Planning A Technology-Ready Orchard to Sustain Efficiency and Profitability for the Next 25 Years

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MSU Cherry Research

The Task: Channeling Tree Growth Into Highly Efficient, Technology-Ready, Compact Orchards

Planning a Profitable, Efficient, Technology-Ready Sustainable Orchard

Planning a new orchard for the next 20-30 years depends on knowledge of several critical factors:

For near-term success:

1) Current market opportunities and labor economics

GOOD FRUIT GROWER

May 9, 2024

-Story and photos by Matt Milkovich

Apple growers facing a crisis in rising guest-worker wage rates

Michigan growers struggle to afford H-2A wage increases.

"Michigan's (H2A guest worker wage) rate has gone up 61 percent in the past decade.... If (these increasing wages and declining apple prices continues), many of those orchards won't be around much longer."

May 9, 2024

-Story by Matt Milkovich
Photo by T.J. Mullinax

"As New York's wages rise and its overtime threshold lowers, more tree fruit growers will rely on platforms and other technology to create efficiencies."

GOOD FRUIT GROWER

"Using a platform, six people can do the job of eight or nine people on ladders." - Kristen DeMarree, New York apple grower

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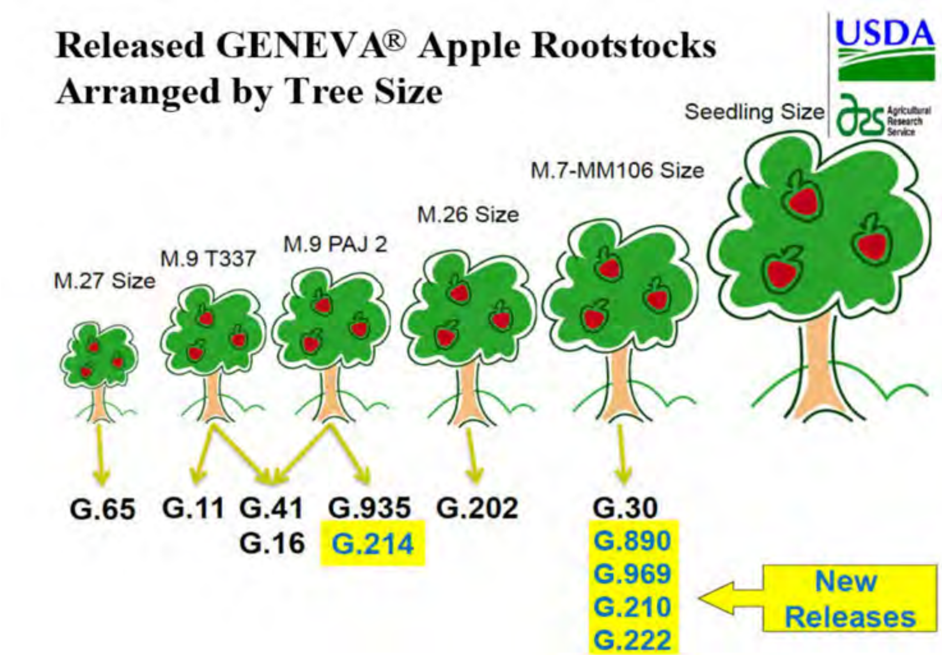

