Review n. 37 – *Italus Hortus* 26 (1), 2019: 25-34 doi: 10.26353/j.itahort/2019.1.xxxx

High efficiency sweet cherry orchard systems research

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Migliorare le performance fisiologiche e l'efficienza produttiva

Riassunto. La grande dimensione degli alberi, combinata alla natura delicata e alla piccola taglia dei frutti, rende il ciliegio dolce tra le colture che tradizionalmente richiedono maggior intensità di lavoro. Nelle ultime due decadi, sono stati ottenuti grandi miglioramenti nell'efficienza dei frutteti, grazie allo sviluppo di portinnesti precoci capaci di controllare il vigore, come la serie Gisela (Gi). Le recenti ricerche sui sistemi di allevamento si sono focalizzate sulla progettazione architettonica della chioma, al fine di migliorarne l'efficienza sotto vari aspetti, tra cui: 1) l'intercettazione e la distribuzione della luce per minimizzare l'ombreggiamento; 2) la fioritura, lo sviluppo e la maturazione del frutto per un raccolto più uniforme; 3) la gestione equilibrata del carico di frutti per ottenere un'elevata qualità degli stessi; 4) strategie semplificate per lo sviluppo ed il mantenimento dei rami a frutto, al fine di ridurre il lavoro di potatura manuale; 5) meccanizzazione parziale per ridurre il lavoro di raccolta e potatura manuale; 6) l'utilizzo di coperture protettive per mitigare il rischio di danni da pioggia, grandine, gelo e vento; e 7) una migliore copertura della chioma tramite nebulizzazione, per la protezione da insetti e malattie. In numerose località del Nord America, il progetto di ricerca regionale NC140 ha valutato le prestazioni di tre cultivar di ciliegio dolce su portinnesti nanizzanti (Gi3), semi-nanizzanti (Gi5) e semi-vigorosi (Gi6) con chioma allevata in tre ed in due dimensioni (forma in parete), rispettivamente, per una durata di nove anni, ad oggi. La forma di allevamento in parete Super Slender Axe (SSA) ha mostrato le produzioni precoci più elevate, sia per albero che per frutteto, ma la forma di allevamento in parete Upright Fruiting Offshoots (UFO) ha sostenuto un più alto raccolto cumulato prima di raggiungere la maturità. Gli alberi allevati tridimensionalmente a Tall Spindle Axe (TSA) hanno mostrato una produzione precoce più elevata di quelli allevati in tre dimensioni con la forma a Kym Green Bush (KGB), raggiungendo però una produttività cumulata simile. Le strategie di rinnovo del legno a frutto sono critiche per il mantenimento della produttività e della qualità dei frutti. Per ognuna di queste forme di allevamento è possibile raggiungere raccolti economicamente convenienti e di alta qualità, ma a seconda della forma essi presentano vantaggi e sfide, tra cui la compatibilità specifica tra diversi portinnesti e cultivar. Questi aspetti sono discussi in questo lavoro, che include i confronti tra le architetture delle chiome bi- e tridimensionali sviluppate come astone centrale (SSA vs. TSA) e come astoni multipli (UFO vs. KGB). Il vantaggio di utilizzare la naturale efficienza di intercettazione della luce e l'habitus di crescita del ciliegio dolce in strutture semplificate di stile UFO con forme di allevamento in parete si sta espandendo, oltre al ciliegio, anche ad altre colture frutticole in tutto il mondo.

Parole chiave: *Prunus avium*, alta densità, architettura della chioma, allevamento in parete

Introduction

In nature, sweet cherry (*Prunus avium* L.) is a forest tree, with a strong apical dominance that promotes vertical growth of a single leader and limited branching (Lang *et al*., 2004). Usually, new branches are initiated in the spring by elongation of only a few lateral buds located directly below the terminal meristem. Older branches lower in the canopy that initiated during previous seasons tend to grow less vigorously with time, particularly as they become shaded by the development of canopy above them.

This growth habit is likely to have evolved to compete successfully for light in the forest, with the most vigorous shoot elongation occurring as the terminal meristem extends vertically to outgrow nearby trees of a similar height. The subtending whorl of new branches elongate with slightly less vigor; the uppermost 2-3 lateral branches develop with acute vertically-oriented angles, ready to replace the terminal leader if it is damaged. Lower lateral branches develop with less vigor and at broader angles to the central leader. This growth strategy promotes their capture of light horizontally to shade out nearby competing trees of lower heights. Fruit production follows the vigor in the tree, moving ever upward where light is most abundant and declining lower in the canopy as light and vigor becomes limiting.

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This evolutionary growth habit creates a major challenge for fruit growers who must adapt this forest tree to a managed orchard, which given the small size and delicate nature of the fruit, must be harvested by hand. Consequently, sweet cherries are among the most labor-intensive and -inefficient fruits to produce, traditionally requiring tall ladders and significant effort to reduce vigor in the tops of trees to improve light, vigor, and fruiting lower in the canopy.

Since the 1990s, with the increasing availability of precocious, vigor-controlling hybrid rootstocks, particularly the Gisela (Gi) series (Gruppe, 1985), significant advances have been made in adapting sweet cherry production to high density, smaller statured trees and training systems (Lang, 2000, 2005). Rootstock evaluation trials from the late 1980s through the first decade of the 21st century (e.g., Kappel *et al*., 2013) provided recommendations for new rootstocks that, above all, impart precocious fruiting to commercial varieties, and secondarily, limit vigor to varying degrees. Within the Gisela series, there is now availability of a wide range of precocious rootstocks that include dwarfing (Gi3), semi-dwarfing (Gi5), semi-vigorous (Gi6, Gi12, Gi13), and vigorous (Gi17) genotypes. Other rootstock breeding or selection programs have contributed additional hybrids that fall at various points within this vigor range, including the Krymsk series from Russia, the Weiroot and WeiGi series from Germany, and the MSU series from the United States.

