop removal resulting from the spiked-drum shaker was greater than that resulting from the string thinner. While the operating speed and drum rotation in the 2007 trials were adjusted to reduce the severity of thinning, based on the earlier trials on pillar trees, these results also illustrate that the efficacy of mechanical thinners will be influenced by any factor that influences canopy shape, size, and scaffold position such as cultivar phenology, tree vigor, and tree training. Tree training deserves additional attention as it may be an important factor in obtaining the most efficient operation of the spiked-drum mechanical shaker. Other

Table 6. Effect of mechanical blossom thinner or oil plus lime sulfur spray on fruit set, hand thinning time, yield, and fruit size of 'Goldrush' apple.

Treatment	Fruit set (%)	Hand thinning (min/tree)	Yield (lb/tree) ^z	Fruit size category (% of crop)			
				≥3 inches ^y	2.99–2.75 inches	2.74–2.5 inches	<2.5 inches
Control	69 a ^u	6.4 a	46 a	1.5 b	18.3 b	51.4 ab	28.8 a
String thinner PB ^x	35 b	4.8 b	31 b	9.9 a	36.1 a	42.7 b	11.3 a
Stylect oil ^w + lime sulfur 80% FB ^v	66 a	7.0 a	43 a	2.7 b	24.4 ab	59.4 a	13.5 a

^z1 lb = 0.4536 kg.^y1 inch = 2.54 cm.^xPB = prebloom.^wStylect oil (organic oil formulation from JMS Flower Farms, Vero Beach, FL).^vFB = full bloom.^uMean separation by Fisher's protected least significant difference at $P \leq 0.05$.

factors that warrant additional study include drum frequency, travel speed, size of the drum rods, and equipment modifications to allow for greater maneuverability of the drum shaker within the canopy. These studies are needed to refine this mechanical technique for thinning green peach fruit and to obtain an acceptable level of cropping at harvest. The potential for bloom thinning upright growth habit peach trees with the spiked-drum shaker should also be investigated.

Although these studies identified several areas for additional study, our results show that mechanical thinners are highly effective for thinning apple and peach grown on production systems trained to a narrow tree wall canopy. Given the current premiums for large fruit in the fresh fruit market, and the growing expense and potential shortage of farm labor, the application of mechanical thinners and adoption of narrow tree wall systems that facilitate the use of this technology offer a near-term solution to these two critical components of fruit grower profitability.

Literature cited

- Baughner, T.A., K.C. Elliott, B.D. Horton, S.S. Miller, and D.W. Leach. 1991. Improved methods of mechanically thinning peaches at full bloom. *J. Amer. Soc. Hort. Sci.* 116:766–769.
- Berlage, A.G. and R.D. Langmo. 1982. Machine vs. hand thinning of peaches. *Trans. Amer. Soc. Agr. Eng.* 25:538–543.
- Bertschinger, L. and W. Stadler. 1998. Mechanische ausdünnung: von apfelanlagen mit dem Fadengerät. *Swiss Federal Res. Sta. Fruit, Wine Veg. Growing Bul.* 401.
- Bertschinger, L., W. Stadler, F.P. Weibel, and R. Schumacher. 1998. New methods for an environmentally safe regulation of flower and fruit set and of alternate bearing of the apple crop. *Acta Hort.* 466:65–70.
- Byers, R.E. 1990. Thin peaches with water. *Amer. Fruit Grower* 110:20–21.
- Byers, R.E. 1999. Effects of bloom-thinning chemicals on peach fruit set. *J. Tree Fruit Production* 2:59–78.
- Diezma, B. and U.A. Rosa. 2005. Monitoring of fruit removal for mechanical thinning of peaches. *Frutic* 5:12–16.
- Fallahi, E., B. Fallahi, J.R. McFerson, R.E. Byers, R.C. Ebel, R.T. Boozer, J. Pitts, and P.S. Wilkins. 2006. Tergitol-TMN-6 surfactant is an effective blossom thinner for stone fruits. *HortScience* 41:1243–1248.
- Glenn, D.M., D.L. Peterson, D. Giovannini, and M. Faust. 1994. Mechanical thinning of peaches is effective postbloom. *HortScience* 29:850–853.
- Glozer, K. and J. Hasey. 2006. Mechanical thinning in cling peach. *HortScience* 41:995. (Abstr.).
- Grossman, Y.L. and T.M. DeJong. 1998. Training and pruning system effects on vegetative growth potential, light interception, and cropping efficiency in peach trees. *J. Amer. Soc. Hort. Sci.* 123:1058–1064.
- Hansen, M. 2004. New company labels lime sulfur as thinner. *Good Fruit Grower* 55(6):8.
- Havis, A.L. 1962. Effects of time of fruit thinning of Redhaven Peach. *Proc. Amer. Soc. Hort. Sci.* 80:172–176.
- Hoying, S.A., T.L. Robinson, and R.L. Anderson. 2007. More productive and profitable peach planting systems. *New York Fruit Quarterly* 15(4):13–18.
- Johnson, R.S. and D.F. Handley. 1989. Thinning response of early, mid-, and late-season peaches. *J. Amer. Soc. Hort. Sci.* 114:852–855.
- Klein, J.D. and S. Cohen. 2000. Thinning nectarines and peaches at flowering with organosilicone surfactants. *HortScience* 35:496.
- McArtney, S., J. Palmer, S. Davies, and S. Seymore. 2006. Effects of lime sulfur and fish oil on pollen tube growth, leaf photosynthesis and fruit set in apple. *HortScience* 41:357–360.
- McFerson, J. 2003. Crop load management in Washington via chemical thinning. *HortScience* 38:690. (Abstr.).
- Noordijk, H. and J. Schupp. 2003. Organic post bloom apple thinning with fish oil and lime sulfur. *HortScience* 38:690–691. (Abstr.).
- Osborne, J.L., T.L. Robinson, and R. Parra-Quezada. 2005. Chemical blossom thinning agents reduce crop load of 'Rising Star' peach in New York. *Acta Hort.* 727:423–428.
- Peterson, D.L. 1985. Cultural modifications of deciduous tree fruits for mechanized production. *HortScience* 20:1015–1018.
- Peterson, D.L. 1998. Mechanical harvester for processing oranges. *Appl. Eng. Agr.* 14:455–458.
- U.S. Department of Agriculture. 2007. USDA Agricultural Marketing Service report, Appalachian district. *USDA Fruit Veg. Market News*. 1 Sept. 2007. <http://marketnews.usda.gov/portal/fv?paf_dm=full&paf_gear_id=1200002&startIndex=1&cdr=1&rowDisplayMax=25&repType=termPriceDaily&cdr=1&locName=&commAbr=PCH&commName=PEACHES>.
- Schupp, J., K. Reichard, and L. Kime. 2007. Thinning 'GoldRush' apples in a certified organic orchard. *HortScience* 42:992. (Abstr.).
- Stover, E.W. and D.W. Greene. 2005. Environmental effects on the performance of foliar applied plant growth regulators. *HortTechnology* 15:214–221.
- Wilkins, B.S., R.C. Ebel, W.A. Dozier, J. Pitts, and R. Boozer. 2004. Tergitol TMN-6 for thinning peach blossoms. *HortScience* 39:1611–1613.