Planting Angle and Meristem Management Influence Sweet Cherry Canopy Development in the “Upright Fruiting Offshoots” Training System

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Abstract. Upright Fruiting Offshoots (UFO) is a novel high-density training system for sweet cherry (*Prunus avium* L.) that produces fruit on multiple vertical leaders (“offshoots”) arising from a cordon-like trunk. The promotion of sufficient upright shoot number and uniform shoot distribution during establishment are key to development of this training system. Trunk angle, meristem management (selective bud retention and removal), and cordon height at establishment were evaluated for influence on shoot number, shoot distribution, total shoot length, and early fruiting potential. At planting, trunk angles of 45° or 60° from the horizontal resulted in increased shoot growth compared with 30°, and also increased shoot distribution when bud selection was not imposed. A cordon height of 45 cm increased total shoot length by 20% compared with a 60-cm cordon height. Bud selection (retaining buds for optimal upright shoot distribution and removing all others) improved canopy development by reducing the number of shoots in the terminal third of the cordon and increasing the number of shoots in the basal and middle thirds compared with no bud selection. Bud selection reduced fruiting potential in the 2nd and 3rd years compared with unmanaged treatments, but subsequently surpassed those treatments in projected annual yield in Year 4 and cumulative yield in Year 5. Bud selection increased total and average shoot length, and improved distribution while moderating early crop load potential. Planting angle, cordon height, and bud selection significantly impact canopy establishment of UFO trees by affecting shoot number, length, and distribution.

High-density tree training systems are important for overcoming some of the challenges of sweet cherry (*P. avium* L.) production. Cherry fruit are susceptible to many pests and diseases, rain-induced cracking, and bird damage, requiring multiple sprays for pests, rain covers, and nets to ensure marketable crops in locations prone to rain during ripening. High-density training systems can make sweet cherry production more efficient, by reducing pesticide and herbicide use and facilitating mechanization of orchards and the use of nets and covers for fruit protection. Recent developments in rootstocks have provided precocious fruiting and dwarfism (Lang, 2000), and allowed high-density training systems to be developed (Lang, 2005; Lang et al., 2014; Musacchi et al., 2015; Robinson, 2005).

There are several important factors to consider when designing a high-density training system to maximize yields, minimize disease, and facilitate easy pruning and harvesting. Training goals for producing high quality fruit include 1) good light interception and distribution by the canopy, 2) a balanced

leaf to fruit ratio (Lang, 2005), and 3) renewable fruit-bearing sites on minimal permanent structure. A good high-density training system should address these principles and be efficient to prune, train, and harvest. The UFO training system develops a trellised, planar multiple leader tree to create a narrow fruiting wall with evenly distributed vertical fruiting branches (or “uprights”) along a cordon-like trunk (Long et al., 2015). This provides a tall, narrow fruiting canopy that is easy to train and prune for renewal of uprights. The UFO system’s planar architecture and pedestrian size also help increase harvest efficiency (Ampatzidis and Whiting, 2013). The efficient interception of light by UFO orchards has been described (Zhang et al., 2015); however, too few or uneven spacing of fruiting uprights creates gaps in the fruiting wall and reduces orchard efficiency by failing to optimize both interception and distribution of light throughout the canopy. Little work has been published to determine how to achieve the ideal canopy structure and maximize early shoot growth for UFO trees.

Sweet cherry trees exhibit strong apical dominance (the suppression of subtending buds by the shoot terminal) resulting in vigorous top growth and minimal branch development lower in the canopy. It can be difficult to redistribute that vigor during the

first year of establishment into balanced secondary shoots along the trunk, whether oriented vertically or horizontally. The mechanism of apical dominance is not fully understood, but it is generally accepted that basipetal transport of auxin produced in the terminal meristem suppresses growth of lower buds and branches (Leyser, 2005). Different training techniques can alter shoot growth patterns. In apple [*Malus × domestica* (Borkh.)], changing the orientation of vertical branches released lower buds from apical dominance (Ferree and Schupp, 2003). As deviation from vertical increased, more buds were released. Bending sweet cherry branches below horizontal reduced subsequent growth of the leader and subtending shoots, compared with unbent branches (Lauri et al., 1998). Bending also increased the number of flower buds and flowers per flower bud. Placing sweet cherry trunks horizontally caused a reduction in shoot growth, relative to upright trees, by reducing node number and internode spacing (Wareing and Nasr, 1961). The more horizontal orientation of the trunk in the UFO system may partially reduce the effects of apical dominance, but that alone will not ensure well-distributed uprights.

