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Peach Blossom String Thinner Performance Improved with Selective Pruning

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***Abstract*. Hand-thinning of fruit is among the most labor-intensive orchard practices and consequently contributes significantly to peach (*Prunus persica*) production costs. Prior research conducted by the authors on string blossom thinners for managing peach tree cropload demonstrated that this new technology reduces labor requirement and also improves fruit size. Studies were conducted over two seasons in peach orchards trained to perpendicular V or open-center systems to evaluate possible pruning strategies to improve tree canopy access by string thinners. The objectives were to demonstrate if modifications in fruiting shoot orientation, pruning detail, and/or scaffold accessibility improved flower removal, reduced follow-up hand-thinning requirement, and/or increased fruit size. Blossom removal was improved by either detailed pruning or partial pruning (elimination of all shoots on the side of a limb inaccessible by the thinner spindle) in both training systems. Flower density and fruit set measurements revealed greater differences among pruning treatments compared with hand-thinned control treatments with both fruiting shoot orientation pruning modifications and detail pruning resulting in improved thinning. Thinning efficacy was unaffected by scaffold angle but increased as canopy accessibility ranking increased. Follow-up hand-thinning time was reduced by all treatment, system/cultivar, and year combinations except standard pruning in an open center-trained 2009 trial. Detail pruning consistently improved fruit size compared with hand-thinned control and other pruning treatments in both perpendicular V- and open center-trained orchard plots. The best treatments resulted in a thinning savings of \$120/ha to \$282/ha in perpendicular V plantings and \$26/ha to \$46/ha in open-center plantings. Realized economic savings beyond hand-thinning alone ranged from \$473/ha to \$2875/ha in perpendicular V trials and \$28/ha to \$293/ha in open-center trials.**

Crop thinning is required in tree fruit production to ensure optimum fruit size and quality. The conventional method of cropload management in peach orchards is to remove excess fruit by hand after danger of frost is over, which is generally 35 to 40 d after full bloom (DAFB). This is labor-intensive with time for hand-thinning ranging from 62 $h \cdot ha^{-1}$ to over 247 $h \cdot ha^{-1}$ (Glozer and Hasey, 2006; Krawczyk, 2010). Plant growth regulators are available for thinning pome fruit; however, chemical thinning options for stone fruit are limited and unpredictable (Byers, 1999; Fallahi et al., 2006; Klein and Cohen, 2000; Miller and Tworkoski, 2010; Osborne et al., 2005; Stover and Greene, 2005; Wilkins et al., 2004).

Various peach mechanical thinning devices have been tested over the years, including trunk shakers (Berlage and Langmo, 1982; Powell et al., 1975), low-frequency electrodynamic limb shakers (Diezma and Rosa, 2005; Glozer and Hasey, 2006; Rosa et al., 2008), high-pressure water streams (Byers, 1990), rotating rope curtains (Baugher et al., 1991), and vibrating canopy shakers (Glenn et al., 1994; Miller et al., 2011). As growers have modified training systems for automation by maintaining narrow canopy widths, mechanical thinning options have become more attainable (Miller et al., 2011; Schupp et al., 2008).

Two types of string blossom thinners have in recent years been successfully tested and commercialized in European apple orchards trained to narrow canopies (Bertschinger et al., 1998; Damerow and Blanke, 2009; Damerow et al., 2007). Research with this new string thinner technology for managing peach cropload began in U.S. orchards in 2007 (Schupp et al., 2008). Studies on narrow canopies trained to perpendicular V or quadrilateral V systems demonstrated that mechanical thinning reliably reduces cropload, reduces labor requirement, and increases fruit size beyond that achieved with conventional hand-thinning of green fruit at 30 to 40 DAFB. A 2008 prototype designed to operate in a horizontal position had similar effects on peach trees trained to an open-center system (Baugher et al., 2009). The next year, a string thinner was manufactured that operated in either a vertical or horizontal position, and trials conducted in four peach-producing regions on both narrow vertical and open-center canopies demonstrated reductions in follow-up hand-thinning requirement and increases in yield and fruit size (Baugher et al., 2010a). Pennsylvania trials conducted with the hybrid thinner on both perpendicular V- and open center-trained trees at various bloom stages showed that the window for thinning peach and nectarine trees ranges from the pink to the petal fall stage of bloom development (Baugher et al., 2010b).

Studies were conducted in Pennsylvania peach orchards in 2008 and 2009 to evaluate possible pruning strategies to improve peach tree canopy access by string thinners. Research on scaffold angle and accessibility was conducted in 2009. The objectives were to demonstrate if modifications in fruiting shoot orientation, pruning detail, and/or scaffold accessibility improved string thinner performance based on 1) increased flower removal; 2) reduced follow-up hand-thinning requirement; and/or 3) increased fruit size.