The overriding physiological impact of these rootstocks on sweet cherry orchard management has been the shift in precocity (earlier flowering) and the shift in harvest index (a greater proportion of growth resources partitioned to fruit rather than structural wood). Whereas traditional cherry orchards often took between 6 and 10 years to begin significant fruiting, orchards on precocious rootstocks begin some fruiting as early as year 2 and, when planted at high densities, can reach mature production by year 5 or 6. The higher harvest index is a function of a greater number of nodes that become reproductive relative to the number of nodes that remain vegetative. Consequently, orchard management no longer needs to focus so much on limiting vigor, but rather on promoting vigor and leaf area, and limiting fruiting sites, to maintain a favorable balance between the fruiting potential and the light-harvesting, carbohydrate-producing supporting canopy structure.

Advances in Orchard System Design

A number of physiological studies were undertaken over the past 20 years to better understand how the rootstock-induced shift in harvest index affects photosynthesis (e.g., Whiting and Lang, 2004), carbohydrate partitioning (e.g., Ayala and Lang, 2017, 2018), and nutrient partitioning (e.g., Neilsen *et al*., 2007; 2010; 2017). Briefly, the overriding factors for yield and fruit quality are the amount of leaf area exposed to light for photosynthesis in balance with the number of fruit that are set, with relatively uniform distributions of fruit throughout the canopy and minimization of excessive fruit clusters. Based on this knowledge, more recent research has focused on the manipulation of canopy structure (Lang and Lang, 2009; Law and Lang, 2016; Musacchi *et al*., 2015) and architecture (Lang *et al*., 2014) to advance orchard efficiencies for light interception, crop load management, and labor. A sweet cherry research trial was designed in 2008 and planted in 2010 as part of the NC140 Regional Research Project, which duplicates and coordinates multi-site trials across North America. To date, this trial has completed 9 years of data collection from sites in Michigan (with 'Benton'), New York (2 sites, with 'Regina'), and British Columbia and Nova Scotia (both with 'Skeena'). The trial examines 3-4 (depending on site) distinct canopy architectures developed on each of three rootstocks that impart differing levels of vigor: Gi3, Gi5, and Gi6.

The training systems under study include two relatively typical, "three-dimensional" canopy architectures: 1) Tall Spindle Axe (TSA), a central leader-based, conical tree at maturity that is an evolution of the classic spindle training systems (developed by German scientists/advisors Fritz Zahn and Tobias Vogel) for apple, and 2) Kym Green Bush (KGB, developed by cherry grower Kym Green in Australia), a multi-leader-based tree that diffuses tree vigor into many (10-15) vertical leaders arising from a stump-like base. Pruning of the TSA focuses on developing horizontal branches along the length of the central leader, retaining longer branches in the lower canopy, medium-length branches in the mid-canopy, and short branches at the top of the canopy. The structural goal is to optimize light distribution and reduce shade from top to bottom, and to retain vigor in the lower canopy while minimizing vigor in the top (this branch structure and vigor management is the exact opposite of the natural growth of sweet cherry). At maturity, fruiting occurs on both spurs and on basal buds of new shoots, a proportion of the fruiting sites are renewed annually by cutting out the largest 1-3 branches to promote regrowth, and the maximum width of the fruiting structure of a TSA canopy on semi-dwarfing Gi5 is about 1.5 m (fig. 1A). Pruning of the KGB focuses on multiple low heading cuts imposed during the first 2-3 years after planting to multiply the number of vertically-oriented leaders with each pruning, ultimately forming as many as 25-30 leaders from which 10-15 (depending on rootstock vigor) are selected for uniformity, eliminating the strongest and the weakest and promoting the penetration and distribution of light between each leader. Upon achieving the target number of moderate vigor leaders, annual pruning focuses on removal of any lateral branches so that fruiting occurs primarily on spurs along the length of each multiple leader. At maturity, a proportion of the fruiting sites are renewed annually by cutting out the largest 1-2 leaders to promote re-growth, and the maximum width of a KGB canopy on semi-vigorous Gi6 is about 2 m (fig. 1B).

The other two training systems under study are, to some extent, "two-dimensional" evolutions of the more traditional canopy architectures: 3) Super Slender Axe (SSA, developed by Stefano Musacchi in Italy), a central leader-based, narrow conical tree at maturity that is planted at very high densities, and 4) Upright Fruiting Offshoots (UFO, developed by Greg Lang and Matthew Whiting in the U.S.), a multi-leader-based tree that diffuses tree vigor into many (8-15) vertical leaders arising from a grape cordon-like horizontal base. Formation of the SSA focuses on developing many weak horizontal branches along the length of the central leader, each of which is pruned severely every year to retain only the basal flower buds plus 1-3 basal vegetative buds for regrowth. More vegetative buds may be retained in the lower canopy and fewer at the top of the canopy. The key to success with the SSA is the development of many weak lateral branches during the first two years of canopy development, since higher numbers