Various techniques have been used to promote precise placement of new branches, enabling efficient use of storage reserves during tree establishment. In sweet cherry, heading cuts can promote branching, but the branches are poorly distributed and have acute crotch angles (Hoying et al., 2001). Other techniques to alter meristem outgrowth include the topical use of Promalin® (Valent Biosciences, Libertyville, IL) (containing gibberellic acids 4 and 7, and 6-benzyladenine) to alter the hormone balance at a bud and cause it to elongate into a new shoot, but effectiveness can vary due to temperature (Lang, 2005). Notching (or scoring), by cutting through the bark and phloem just above a bud, facilitates branch placement by disrupting hormone flow and promoting elongation of the bud into a new shoot (Hoying et al., 2001). Another meristem management technique is bud selection and removal. When a portion of buds is removed, the remaining buds are more likely to grow into shoots (Lang, 2005). Selective bud removal (selecting buds to be retained for placement of branches and removing all others) has been more effective than Promalin® or notching for producing laterals from remaining buds (or nodes) in the lower portions of the trunk (Hoying et al., 2001). However, with bud selection or notching, caution should be taken to remove buds during warm, dry weather when risk for bacterial canker infection is low. Furthermore, gaps may be left in the canopy if any of the selected buds fail to grow.

Current recommendations for UFO tree training are to use precocious rootstocks, such as the Gisela series, to bring trees into production quickly (Long et al., 2015). Trees on precocious rootstocks enable earlier yields, but they can be susceptible to poor structural development and/or overcropping

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if poorly managed (Lang, 2001; Long, 2001). Understanding how fruiting branches develop can help growers make wise training and pruning decisions to maximize early yields. The year a shoot forms, a single leaf is produced at each node. The next year, that shoot usually forms a small number of non-spur flower buds at its basal nodes which then become blind wood after fruiting (Lang, 2005). The other nodes each form nonfruiting leafy spurs with 5–9 leaves. In the 3rd and subsequent years, those nodes will be the fruiting spurs that will bear fruit until they become damaged or diseased. This fruiting progression often brings trees on Gisela rootstocks into significant flowering in the 3rd or 4th year in the orchard. These different populations of fruit-bearing sites (onetime nonspur fruiting nodes and multiyear fruiting spurs) illustrate how shoot growth in the first year becomes minor fruiting area in Year 2 and significant fruiting area in Year 3. This underscores the importance of maximizing canopy shoot growth in the first year to optimize yield potential from fruiting spurs in Year 3 and beyond.

Successful development of the UFO fruiting wall canopy architecture requires several decisions to be made at planting or soon thereafter. First-year establishment of UFO sweet cherry trees was investigated to determine the effects of planting angle, height of cordon bending to horizontal, and selective bud removal on number of structural shoots, shoot growth and distribution, and early fruiting potential.

Materials and Methods

Unbranched (whip) nursery trees of ‘Rainier’ on ‘Gisela 3’, with a central leader ≈ 1.5 m long, were divided into 12 treatments and planted at a spacing of ≈ 1.5 m. The first experimental factor was trunk angle, with the trees planted at 30°, 45°, or 60° from horizontal (Fig. 1). Imposed on the angle factor was the height at which the trunk was attached horizontally to the first trellis wire, 45 or 60 cm, and bent in early summer to form the horizontal cordon (Fig. 1). The last factor was bud selection, either leaving all buds intact or removing nearly all buds except one upward oriented bud every ≈ 15 cm. If no upward bud was present, a side bud was used instead. Six single-tree replications were planted in mid-May of 2010 in a randomized complete block design at the Clarksville Research Center, Clarksville, MI (lat. 42.8°N, long. 85.2°W), in a coarse-loamy, mixed, mesic Typic Hapludalf soil of the Lapeer series. Trees were irrigated and sprayed for pests as needed, and weed barrier fabric (Dewitt Pro 5; Dewitt Co., Sikeston, MO) was used for weed control. Data were taken in Fall 2010 for shoot number, length, and spatial distribution, and in Spring 2011 for flower bud number (i.e., spur flower buds on the cordon and basal flower buds on the upright shoots).

The length of each upright shoot was measured from its base to its tip. Meristem growth was considered to be a shoot if it was

at least 2.5 cm long. Average shoot length was determined by dividing the total shoot length by the number of shoots. Shoot distribution data were quantified by measuring the distance from the base of the tree to each upright. The trunk was then divided into three equal segments and the data for uprights within each segment were segregated for distributional analysis.

