Peach Fruit Weight, Yield, and Crop Value Are Affected by Number of Fruiting Shoots per Tree

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Abstract. Mature 'Norman' peach [*Prunus persica* (L.) Batsch] trees were dormant pruned to retain a range of fruiting shoots per tree (71 to 250) during 3 years from 1997 to 1999. About 40 days after bloom each year, fruits on all trees were thinned to similar crop loads, so only the number of fruits per shoot varied. Fruit set and number of fruits removed by hand thinning were positively related to number of fruiting shoots retained per tree. Number of fruits harvested per tree was not related to number of shoots per tree, whereas average fruit weight at thinning and at harvest, and crop value per tree were negatively related to the number of shoots retained per tree. These results indicate that commercial peach producers should consider modifying pruning and thinning strategies. Rather than retaining a large number of fruiting shoots per tree and hand thinning to distribute fruits every 15 to 20 cm along each fruiting shoot, producers should first determine the number of fruits that trees of a given cultivar can adequately size and then perform the thinning operation to obtain the desired crop load. The number of fruiting shoots retained per tree during pruning should be one-fifth to one-seventh of the number of fruits desired per tree, so that five to seven fruits per fruiting shoot are retained after hand thinning.

Peach buyers prefer large fruits. In the mid-Atlantic region of the United States, peaches <57 mm in diam. are no longer marketable, and prices usually increase as fruit size increases from 57 to 75 mm. Crop load adjustment, by hand thinning, to remove excess fruit before pit-hardening often costs \$750 to \$860/ha (Marini, 2002b; Southwick and Fritts, 1995) and is one of the most expensive orchard operations associated with peach production. Although hand thinning of fruits is expensive and requires a large labor force, the practice improves fruit size at harvest and is cost-effective.

Fruit size at harvest is negatively related to the number of fruits harvested per tree (Johnson and Handley, 1989) as well as to the number of days after bloom that fruit thinning is performed (Havis, 1962). To obtain benefits of early thinning, many peach growers in Virginia perform partial bloom thinning by removing blossoms with fingers or stiff brushes, and then hand thin excess fruits 30 to 50 d after full bloom. My orchard observations indicate that this method of crop load adjustment spreads out the labor requirement, reduces the potential risks associated with over-thinning during bloom before fruit set can be assessed, and the improvement in fruit size is greater than when fruits are thinned only during the post-bloom period. However bloom thinning, before the danger of frost is over, can be risky.

Researchers have been evaluating alternative, less expensive, methods of adjusting peach crop load. Compared to hand-removal of excess fruits at 30 to 50 d after bloom, blossom thinning using rope curtains resulted in increased fruit size (Baughner et al., 1988), however, this

operation required well-pruned trees to avoid inadequate thinning of flowers in narrow crotches on tree tops and sides (Baughner et al., 1991). Inhibiting pollination or fertilization by applying caustic chemicals during bloom has improved fruit size (Byers et al., 1990; Byers and Lyons, 1985; Southwick et al., 1996). Although the practice was relatively inexpensive, results with pollination inhibiting chemicals were inconsistent (Byers et al., 1990; Byers and Lyons, 1985). Application of gibberellins reduced bloom density the following season, resulting in reduced fruit set and increased fruit size (Byers et al., 1990; Southwick et al., 1995). Unfortunately, the gibberellin product, Ralex (Valent Biosciences Corp., Libertyville, Ill.), is registered for stone fruits only in California, Oregon, and Washington.

Peach trees are pruned to maintain tree size and shape, to improve light distribution throughout the canopy, to improve spray penetration and drying conditions for pest control, and to reduce the number of flower buds per tree (Marini, 2002a). Heading back all fruiting shoots by 50% during dormant pruning slightly reduced fruit set and fruit thinning cost, and sometimes improved fruit size compared to not heading fruiting shoots (Marini, 2002b). Heading to remove more than 50% of each shoot further reduced crop load and fruit thinning cost, but negatively affected fruit size. The reason for severe heading back did not adequately reduce crop load is that the flower bud density is maximum at the base of the fruiting shoot (Byers et al., 1990; Coston, 1983). Therefore, removing entire shoots may be more effective for reducing the initial crop load. The purpose of this study was to determine the effect of retaining different number of fruiting shoots per tree, while maintaining a particular crop

load, on fruit set, fruit weight, yield, and crop value of mature peach trees.