Materials and Methods

Mechanical string thinner description. A vertical string thinner originally designed to thin blossoms from pyramid-shaped apple trees (Darwin 300; Fruit-Tec, Deggenhausertal, Germany; Fig. 1A) was evaluated on perpendicular V-trained peach trees. The thinner has a 3.0-m-long spindle that is oriented in a vertical position and tilts 30° in either direction from center. A hybrid string thinner (PT 250; Fruit-Tec; Fig. 1B) was used to thin open center-trained peach trees. This thinner, designed to thin peach trees of variable forms (Baugher et al., 2010a), has a 2.5-m-long spindle that tilts from 120° to 270° from vertical and can thus be oriented in either a vertical or a horizontal position. On both string thinner models, the spindle is powered by a hydraulic motor

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and speed is adjusted by a proportional flow control valve. The intensity of thinning is adjustable by changing the spindle rotation speed, the tractor speed, or the string arrangement. Two columns of strings were used, arranged with alternating gaps, for a total of 90 strings. The string thinner was fitted with plastic strings and operated at 180 rpm and 4.0 $km \cdot h^{-1}$ in 2008 and fitted with molded strings and operated at 150 rpm and 4.0 $km \cdot h^{-1}$ in 2009. Length of both string types was 61.5 cm. The manufacturer changed the string technology in 2009, and it was important to test the strings that commercial growers would be using as they adopted the non-selective thinning strategy. Extensive pre-tests were conducted in 2009 to ensure that the string arrangement, rpm, and tractor speed used with both string types produced similar levels of thinning (data not presented).

Pruning modification trials conducted in commercial orchards. Mechanical thinning trials were conducted over two seasons in commercial Pennsylvania plantings of mature perpendicular V-trained 'Sugar Giant' and 'John Boy' peach trees and during one season in open center-trained 'Loring' and 'PF20-007'. Tree spacing was 6.1 × 1.8 m and 6.1 × 3.7 m, respectively. Pruning treatments in perpendicular V blocks included 1) standard (fruiting shoots left on all sides of each of two scaffolds); 2) fan (fruiting shoots selected in two directions parallel to the row); and 3) partial fan (fruiting shoots left parallel to the row or extending toward row middles but not toward the center of the tree) (Fig. 2A). Two additional pruning treatments—4) standard pruning with detailed cuts to eliminate short (less than 15 cm) or excessively long (greater than 45 cm) shoots; and 5) standard pruning post-bloom (after mechanically thinning)—were evaluated in 2009. Pruning treatments in open center blocks included 1) standard (fruiting shoots left on all sides of each of four scaffolds); 2) partial (secondary branches minimized and fruiting shoots selected on the sides and tops of each scaffold but not the undersides); and 3) detail (standard pruning with detailed cuts to eliminate short or excessively long shoots) (Fig. 2B). Uniform numbers of fruiting shoots were left in each treatment within a training system—60 in perpendicular V-trained trees and 125 in open center-trained trees. Based on earlier studies that determined optimum bloom stage for thinning, trees were mechanically thinned when 20% to 80% of the blossoms were open (Baugher et al., 2010b). Mechanically thinned pruning treatments were compared with green fruit hand-thinned (35 DAFB) control treatments on trees with standard pruning.

The experimental design in each trial was a randomized complete block with six blocks and six-tree plots. Data were collected from two center trees in each plot. Flower density and cropload were determined on two pre-tagged scaffolds on each of the test trees. Initial blossom density ranged from 10 to 16 flowers/cm^2 limb cross-sectional area in

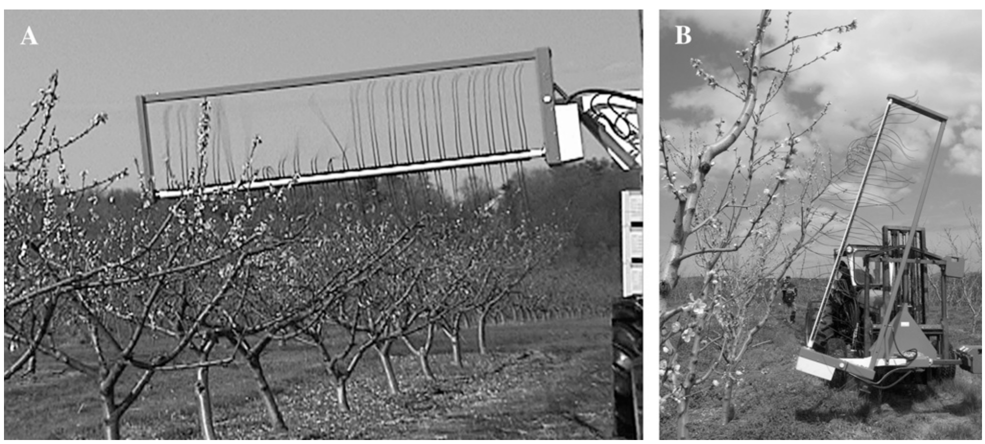

Fig. 1. Vertical string blossom thinner evaluated for thinning peach trees trained to perpendicular V (**A**) and hybrid string thinner prototype tested on peach trees trained to an open center system (**B;** photograph by M. Wherley). The string thinner spindles were fitted with two columns of strings arranged with alternating gaps. Plastic strings (shown in **A**) made for pre-2009 versions of the string thinner were used in 2008, and molded strings (**B**) developed for 2009 and 2010 string thinner models were used in 2009. Extensive pre-tests were conducted to ensure that the string arrangement, rpm, and tractor speed used with both string types produced similar levels of thinning.