Yield potential for the first 5 years of the orchard was determined by counting the number of flower buds in Spring 2011 and extrapolating future yield potential based on initial shoot growth, spur and shoot basal flower bud density, and multiyear data for shoot growth from other trees on ‘Gisela 3’ rootstocks trained to UFO. On bud-selected trees (where all spurs were removed), all flower buds were basal. On the trees without bud selection, spur bud number was derived by subtracting the number of basal buds from the total number of flower buds. Spur flower bud density was calculated based on the 150 cm length of the cordon leader minus the cumulative 20-cm portion from which upright shoots arose (i.e., 33 spur flower buds/130 cm = 0.25 spur flower buds/cm). Shoot growth rates (as a proportion of previous season average shoot length) in Years 2, 3, and 4 were 2.7, 1.3, and 0.5, respectively, based on multiyear annual shoot growth measurements from an adjacent UFO-trained ‘Benton’/‘Gisela 3’ plot. For example, projected mean shoot length in Year 2 for the pooled bud-selected treatments used the actual growth in Year 1 plus $2.7 \times$ the growth in Year 1 [$17.6 \text{ cm} + (2.7 \times 17.6) = 65.1 \text{ cm/shoot}$]. The projected shoot length in Year 2 was used to project total spur flower bud formation in Year 4 (since 2 years are required for spur formation), such that $8 \text{ shoots} \times (65.1 \text{ cm} \times 0.25 \text{ flower buds/cm}) = 130 \text{ spur flower buds}$. To this value was added the number of basal flower buds (assumed to be constant for each year’s previous shoot extension) as well as spur flower buds on the cordon for the no bud-selection treatments. Although flower bud density and flower number per bud have been shown to be related inversely to previous season crop load (Einhorn et al., 2011; Whiting and Lang, 2004), for the simplicity of our yield potential estimates, bud density on flowering spurs was assumed to not be affected by differences in total shoot growth. Basal flower buds on upright shoots were assumed to set the same number of fruit per bud as spur flower buds, which was calculated using a value of 2.5 fruit per bud. Potential fruiting on lateral shoots was not considered since any lateral shoots that form are removed annually in the UFO training system. Projected yields per hectare were then estimated from number of fruits per tree, 12 g per fruit, and 2222 trees per hectare (a tree spacing of $1.5 \text{ m} \times 3.0 \text{ m}$). Although the absolute values for the various assumptions made in these estimates could be modified to be more or less conservative, the estimates are calculated to illustrate relative comparisons between treatments

that would be consistent and proportional to the assumed values used.

Statistics included analysis of variance using Proc Mixed in the Statistical Analysis System program (SAS Institute Inc., Cary, NC). All pairwise comparisons were done with *t* tests using the LSmeans pdiff option and reported as significant if they had a *P* value < 0.05 . A natural logarithmic transformation was used for the average shoot length per tree and means were back transformed for presentation.

Results

The angle at planting and bud selection had some independent and some synergistic effects (Tables 1 and 2) on number of shoots, total and mean shoot length, shoot distribution, and number of flower buds. Number of shoots was only significant for angle and the angle $\times$ bud interaction (Table 1). Trees developed seven shoots when planted at a 30° angle, and eight to nine shoots when planted at 45° or 60° (Table 3). Bud selection only significantly impacted the number of shoots for trees planted at 30° angles. Without bud selection, trees at 30° only grew six shoots, but with bud selection eight shoots developed (Table 3). However, total shoot number for treatments without bud selection included not only the structurally desirable upright shoots (which predominated in the bud selection treatments), but also undesirable horizontal and downward-growing shoots that developed from the sides and bottom of the cordon.

Fig. 1. Dormant ‘Rainier’/‘Gisela 3’ sweet cherry trees after two growing seasons trained to the Upright Fruiting Offshoot canopy architecture illustrating planting angle (30°, 45°, or 60°), cordon height (45 or 60 cm), and (A) no bud selection at planting vs. (B) bud selection imposed at planting.

Table 1. *P* values from analysis of variance testing of the treatment effects of angle, height, bud selection (bud), and all interactions for shoot number, total shoot length, mean shoot length, and flower bud number of ‘Rainier’/‘Gisela 3’ trees.

Effect	Shoot no.	Total shoot length	Mean shoot length	Flower bud no.
Angle	0.0043	0.0012	0.0217	0.0189
Height	0.1737	0.0046	0.0369	0.131
Bud	0.7022	<0.0001	<0.0001	<0.0001
Angle × height	0.6169	0.7388	0.6641	0.1933
Angle × bud	0.0495	0.0117	0.0788	0.0822
Height × bud	0.2467	0.2828	0.1227	0.9341
Angle × height × bud	0.0782	0.0748	0.3923	0.4155

Table 2. *P* values from analysis of variance testing of the treatment effects of angle, height, bud selection (bud), and all interactions for shoot number and average shoot length in basal, middle, and terminal thirds of ‘Rainier’/‘Gisela 3’ trees.

