Intensive Orchard Systems: Improving Physiological Performance and Sweet Cherry Production Efficiency

Gregory Lang

Funding includes support from the USDA’s National Institute of Food and Agriculture Hatch projects #MICL01305 and #MICL02002
<table>
<thead>
<tr>
<th>Revolutionary Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>- <strong>Self-fertile cultivars</strong> (1980s-1990s: Stella, Lapins, Sweetheart, consistent fruit set and yields)</td>
</tr>
<tr>
<td>- <strong>Rain covers</strong> (1990s-2000s: no significant industry in UK, Norway without covers, reliable yields)</td>
</tr>
<tr>
<td>- <strong>Dwarfing, precocious rootstocks</strong> (2000s: <em>e.g.</em>, Netherlands industry +100% from 2001-11, labor efficiencies)</td>
</tr>
<tr>
<td>- <strong>Physiological canopy optimization</strong> (single- and multi-leader simplified tree architecture) (2010s: <em>i.e.</em>, orchard labor efficiencies and fruit quality management)</td>
</tr>
</tbody>
</table>
Physiological Factors for Optimizing Intensive Cherry Production Efficiency and Quality

**Water** (needed for photosynthesis, nutrient uptake, turgor pressure for optimal fruit size)
- Smaller root systems require more frequent delivery of small amounts of water

**Nutrients** (leaf size, photosynthesis, fruit flavor and firmness/texture)
- Smaller root systems require more frequent delivery of small amounts of nutrients
High frequency drip irrigation / fertigation
- Short applications 4 times per day (03:00, 09:00, 15:00, 21:00)
- Replacement of ET (evapotranspiration of previous day)
- 8 weeks of N and Ca (CaNO$_3$, 20 g/tree, beginning post-bloom)
- 4 weeks of K and B (KCl and Solubor, beginning pit-hardening)

High frequency irrigation / fertigation compensated for the reduced root-to-shoot ratio, **improving canopy growth ~80%, yield ~55%, and fruit size ~4%** (cumulative effects over 7 years of treatment)
Physiological Factors for Optimizing Intensive Cherry Production Efficiency and Quality

**Water** (needed for photosynthesis, nutrient uptake, turgor pressure for optimal fruit size)
- Smaller root systems require more frequent delivery of small amounts of water

**Nutrients** (leaf size, photosynthesis, fruit flavor and firmness/texture)
- Smaller root systems require more frequent delivery of small amounts of nutrients

**Photosynthesis** (fruit size, sweetness, yield)
- Light interception (carbon gain) is directly proportional to yield
- Shade (respiration, carbon loss) negatively affects fruit quality and long-term orchard productivity
Do Dwarfing Cherry Rootstocks Change Fruit-to-Leaf Ratio Effects?

Bing/Gi5 Crop Loads

1) Control: 84 fruit/m² LA
2) Thinned: 20 fruit/m² LA
3) No Crop

Results:
Increasing crop loads did not change single leaf or whole canopy photosynthesis.

Higher crop loads increased **fruit yield**, but decreased **fruit size, sugar, firmness, and tree growth.**
Sweet Cherry Fruit and Leaf Relationships: Gisela 5

Fruit size and sugar approached maximum levels around 210 to 250 cm² Leaf Area

2-3 shoot leaves per fruit or 4-8 spur leaves per fruit

Whiting and Lang, 2004 JASHS
A 12.0 g fruit required about 210-250 cm² LA.

\[ y = \frac{14.5x}{43.4} + x \]

\[ R^2 = 0.69 \]

Gi3, Gi5, Gi6 rootstocks and TSA, UFO, KGB tree training
Cherry Crop Load Management / Grapevines?

Nelson Shaulis / Cornell viticulturist (1960s)
Alain Carbonneau, Richard Smart, others

Pruning decisions to manage crop load:

Spur pruning:
# spurs per cordon
# buds per spur
2 clusters / bud =
A Precision Crop Load

Managed Leaf Area for High Quality Fruit, in balance
Precision Cropping: Simplifying Leaf Area and Fruit

Lang, 2000

UFO - LA:F Quantification, Crop Load Management
$^{13}\text{CO}_2$ Photosynthesis (Are All Leaves Created Equal?)

Marlene Ayala
What Is the Relative \( \text{Ps} \) Contribution of Each Leaf Population to Fruit?