Materials and Methods

Three experiments were conducted at the Virginia Tech College of Agriculture and Life Sciences Kentland Farm, near Blacksburg, Va. Self-rooted 'Norman' peach trees, planted in 1988 at a spacing of 5.5 × 5.0 m (370 trees/ha), and trained to the open-vase form were used for experiments in 1997, 1998, and 1999. The trees were 10 years old in 1997. To supplement precipitation, trees were trickle-irrigated with emitters placed 45 cm from trunks and each tree received ≈40 L of water per day during the 7 weeks before harvest.

In early Mar. 1997, ≈3 weeks before bloom, four pruning treatments were assigned randomly to 36 trees selected for uniformity. There were nine single-tree-replicates in a completely randomized design (CRD). All trees were lightly pruned to remove overly vigorous shoots, 1-year-old shoots shorter than 30 cm and 1-year-old shoots hanging below the horizontal. Additional shoots were removed to retain 73, 110, 146, or 220 one-year-old fruiting shoots per tree. In Mar. 1998, ≈10 d before bloom, a different group of 44 trees was selected, and the same four pruning treatments were applied to 11 single-tree-replicates in a CRD. In Mar. 1999, ≈6 d before bloom, a new group of 48 trees was selected, but treatments were modified to retain 71, 83, 100, 125, 167, and 250 one-year-old fruiting shoots per tree. There were 8 single-tree-replicates in a CRD.

Each year, crop load was adjusted by hand thinning excess fruits about 40 days after full bloom (DAFB). Based on previous work with these trees (Marini and Sowers, 2000), it was felt that a crop load of 440 fruits per tree would result in high yield of acceptable size (57 mm or larger) fruit. Therefore, 440 fruits per tree were retained in 1997 and 1998, by removing the smallest and insect-damaged fruits to retain only 6, 4, 3, or 2 fruits per shoot for the 73, 110, 146, and 220 shoots per tree treatments, respectively. Fruit set was poor in 1997 following a frost during the bloom period. Although many trees had less than the desired number of fruits, they were hand thinned 40 DAFB to eliminate fruit clusters and to attain at least 5 cm between fruits on a shoot. In 1999, to determine if fruit size could be maintained at higher crop loads by retaining fewer fruiting shoots, the crop load was increased to 500 fruits per tree and the range of fruiting shoots per tree was increased from 4 to 6. The crop load of 500 fruits per tree was achieved by retaining 7, 6, 5, 4, 3, and 2 fruits per shoot on 71, 83, 100, 125, 167, and 250 fruiting shoots per tree, respectively. Thus, all trees had about the same number of fruits, but on differing number of shoots.

Fruits removed by thinning were counted and weighed, and average thinned fruit weight (TFW) was calculated for each tree. Depending on the year, fruits were harvested in 3 to 4 spot pickings when ground color was yellowish-green. During harvest, the number of fruits per tree was recorded and fruits were

separated into five categories with a weight sizer. The number and weight of fruits in each size category were recorded and average fruit weight was calculated for each tree. The proportion of the marketable crop (>57 mm diam.) was calculated. Although not measured, characteristics that make a fruit unmarketable, such as inadequate color and incidence of pest injury did not appear to be affected by treatments. Thus, fruit size was the only criteria used to determine the marketability of the crop. Crop value for each tree was calculated using wholesale prices typical for Appalachian peaches during Aug. 1997–99; where the value of 57 to 64 mm diam. fruits = \$0.79/kg (\$9.00 per 11.35-kg box), 65 to 70 mm diam. fruits = \$0.97/kg (\$11.00 per 11.35-kg box), and >70 mm diam. fruits = \$1.06/kg (\$12.00 per 11.35-kg box).