Effect	Basal third		Middle third		Terminal third	
	Shoot no.	Shoot length	Shoot no.	Shoot length	Shoot no.	Shoot length
Angle	0.4047	0.2884	0.0267	0.8731	0.0078	0.0007
Height	0.2583	0.0839	0.6909	0.1015	0.0689	0.0814
Bud	0.001	0.0004	<0.0001	<0.0001	<0.0001	<0.0001
Angle × height	0.1169	0.1789	0.4334	0.5629	0.9886	0.3844
Angle × bud	0.019	0.0582	0.6187	0.1083	0.0068	0.061
Height × bud	0.2583	0.3459	0.8423	0.7663	0.1722	0.2458
Angle × height × bud	0.0053	0.1419	0.5046	0.2516	0.4344	0.2426

Table 3. Establishment season shoot number, total shoot length (cm), mean shoot length (cm), and following season flower bud number for planting angle (30°, 45°, and 60°), meristem management [bud selection (B) and no bud selection (NB)], treatment combinations of angle and bud selection, and cordon height (45 or 60 cm) of ‘Rainier’ sweet cherry trees on ‘Gisela 3’ trained to the Upright Fruiting Offshoots canopy architecture.

Treatment	Shoot no.	Total shoot length (cm)	Mean shoot length (cm)	Flower bud no.
30°	7.0 a	91.0 a	11.2 a	28 ab
45°	9.2 b	128.8 b	14.0 b	23 a
60°	8.8 b	124.4 b	12.6 ab	32 b
B	8.4 a	148.3 a	17.6 a	12 a
NB	8.3 a	80.9 b	8.9 b	45 b
30°/B	8.1 b	133.1 c	16.2 c	13 a
30°/NB	6.0 a	46.3 a	7.5 a	47 bc
45°/B	8.7 b	143.5 cd	17.7 c	11 a
45°/NB	9.7 b	114.2 c	11.1 b	35 b
60°/B	8.6 b	168.3 d	19.1 c	13 a
60°/NB	9.1 b	80.5 b	8.4 a	53 c
45 cm	8.7 a	127 a	13.7 a	23 a
60 cm	8.0 a	101 b	11.6 b	31 a

Data were pooled to analyze effects of planting angle, meristem management, and cordon height. Means in the same column followed by the same letter are not significantly different at $P < 0.05$.

When pooling data to examine trunk angle effects, total shoot length was highest (124 or 129 cm) for trees planted at 45° and 60°, which was 30% higher than for the trees at 30° (91 cm) (Table 3). Across treatment combinations, bud selection increased total shoot length by 85% (148 vs. 80 cm). The greatest impact of bud selection on total shoot length was for trees planted at 30° and 60°, which increased by 185% and 100%, respectively, compared with the corresponding treatments without bud selection. Trees planted at 45° had the highest total shoot length without bud selection, and growth increased by only 25% when bud selection was applied (Table 3). Bud selection also increased average shoot length across the entire tree by 97% compared with no bud selection. Average shoot length on trees planted at 30° and 60° angles increased by 116% and 127%, respectively, with bud selection. Average shoot length for trees

planted at 45° only increased 59% with bud selection (Table 3).

The height at which the angled trunk was bent to the wire to create the cordon did not significantly affect shoot number, though it did affect total and average shoot length (Table 1). Establishment year shoot growth was 101 cm for trees bent at 60 cm, compared with 127 cm for those bent at 45 cm. Thus, bending at 45 cm caused a 20% increase in total shoot length compared with bending at the higher height. Average shoot length increased from 11.6 to 13.7 cm for the 45 cm height compared with 60 cm (Table 3).

Flower bud number in Year 2 was affected significantly by both angle and bud selection (Table 1), but the effect of bud selection was more pronounced. Across all treatments with no bud selection, flower bud number per tree was 45, but only 12 for treatments with bud selection (Table 3). Without bud selection, flower bud number

ranged from 35 (trees at 45°) to 53 (trees at 60°). With bud selection, flower bud number did not differ significantly by tree planting angle, ranging from 11 to 13 (Table 3). Height of bending to form the cordon did not affect flower bud number significantly (Table 1).

Shoot distribution was impacted significantly by angle, bud selection, and the interactions of angle × bud selection and angle × height × bud selection (this latter was only significant for shoot number in the basal third) (Table 2). Across treatment combinations, trees without bud selection averaged only half as many shoots in the basal (0.6 vs. 1.2) and middle (1.3 vs. 2.6) sections of the cordon, compared with the bud selection treatments (Table 4). Although the trees without bud selection had higher shoot numbers in the terminal section (6.4 vs. 4.6), these shoots were too close together (6 to 8 cm apart on average) compared with the bud selection trees (8.5 to 11 cm apart), considering that ideal spacing is 15 to 20 cm apart. Trees planted at 30° and 60° had an increase of 0.5 and 1.1 shoots, respectively, in the basal section when bud selection was applied. Trees planted at 45° had an increase of only 0.1 shoot in the basal section with bud selection. The middle section had an increase of 1.7, 1.4, and 1.0 shoots in the 30°, 45°, and 60° treatments, respectively. In the terminal section, the 45° and 60° treatments that were not bud selected had 7.1 or 7.3 shoots, respectively, and all other treatment combinations were not statistically different from each other, ranging from 4.4 to 4.8 shoots (Table 4).