<table>
<thead>
<tr>
<th>Fruit Growth Stage</th>
<th>Leaf Population</th>
<th>Fruit Spurs</th>
<th>Non-Fruit Spurs</th>
<th>Shoots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I (25 DAFB)</td>
<td></td>
<td>49</td>
<td></td>
<td></td>
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<tr>
<td>Stage II (40 DAFB)</td>
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<td>51</td>
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<tr>
<td>Stage III (44 DAFB)</td>
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<td></td>
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<tr>
<td>Stage III (56 DAFB)</td>
<td></td>
<td>44</td>
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<td></td>
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<tr>
<td>Stage III (75 DAFB)</td>
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*CO₂*
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**Spur leaves** provide 75-90% of the carbon to fruit throughout development; as new shoots elongate, they provide an increasing proportion of the carbon to fruit.
The higher the proportion of the fruit that is exposed to adequate sunlight, the more uniform will be fruit ripening, quality, and postharvest performance.

**Sun-exposed fruit** lose more water than shaded fruit, but this also drives the import of more sugar (and nutrients), promoting greater fruit growth overnight (compared to shaded fruit).

Fruit exposed to light tend to be higher in:
- sugars (improves flavor),
- overall dry matter and Ca (improves firmness and postharvest life), and
- color (especially for blush cherries like Rainier).
Sweet Cherry
Efficient Sunlight Interception:
Fibonacci Arrangement of Leaf Formation

Node Angle 137.5°
**Fibonacci Arrangement of Sweet Cherry Leaves:**
Optimizes light interception, Minimizes shade

**Evolutionary Strategy for Efficiency:** each leaf forms at the best position to intercept light, with minimal shading of the leaves below it.
Fibonacci Arrangement of Sweet Cherry Leaves:
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Evolutionary Strategy for Efficiency: each leaf forms at the best position to intercept light, with minimal shading of the leaves below it
Fibonacci Arrangement of Sweet Cherry Shoots
Moving from 2-Dimensional to 3-Dimensional Canopies

Each shoot follows the same pattern for light interception; Shade begins increasing due to the 3rd dimension of the canopy.
As the canopy develops further and increases in complexity, the potential for shade increases significantly, requiring pruning to optimize.
Potential for Shade in Orchard Canopy Architectures

- Central Leader
- Spindle
- Bush
Precision Cropping: Optimized Light Distribution

Lang, 2000

UFO Light Interception Uniformity, Shade Minimization
2-Dimensional UFO Canopy, Washington
2010 Sweet Cherry Training Systems Trial

KGB
TSA
SSA
UFO

Kym Green Bush
Tall Spindle Axe
Super Slender Axe
Upright Fruiting Offshoots

Rootstock Vigor:
- Gisela 3 – dwarfing
- Gisela 5 – semi-dwarfing
- Gisela 6 – semi-vigorous

NC-140
New Systems for Cherry Training

Download for free at: www.hrt.msu.edu/greg-lang

Available free for iPhones, iPads and Android phones and tablets
TALL SPINDLE AXE (TSA)

Like other spindle-type canopy training systems (e.g., the Vogel Central Leader, the Zahn Spindle), the Tall Spindle Axe (TSA) tree canopy is characterized by the sweet cherry tree’s natural forest growth habit of developing a central leader. However, the TSA modifies the natural branching habit, replacing annual tiers of four to five strong lateral branches with a continuously spiraled whorl of moderately vigorous lateral branches, preferably forming about 10 or more per year during canopy development, to ultimately form a conical “Christmas tree” shape. The system is further differentiated by two key concepts: 1) annual heading of lateral shoots to balance leaf-to-fruit ratios and future crop loads, and 2) annual renewal of the oldest fruiting branches so that the only permanent structure is the central leader.

The TSA is a training system well-suited for dwarfing to semi-vigorous rootstocks, or vigorous rootstocks on weak soils, since growth is comprised primarily of lateral shoots of moderate vigor borne on a single vertical leader.

STAGE: Third and subsequent growing seasons

**GOALS**

- First commercial harvest (mixed spur and shoot basal fruiting sites) in Year 3
- Complete 100 percent of the final leader height in Year 3. Lowest tertiary branches should fill 100 percent of the allotted orchard area per tree by Year 3
- Continue filling canopy fruiting volume with secondary and tertiary branches in Years 3 and 4

**SYSTEM DEVELOPMENT**

- Once the leader has reached its mature height, it should be headed back to a relatively weak lateral shoot just below the preferred mature height, either done at a delayed budbreak timing (4 to 6 weeks after budbreak) or postharvest (midsummer) to minimize regrowth (Figure 61).