SAS's GLM procedure (SAS Inst., 1990) was used to perform regression analyses, where the number of shoots per tree was the regressor variable. Two models were evaluated for each response variable. The first model contained a linear and a quadratic term. When the partial sums of squares (Type III sums of squares) were significant ($P < 0.05$) for the quadratic term, the relationship was considered to be quadratic. The relationship was considered to be linear if the sequential sums of squares (Type I sums of squares) were significant ($P < 0.05$) for the linear term and the partial sums of squares were nonsignificant for the quadratic term. In such cases a simple linear model, containing only the linear term, was selected.

Results and Discussion

In this study, the number of fruits per tree rather than per unit of trunk cross-sectional

area, was used to quantify crop load because average fruit weight correlated better with number of fruits in a previous study (Marini, 2002b). Target levels for crop load were usually not achieved in any of the three experiments. In 1997, the crop on trees with 73 or 110 fruiting shoots was reduced below the desired level by spring frost. For unknown reasons, crop load was the greatest for trees with the fewest shoots in 1998 and 1999, when the number of fruits per tree was usually within 20% of the target values. In a previous study (Marini, 2002b), all fruits on each tree were counted before thinning. Unwanted fruits were thinned to obtain specific crop load, which at harvest differed from the desired values by 20% to 50% (Marini, 2002b). This is because adjusting peach crop loads to specific levels with hand thinning is difficult since the small fruits are hard to distinguish from the leaves.

In all three years, the number of fruits set per tree, the number of thinned fruits per tree, and the percentage of thinned fruits per tree increased as the number of fruiting shoots per tree increased (Table 1). The TFW (g/fruit) was negatively related to the number of shoots per tree in 1998 and 1999, the years when fruit set was excessive. In 1997, when there was a partial crop due to spring frost injury, the TFW was not related to the number of shoots per tree, but was 25% greater than in 1998 and 1999. This is consistent with data from California, where fruits on trees with light crops had higher dry weights than fruits on trees with heavy crops at 35 d after bloom (Grossman and DeJong, 1995a). During the first 36 d after bloom, much of the increase in fruit size is due to cell division (Scorza et al., 1991). Our data indicated that the number of fruits on the tree can influence fruit growth

before pit hardening, whether crop load is reduced by spring frost or shoot removal during dormant pruning. Fruits on low crop trees probably had more cells and could be expected to produce large fruits because fruit size at harvest is positively related to the number of cells per fruit (Scorza, et al., 1991). During the early season, when peach shoots and fruits are growing simultaneously, fruit growth may be limited by availability of resources (Grossman and DeJong, 1994, 1995b). In the present study, shoot-removal treatments reduced the number of both reproductive and vegetative sinks. The increased early-season fruit growth on severely pruned trees indicates that fruit growth was less limited by resources for severely pruned trees than for lightly pruned trees. However, this experiment was not designed to determine if the increased resources for fruit growth were due to reductions in sink strength of reproductive and/or vegetative organs.

The time required to prune and thin each tree was not recorded because the number of shoots had to be counted and recorded and the number of thinned fruits had to be counted and weighed for each tree. The additional time required for counting shoots at pruning time, and for counting, collecting, and weighing thinned fruits would have drastically increased the time required to perform these operations in a commercial setting. However, costs for shoot pruning and fruit thinning can be estimated from data obtained in a similar study where these types of data were collected (Marini, 2002a). The difference in pruning time between 73 and 220 fruiting shoots was ≈ 4 min/tree. If pruners were paid \$7.00/h, the most severe pruning treatment would cost $\approx \$0.47$ /tree more than the least severe treatment. Data from the same study where number of fruits thinned per tree

Table 1. The effect of retaining varying number of fruiting shoots per tree on the number and weight of fruits removed by hand thinning, fruit weight (FW) at harvest, number of fruits harvested, yield, marketable fruit, and crop value. Fruit set is the number of fruits removed plus the number of fruits harvested. Crop load was adjusted to 440 fruits per tree in 1997 and 1998, and 500 fruits per tree in 1999.