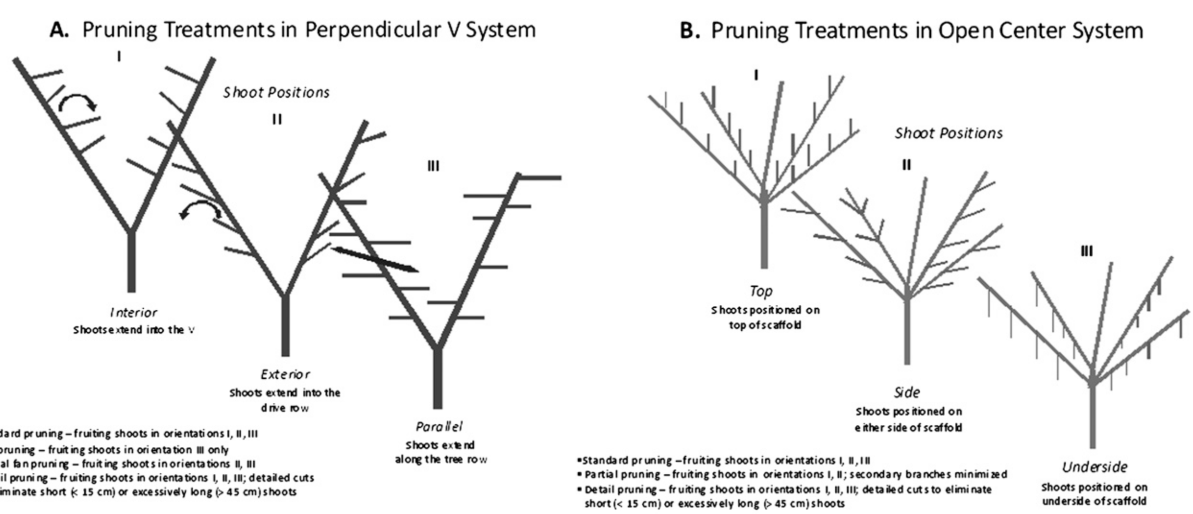

Fig. 2. Line drawings illustrating pruning treatments in perpendicular-V trained 'Sugar Giant' and 'John Boy' peach trees (**A**) and in open center-trained 'Loring' and 'PF20-007' peach trees (**B**).

perpendicular V-trained trees and 23 to 26 flowers/cm^2 limb cross-sectional area in open center-trained trees. Blossom removal with mechanical thinners was evaluated by counting all blossoms in the upper and lower canopy regions of the tagged scaffolds immediately before and after thinning. The total number of blossoms per scaffold also was compared. Reduction in flower/fruit density was evaluated the day of thinning and again after physiological drop (35 to 40 DAFB) by calculating number of blossoms or fruit per limb cross-sectional area in the upper and lower canopies and scaffold. All trees were uniformly hand-thinned by growers to commercial levels, during which follow-up hand-thinning time was recorded. At harvest, a sample of 40 firm-ripe fruit collected from the two center trees in each plot was evaluated for mean fruit diameter and fruit size distribution. Yields were calculated from fruit per scaffold counts and percent size distribution. All data were subjected to an analysis of variance and treatments were separated using Fisher's protected least significant difference test.

Economic partial budget analyses (described by Harper et al., 2002) were performed to evaluate the potential impact of each thinning treatment on fruit returns. Mechanical thinning costs, based on a 15-year life of equipment and 8% interest rate, averaged \$37/ha for the string thinner, including tractor cost (\$12.00/h) and labor (\$12.00/h). Realized economic savings were calculated from follow-up hand-thinning time, fruit size distribution, and average yield. Follow-up hand-thinning costs were based on a labor rate of \$8.50/h in 2008 and \$8.75/h in 2009. Commercial prices for the various size categories for each cultivar and year were obtained from the USDA Agricultural Marketing Service Report, Appalachian Region (USDA, 2009).

Commercial-scale trial to evaluate thinning efficacy with variable scaffold angles and accessibility rankings. Regression analyses were conducted to access string thinner efficacy on 'Allstar' and 'Saturn' perpendicular V-trained peach trees with variable scaffold angles and accessibility rankings. Plot size averaged 245 trees. Treatments were applied with the vertical string thinner fitted with molded strings and operated at 150 rpm and 4.0 km·h^{-1}. Estimated percent blossom removal for each scaffold was compared with scaffold angle and also a canopy accessibility score of 1 (poor accessibility) to 5 (excellent accessibility). Crooked scaffolds or scaffolds that were not perpendicular to the row were given the lower rankings, and straight, unobscured scaffolds that were oriented close to 90° from the row direction were given the highest accessibility ratings.