Bud selection also increased average shoot length in each section of the cordon (Table 2). Across treatments, bud selection increased average shoot length by 330%, 185%, and 93% for the basal, middle, and terminal sections, respectively (Table 4).

Discussion

When establishing high-density orchards on precocious rootstocks, new structural shoot growth and distribution is important for early canopy development. Since first year tree growth on ‘Gisela 3’ creates sites for fruiting spurs in Year 3, structural shoot growth in the first year impacts early yield potential. The goal in establishing a UFO tree structure is to develop well-distributed upright shoots and maximize vertical shoot growth in the trellis plane. This optimizes yield potential, facilitates good light interception and distribution, good spray penetration, and reduces losses of storage resources from remedial pruning of poorly placed shoots.

Recommended spacing for UFO upright shoots is ≈20 cm (Long et al., 2015). With a 150 cm nursery tree and an in-row spacing of 120 (for trees planted at a 60° angle) to 140 cm (30° planting angle), six to seven vertical shoots arising from the horizontal cordon structure are needed to fill the canopy. In this study, the target shoot number was achieved

in all treatment combinations except the 30° angle without bud selection (which would require seven shoots), though not all of the resulting shoots were oriented vertically in the treatments without bud selection. Unfortunately, upright vs. nonupright shoot orientations were not quantified. Among the

treatments without bud selection, a 45° planting angle gave the best total shoot length, number, and distribution (Fig. 2A–C). However, all of the treatments without bud selection had poor shoot distribution in the basal and middle sections of the cordon, and an excessive number of shoots in the terminal

section that would ultimately result in removal of perhaps 50% due to crowding.

Bud selection improved shoot distribution, orientation (since top-selected buds always grew vertically), and growth uniformity (Fig. 2D–F). The number of shoots increased in the basal and middle sections of the cordon and decreased in the terminal section. For shoot distribution, bud selection was more important than angle, overcoming most of the disadvantages of the 30° angle. Bud selection made planting angle insignificant for vertical shoot number, distribution, and average length. Bud selection has been reported to promote lateral branching in central and multiple leader sweet cherry training systems (Hoying et al., 2001) and, in this study, increased desirable shoot number and improved distribution of future fruiting structure in the cordon leader-based UFO training system.

In training UFO trees, once optimal upright shoot number and distribution are attained, the next canopy development goal is to maximize shoot growth. Trees bent at a 45-cm trellis wire height to create the UFO cordon had 20% more total shoot length compared with trees bent at 60 cm (Table 3). Height of the bottom trellis wire affects the length of the cordon in the UFO canopy architecture. For a 150-cm nursery tree, the approximate length of the horizontal portion of the cordon leader at a 45-cm wire height is 60, 86, or 98 cm for planting angles of 30°, 45°, and 60°, respectively (Fig. 2). At the 60-cm wire height, these lengths are reduced to 30, 65, and 80 cm, respectively. This could explain the effect of bending height on total length of shoots arising from the cordon. Apple branches that were horizontal produced more water sprouts, which formed earlier and grew longer, than branches at less horizontal angles (Hamzakheyl et al., 1976). At the 45-cm wire height, a greater proportion of the cordon length is horizontal compared with that at 60 cm. However, although the increased horizontal length was related to increased total shoot length in bud-selected treatments, this was not the case in treatments without bud selection. Bud selection independently increased total shoot length, regardless of planting angle. Maximum new shoot growth was achieved with a 60° planting angle and bud selection. This could be due to a greater length of horizontal cordon than the other angles. However, without bud selection, 60° trees had significantly less growth than 45°. When sweet cherry branches are bent below horizontal, more flower bud formation is promoted (Lauri et al., 1998). In our study, nonbud-selected 60° trees had more flower buds (largely spur flower buds) than nonbud-selected 45° trees. Removal of these spurs by bud selection reduced the number of meristems competing for water and nutrients, which subsequently may have promoted increased shoot growth. Without bud selection, the 45° angle had the most shoot growth; consequently, the relative increase in shoot growth resulting with bud selection was less

Table 4. Mean number of shoots and shoot length in the basal (closest to ground), middle, and terminal thirds of the trunk (cordon), for meristem management [bud selection (B) and no bud selection (NB)] and planting angle (30°, 45°, and 60°) treatment combinations of ‘Rainier’ sweet cherry on ‘Gisela 3’ trained to the Upright Fruiting Offshoots canopy architecture.