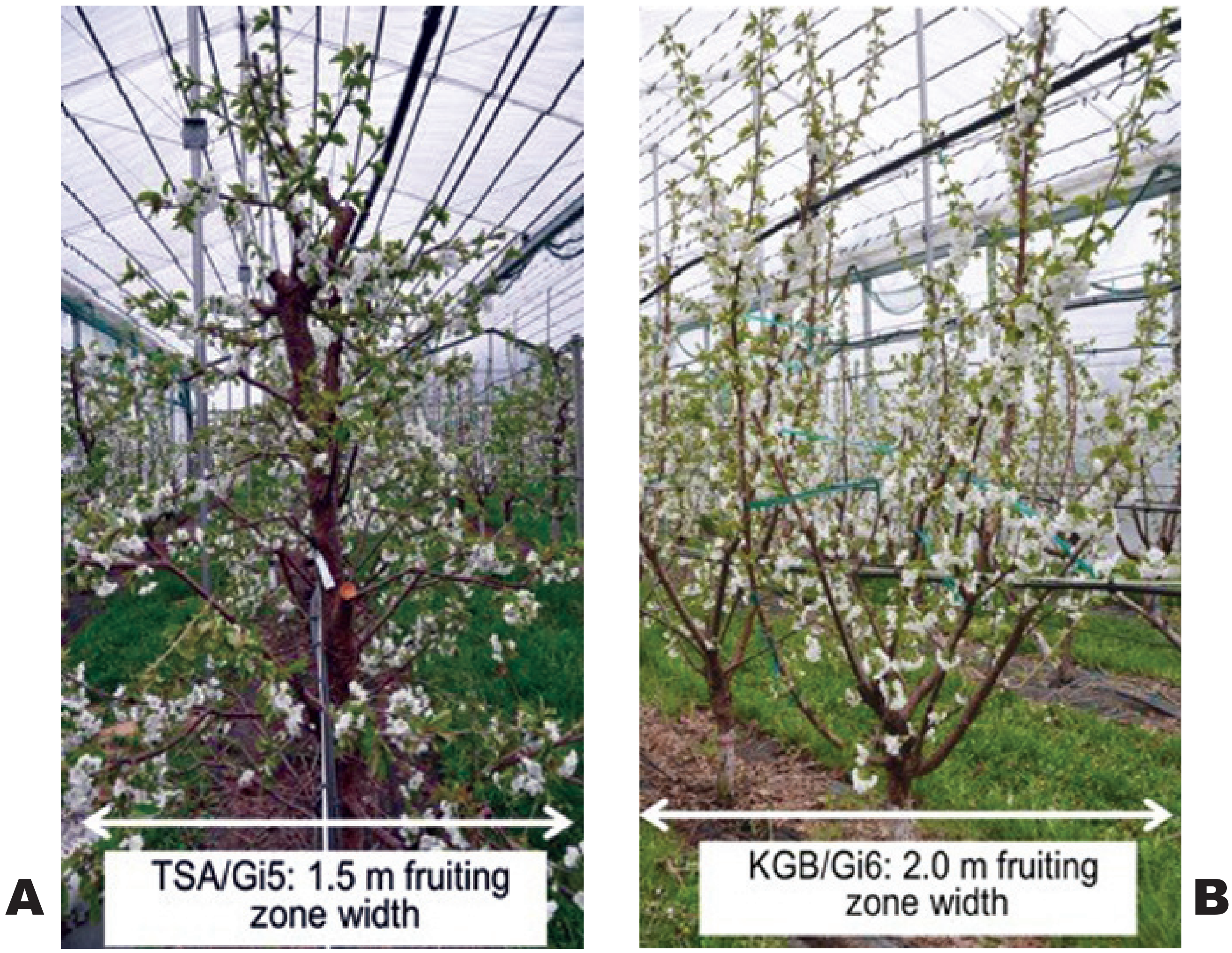

Fig. 1 - Distribuzione delle strutture fruttifere all’interno di chiome della cultivar di ciliegio dolce ‘Benton’ allevate a A) Tall Spindle Axe (TSA) su portinnesto Gisela 5 (Gi5) e B) Kym Green Bush (KGB) su portinnesto Gisela 6 (Gi6) nella prova NC140, relativa ad impianti di ciliegio x portinnesto, presso il Centro di Ricerca Clarksville dell’Università di Michigan State.

Fig. 1 - The spread of the fruiting canopy structure of 'Benton' sweet cherry trees trained to a A) Tall Spindle Axe (TSA) canopy on Gisela 5 (Gi5) rootstock and a B) Kym Green Bush (KGB) canopy on Gisela 6 (Gi6) rootstock in the NC140 cherry systems x rootstocks trial at Michigan State University's Clarksville Research Center.

reduce the overall vigor of each individual shoot. At maturity, fruiting occurs primarily on basal buds of new shoots, which are all renewed annually, resulting in the maximum width of the mature fruiting structure of an SSA canopy on dwarfing Gi3 being about 65 cm (fig. 2A). Development of the UFO focuses on formation of the vertically-oriented multiple leaders along the horizontal cordon, with the target number of leaders being proportional to rootstock vigor. The leaders are selected for uniformity, eliminating the strongest and weakest, and are trained to a multi-wire vertical trellis such that they are spaced about 20 cm apart. As with KGB, annual pruning focuses on removal of any lateral branches so that fruiting occurs primarily on spurs along the length of each multiple leader. At maturity, a proportion of the fruiting sites are renewed annually by cutting out the largest 1-2 leaders to promote re-growth, and the maximum width of a UFO canopy on dwarfing Gi3 is about 25 cm (fig. 2B). The formation and maintenance of all four of these canopy training systems are described in Long *et al*. (2015).

Although this trial is scheduled to run for 10 years (through 2019), some preliminary analyses and tentative conclusions can be drawn following the 2018 season with 9 years of data from the Michigan trial. The projected annual and cumulative orchard yields (based on actual tree yield data multiplied by the appropriate tree spacing for each canopy architecture and rootstock vigor combination) reveal several trends. The highest early yields (Year 4) were for the SSA/Gi3 combination (fig. 3A); this combination also had the highest flower counts in Years 2 and 3, when yield data were not taken. However, in Year 5, the