- As fruiting branches reach 5-6 years old, the largest two or three should be cut back to a basal weak shoot, spur, or bud (if present), or approximately 8-inch stub from the leader, to stimulate fruiting branch replacement (Figures 62-63).

**SUMMARY**

The TSA system will produce relatively compact, freestanding trees that fruit precociously with good yields of high-quality fruit that can be picked mostly from the ground.
The Super Slender Axe (SSA) was developed as a modification of the spindle to gain greater control of tree growth. The SSA needs dwarfing and precocious rootstocks such as Gisela® 5 and Gisela® 3. In the case of low vigor sites or self-fertile varieties, it may be possible to use more vigorous precocious rootstocks, such as Gisela® 6 or Gisela® 12. Varieties with good vigor, upright growth habits, and the ability to produce lateral shoots are preferred. The most important characteristic for a suitable variety is the capacity to produce fruit on basal buds of 1-year-old shoots. The production habit of this system is significantly different from other systems. Instead of producing fruit on spurs with multiple small flower buds, SSA utilizes the solitary large flower buds at the base of 1-year-old shoots. This results in a favorable fruit/leaf ratio that yields very good fruit size and quality. The low production capacity per tree is compensated by the high planting density.

**Recommended Spacing**

<table>
<thead>
<tr>
<th>Between rows</th>
<th>10'</th>
</tr>
</thead>
<tbody>
<tr>
<td>on dwarfing or semi-dwarfing rootstocks, e.g., Gisela 3 or Gisela 5</td>
<td>11.5'</td>
</tr>
<tr>
<td>on semi-vigorous, precocious rootstock, e.g., Gisela 6 or Gisela 12</td>
<td>not recommended</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Between trees</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>dwarfing rootstock</td>
<td>20'</td>
</tr>
<tr>
<td>semi-vigorous rootstock</td>
<td>40'</td>
</tr>
</tbody>
</table>

**Training System: Super Slender Axe**

**Stage:** Second and subsequent growing seasons (con't)

- When fruiting feathers become too long, they can be removed with a short stub to promote renewal of shoots close to the leader (Figure 51).
- On SSA trees, flowering (Figure 52) and cropping (Figure 53) should occur primarily on basal buds of 1-year-old shoots throughout the life of the orchard.

**Summary**

The SSA training system produces a high-density orchard of central axis trees with short limbs and fruiting primarily on 1-year-old shoots. Renewal of nearly 100 percent of the fruiting units is accomplished with annual dormant pruning. All operations, such as pruning and harvest (approximately 80 percent), can be managed from the ground. A limitation of this system is the inability of specific cultivars to form fertile basal flower buds; therefore, this trait must be evaluated for each potential cultivar to be considered.
KYM GREEN BUSH (KGB)

The Kyn Green Bush (KGB) is the only system covered in this manual that creates a fully pedestrian orchard—one that can be harvested without ladders or platforms. Tree formation is easy and requires minimal labor; mature pruning is simple and follows a repeatable plan. Although most varieties grow and produce well with a KGB system, it is not recommended for non-spur type varieties such as ‘Regina’ and ‘Attila,’ which produce a significant proportion of fruit at the base of 1-year-old shoots. This wood is eliminated in the KGB system.

The establishment years of the KGB system are similar to the Spanish Bush (SB); however, once the structure is formed, the two systems diverge significantly. In the SB tree, all upright leaders are permanent and fruit is produced on small laterals that are renewed regularly. This contrasts with the KGB tree, where all vertical leaders eventually are renewed and the only permanent wood is the lower framework of the tree. The KGB utilizes vigorous or semi-vigorous rootstocks, and the number of vertical leaders established should be proportional to tree vigor.

**STAGE:** Third dormant season

**GOALS**

- Begin crop load management

**SYSTEM DEVELOPMENT**

- Leaders on moderately or highly productive varieties of semi-vigorous rootstocks and highly productive varieties of full-sized rootstocks must be tipped. Remove a quarter of the new growth to balance the leaf-area-to-fruit ratio and produce high-quality fruit. (Figure 8)
UPRIGHT FRUITING OFFSHOOTS (UFO)

The Upright Fruitings Offshoots (UFO) system was developed to:

1. Simplify training, pruning, and crop load management
2. Utilize the sweet cherry’s natural upright growth habit and manage vigor by establishing multiple vertical structural fruiting units (number of vertical units should be proportional to tree vigne)
3. Optimize input efficiencies (e.g., light, labor, agrochemicals) and achieve high, uniform light distribution to fruiting sites
4. Facilitate the adoption of orchard mechanization and automation technologies

