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Effects of Size-Controlling Rootstocks on Growth and Yield of Peach Trees with Upright and Spreading Growth Habits

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Additional index words: fruit number, fruit size, planting density, yield, yield efficiency

Abstract

New genotypes of peach with upright, narrow canopies have been developed that have novel management challenges but high production value. While these novel genotypes are easily adapted to high density planting systems the increased tree height of narrow canopies can present problems in maintaining bearing surface low in the canopy, in harvesting, and the need for additional pruning. Size-controlling rootstocks have been used to manage tree size and productivity in apple and new size-controlling rootstocks have been developed for peach. These rootstocks may be highly beneficial for upright peach trees. In this experiment two Controller rootstocks (C5 and C9) and two standard (STD) rootstocks (Tennessee Natural and Bailey) were used with the cultivars 'Sweet-N-Up' (SU), which has an upright growth habit, and 'Redhaven' (RH), which has a standard spreading habit, to evaluate effects of rootstock on scion growth and yield. Trees on C5, C9, and STD were planted at 2.4, 3.0, and 4.3 m spacing, respectively. Training of SU and RH was to Quad-V and Open Center, respectively. Over the five years of this experiment, individual tree yield and average fruit size of SU was consistently greater than RH. Trees on C5 and C9 produced fewer fruit per tree than on the two STD rootstocks. However, yield (kg·ha-1) of all rootstocks with either cultivar was not different when adjusted for tree planting density. Yield per tree and individual fruit weights were most reduced on C5 rootstock and least on STD. In general, the smallest-to-largest trees grew on C5, C9, and STD rootstocks. SU or RH trees grafted on C5 and C9 rootstocks and planted at higher density had equivalent yield per hectare as trees on STD at low planting density. However, the trees on dwarfing rootstocks planted at higher densities may be economically advantageous due to reduced pruning and harvesting costs and the increased potential for mechanized orchard operations.

In apple (*Malus domestica* Borkh.), size-controlling rootstocks have contributed to management systems that facilitate earlier and greater yield. These systems often include high density plantings that are efficient and amenable to mechanization. In peach [*Prunus* persica L. (Batch)], greater yield has been attained from trees with new growth habits that have upright or columnar canopies (Miller and Scorza, 2003). In a 6-year study upright trees had 27% higher yield per tree than a standard peach growth habit tree ('Harrow Beauty') on Lovell seedling rootstock (Miller, unpublished). Trees with upright or pillar growth habits could be used in high-density plantings but reduction in size, particularly height, would ease pruning, thinning, and harvesting, and favor mechanization. Trees with the upright growth habit were vigorous and it was proposed that size control was necessary (Miller and Scorza, 2010). In apple, dwarfing rootstocks reduced overall tree size without consistently affecting other factors associated with canopy development and growth habit characteristics (e.g. branch angle) (Tworkoski and Miller, 2007). Size-controlling rootstocks could complement plantings of peach trees with upright growth habits. Rootstocks have been developed that show promise to reduce peach tree size (Reighard et al., 2011; Weibel et al., 2003).

In a study in Pennsylvania, yield was the same for 'Redhaven' on Controller 5 (C5; Tombesi et al., 2010) and Lovell rootstocks but C5 reduced tree size by 33% (Schupp et

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al., 2012). These size-controlling rootstocks could complement scion varieties with an upright canopy to improve the management of high density peach plantings but virtually nothing is known about such combinations. Maintenance of desired scion architecture combined with rootstock-induced dwarfing would be beneficial in new orchard management systems with peach. From a practical perspective it is likely that trees on dwarfing rootstocks would be planted at higher densities and the trees with upright growth habits would be trained differently from standard trees to exploit the fundamental differences in tree architecture (Miller, unpublished). The objective of this study was to determine the effects of three rootstock-density combinations and two growth habit-training combinations on growth and yield of a promising new upright growth habit of peach. In this experiment we present preliminary but new and unique data that suggests there is merit in combining different growth habits with size-controlling rootstocks.