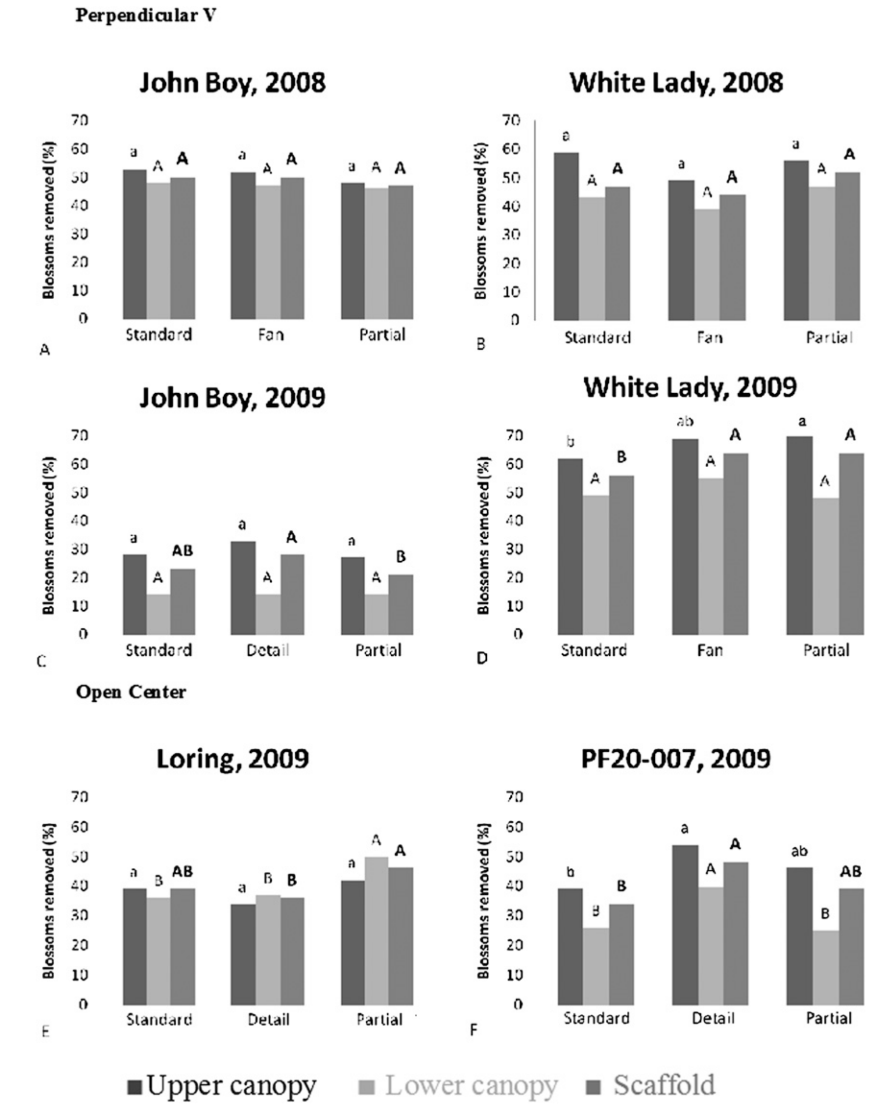

Fig. 3. Peach blossom removal with a string thinner in response to various pruning treatments. The string thinner was fitted with plastic strings and operated at 180 rpm and 4.0 km·h^{-1} in 2008 and fitted with molded strings and operated at 150 rpm and 4.0 km·h^{-1} in 2009. Mean separation within cultivars, years, and canopy position by Fisher's protected least significant difference at $P \leq 0.05$ (lower case letters for upper canopy, upper case letters for lower canopy, bold letters for scaffold).

Results and Discussion

Blossom removal, flower density, fruit set, and follow-up hand-thinning comparisons. Blossom removal was improved by either detailed pruning or partial pruning in both training systems (Fig. 3). The detailed pruning and partial pruning treatments compared with standard pruning treatments resulted in a greater number of blossoms thinned in the 2009 'John Boy' and 'PF20-007' trials and the 2009 'White Lady' trial, respectively. Blossom removal was similar across pruning treatments in 2008 with the exception that removal in the fan treatment was no different from the control. Pruning in the detail and partial pruned plots was more selective than pruning in the standard pruned plots, which resulted in improved access for mechanical thinning.

Flower density and fruit set measurements revealed greater differences among pruning treatments compared with hand-thinned control treatments, especially in upper canopy regions of the trees (Table 1). In perpendicular V-trained trees, blossom density in upper canopy regions was reduced in the 2009 'John Boy' trial by delayed (post-bloom) pruning or detail pruning and in both years of 'White Lady' trials by fan or partial pruning compared with other pruning treatments. Whole scaffold blossom density was reduced in the 2009 'John Boy' study by detail pruning and in the 2009 'White Lady' study by fan pruning (although the difference was insignificant compared with partial pruning). Fruit set (upper canopy, lower canopy, and scaffold) in the same trials was reduced in 'John Boy' by detail pruning and in 'White Lady' (upper scaffold, 2008 only) by partial pruning. Fruit set in post-bloom-pruned trees was similar to hand-thinned control trees, and the fruitlets were small compared with the other treatments. In open center-trained trees, blossom density and cropload were reduced in all canopy regions of 'Loring' by partial compared with standard pruning, but the numbers of flowers or fruit were similar to detail pruning. Blossom density and cropload (lower canopy and total scaffold) were reduced by detail pruning compared with standard pruning, yet the numbers of flowers were similar

Table 1. Peach blossom thinning and fruit set response to vertical string thinner treatments applied to varying pruning modifications in 2008 and 2009.