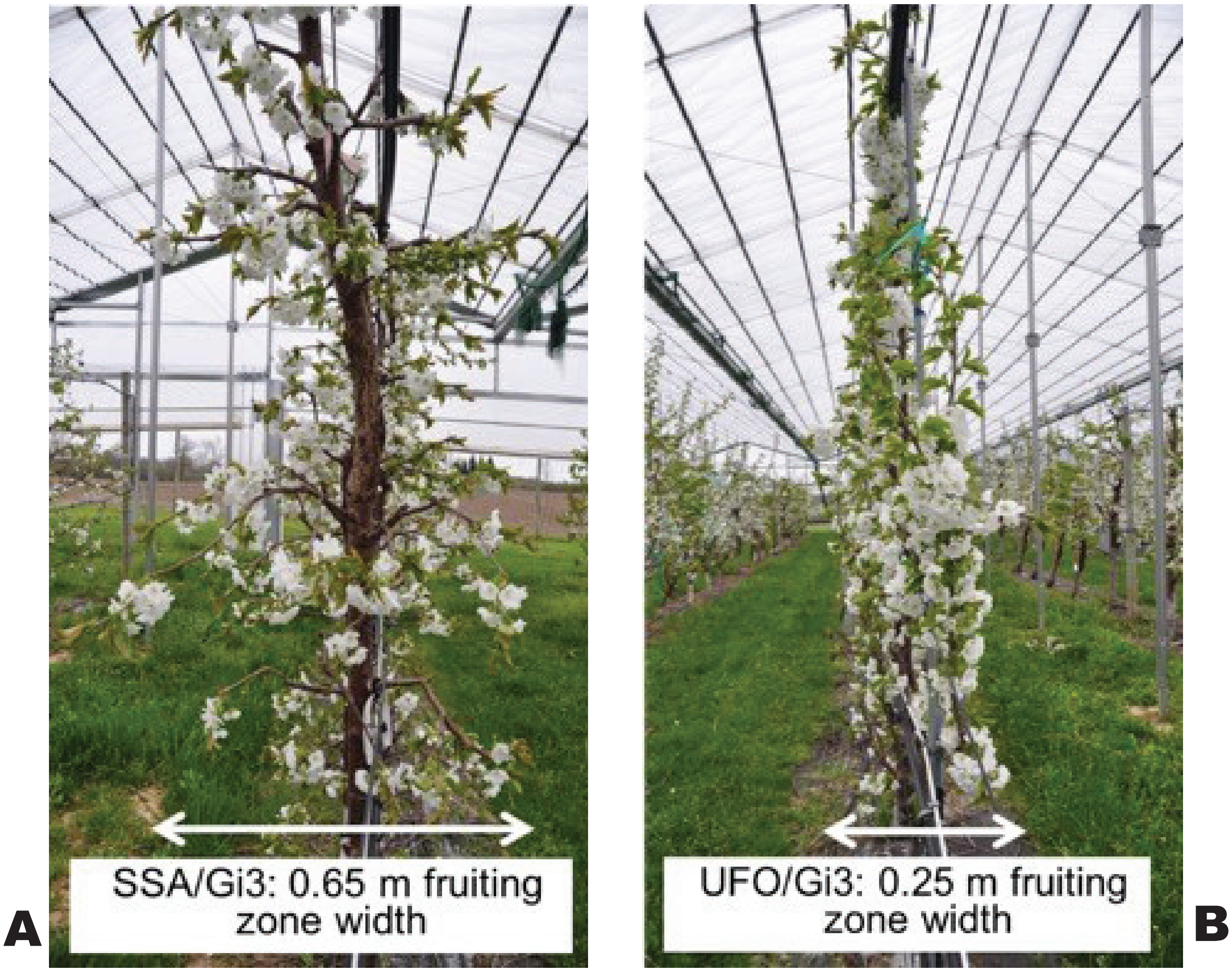

Fig. 2 - Struttura della chioma in alberi di ciliegio dolce cv. “Benton” allevati a A) Super Slender Axe (SSA) su portinnesto Gisela 5 (Gi5) ed a B) Upright Fruiting Offshoots (UFO) su portinnesto Gisela 6 (Gi6) nell’ambito della prova NC140 presso il Centro Ricerca di Clarksville, Università del Michigan.

Fig. 2 - The spread of the fruiting canopy structure of 'Benton' sweet cherry trees trained to a A) Super Slender Axe (SSA) canopy on Gisela 5 (Gi5) rootstock and a B) Upright Fruiting Offshoots (UFO) canopy on Gisela 6 (Gi6) rootstock in the NC140 cherry systems x rootstocks trial at Michigan State University's Clarksville Research Center.

TSA/Gi3, UFO/Gi5, TSA/Gi5, UFO/Gi3, and KGB/Gi3 annual yield surpassed that of the SSA/Gi3 trees. By the 6th year, the TSA/Gi3 and UFO/Gi3 cumulative yields were highest, followed by the UFO/Gi5 and KGB/Gi3 combinations, followed closely by the SSA/Gi3 trees. The lowest initial yields were with the KGB/Gi6 and KGB/Gi5 trees, and the lowest cumulative yield after 6 years was with the SSA/Gi6 trees, which were too vigorous for such a high density planting.

Examination of the next three-year period, Years 7-9, found the highest cumulative yields with the UFO/Gi3 trees, followed by the UFO/Gi5 and KGB/Gi3 trees, and then the SSA/Gi3 trees. The lowest cumulative yields for this three-year period remained with the SSA/Gi6 trees. Overall for the 6-years of harvest data, the highest yielding combination was the UFO/Gi3 trees, followed by the UFO/Gi5, KGB/Gi3, and TSA/Gi3 trees. However, the first three combinations had stable or increasing years as the canopies matured and were maintained, while the TSA/Gi3 trees declined in yield as the trees aged. The SSA/Gi3 trees were 5th in overall cumulative yield and showed a slight decline as the trees aged. The TSA/Gi5 trees were 6th in overall cumulative yield, also with a decline as trees aged. All of the canopy architectures achieved generally higher orchard yields on the dwarfing and semi-dwarfing rootstocks than on the semi-vigorous rootstock.