Materials and Methods

Scions of 'Sweet-N-Up' (SU) and 'Redhaven' (RH) were grafted to four rootstocks in 2006. Rootstocks used represented three different vigor classes: high (Bailey and Tennessee Natural; standard, STD), intermediate (hybrid *Prunus salicina* Lindl. × *P. persica* L. Batsch; Controller 9™; C9) and low (hybrid *P. salicina* Lindl. × *P. persica* L. Batsch; Controller 5™; C5) (Tombesi et al., 2010). Selection of Bailey and Tennessee Natural as STD rootstocks was based on their common use in the location of the test orchard and of their similar vigor (Beckman, 2008). Trees grafted onto Controller rootstock came from Fowler Nursery, Newcastle, California. Trees grafted on STD rootstocks came from Adams County Nursery, Aspers, Pennsylvania. Trees were planted at the Appalachian Fruit Research Station (AFRS) in 2007 to serve as a demonstration and research orchard. Tree rows were 100 m long and 5.5 m apart. Within each row trees were planted at various spacing from 1.5 to 4.3 m. At least five replications were used in this experiment. Spacing between trees on STD, C9 and C5 were 4.3, 3, 2.4 m, respectively. The tree spacing was based on estimates of densities that would likely be used in commercial orchards and following the results of Miller and Scorza (2010).

A commercially recommended pest control schedule was followed throughout this study (Pfeiffer, 2008). Trees were maintained in a 2 m wide weed-free strip with the use of herbicides according to local recommendations.

'Redhaven' (RH) was pruned as a traditional open center (spreading) tree as "standard" growth habits are generally trained with three to five main scaffolds radiating from the trunk (Marini, 1990; Marini et al., 1995). In previous work, Miller and Scorza (2010) demonstrated the necessity of unique management practices for peach trees with different architectures. Based, in part, on that work 'Sweet-N-UP' with its upright growth habit was trained similar to a Quad-V with four leaders, two to each side of the row and parallel to the row). Fruit were thinned to 15 cm spacing when they were 1-2 cm in diameter.

Growth parameters measured were tree height, canopy width (measured within the row), canopy volume (height x width x depth), and trunk cross sectional area (TCSA) at 30 cm above the graft union. Fruit from RH were harvested July 16 and 20 in 2009, July 19 and 23 in 2010, and July 20 and 25 in 2011. Fruit from SU were harvested August 7 in 2009, August 9 and 13 in 2010, and August 12 and 18 in 2011. Fruit parameters were total number and weight per tree and average fruit weight and diameter based on a 10-fruit subsample per tree. Yield ($kg \cdot ha^{-1}$) was calculated as the average total fruit weight per tree multiplied by the number of trees per hectare. Yield efficiency (YE) for each tree was calculated as total fruit weight of a tree divided by TCSA ($kg \cdot cm^{-2}$). Yield based on canopy volume was calculated as total fruit weight of a tree divided by canopy volume ($kg \cdot m^{-3}$).

The number of trees per ha on the rootstocks used were 427 (STD), 598 (C9), and 748 (C5). Trees were planted in five rows in which each growth habit-pruning and rootstock-spacing combination was randomly assigned a location along with two border trees. The experiment was a completely randomized design with at least five single-tree replications. Data were analyzed with the MIXED procedure and means separated by the PDIFF procedure (SAS Institute, Inc. 2003, The SAS system for Windows, Release 9.1. SAS Inst. Inc., Cary, NC 27513). Data were analyzed within each year separately. In this experiment rootstock and tree spacing are referred to as "rootstock" and scion and training are referred to as "scion".

Results and Discussion

Scion-training and rootstock-spacing significantly affected growth and yield and there were significant interactions between the main effects of scion, rootstock, and year (Tables 1 and 2). Trees were planted in 2007 and trees bore a small fruit crop in 2008. There were 1 to 3 fruit per tree, with an average diameter of 6 cm, and yield of 0.1 to 0.4 kg per tree. By 2009 fruit loads were still small but could be commercially significant and SU bore more fruit than RH (average of 41 v. 29 fruit per tree).

In all years and on all rootstocks, SU consistently and generally significantly, had as much or more fruit weight per tree and yield ($kg \cdot ha^{-1}$) as RH (Table 1). Differences in fruit weight may in part be attributed to cultivar differences such as fruit ripening and harvest being 20 to 22 days later for SU than RH. Individual fruit diameter and weight also were consistently greater in SU than RH. The number of fruit per tree differed between SU and RH from year to year and neither SU

Table 1. Effects of cultivar 'Redhaven' (RH) and 'Sweet-N-Up' (SU) and rootstock (STD, C9, and C5) on individual fruit characteristics, tree, and orchard productivity in 2009, 2010, and 2011.