	Flower density after thinning[z] (flowers/cm² limb-cross-sectional area)			Cropload (density) 35 DAFB[y] (fruit/cm² limb-cross-sectional area)		
Thinning treatment[x]	Upper canopy	Lower canopy	Scaffold	Upper canopy	Lower canopy	Scaffold
Perpendicular V						
John Boy *2008*						
Fan pruning, 20% FB[w]	7.3 b[v]	3.3 b	7.2 b	3.5 b	1.9 b	3.8 b
Partial pruning, 20% FB	6.9 b	3.2 b	7.0 b	3.5 b	1.8 b	3.8 b
Standard pruning, 20% FB	8.4 b	3.3 b	7.4 b	3.9 b	1.8 b	3.9 b
Hand-thinned control, 35 DAFB	19.5 a	6.2 a	15.8 a	7.8 a	2.8 a	6.7 a
John Boy *2009*						
Delayed pruning, 80% FB	9.2 c	5.7 a	10.9 b	10.0 ab	3.1 a	8.7 a
Detail pruning, 80% FB	9.2 c	2.5 b	7.4 c	5.6 c	1.7 b	4.6 b
Standard pruning, 80% FB	14.3 b	5.2 a	12.9 b	7.4 bc	3.6 a	7.6 a
Hand-thinned control, 35 DAFB	19.4 a	5.7 a	15.8 a	10.3 a	3.5 a	8.9 a
White Lady *2008*						
Fan pruning, 20% FB	7.9 c	3.2 b	5.8 b	3.9 bc	1.3 b	2.6 b
Partial pruning, 20% FB	8.0 c	3.1 b	5.7 b	3.2 c	1.4 b	2.5 b
Standard pruning, 20% FB	12.1 b	3.6 b	7.3 b	4.7 b	1.2 b	2.5 b
Hand-thinned control, 35 DAFB	20.4 a	5.9 a	13.0 a	7.6 a	2.2 a	4.9 a
White Lady *2009*						
Fan pruning, 60% FB	3.3 c	1.3 b	2.7 c	1.0 b	0.5 b	0.9 b
Partial pruning, 60% FB	2.8 c	1.8 b	3.1 bc	0.9 b	0.5 b	0.9 b
Standard pruning, 60% FB	6.9 b	2.2 b	4.9 b	1.8 b	0.7 b	1.4 b
Hand-thinned control, 35 DAFB	16.9 a	3.6 a	10.7 a	5.6 a	1.1 a	3.5 a
Open center						
Loring *2009*						
Detail pruning, 60% FB	15.7 bc	5.8 bc	13.0 b	10.8 bc	3.9 bc	9.0 b
Partial pruning, 60% FB	10.8 c	3.4 c	8.1 c	6.9 c	1.9 c	4.7 c
Standard pruning, 60% FB	17.5 ab	7.4 b	16.7 b	11.0 bc	5.3 b	11.3 b
Hand-thinned control, 35 DAFB	22.7 a	11.8 a	23.4 a	13.7 a	7.6 a	14.5 a
PF20-007 *2009*						
Detail pruning, 60% FB	11.8 c	4.4 c	9.2 c	3.5 c	1.3 b	2.7 c
Partial pruning, 60% FB	14.6 bc	6.2 bc	14.5 bc	5.3 ab	2.6 a	5.5 b
Standard pruning, 60% FB	10.5 c	8.6 b	15.7 b	3.5 b	5.6 a	4.9 b
Hand-thinned control, 35 DAFB	20.4 a	11.1 a	25.5 a	7.0 a	3.5 a	8.4 a

[z]1 flower or fruit/cm² = 6.4516 flowers or fruit/inch².
[y]DAFB = days after full bloom; before follow-up hand-thinning.
[x]The vertical string thinner was fitted with plastic strings and operated at 180 rpm and 4.0 km·h^{-1} in 2008 and fitted with molded strings and operated at 150 rpm and 4.0 km·h^{-1} in 2009. 1.0 km^{-1} = 0.6214 mph.
[w]FB = full bloom.
[v]Mean separation within columns, cultivars, and years by Fisher's protected least significant difference at $P \leq 0.05$.

to partial pruning. Thinning improvements related to shoot position were consistent with those reported by Schupp et al. (2008) in a study in which flower removal on shoots growing toward the row, toward the center of the tree, and parallel to the row was compared. Thinning improvements with detailed pruning resulted from prior removal of long shoots that tend to get bent by the strings and short shoots that are often missed. These shoots produce poorer quality fruit based on research conducted by Marini (2009); therefore, removal by pruning further impacts fruit size.

Follow-up hand-thinning time was reduced by all treatment, system/cultivar, and year combinations except the standard pruning in the open center-trained 'Loring' in the 2009 trial (Table 2). Detail pruning was the only treatment that reduced hand-thinning time compared with other pruning strategies. Follow-up hand-thinning on mechanically thinned, detail-pruned trees compared with green fruit thinned, standard-pruned trees was reduced by 46% in perpendicular V-trained 'John Boy' (2009) and by 22% and 47%, respectively, in open center-trained 'Loring' and 'PF20-007' (2009). Mechanically thinned 'White Lady' (2009) trees did not require follow-up thinning because they had been bloom-thinned too heavily. In mechanically thinned 'John Boy', 'White Lady' (2008), 'Loring', and 'PF20-007', follow-up hand-thinning time ranged from 42.1 to 66.4 h·ha^{-1}, 19.0 to 21.7 h·ha^{-1}, 24.0 to 27.8 h·ha^{-1}, and 10.3 to 14.8 h·ha^{-1}, respectively. Follow-up thinning time for hand-thinned control trees was 78.3, 36.6, 30.7, and 19.3 h·ha^{-1} in the same trials. The follow-up hand-thinning data, along with bloom and fruit set data, confirm previous reports indicating the importance of careful assessment of bloom density to determine best use of mechanical thinning technology (Baugher et al., 2009, 2010a; Schupp et al., 2008).