Treatment	Basal third		Middle third		Terminal third	
	Shoot no.	Shoot length (cm)	Shoot no.	Shoot length (cm)	Shoot no.	Shoot length (cm)
B	1.2 b	14.2 a	2.6 b	17.4 a	4.6 a	18.4 a
NB	0.6 a	3.3 b	1.3 a	6.1 b	6.4 b	9.5 b
30°/B	1.1 bc	10.4 bc	2.3 c	18.9 c	4.7 a	16.0 c
30°/NB	0.6 ab	1.7 a	0.6 a	2.9 a	4.6 a	7.9 a
45°/B	1.1 bc	9.1 bc	2.8 c	14.8 bc	4.8 a	18.6 cd
45°/NB	1.0 bc	6.4 b	1.4 ab	9.5 ab	7.3 b	11.8 b
60°/B	1.3 c	23.0 c	2.8 c	18.6 c	4.4 a	20.7 d
60°/NB	0.2 a	1.7 a	1.8 bc	5.6 a	7.1 b	8.7 ab
45 cm	1.0 a	11.5 a	1.9 a	13.7 a	5.8 a	14.9 a
60 cm	0.8 a	6.2 a	2.0 a	10.0 a	5.2 a	13.2 a

Data were pooled to analyze effects of meristem management.

Means in the same column followed by the same letter were not significantly different at $P < 0.05$.

Fig. 2. Schematic diagram of ‘Rainier’/‘Gisela 3’ sweet cherry shoot formation and growth during the year of planting for Upright Fruiting Offshoots tree canopies planted at 30°, 45°, or 60°. Diagrams depict positioning of the “cordon” portion of the leader at a height of 45 cm for simplicity, though the data are the combined means of results at both 45 and 60 cm. Dotted background lines depict partitioning of canopies into three equal sections to quantify locational shoot distribution. (A) 30° with no bud selection, (B) 45° with no bud selection, (C) 60° with no bud selection, (D) 30° with bud selection, (E) 45° with bud selection, and (F) 60° with bud selection. Note that diagrams A–C (no bud selection) indicate shoot positions and lengths where growth occurred, but not all shoots were oriented upright as is depicted.

Table 5. Projected year-by-year shoot growth, flower bud formation, and yield potential during establishment, comparing bud selection (B) and no bud selection (NB) for 'Rainier' sweet cherry on 'Gisela 3' trained to the Upright Fruiting Offshoots canopy architecture.

Yr	Mean length per upright shoot (cm)	Total spur flower buds on the cordon (no.)	Total basal flower buds on upright shoots (no.)	Total spur flower buds on upright shoots (no.)	Total flower buds/tree (no.)	Total yield ² (t·ha ⁻¹)	Cumulative yield (t·ha ⁻¹)
B							
1	17.6	0	0	0	0	0	0
2	65.1	0	12	0	12	0.8	0.8
3	149.7	0	12	35	47	3.1	3.9
4	224.6	0	12	130	142	9.5	13.4
5		0	12	300	312	20.8	34.2
NB							
1	8.9	0	0	0	0	0	0
2	32.9	33	12	0	45	3.0	3.0
3	75.7	33	12	18	63	4.2	7.2
4	113.6	33	12	66	111	7.4	14.6
5		33	12	152	197	13.1	27.7

²2222 trees/ha and 2.5 fruits/flower bud.

than for the other treatments. The 45° angle promoted the widest distribution of shoots when bud selection was not used, and total and average shoot length was best across all treatments that resulted in a wider distribution of new shoots along the cordon (Fig. 2; Table 3).

Although the UFO trees developed by bud selection generally created canopies closest to the target upright shoot number as well as having the best vertical shoot distribution and total length, the trees without bud selection were significantly more precocious, with 3.75 times the number of flower buds in Year 2 (Table 3). This was because bud selection removed meristems on the cordon that would have developed into fruiting spurs. To evaluate the economic trade-off of early canopy structural development vs. precocious cropping, projected future yields through Year 5 were calculated from the pooled data for trees with and without bud selection. Both sets of data average ≈8 upright shoots, which was considered to be sufficient for projecting a well-structured future UFO canopy. Therefore, the measured total flower bud count on the bud-selected trees represents the number of basal flower buds that would be expected to form at the base of each year's extension growth on the eight upright shoots annually (Table 3). The 33 spur flower buds present on the cordon of the trees without bud selection are assumed to persist through Year 5. The number of spur flower buds that begin appearing in Year 3 is directly proportional to the shoot growth from Year 1, and the increase in these spur flower buds in Years 4 and 5 is proportional to the projected shoot growth in Years 2 and 3. Although some of the shoots that form without bud selection tend to be poorly located or downward growing, this possibility was not taken into account in the potential yield projections; all eight shoots on each group of trees were assumed to grow vertically and at equal growth rates (therefore, any effect of differential crop loads also was not taken into account).