Year	Fruiting shoots per/tree	Fruit set (No./tree)	No. fruits removed by thinning	Thinned FW (g/fruit)	Wt removed (kg/tree)	Fruit thinned (% of set)	Fruits harvested/tree	FW (g)	Yield (kg/tree)	Marketable fruit (%) ^x	Crop value (\$/tree)
1997	73	296	27	30	0.8	9.1	269	156	42.1	100	34.90
	110	351	58	31	1.7	16.5	294	151	44.1	100	32.87
	146	432	81	30	2.2	18.8	351	146	50.9	100	37.66
	220	510	168	30	4.3	32.9	342	147	49.1	100	37.54
	Significance ^a	L	L	L	L	L	L	L	L	---	L
1997		r^2	0.15	0.01	0.15	0.15	0.07	0.06	0.04	---	0.01
		P -value ^y	0.02	0.66	0.02	0.02	0.11	0.15	0.22	---	0.51
1998	73	758	222	25	5.6	29.3	536	122	63.8	74.4	62.55
	110	932	439	24	10.5	47.1	492	115	56.6	72.5	56.88
	146	950	506	23	11.5	53.3	444	111	49.0	64.1	43.30
	220	1635	1116	21	24.8	68.3	474	107	51.5	59.4	60.27
	Significance ^a	Q	L	L	L	L	L	L	L	L	L
1998		r^2	0.65	0.78	0.28	0.75	0.03	0.13	0.08	0.10	0.01
		P -value ^y	<0.01	<0.01	<0.01	<0.01	0.26	1.02	0.06	0.04	0.80
1999	71	829	240	23	5.6	28.9	599	136	81.6	93	72.29
	83	987	390	23	8.9	39.5	605	142	85.4	93	77.63
	100	1034	505	23	11.4	48.8	535	136	72.5	88	62.03
	125	1321	761	22	16.8	57.6	570	140	80.1	94	73.29
	167	1510	936	21	19.4	62.0	577	125	72.0	82	54.98
	250	1929	1408	19	27.4	73.0	541	132	71.6	90	60.71
	Significance ^a	Q	Q	L	Q	Q	L	L	L	L	L
1999		r^2	0.81	0.88	0.27	0.83	0.05	0.05	0.09	0.02	0.08
		P -value ^y	<0.01	0.01	<0.01	<0.01	0.14	0.13	0.04	0.37	0.05

^aL = linear model; Q = quadratic model.

^y P -value is for the model: $n = 36, 44$, and 48 in 1997, 1998, and 1999, respectively.

^xMarketable fruits are >57 mm in diameter.

and thinning time per tree were recorded indicated that workers can remove about 17.5 fruits per min. Using these values, the estimated time to thin trees was about 13 and 63 min./tree for trees with 73 and 220 fruiting shoots per tree, respectively; thinning costs would be \$1.52 and \$7.35 per tree, respectively. Therefore, trees with 220 fruiting shoots cost \$5.83/tree more to thin than trees with 73 shoots. Compared to trees with 73 fruiting shoots, trees with 220 shoots cost \$0.47 less to prune, but \$5.83 more to thin. Thus the cost difference of pruning plus thinning ($-\$0.47 + \5.83) is \$5.36/tree (\$1,983/ha) per year more for trees with 220 fruiting shoots compared to trees with 73 fruiting shoots/tree.