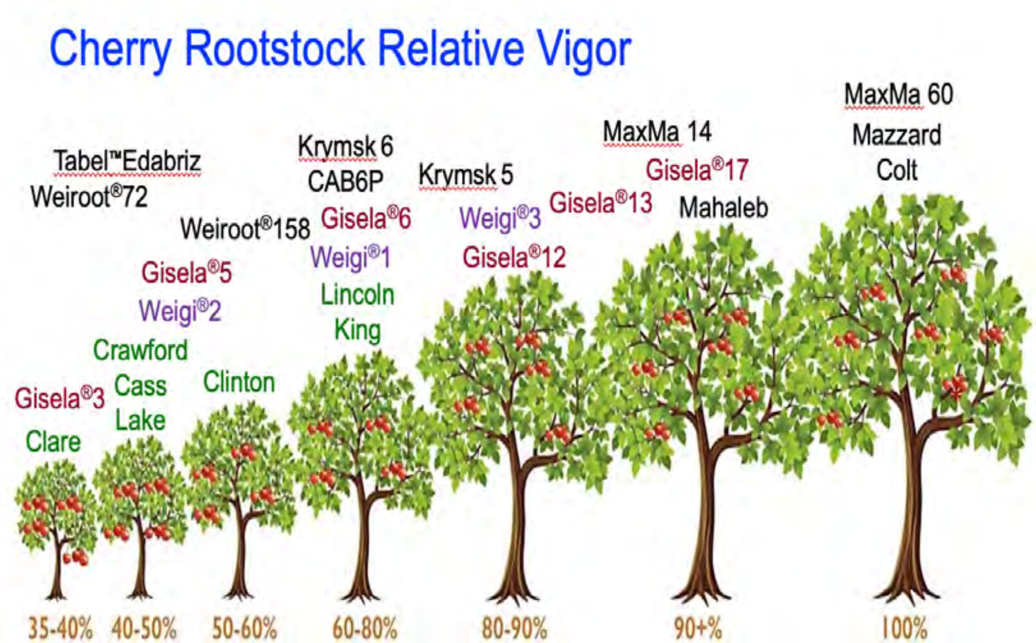

Modern Apple Production Trends

1) Vigor-controlling rootstocks

2) Narrow fruiting wall orchards that optimize light distribution and labor efficiency

25-Year U.S. Tree Fruit Production and Acreage Trends (5-year averages, 1995-2020)

Fruit	5-Year Period	U.S. Production			
		Tons x 1,000	% Change	Acres	% Change
Apple	1995	5,347		463,000	
	2020	5,463	+2%	308,000	-29%
Sweet Cherry	1995				
	2020				
Peach &	1995				
Nectarine	2020				

So, while apple plantings have declined significantly, orchards have become 31% more productive in the past 25 years

Emerging Cherry Production Trends

1) Vigor-controlling rootstocks

2) Planar, fruiting wall orchards that optimize light distribution and labor efficiency

UFO Cherries, Michigan State University

25-Year U.S. Tree Fruit Production and Acreage Trends (5-year averages, 1995-2020)

Fruit	5-Year Period	U.S. Production			
		Tons x 1,000	% Change	Acres	% Change
Apple	1995	5,347		463,000	
	2020	5,463	+2%	308,000	-29%
Sweet Cherry	1995	184		52,000	
	2020	362	+97%	88,000	+69%
Peach &	1995				
Nectarine	2020				

So, sweet cherry plantings have increased almost 100%, and orchards have become 28% more productive as well

Traditional Peach Production

1) Vigorous seedling rootstocks

2) Open vase complex tree canopies that diffuse rootstock vigor into multiple leaders

25-Year U.S. Tree Fruit Production and Acreage Trends (5-year averages, 1995-2020)

Fruit	5-Year Period	**U.S. Production**			
		Tons x 1,000	% Change	Acres	% Change
Apple	1995	5,347		463,000	
	2020	5,463	+2%	308,000	-29%
Sweet Cherry					
Peach &	1995	1,444		199,000	
Nectarine	2020	698	-52%	96,000	-52%

So, peach plantings have declined significantly, and peach orchard productivity has essentially remained unchanged over the past 25 years