Fruit size, yield, and labor comparisons. Detail pruning consistently improved fruit size compared with hand-thinned control and other pruning treatments in both open center- and perpendicular V-trained orchard plots (Table 3). Partial pruning was equal to detail pruning in just one trial—the 'PF20–007' plot. Detail pruning also increased the percentage of fruit in higher market value size categories (fruit 7.0 cm or greater and/or 7.6 cm or greater) in all trials except 'Loring'. Detail pruning was not included as a treatment in the 2008 'John Boy' trial, and fan pruning was the only treatment that resulted in improved size distribution compared with the hand-thinned control. Previous research showed no difference in effects on fruit size in the upper versus lower canopy (Schupp et al., 2008). Although total calculated yield

Table 2. Follow-up hand-thinning time required with vertical string thinner treatments applied to varying pruning modifications in 2008 and 2009.

Thinning treatment[y]	Hand-thinning at 35 to 40 DAFB[z] ($h \cdot ha^{-1}$)[x]
	Perpendicular V
	John Boy
	2009[w]
Delayed pruning, 80% FB	66.2 b[v]
Detail pruning, 80% FB	42.1 c
Standard pruning, 80% FB	66.4 b
Hand-thinned control, 35 DAFB	78.3 a
	White Lady
	2008
Fan pruning, 20% FB	19.0 b
Partial pruning, 20% FB	14.6 b
Standard pruning, 20% FB	21.7 b
Hand-thinned control, 35 DAFB	36.6 a
	White Lady
	2009
Fan pruning, 60% FB	0.0 b
Partial pruning, 60% FB	0.0 b
Standard pruning, 60% FB	0.0 b
Hand-thinned control, 35 DAFB	40.6 a
	Open center
	Loring
	2009
Detail pruning, 60% FB	24.0 c
Partial pruning, 60% FB	24.8 bc
Standard pruning, 60% FB	27.8 ab
Hand-thinned control, 35 DAFB	30.7 a
	PF20-007
	2009
Detail pruning, 60% FB	10.3 c
Partial pruning, 60% FB	14.3 b
Standard pruning, 60% FB	14.8 b
Hand-thinned control, 35 DAFB	19.3 a

[z]DAFB = days after full bloom; FB = full bloom.
[y]The vertical string thinner was fitted with plastic strings and operated at 180 rpm and 4.0 $km \cdot h^{-1}$ in 2008 and fitted with molded strings and operated at 150 rpm and 4.0 $km \cdot h^{-1}$ in 2009. 1.0 $km \cdot h^{-1}$ = 0.6214 mph.
[x]1 $h \cdot ha^{-1}$ = 0.4047 h/acre.
[w]No data for 'John Boy' in 2008.
[v]Mean separation within cultivars and years by Fisher's protected least significant difference at $P \leq 0.05$.

Table 3. Peach fruit size, packout distribution, and high market value yield as affected by string thinner treatments applied to varying pruning modifications in 2008 and 2009.

Thinning treatment	Fruit diam (cm)[z]	Fruit 7.0 cm or greater (%)	Fruit 7.6 cm or greater (%)	Total yield ($kg \cdot ha^{-1}$)[y]	Yield of high market value size fruit ($kg \cdot ha^{-1}$)[x]
			Perpendicular V		
			John Boy		
			2008		
Fan pruning, 20% FB[w]	7.2 a[v]	99 a	60 a	18,240 c	13,594 b
Partial pruning, 20% FB	7.2 a	96 ab	46 ab	22,175 bc	11,396 c
Standard pruning, 20% FB	7.2 a	96 ab	58 a	24,578 b	15,495 a
Hand-thinned control, 35 DAFB	7.0 b	91 b	33 b	32,090 a	12,340 bc
			John Boy		
			2009		
Delayed pruning, 80% FB[u]	—	—	—	—	—
Detail pruning, 80% FB	7.5 a	78 a	21 a	50,757 b	13,059 a
Standard pruning, 80% FB	7.1 b	54 b	4 b	63,197 a	3,192 b
Hand-thinned control, 35 DAFB	6.9 b	59 b	3 b	76,074 a	3,460 b
			White Lady		
			2008		
Fan pruning, 20% FB	6.8 a	69 a	16 a	8,978 b	7,026 ab
Partial pruning, 20% FB	6.9 a	62 a	19 a	8,539 b	5,937 b
Standard pruning, 20% FB	6.8 a	66 a	14 a	10,107 b	7,298 a
Hand thinned control, 35 DAFB	6.6 b	41 b	4 b	13,565 a	6,390 ab
			White Lady		
			2009		
Fan pruning, 60% FB	7.4 a	76 a	35 a	5,063 c	4,149 b
Partial pruning, 60% FB	7.7 a	83 a	57 a	6,611 bc	5,819 ab
Standard pruning, 60% FB	7.6 a	90 a	54 a	7,472 b	6,924 a
Hand thinned control, 35 DAFB	6.9 b	41 b	8 b	9,415 a	4,681 b
			Open center		
			Loring		
			2009		
Detail pruning, 60% FB	8.1 a	100 a	72 a	12,078 a	9,178 a
Partial pruning, 60% FB	7.9 b	98 a	61 a	9,409 b	6,242 b
Standard pruning, 60% FB	7.9 b	98 a	58 a	11,314 a	7,207 ab
Hand thinned control, 35 DAFB	7.7 b	98 a	54 a	12,834 a	7,641 ab
			PF20-007		
			2009		
Detail pruning, 60% FB	8.3 a	100 a	94 a	9,063 b	8,650 a
Partial pruning, 60% FB	8.1 ab	100 a	82 b	11,033 ab	9,415 a
Standard pruning, 60% FB	8.0 b	100 a	86 ab	11,136 ab	9,894 a
Hand thinned control, 35 DAFB	7.9 b	100 a	80 b	12,606 a	10,537 a