In 2015, harvest labor efficiency data were also taken, using several pickers who were assigned an equal number of trees for each canopy architecture across all rootstock combinations. The average time required to harvest 1 kg of fruit (2.0 min) was lowest for the UFO trees, increasing by 5% for the KGB trees, 10% for the SSA trees, and 39% for the TSA trees. The narrow canopy of the UFO trees facilitated picking the entire tree from one side of the UFO trellised fruiting wall. The KGB trees facilitated picking almost entirely without ladders since the fruiting lea-

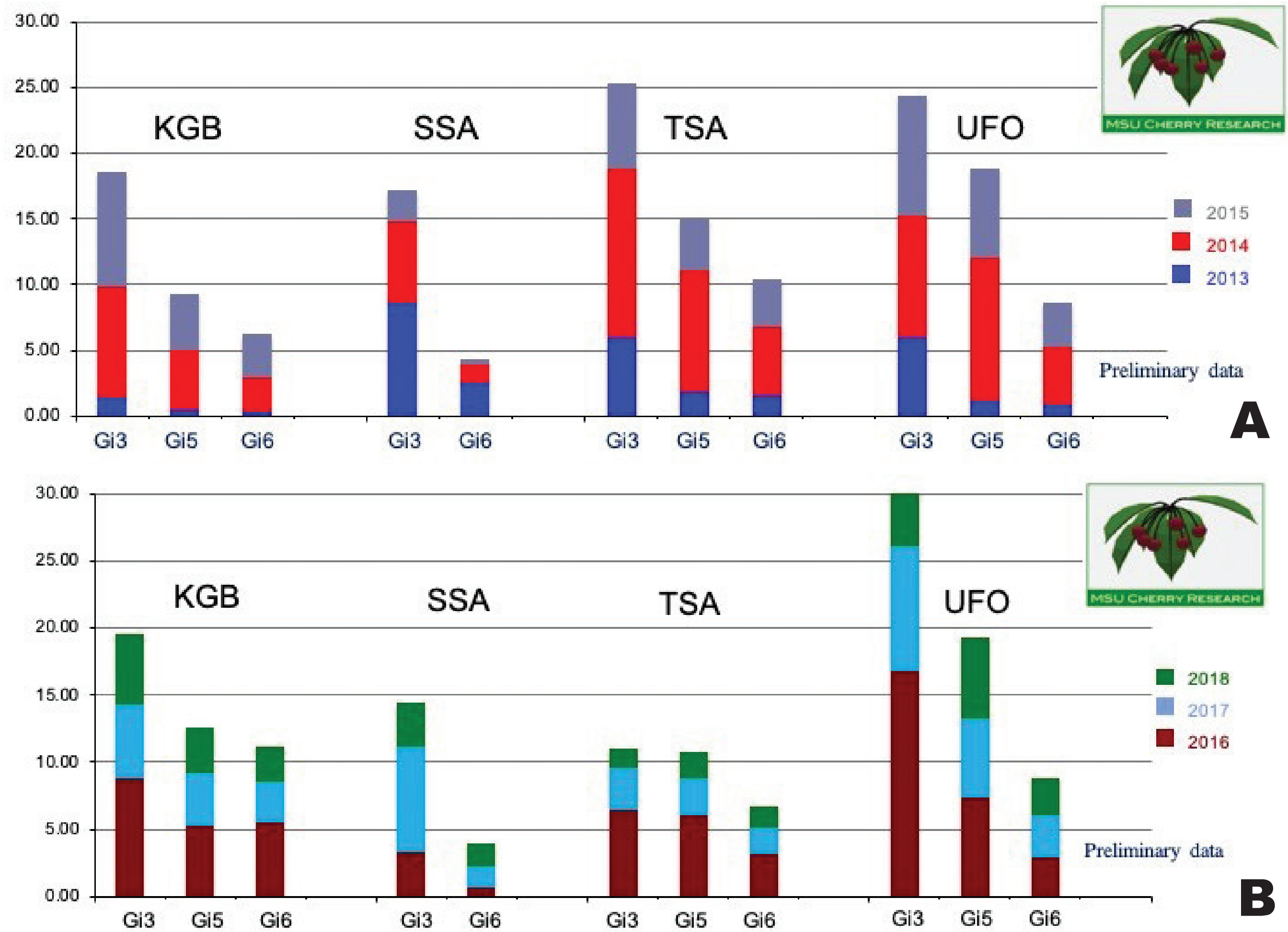

Fig. 3 - Produttività annuale e cumulata su ciliegio dolce cv. "Benton" durante A) anni dal 4° al 6° (2013-2015) e B) anni dal 7° al 9° (2016-2018) nell'ambito della prova NC140 presso il Centro Ricerca di Clarksville, Università del Michigan.

Fig. 3 - Annual and cumulative orchard yields for 'Benton' sweet cherry during A) Years 4 to 6 (2013-2015) and B) Years 7-9 (2016-2018) in the NC140 cherry systems x rootstocks trial at Michigan State University's Clarksville Research Center.

ders could be pulled down by pickers standing on the orchard ground, moving around the canopy. The SSA trees were not quite narrow enough to be picked from one side, and the orientation of the various lateral branches was irregular enough to slightly slow the pickers. The great irregularity and three-dimensionality of the TSA trees made it difficult for placement of ladders and even movement in and out of the canopy with picking from the ground.

Consequently, although the trial will continue for one more year, after which the data from all of the coordinated research sites will be analyzed and interpreted as a whole, the following preliminary generalizations can be made for 'Benton' sweet cherry trial at the Clarksville, Michigan, site.

The TSA canopy architecture had:

- the second-highest initial yields due to fruiting on basal buds of the structural shoots formed in Years 1 and 2;
- very good quality fruit, with a balance between fruit borne on basal buds and spurs;
- good yield potential per tree, though this declined with canopy maturation, suggesting that the renewal of fruiting wood in this trial needed to be improved;
- relatively complex pruning, with many varied decisions not easily taught to orchard workers (least labor efficient training system);
- the second-highest pruning cost due to the irregularity and complexity of the canopy;
- the highest harvest cost due to the irregularity and complexity of the canopy;
- minimal scion genotype interactions, though cultivars that readily form lateral shoots are easiest to train;
- rootstock genotype interactions, being very suitable for dwarfing to semi-vigorous rootstocks, though as vigor increases, the more difficult it becomes to prevent excessive vigor in the top of the canopy.