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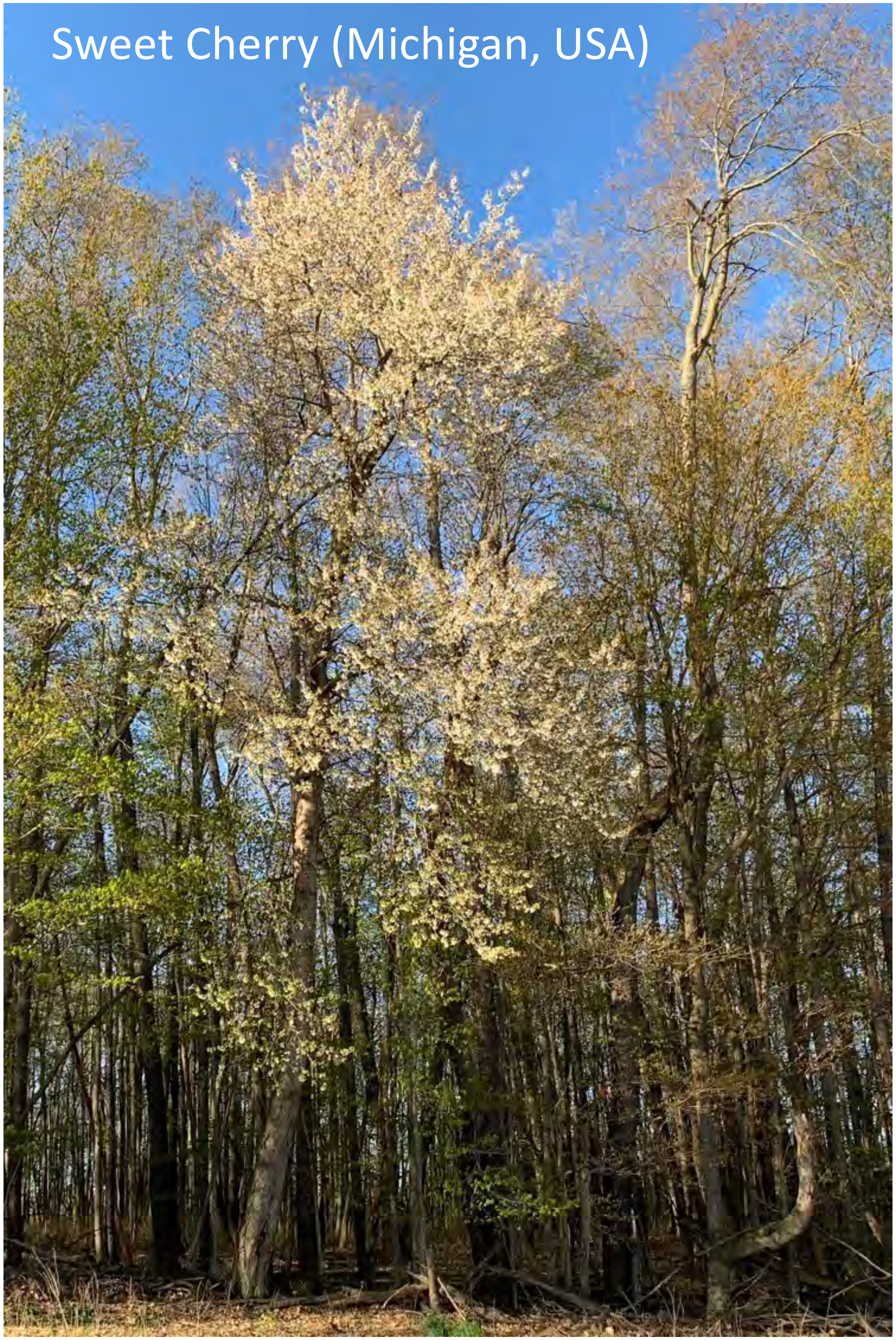
Light Interception

Photosynthesis

Fruit Thinning

Soil Nutrients

Pruning



Natural (evolutionary) growth habit of fruit trees

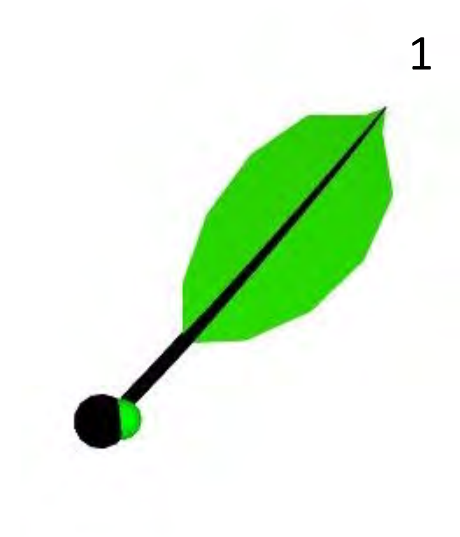
The impact of rootstock + training system (genetics + horticulture) on vigor control to change the "harvest index" – the production of *more* fruit biomass with *less* structural biomass – is one of the greatest advances in fruit production