The estimated potential yield on a per orchard basis was 3.0 t·ha⁻¹ in Year 2 for the trees without bud selection, an impressive level of precocity, and far higher than that for the bud-selected trees at 0.8 t·ha⁻¹ (Table 5). Projected yields in Year 3 continued to be

higher, 4.2 vs. 3.1 t·ha⁻¹, for the trees without bud selection. However, projected annual yield for the bud-selected trees surpassed that of the nonbud-selected trees in Year 4, 9.5 vs. 7.4 t·ha⁻¹, as did cumulative yield in Year 5, 34.2 vs. 27.7 t·ha⁻¹. The average length (225 cm) of the eight vertical shoots of the bud-selected trees is projected to have essentially filled a 2.5 m trellis by the end of Year 4 and reached full productivity by Year 5, whereas the trees without bud selection are projected to have only filled half their allotted canopy space. At the end of Year 5, the projected yield differential would be 6.5 t·ha⁻¹; at a crop value of \$6,000 per ton, the projected economic differential would be \$39,000 per ha higher for the bud-selected trees. If, as discussed above, the early high yields subsequently resulted in reduced flower bud number, flowers per bud, and shoot growth (which our projections did not take into account), this differential might have been achieved earlier than our conservative projection.

Heavy crop loads can stunt trees on dwarfing rootstocks, with fruit production significantly reducing shoot growth (Kappel, 1991; Whiting and Lang, 2004). Quickly filling canopy fruiting volume is essential to attain full production early and help recoup orchard establishment costs. In this study, although the trees without bud selection were projected to attain impressive early yields (3–4 t·ha⁻¹ each in Years 2–3), they did not attain projected full yields as quickly as the bud-selected trees (Table 5). A balanced crop load is essential for high quality fruit, and a slight delay in precocious cropping can be beneficial for establishing enough leaf area to support subsequent cropping as spurs become reproductive. In the Solaxe training system (a central leader canopy with lateral branches bent below horizontal), removal of 30% to 50% of the fruiting spurs is recommended to promote larger fruit size balanced against the subsequent reduction in fruit number (Claverie and Lauri, 2005). Others have recommended removal of 25% to 45% of the potential crop load (depending on tree age) to balance fruit quality with yield (Lang, 2005). Although bud selection in Year 1 reduced crop load potential in Year 2 by 73%, it increased canopy development by nearly 50%, resulting in more rapid attainment of

full fruiting capacity and adequate leaf area to support quality fruit production and delay the potential need for crop reduction strategies.

Growers interested in planting a UFO orchard must match rootstock vigor and planting density to the orchard site. These factors affect the length of the cordon leader and the number of vertical shoots to be developed per tree. In this study, 'Gisela 3' did not confer enough vigor to quickly fill the orchard space allotted (1.5-m linear tree row). 'Gisela 3' is a dwarfing rootstock, only imparting 35% to 50% of the vigor of 'Mazzard', but requires good soil, irrigation, tree support, and intensive cultural management (Balmer and Blanke, 2005; Franken-Bembenek, 2004). Other rootstocks to consider would be 'Gisela 6', 'Gisela 12', or 'Krymsk 6', which are semivigorous and impart 80% to 95% of the vigor of 'Mazzard', or 'Gisela 5' which is semidwarfing and imparts 50% to 65% of 'Mazzard' vigor (Facteau et al., 1996; Kemp and Wertheim, 1996; Lang, 2000; Perry et al., 1998; Robinson et al., 2008; Whiting et al., 2005). Trees on dwarfing rootstocks like 'Gisela 3' should be planted at higher densities and developed with fewer upright shoots. Conversely, trees on semidwarfing to semivigorous rootstocks should be planted at more moderate densities and developed with more upright shoots. Tree angle at planting can further modulate canopy development. For a vigorous rootstock-site combination, a 30° angle could help reduce excessive vigor, whereas a 60° angle would increase shoot growth for a less vigorous combination. A lower trellis wire height results in a greater proportion of the cordon being horizontal, and increases upright shoot length. Bud selection can optimize the distribution and growth of well-distributed uprights, albeit at a temporary cost of precocious cropping. Although bud selection requires more labor during planting, the improved upright canopy formation reduces the labor needed later for corrective pruning. The improved shoot distribution and orientation, increased shoot growth, and moderated early crop reduction of bud-selected trees improves precision canopy development and full yield potential for the UFO sweet cherry production system.