At maturity, the UFO system yields a planar fruiting wall architecture that is precocious, productive, and simple to maintain. Each tree is comprised of a permanent single horizontal trunk (or cordon) from which renewable fruiting leaders are grown vertically. Fruit are borne predominantly on spurs but also at the base of 1-year-old shoots, all on vertical wood. The UFO system may be configured to a single vertical or dual angled (V, each plane 30 degrees off vertical) system, both requiring trellising (about five wires per plane). UFO training may be used to establish a pedestrian orchard, though higher yields in the single vertical wall UFO can be achieved by maintaining a tree height about 20 percent taller than the inter-row spacing.

Establishing the UFO system is straightforward with little to no pruning required at planting.

STAGE: First dormant season

- Promote uniformity in upright shoot growth
- Space and orient upright shoots uniformly to upper wires

STAGE: Second growing season

- Fill in horizontal gaps with upright shoots every 8 inches (UFO) or 4 inches (UFO-Y)
- Begin filling vertical space in fruiting wall by promoting balanced upright growth of 24–30 inches per shoot
- Harvest initial fruit along the horizontal scaffold or base or both of previous season vertical shoots

SYSTEM DEVELOPMENT

<table>
<thead>
<tr>
<th>GOALS</th>
<th>SYSTEM DEVELOPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin out weakest or most vigorous shoots if density exceeds one per approximately 8 inches (UFO) or approximately 4 inches (UFO-Y).</td>
<td>Where gaps on the horizontal trunk exist, impose bud activation techniques to upper facing buds to promote completion of vertical shoot formation.</td>
</tr>
<tr>
<td>Where possible, clip or tie shoots to the second wire (UFO) or to the dual second wires (UFO-Y, in an alternating pattern) as appropriate.</td>
<td>Tie or clip upright shoots to successive vertical (UFO) or angled (UFO-Y) trellis wires as growth allows (Figure 67).</td>
</tr>
<tr>
<td>Using thinning cuts, remove any shoots growing below horizontal from the main leader.</td>
<td>Using thinning cuts, remove any new shoots from below the first trellis wire.</td>
</tr>
<tr>
<td></td>
<td>In late spring, evaluate growth uniformity of new vertical shoots; head any excessively strong shoots to a stub of no more than 2 inches with several leaves to promote regrowth of each as new dual shoots to be more in balance with the existing moderate shoots.</td>
</tr>
<tr>
<td></td>
<td>In mid summer, remove excessively vigorous uprights with a thinning cut.</td>
</tr>
</tbody>
</table>

Figure 67
## NC140 Sweet Cherry Canopy Systems x Rootstock Trial

### 3-D vs. 2-D Fruiting Wall Architectures

<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
<th>Fruiting Zone Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kym Green Bush</td>
<td>KGB/Gi6: 2.0 m</td>
<td></td>
</tr>
<tr>
<td>Tall Spindle Axe</td>
<td>TSA/Gi5: 1.5 m</td>
<td></td>
</tr>
<tr>
<td>Super Slender Axe</td>
<td>SSA/Gi3: 0.65 m</td>
<td></td>
</tr>
<tr>
<td>Upright Fruiting Offshoots</td>
<td>UFO/Gi3: 0.25 m</td>
<td></td>
</tr>
</tbody>
</table>
2013 Annual Orchard Yields (Year 4)

KGB    SSA    TSA    UFO

SSA and Gi3 most precocious

2016-2018 Annual and Cumulative Orchard Yields (Years 7-9)

KGB    SSA    TSA    UFO

Preliminary data, not for publication
2013-2014 Annual and Cumulative Orchard Yields (Years 4-5)

KGB
SSA
TSA
UFO

KGB and Gi6 least precocious

Preliminary data, not for publication

2016-2018 Annual and Cumulative Orchard Yields (Years 7-9)

KGB
SSA
TSA
UFO

Preliminary data, not for publication
Annual/Cumulative Yields (Years 4-6)  TSA, UFO, and Gi3 most productive

KGB  SSA  TSA  UFO

Preliminary data, not for publication

2016-2018 Annual and Cumulative Orchard Yields (Years 7-9)

KGB  SSA  TSA  UFO

Preliminary data, not for publication
2013-2015 Annual and Cumulative Orchard Yields (Years 4-6)