Max. tree height *in nature*:

Peach, Plum, Apricot:	8 m
Apple:	12 m
Pear:	20 m
Sweet cherry:	40 m

Acrotonic Vigor, Apical Dominance, Leaf Phyllotaxy, and Light Interception Efficiency – *vertical* shoot orientation and the *Fibonacci arrangement* of sweet cherry leaves are growth traits for survival in the forest

Top View



Side View

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Acrotonic Vigor, Apical Dominance, Leaf Phyllotaxy, and Light Interception Efficiency – *vertical* shoot orientation and the *Fibonacci* *a*rrangement of sweet cherry leaves are growth traits for survival in the forest

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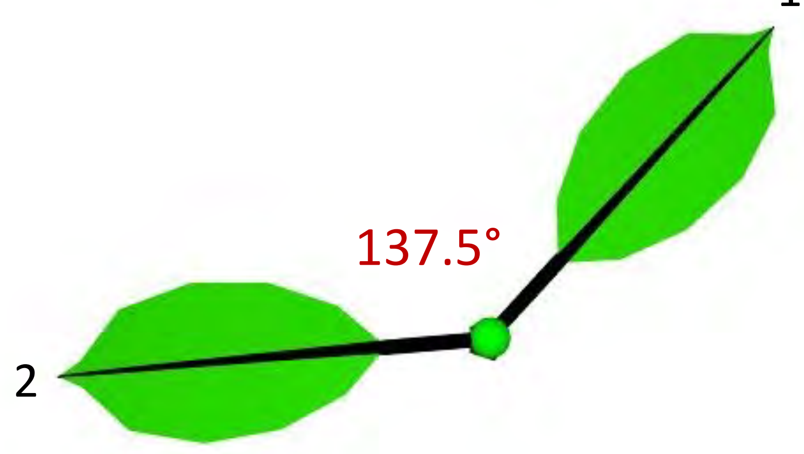

Side View

Evolutionary Strategy for Efficient Light Interception: each leaf forms at the optimal position, 137.5° from the previous leaf, to intercept light with minimal shading of the leaves below it

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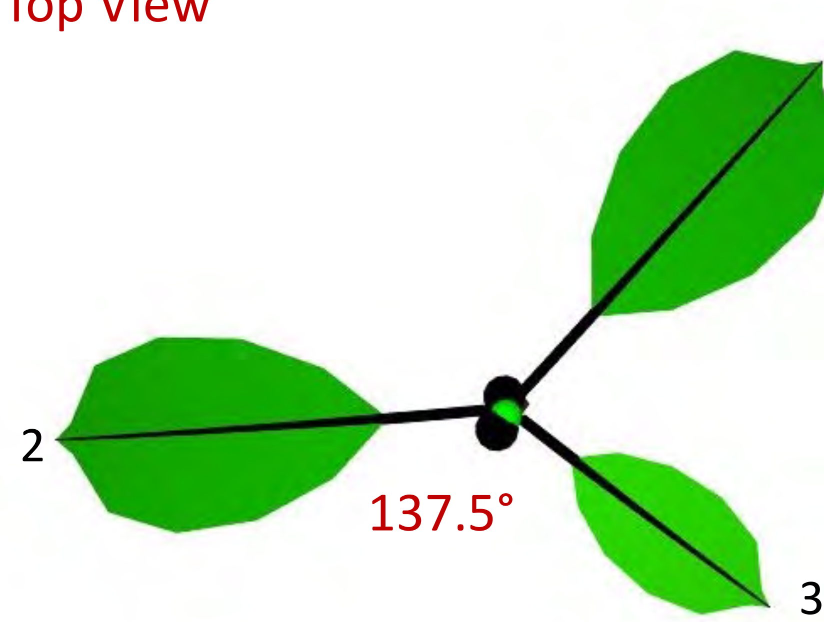