Literature Cited

- Ampatzidis, Y.G. and M.D. Whiting. 2013. Training system affects sweet cherry harvest efficiency. *HortScience* 48:547–555.
- Balmer, M. and M. Blanke. 2005. Developments in high density cherries in Germany. *Acta Hort.* 667:273–277.
- Claverie, J. and P.E. Lauri. 2005. Extinction training of sweet cherries in France—appraisal after six years. *Acta Hort.* 667:367–372.
- Einhorn, T., D. Laraway, and J. Turner. 2011. Cropload management does not consistently improve crop value of ‘Sweetheart’/‘Mazzard’ sweet cherry trees. *HortTechnology* 21:546–553.
- Facteau, T.J., N.E. Chestnut, and K.E. Rowe. 1996. Tree, fruit size and yield of ‘Bing’ sweet cherry as influenced by rootstock, replant area, and training system. *Sci. Hort.* 67:13–26.
- Ferree, D.C. and J.R. Schupp. 2003. Bending, p. 337–339. In: D.C. Ferree and I.J. Warrington (eds.). *Apples: Botany, production and uses*. CABI Publishing, Cambridge, MA.
- Franken-Bembek, S. 2004. GiSelA 3 (209/1)—A new cherry rootstock clone of the Giessen series. *Acta Hort.* 658:141–143.
- Hamzakheyli, N., D.C. Ferree, and F.O. Hartman. 1976. Effect of lateral shoot orientation on growth and flowering of young apple trees. *HortScience* 11:393–395.
- Hoying, S.A., T.L. Robinson, and R.L. Andersen. 2001. Improving sweet cherry branching. *New York Fruit Quarterly* 9:13–16.
- Kappel, F. 1991. Partitioning of above-ground dry matter in ‘Lambert’ sweet cherry trees with or without fruit. *J. Amer. Soc. Hort. Sci.* 116:201–205.
- Kemp, H. and S.J. Wertheim. 1996. First results of two international cherry rootstock trials. *Acta Hort.* 410:167–176.
- Lang, G.A. 2000. Precocious, dwarfing, and productive—how will new cherry rootstocks impact the sweet cherry industry? *HortTechnology* 10:719–725.
- Lang, G.A. 2001. Intensive sweet cherry orchard systems—rootstocks, vigor, precocity, productivity and management. *Compact Fruit Tree* 34:23–26.
- Lang, G.A. 2005. Underlying principles of high density sweet cherry production. *Acta Hort.* 667:325–336.
- Lang, G.A., S. Blatt, C. Embree, J. Grant, S. Hoying, C. Ingels, D. Neilsen, G. Neilsen, and T. Robinson. 2014. Developing and evaluating intensive sweet cherry orchard systems: The NC140 regional research trial. *Acta Hort.* 1058:113–120.
- Lauri, P.E., J. Claverie, and J.M. Lespinasse. 1998. The effect of bending on the growth and fruit production of INRA Fercer® sweet cherry. *Acta Hort.* 468:411–417.
- Leyser, O. 2005. The fall and rise of apical dominance. *Curr. Opin. Genet. Dev.* 15:468–471.
- Long, L. 2001. Sweet cherry training systems. *Compact Fruit Tree* 34:66–69.
- Long, L., G. Lang, S. Musacchi, and M. Whiting. 2015. PNW 667 cherry training systems. *Pacific Northwest Ext. Publ.* 667:50–56.
- Musacchi, S.M., F. Gagliardi, and S. Serra. 2015. New training systems for high-density planting of sweet cherry. *HortScience* 50:59–67.
- Perry, R., G. Lang, R. Andersen, L. Anderson, A. Azarenko, T. Facteau, D. Ferree, A. Gaus, F. Kappel, F. Morrison, C. Rom, T. Roper, S. Southwick, G. Tehrani, and C. Walsh. 1998. Performance of the nc-140 cherry rootstock trials in North America. *Acta Hort.* 468:291–296.
- Robinson, T.L. 2005. Developments in high density sweet cherry pruning and training systems around the world. *Acta Hort.* 667:269–272.
- Robinson, T.L., R.L. Andersen, and S.A. Hoying. 2008. Performance of Gisela® rootstocks in six high density sweet cherry training systems in the northeastern United States. *Acta Hort.* 759:245–253.
- Wareing, P.F. and T.A.A. Nasr. 1961. Gravimorphism in trees: 1. Effects of gravity on growth and apical dominance in fruit trees. *Ann. Bot. (Lond.)* 25:321–340.
- Whiting, M.D. and G.A. Lang. 2004. ‘Bing’ sweet cherry on the dwarfing rootstock ‘Gisela 5’: Thinning affects fruit quality and vegetative growth but not net CO₂ exchange. *J. Amer. Soc. Sci.* 129:407–415.
- Whiting, M.D., G. Lang, and D. Ophardt. 2005. Rootstock and training system affect sweet cherry growth, yield, and fruit quality. *HortScience* 40:582–586.
- Zhang, J., M.D. Whiting, and Q. Zhang. 2015. Diurnal pattern in canopy light interception for tree fruit orchard trained to an upright fruiting offshoots (UFO) architecture. *Biosystems Eng.* 129:1–10.