- KGB
- SSA
- TSA
- UFO

2016 Annual Orchard Yields (Year 7)

- KGB
- SSA
- TSA
- UFO

UFO on Gi3 most productive

Preliminary data, not for publication
2013-2015 Annual and Cumulative Orchard Yields (Years 4-6)

- KGB
- SSA
- TSA
- UFO

Preliminary data, not for publication

2016-2017 Annual and Cumulative Orchard Yields (Years 7-8)

- UFO and SSA on Gi3 most productive, followed by KGB/Gi3 and UFO/Gi5

Preliminary data, not for publication
2013-2015 Annual and Cumulative Orchard Yields (Years 4-6)

- KGB
- SSA
- TSA
- UFO

Preliminary data, not for publication

2016-2018 Annual and Cumulative Orchard Yields (Years 7-9)

- KGB
- SSA
- TSA
- UFO

KGB/Gi3 and UFO/Gi5 most productive

Preliminary data, not for publication
2013-2018 Annual and Cumulative Orchard Yields (Years 4-9)

Preliminary data, not for publication
NC140 Sweet Cherry Rootstock x Canopy Architecture Trial Sites (13 Sites Planted in 2010)

- **Cultivar: Skeena**
  - Summerland, BC (Denise Neilsen, Tom Forge)
  - Kentville, Nova Scotia (Suzanne Blatt)

- **Cultivar: Benton**
  - Clarksville, Michigan (Greg Lang)

- **Cultivar: Regina**
  - Geneva, NY (Jaume Lordan)
  - Hudson Valley, NY (Gemma Reig)
<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Rootstock</th>
<th>KGB</th>
<th>TSA</th>
<th>UFO</th>
<th>SSA</th>
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<tbody>
<tr>
<td>Skeena</td>
<td>Gi3</td>
<td>85</td>
<td>124</td>
<td>177</td>
<td>-</td>
</tr>
<tr>
<td>(British Columbia, Canada)</td>
<td>Gi5</td>
<td>79</td>
<td>100</td>
<td>170</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Gi6</td>
<td>68</td>
<td>74</td>
<td>114</td>
<td>-</td>
</tr>
<tr>
<td>Skeena</td>
<td>Gi3</td>
<td>20</td>
<td>26</td>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td>(Nova Scotia, Canada)</td>
<td>Gi5</td>
<td>26</td>
<td>37</td>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Gi6</td>
<td>24</td>
<td>31</td>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td>Benton</td>
<td>Gi3</td>
<td>33</td>
<td>33</td>
<td>50</td>
<td>28</td>
</tr>
<tr>
<td>(Michigan, USA)</td>
<td>Gi5</td>
<td>20</td>
<td>24</td>
<td>33</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Gi6</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Regina</td>
<td>Gi3</td>
<td>11</td>
<td>22</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>(New York, USA)</td>
<td>Gi5</td>
<td>11</td>
<td>31</td>
<td>31</td>
<td>22</td>
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<tr>
<td></td>
<td>Gi6</td>
<td>9</td>
<td>22</td>
<td>13</td>
<td>15</td>
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Rootstock and Canopy Architecture Effects on Harvest Labor Efficiency (min/kg) Michigan (2015)

<table>
<thead>
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<th>TSA</th>
<th>SSA</th>
<th>UFO</th>
</tr>
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<tbody>
<tr>
<td>Gi3</td>
<td>4.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gi5</td>
<td>4.8</td>
<td>4.6</td>
<td></td>
<td>4.4</td>
</tr>
<tr>
<td>Gi6</td>
<td>5.5</td>
<td></td>
<td>6.2</td>
<td></td>
</tr>
</tbody>
</table>

Fruit Picking Rate (min/kg): [+5%] [+39%] [+10%]
Mechanized Platforms for Safer, More Efficient Labor for Pruning and Harvest
Simplified canopy for mechanized pruning and/or thinning

Photo Courtesy of Mark and Ines Hanrahan
Mechanical Pruning / Hedging
UFO New Zealand (100+ ha)
V-UFO Washington
Y-UFO and UFO (Chile) on CAB6P Rootstock
28,565 upright leaders/ha, 20 cm spacing, alternating trees

Skeena/Gi5: 1.2, 1.8, or 2.4 m tree spacing
6, 9, or 12 upright leaders / tree

Santina/Gi6: 1.6, 2.2, or 2.8 m tree spacing
8, 11, or 14 upright leaders / tree

Tree + Berm Height 4.0 m

Orchard Platform

1.75 m

Upright Length

3.25 m

0.8 m

0.5 m

0.25 m