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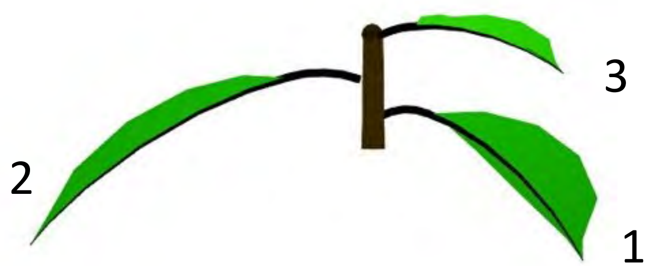

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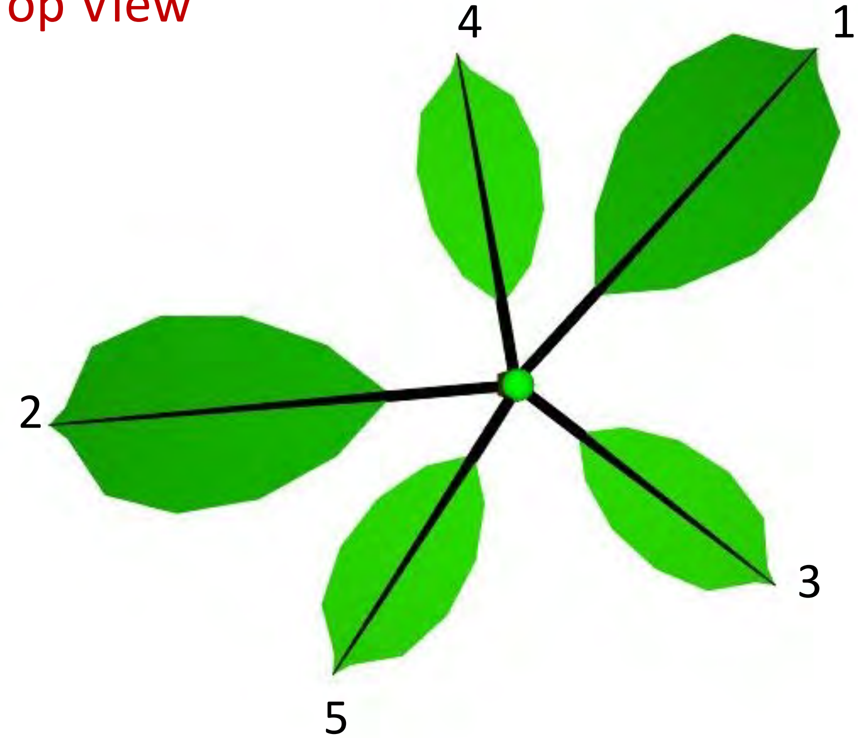

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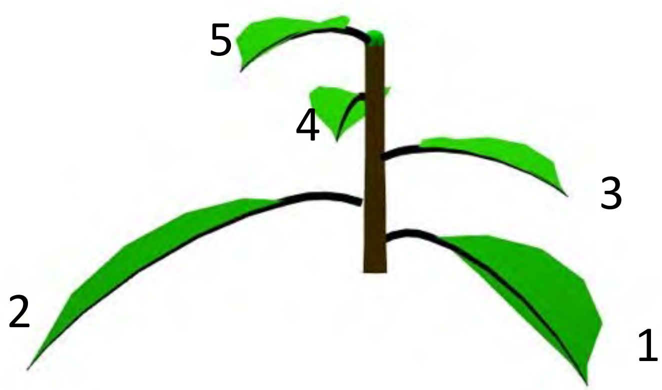

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vertical shoot orientation and the *Fibonacci arrangement* of sweet cherry leaves are growth traits for survival in the forest