The KGB canopy architecture had:

- delayed initial yields (the least precocious training system);
- very good quality fruit, although some clusters of spurs on the leaders may need to be thinned;
- eventually, good yield potential per tree which was maintained upon reaching maturity, requiring the lowest number of trees per hectare;
- very simple pruning, easily taught to orchard workers;
- the lowest pruning and training cost due to simplified pruning and free-standing trees;
- a low harvest cost due to the regularity of the multiple leaders and ability to harvest from the ground;
- scion genotype interactions, with better performance of cultivars having an upright growth habit and a propensity to retain spurs rather than form lateral shoots;
- rootstock genotype interactions, with better performance on rootstocks that promote vertical growth (Gi3, Gi5, and Gi6 tend to promote more horizontal growth, which led to the tying of upright leaders and loss of some of the benefits of free-standing trees).

The SSA canopy architecture had:

- the earliest and highest initial yields due to fruiting on basal buds of the numerous shoots formed in Years 1 and 2 (the most precocious training system);
- very uniform and high quality fruit, with a very balanced crop load;
- the lowest yield potential per tree, therefore requiring the highest number of trees per hectare;
- very simple pruning, easily taught to orchard workers, although identifying the difference
- between basal productive and vegetative buds can be difficult before bud swell in the spring;
- the highest pruning cost due to the extensive annual pruning of every shoot on every tree;
- a low harvest cost due to the regularity and compactness of the lateral fruiting shoots around the central leader;
- scion genotype interactions, with better performance of cultivars that readily form lateral shoots rather than retain spurs and a modest propensity for basal flower bud formation;
- rootstock genotype interactions, being very suitable for dwarfing to semi-dwarfing rootstocks and being unsuitable for semi-vigorous to vigorous rootstocks.

The UFO canopy architecture had:

- the second-highest initial yields, similar to TSA, due to fruiting on basal buds of the upright shoots formed in Years 1 and 2;
- very good quality fruit, although some clusters of spurs on the upright leaders may need to be thinned;
- good yield potential per orchard area, which was maintained upon reaching maturity;
- very simple pruning, easily taught to orchard workers;
- the highest initial training cost due to upright shoot positioning in the trellis, but lowest maintenance pruning cost due to simplified pruning and potential for summer hedging;

- the lowest harvest cost due to the regularity and compactness of the upright leaders and ability to harvest all fruit from one side of the tree;
- scion genotype interactions, with better performance of cultivars having a propensity to retain spurs rather than form lateral shoots;
- minimal rootstock genotype interactions, since upright leader number can be increased proportionally to vigor, and vertical leader orientation is assured by the trellis.

Although each canopy architecture exhibited certain advantages and disadvantages, it seems clear that future sweet cherry orchard systems will continue to evolve towards narrow, planar, fruiting wall architectures like the UFO. Such canopies optimize the uniformity of light interception from top to bottom while minimizing shade within the canopy (fig. 4). This subsequently optimizes the uniformity of flower bud development, bloom, photosynthate partitioning to fruit for development, fruit quality, and ripening time, which can increase not only harvest labor efficiency but also packing efficiency. The simplification of the planar UFO canopy by developing evenly-spaced mini-leaders is a radical approach to utilizing the evolutionary growth habit of sweet cherry in a high precision orchard management system, allowing its natural upright growth and minimal branching, while diffusing natural vigor among multiple leaders to make it easier to maintain a lower canopy height. In fact, the phyllotaxy (developmental arrangement) of leaves on vertical cherry shoot growth is a Fibonacci pattern, with each successive leaf arising at a node that is 137.5° around the leader axis from the previous node (fig. 5). This is assumed to be the evolutionary arrangement of leaves (and ultimately branches as the canopy develops and its diameter expands) that most efficiently intercepts light with minimal shading of the older leaves below the newly-developing leaves. Thus, the UFO canopy architecture organizes the sweet cherry canopy into multiple, relatively uniform simplified units of its most light-efficient arrangement of leaves, fruiting sites, and growth habit, in sharp contrast to the more traditional single leader spindle canopy that originates as an effi-

Fig. 4 - Intercettazione uniforme della luce, maturazione dei frutti, e minimizzazione dell'ombreggiamento della chioma in una parete verticale UFO di ciliegio dolce in un frutteto a Washington state, USA.

Fig. 4 - Uniform light interception, fruit ripening, and minimization of canopy shade in a vertical UFO fruiting wall sweet cherry orchard in Washington state, USA.