[z]Fruit diameter and packout distribution determined on 40 fruit harvested per treatment from each of six replicates. 1 cm = 0.3937 inch.
[y]Yield calculated from fruit counts per scaffold and percent size distribution at harvest.
[x]Higher market value fruit are all fruit 7.62 cm or greater (3.0 inches) diameter for 'John Boy' and all fruit 6.985 cm or greater (2.75 inches) for 'While Lady', 'Loring', and PF20-007. 1 $kg \cdot ha^{-1}$ = 0.8922 1b/acre.
[w]FB = full bloom; DAFB = days after full bloom.
[v]Mean separation within columns, cultivars, and years by Fisher's protected least significant difference test at $P \leq 0.05$.
[u]No data, because trees were pruned too late for comparison.

of mechanically thinned trees was sometimes reduced compared with hand-thinned control trees, yield of high market value-sized fruit was sometimes increased (Table 3). This finding is similar to results of earlier research with either the hybrid or vertical string thinner (Baugher et al., 2010a; Schupp et al., 2008). A 2008 mechanical thinning trial in which detailed yield data were collected at each harvest date demonstrated that early harvest yield of mechanically blossom-thinned trees was greater than early yield of trees in hand-thinned control and non-thinned treatments and that thinning treatment did not affect total yield (Baugher et al., 2009).

Follow-up hand-thinning costs for the green fruit-thinned control treatments averaged \$419/ha in the perpendicular V trials and \$219/ha in the open-center trials (Table 4). The best treatments resulted in a thinning savings of \$120/ha to \$282/ha and \$26/ha to \$46/ha, respectively. Thinning savings calculations included reduced follow-up hand-thinning inputs and added mechanical thinner, tractor, and labor inputs.

Realized economic savings. The savings in hand-thinning time and increases in fruit size associated with the detail and partial pruning treatments increased the value of the peach crops beyond that of hand-thinning alone (Table 4). Net positive economic impact (realized economic savings beyond hand-thinning alone) ranged from \$473/ha to \$2875/ha in perpendicular V trials and \$28/ha to \$293/ha in open-center trials. The only treatment that resulted in a negative net economic impact was standard pruning in the 2009 'John Boy' study, and although follow-up hand-thinning time was reduced by this treatment, fruit size was unaffected.

We did not measure pruning time in these studies. Pruning labor ranks third and represents ≈21% of total labor in peach, behind harvest (42%) and hand-thinning (28%) (Krawczyk, 2010). Pruning modifications such as ours, which remove fruiting branches, could be expected to reduce fruit numbers by removing the bearing surface, thus reducing the labor required for thinning and harvest. Standard pruning in peach involves selecting desirable branches and thinning out undesirable branches and requires farm workers to make judgments about which branches to remove. Partial and fan pruning methods both impose rules by which those branches growing in the specified orientations are removed without any requirement for judgment; thus, these methods could be expected to reduce pruning time somewhat. Detail pruning took somewhat longer than standard pruning because there were added steps; however, the detail cuts were based on branch size, requiring very little judgment.

Thinning efficacy with variable scaffold angles and accessibility rankings. Thinning efficacy was unaffected by the scaffold angle of perpendicular V-trained peach trees. Average scaffold angle was 65° to 70°, the range was 55° to 90°, and Pearson product moment correlations ranged from –0.24 to 0.16 (data not shown). Thinning efficacy, however, increased for each 1-point increase in accessibility ranking based on regression analyses pooled across plots (Fig. 4). The Pearson product moment correlation for 'Allstar', which had moderate bloom density, was 0.80, and the Pearson product moment correlation for 'Saturn', which had a heavy bloom density, was 0.50 ($P = 0.05$; Fig. 5). The tractor operator could adjust the spindle angle to the scaffold angle and effectively thin a straight scaffold positioned perpendicular to the row, but not a crooked limb or one that was not perpendicular to the row. This finding indicates that extra attention should be given to laying out and training peach blocks that are to be mechanically thinned.