Cultivar [z]	Rootstock	Year	Fruit per tree (no.)	Fruit weight per tree (kg)	Average fruit diameter (cm)	Average fruit weight (g)	Calculated yield ($kg \cdot ha^{-1}$)
RH	STD	2009	34 ab[y]	5 bcd	6.4 d	141 d	2122 b
	C9		27 b	4 cd	6.8 c	169 c	2747 b
	C5		25 b	3 d	6.4 d	141 d	2480 b
SU	STD		35 ab	6 bc	7.3 b	190 b	2934 b
	C9		48 a	11 a	7.6 a	233 a	6815 a
	C5		39 ab	7 b	7.3 b	200 b	5730 a
RH	STD	2010	357 a	31 b	5.6 b	88 b	13093 c
	C9		289 b	23 c	5.5 bc	86 b	14094 abc
	C5		253 bc	18 d	5.2 c	76 b	13849 bc
SU	STD		281 bc	35 a	6.3 a	127 a	15072 abc
	C9		227 cd	27 bc	6.1 a	119 a	15925 ab
	C5		190 d	22 cd	6.1 a	117 a	16713 a
RH	STD	2011	226 ab	30 b	6.4 b	135 c	13012 c
	C9		192 abc	26 bc	6.5 b	143 c	15465 abc
	C5		141 d	19 d	6.4 b	142 c	14287 bc
SU	STD		231 a	43 a	7.1 a	188 a	18341 a
	C9		181 bcd	30 b	6.9 a	169 b	18091 a
	C5		149 cd	23 cd	6.5 b	153 bc	16941 ab

[z] RH was trained as an open center tree and SU was trained similar to a Quad-V and spacing between trees on STD, C9 and C5 rootstocks were 4.3, 3, 2.4 m, respectively

[y] Within each column and year means followed by the same letter do not differ at the 0.05 level of confidence.

nor RH was consistently greater. Fruit load was greater in 2010 than 2011, possibly due to colder monthly low temperatures in March of 2011 than 2010 (0.23 and 1.99°C, respectively). Freezes were more prevalent in late March, after bud break, in 2011.

Within each cultivar in 2010 and 2011 fruit numbers and weight per tree were reduced by C5 and C9 compared to STD (Table 1). In 2010 and 2011 individual fruit diameter and weight were similar comparing the three rootstocks within each cultivar. Although yield (kg·ha^{-1}) was greater with trees on C5 and C9 in 2009, no differences in yield were found due to rootstocks in 2010 and 2011 when trees more fully occupied their allotted orchard space. Previously, fruit weight was reduced at some irrigated sites with peach trees on C5 (Reighard et al., 2011). In our study no irrigation was used raising the question of the potential impact of irrigation on rootstock performance.

As previously noted, fruit were larger on SU than RH (Table 1). This may be attributable to amount and canopy position of fruit-bearing wood or inherent genetic differences. Within each year and rootstock SU trees were taller with narrower canopies than RH trees but canopy volume was similar (Table 2). From these data we infer that SU had more canopy area exposed to direct sunlight and less self-shading than RH.

'Sweet-N-UP' trees are naturally tall having an upright growth habit, and it would be counter-productive to train them to the same height and in the same open center system as the standard RH (Miller and Scorza, 2010). In the first two years there was little

Table 2. Effects of cultivar 'Redhaven' (RH) and 'Sweet-N-Up' (SU) and rootstock (STD, C9, and C5) on tree growth and yield efficiency in 2009, 2010, and 2011.

Cultivar[z]	Rootstock	Year	Tree height (cm)	Canopy width (m)	Canopy volume (m^3)	TCSA[y] (cm^2)	Yield efficiency kg•cm^{-2})
RH	STD	2009	243 b[x]	3.0 a	26 a	46 b	0.12 b
	C9		218 c	2.9 ab	19 b	49 b	0.10 b
	C5		198 c	2.7 b	14 c	33 c	0.12 b
SU	STD		325 a	2.7 b	26 a	59 a	0.12 b
	C9		302 a	2.4 c	18 b	57 a	0.21 a
	C5		259 b	2.2 d	13 c	34 c	0.24 a
RH	STD	2010	254 c	4.2 a	42 b	58 c	0.54 a
	C9		232 d	3.9 b	33 c	64 bc	0.38 c
	C5		220 d	3.4 c	26 d	41 d	0.46 bc
SU	STD		344 a	3.8 b	47 a	82 a	0.49 ab
	C9		320 b	3.3 c	32 c	72 b	0.43 bc
	C5		309 b	2.7 d	23 d	46 d	0.39 c
RH	STD	2011	285 c	4.4 a	47 b	76 bc	0.41 a
	C9		265 c	3.9 b	38 c	86 b	0.31 b
	C5		238 d	3.3 c	27 d	59 d	0.34 ab
SU	STD		364 a	4.1 ab	57 a	112 a	0.39 a
	C9		354 ab	3.4 c	38 c	106 a	0.29 b
	C5		330 b	2.9 d	28 d	64 cd	0.36 ab

[z] RH was trained as an open center tree and SU was trained similar to a Quad-V and spacing between trees on STD, C9 and C5 rootstocks were 4.3, 3, 2.4 m, respectively.