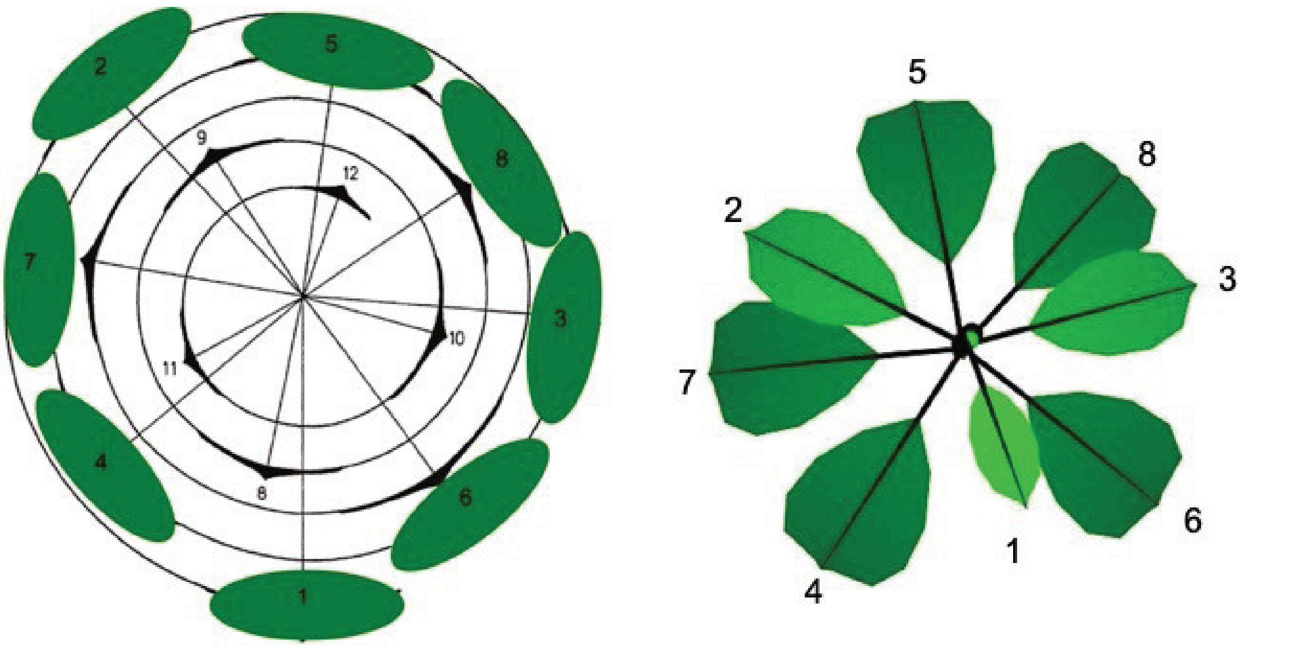

Fig. 5 - Disposizione di Fibonacci delle foglie di ciliegio dolce; ogni nodo successivo si sviluppa con 137.5° di rotazione sull'asse del fusto rispetto al precedente, come mostrato dalla spirale di Fibonacci (sin.) e dallo schema di Whorl delle foglie di ciliegio dolce (destra).
Fig. 5 - Fibonacci arrangement of sweet cherry leaves; each successive node develops 137.5° around the leader axis from the previous node, as illustrated by a fibonacci spiral on the left and sweet cherry leaf pattern whorl on the right.

cient nursery tree leader, but is then artificially manipulated into an orchard tree that requires continuous intervention in opposition of its natural growth habit, resulting in non-uniform growth, shade, and a heterogenous population of fruit.

Similarly, planar vertical and inclined cherry canopy architectures have been developed that fill the planar fruiting wall with many horizontal, even precisely-structured branches borne from a single vertical leader, usually guided along trellis wires. These maintain the fundamental planar canopy advantages of light interception uniformity and minimization of shade, but they can provide a continuous challenge to moderate vigor of the upper branches and maintain adequate vigor in the bottom branches, as well as to continually eliminate vertically-growing shoots that arise from the horizontal branches, which are all hallmarks of sweet cherry's natural growth habit. Such systems are best managed where gibberellin biosynthesis inhibitors, such as paclobutrazol (Cultar®) or prohexidione-Ca (Apogee®, Regalis®) (e.g., Elfving *et al*., 2003), can be used to suppress shoot elongation.

The continued evolution of UFO-style (multiple vertical fruiting leader) planar fruit tree canopies will encounter trade-offs with individual grower priorities for increasing yields or increasing labor efficiencies, such as mechanization of orchard tasks like hedging or the use of mobile platforms for pruning, training, and harvest labor. The planar canopies can be inclined, such as by utilizing a V- or Y-trellis to increase leaf area per hectare to capture light over the tractor alley and therefore increase yield potential by as much as 33%, but this likely will at least slightly reduce the efficiency of hand labor for training and harvest, as well as the ease of mechanical hedging (fig. 6). To date, UFO canopy architectures have been adopted by a number of commercial sweet cherry growers in the U.S. and New Zealand, and have been adapted further to apricots, plums, peaches and nectarines in trials at Michigan State University over the past 8 years. UFO-style canopy architectures are under trial for apples and pears, as well as apricots, in New Zealand, where they are known as FOPS - Future Orchard Production Systems.

Conclusions

The evolution of high density sweet cherry canopy architectures, prompted by the availability of a range of precocious, vigor-limiting rootstocks, has improved a number of orchard efficiencies, including: 1) light interception and distribution for minimization of shade; 2) bloom, fruit development and ripening for more uniform fruit harvest; 3) balanced crop load management for achieving high fruit quality; 4) simplified strategies for fruitwood development and maintenance to reduce hand-pruning labor; 5) partial mechanization to reduce pruning and harvest labor; 6) utilization of protective orchard covers to mitigate the