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. A grower can therefore assess the level of crop removal and adjust the machinery to increase or reduce thinning as needed. However, the ability to ascertain the optimal cropload level

Table 4. Follow-up hand-thinning cost, thinning savings, and net economic impact as affected by string thinner treatments applied to varying pruning modifications in 2008 and 2009.

Thinning treatment	Follow-up hand-thinning cost ($/ha)[z]	Thinning savings ($/ha)[y]	Net economic impact ($/ha)[x]
	Perpendicular V		
	John Boy 944 trees/ha		
	2008		
Fan pruning, 20% FB[w]	169	87	985
Partial pruning, 20% FB	131	126	597
Standard pruning, 20% FB	195	62	749
Hand-thinned control, 35 DAFB	326	—	—
	John Boy 944 trees/ha		
	2009		
Delayed pruning, 80% FB[v]	578	71	—[v]
Detail pruning, 80% FB	368	282	1,346
Standard pruning, 80% FB	581	69	(64)
Hand-thinned control, 35 DAFB	685	—	—
	White Lady 897 trees/ha		
	2008		
Fan pruning, 20% FB	161	83	2,875
Partial pruning, 20% FB	124	120	2,336
Standard pruning, 20% FB	185	59	2,445
Hand thinned control, 35 DAFB	310	—	—
	White Lady 897 trees/ha		
	2009		
Fan pruning, 60% FB	0	322	473
Partial pruning, 60% FB	0	322	929
Standard pruning, 60% FB	0	322	983
Hand thinned control, 35 DAFB	355	—	—
	Open center		
	Loring 450 trees/ha		
	2009		
Detail pruning, 60% FB	210	26	293
Partial pruning, 60% FB	217	18	86
Standard pruning, 60% FB	243	7	28
Hand thinned control, 35 DAFB	269	—	—
	PF20-007 450 trees/ha		
	2009		
Detail pruning, 60% FB	90	46	181
Partial pruning, 60% FB	125	11	27
Standard pruning, 60% FB	129	7	63
Hand thinned control, 35 DAFB	169	—	—

[z]Follow-up hand-thinning cost is based on a labor rate of $8.50/h in 2008 and $8.75/h in 2009.
[y]Thinning savings includes reduced follow-up hand-thinning inputs and added mechanical thinner, tractor, and labor input. Mechanical thinner cost is based on a 15-years useful life of equipment and 8% interest rate. Tractor cost is $12.00/h; equipment operator cost is $12.00/h.
[x]Net economic impact (realized economic savings) is defined as cost/benefit beyond hand-thinning alone and takes into account reduced hand-thinning inputs and increased value of fruit in higher size categories.
[w]FB = full bloom; DAFB = days after full bloom.
[v]No data, because trees were pruned too late for comparison.

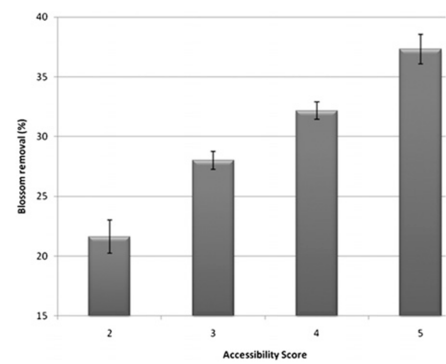

Fig. 4. Effect of scaffold accessibility (1 = poor to 5 = excellent accessibility) on percent blossom removal across four perpendicular V-trained commercial-scale plots. Crooked scaffolds or scaffolds that were not perpendicular to the row were given the lower rankings, and straight scaffolds that were positioned close to 90° from the row were given the highest accessibility ratings.

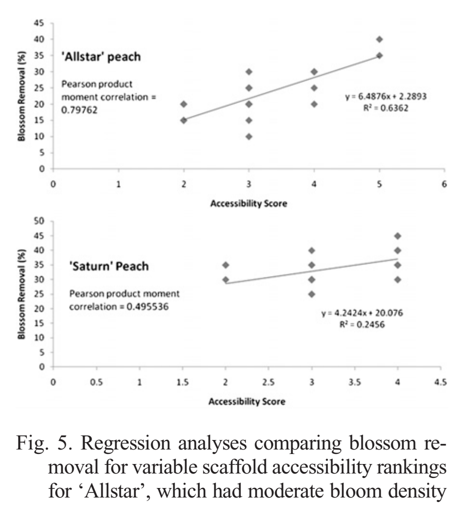

Fig. 5. Regression analyses comparing blossom removal for variable scaffold accessibility rankings for 'Allstar', which had moderate bloom density and 'Saturn', which had a heavy bloom density.

and thus obtain the optimal balance of yield and fruit size distribution is still required. Because the potential negative economic consequence of overthinning a high-value crop such as stone fruit is great, it may be a safer strategy to use non-selective mechanical thinners to reduce but not entirely replace hand-thinning.

In the current trials, tree pruning and training modifications were shown to be factors that warrant special attention for obtaining the most consistent results from mechanical string thinning. Canopy accessibility by the string thinner can be improved by detail pruning to eliminate excessively long or short fruiting shoots, by pruning to remove shoots in less accessible regions of the canopy, and by tree training to maintain straight scaffolds. 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 enhance the benefits of this technology offer a near-term solution to these two critical components of fruit grower profitability.

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