[y] Trunk cross-sectional area (TCSA) is the cross-sectional area of a tree trunk 30 cm above the graft union.

[x] Within each column and year means followed by the same letter do not differ at the 0.05 level of confidence.

[w] Yield efficiency (YE) is the fruit weight of a tree divided by the trunk cross-sectional area TCSA.

difference in the size and canopy spread of the trees except that SU visually project an upright habit. Beginning in the third leaf (2009) differences were clearly observed, where SU was tall and upright whereas RH was shorter in stature and spreading. As trees aged, canopy volume was generally not significantly different between the two tree types (Table 2).

In 2010 and 2011, the number and weight of fruit per tree were greatest on STD and least on C5 rootstocks (Table 1). Accompanying the reduction of fruit number, TCSA was less for RH and SU on C5 than on C9 or STD rootstocks (Table 2). Individual fruit production and tree vegetative growth was integrated with the derived variable, YE (fruit weight divided by TCSA) and in both 2010 and 2011 YE was greater in trees on STD than on Controller rootstocks and YE did not differ between trees on either C5 or C9 rootstocks (Table 2). In apple, YE is generally greater on dwarfing than on vigorous rootstocks (Webster, 1995). Production factors such as YE may change as trees age (Table 2) or with environmental factors such as water stress.

In both 2010 and 2011, individual tree fruit number and weight were reduced by C5 and C9 compared to trees on STD rootstocks (Table 1). However the total weight of fruit per m^3 of canopy volume was the same for all rootstocks (0.75 kg fruit$\cdot$m^{-3} canopy volume). The accompanying reduced vegetative growth of the scion on C5 and C9 rootstocks (Table 2) may have benefits as smaller trees may enable both higher planting density and reduced costs such as labor for pruning and harvesting. In 2010 and 2011 and within any year and cultivar the three rootstocks did not differ in calculated yield (kg$\cdot$ha^{-1}) (Table 1). High density plantings of vigorous trees on dwarfing rootstocks may have significant value for SU trees that have canopies that are tall and narrow.

This work shows that the upright peach tree canopy, as represented by SU, is at least as efficient in fruit production as standard tree canopies. This suggests that upright canopy cultivars of peach may be utilized in high density production systems that include mechanization to provide alternative production practices including mechanization of pruning, thinning, and harvesting.

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Reducing the incidence of calyx cracking in 'Pink Lady' apple using a combination of cytokinin (6-benzyladenine) and gibberellins (GA_{4+7}).

Calyx cracking in 'Pink Lady' apple (*Malus* × *domestica* Borkh.) results in substantial economic losses. 'Pink Lady' apple trees were sprayed with various rates and combinations of synthetic gibberellins (GA_3, or GA_4 plus GA_7) and a synthetic cytokinin (6-benzyladenine; BA) at different phenological stages, starting at 60 d after full bloom (DAFB) until 150 DAFB, to determine if the incidence of cracking could be reduced. The experiments were conducted in Northern Israel between 2008 – 2011. The percentages of fruit with calyx cracking decreased following three applications of 0.2% (v/v) Superlon™ (i.e., 40 mg l^{-1} BA plus 40 mg l^{-1} GA_{4+7}) at 14 d intervals, starting at 60 DAFB. GA_3 or GA_{4+7} alone had no effect on cracking. In addition, the Superlon™ treatments resulted in increases in epidermal cell density at the calyx end, which may have contributed to the increased elasticity of the peel, thus preventing crack formation. No change was observed in cuticle thickness. Fruit quality was not affected by 0.2% (v/v) Superlon™ at harvest, or after 5 months of controlled atmosphere (CA) storage. However, fruit size increased, probably due to the effect of BA. The results from semi-commercial multiple applications of 0.2% (v/v) Superlon™ supported its use in orchards of 'Pink Lady' that tend to suffer from calyx cracking. Abstract from: Raphael Stern, Ruth Ben-Arie and Idit Ginzberg, 2013. The Journal of Horticultural Science & Biotechnology 88(2):147-153.