A

B

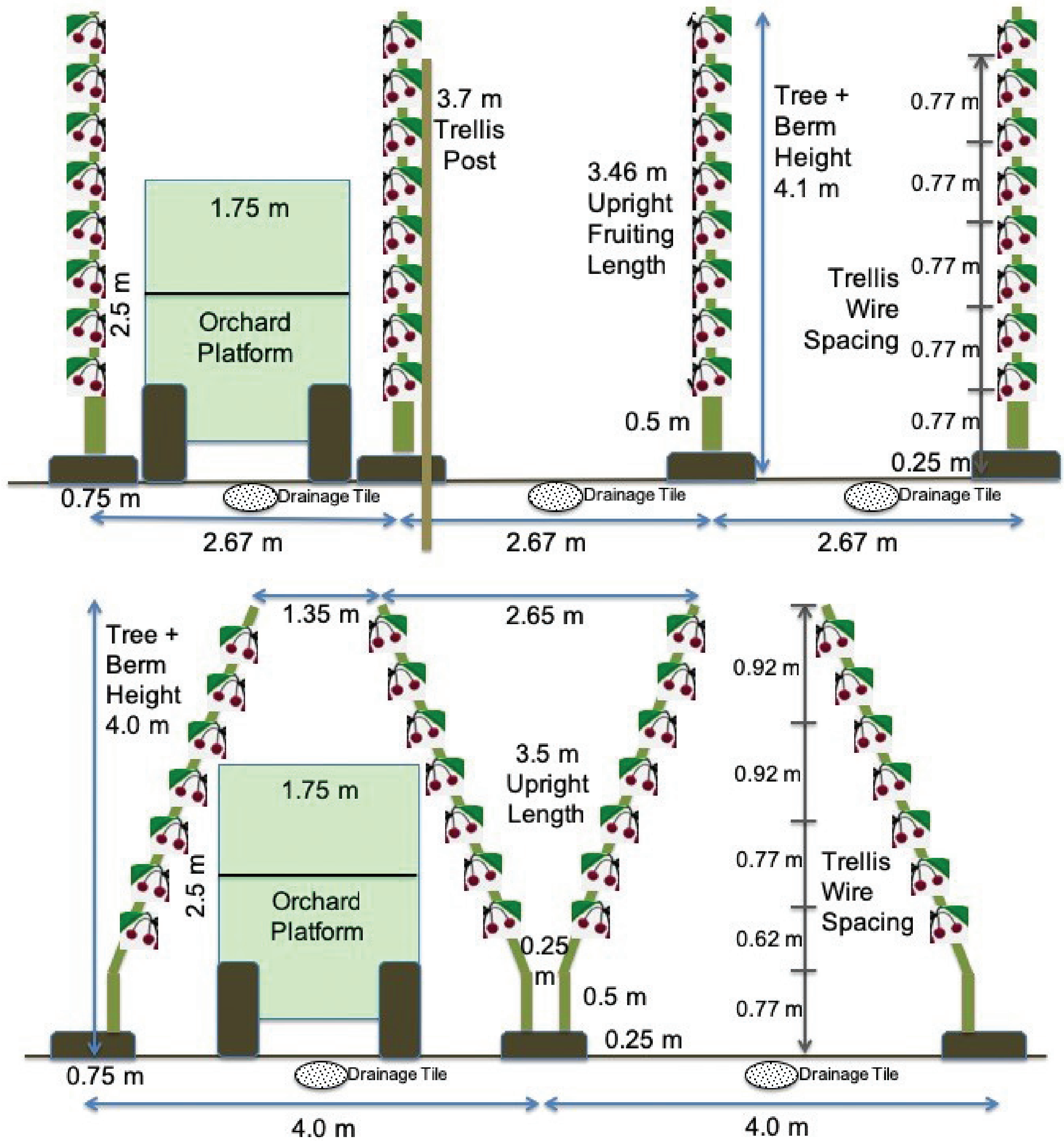

Fig. 6 - Progettazione dell'architettura della chioma in piano "UFO" su ciliegio dolce: A) sostegni verticali per UFO con 7.580 fusti verticali per ha o B) sostegno a V per UFO con 10.120 fusti inclinati per ha, in teoria con il 33% in più di potenziale produttivo, ma leggermente meno per quanto riguarda efficienza di allevamento, raccolta e potatura.

Fig. 6 - Planar UFO sweet cherry canopy architectural orchard designs: A) vertical-trellis UFO with 7580 upright leaders per ha or B) V-trellis UFO with 10,120 inclined leaders per ha, in theory with 33% higher yield potential, but slightly less training, harvest and pruning efficiency.

risk of crop damage from rain, hail, frost, and wind; and 7) better spray coverage for protection from insect pests and diseases. Most of these advantages are optimized by narrow, planar, fruiting wall sweet cherry canopy architectures, such as the UFO training system and its variations. While these bear little outward resemblance to a wild sweet cherry tree in nature, they utilize the fundamental growth habit and light-harvesting efficiencies that evolved over millennia of successful competition in the forest, with relatively minor re-structuring for adaptation to modern orchard efficiencies, labor availabilities, and market quality demands.

Abstract

The large tree size, and delicate nature and small size of the fruit, makes production of sweet cherries

among the most traditionally labor-intensive tree fruits. Great improvements in orchard efficiencies have been achieved over the past two decades, prompted by the development of precocious, vigor-controlling rootstocks such as the Gisela (Gi) series. Recent training systems research has focused on canopy architectural designs that improve various orchard efficiencies, including: 1) light interception and distribution for minimization of shade; 2) bloom, fruit development and ripening for more uniform fruit harvest; 3) balanced crop load management for achieving high fruit quality; 4) simplified strategies for fruitwood development and maintenance to reduce hand-pruning labor; 5) partial mechanization to reduce pruning and harvest labor; 6) utilization of protective orchard covers to mitigate the risk of crop damage from rain, hail, frost, and wind; and 7) better spray coverage for protection from insect pests and diseases. Across several sites in North America, the NC140 regional research project has evaluated the performance of three sweet cherry cultivars on dwarfing (Gi3), semi-dwarfing (Gi5), and semi-vigorous (Gi6) rootstocks trained to "three-dimensional" and "two-dimensional" (planar) canopy architectures over nine years to date. The planar Super Slender Axe (SSA) training system had the highest early yields on a per tree and per orchard basis, but the planar Upright Fruiting Offshoots (UFO) training system sustained higher cumulative yields upon reaching maturity. The three-dimensional Tall Spindle Axe (TSA) trees had higher early yields than those trained to the three-dimensional Kym Green Bush (KGB) training system, but the KGB trees achieved nearly comparable cumulative yields. Fruitwood renewal strategies are critical for maintenance of yields and fruit quality. Profitable yields of high quality fruit are achievable for each of the canopy architectures, but each also has specific advantages and challenges, including suitability for specific rootstocks and cultivars. These are discussed, including comparisons of the two- vs. three-dimensional canopy architectures developed as single leader (SSA vs. TSA) and multiple leader (UFO vs. KGB) training systems. The advantages of utilizing the natural light interception efficiencies and growth habit of sweet cherry in the simplified structure of UFO-style planar canopy architectures is expanding beyond sweet cherries to many other major trees fruits around the world as well.

Key words: *Prunus avium*, high density, canopy architecture, fruiting wall.

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