Fruits removed by thinning represent wasted resources that could otherwise have been allocated to vegetative growth or to fruits that would have been ultimately harvested. Compared to the most severely pruned trees, the fresh weight of thinned fruit was 4.4 and 4.9 times greater for the least pruned trees in 1998 and 1999, respectively. Averaged over the two seasons, the fresh weight of thinned fruit was 2.1 and 9.7 t·ha⁻¹, for the most and the least severely pruned trees, respectively. Although yield was not related to the number of shoots per tree in 1997 ($P = 0.22$), the relationship was negative in years when trees had a full crop (Table 1). Each year, fruit weight at harvest was negatively related to the number of fruiting shoots, but the relationship was weak ($r^2 = 0.05$ to 0.13). The number of fruits set per tree, but not the fruit size distribution, was similar in 1998 and 1999. The higher percentage of fruit in the smaller categories in 1998 probably resulted from lower precipitation during the last 6 weeks before harvest (43 mm in 1998 vs. 121 mm in 1999). The trickle irrigation of only 40 L/tree/day was probably not enough to prevent moderate water stress in 1998 because mature peach trees can use 114 to 136 L/day during mid-season (Worthington et al., 1984). Although not always significant at the 5% level, the percentage of marketable crop (fruit diam. >57 mm) was negatively related to the number of fruiting shoots per tree (Table 1). The percentage of fruits in the two smallest size categories tended to be the highest for trees with high shoot numbers whereas the percentage of fruits in the two largest size categories tended to be the highest for trees with low shoot numbers (Table 2).

In 1997, crop value was not related to the number of fruiting shoots ($r^2 = 0.01$, $P = 0.51$). However, the higher fruit weight combined with higher yields for trees with the fewest shoots in 1998 and 1999, resulted in a negative relationship between crop value and the number of fruiting shoots ($P = 0.05$). During 1998 and 1999, cumulative crop value per tree was about \$170, \$152, \$136, and \$158 for trees with 73, 110, 147 to 167, and 220 to 250 fruiting shoots per tree, respectively.

Coefficients of determination in this study were relatively low, probably because tree-to-tree variation for peach yield was high as previously reported by Marini (1985). Another possible reason for the poor r^2 values was that the experiments had 8 to 11 replicates per treatment and only 4 to 6 levels of shoot number, thus spread in the data was considerable for each treatment level. Coefficients of determination would have probably been improved had there been more treatment levels with fewer replicates per level.

In a previous 3-year study, heading all fruiting shoots on a tree by 50% reduced fruit set by 15% to 30% and the number of thinned fruits by 15% to 50%. Heading did not consistently affect yield or fruit weight, but it increased net profit only once in three years (Marini, 2002b). Removing blossoms from the terminal half of shoots reduced fruit set similar to heading, but improved fruit weight and increased crop value by about \$3.65 to \$3.20/tree. For lowering fruit thinning costs and improving crop value, removing excessive shoots in this study was more effective than either heading back or bloom removal (Marini, 2002b).

The disadvantages of severe pruning or bloom removal are that flower buds or blossoms are removed before fruit set can be assessed, and subsequent frost or poor weather conditions for fruit set may further reduce the crop load below desired levels. Bloom reduction in years with poor fruit set may result in reduced crop value, as occurred in 1997, in the present study. Bloom reducing strategies will have maximum benefits for cultivars with high blossom densities and for orchards on relatively frost-free sites. Results from this study indicate that severe pruning in years with a partial crop may reduce net profit by \$1,700/ha, however this practice may increase net profit by more than \$6,000/ha in years with heavy fruit set. Therefore, severe pruning appears to be cost

effective if heavy fruit set occurs at least once in four years.

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Table 2. The effect of retaining varying numbers of fruiting shoot per tree on fruit size distribution on 'Norman' peach trees. Crop load was adjusted to 440 fruits per tree in 1998 and 500 fruits per tree in 1999.

Year	Fruiting shoot/tree	Fruit size distribution (%)				
		<57 mm	57 to 64 mm	65 to 70 mm	71 to 76 mm	>76 mm
1998	73	38	28	21	13	0
	110	35	37	24	5	0
	146	44	34	18	4	0
	220	47	36	15	3	0
1999	71	7	21	42	27	5
	83	5	19	26	35	18
	100	11	21	32	27	12
	125	5	22	35	23	18
	167	16	36	32	14	1
	250	9	30	38	22	2