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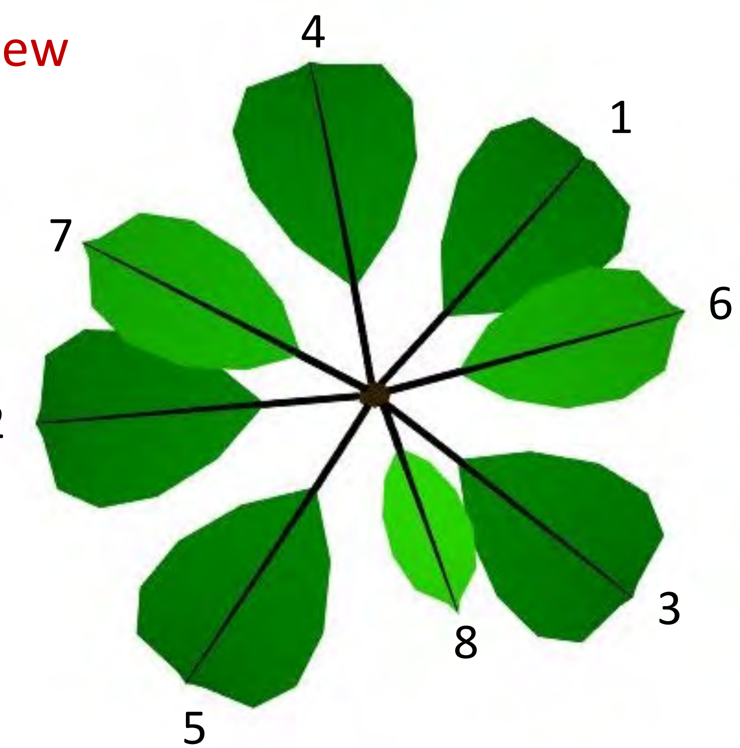
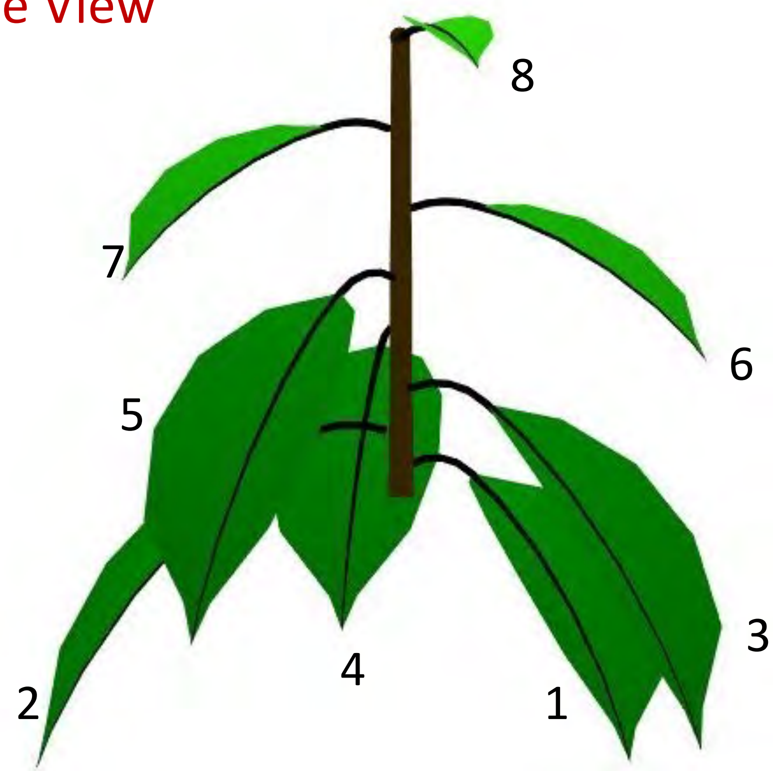


Side View



Evolutionary Strategy for Efficient Light Interception: each leaf forms at the optimal position, 137.5^o from the previous leaf, to intercept light with minimal shading of the leaves below it

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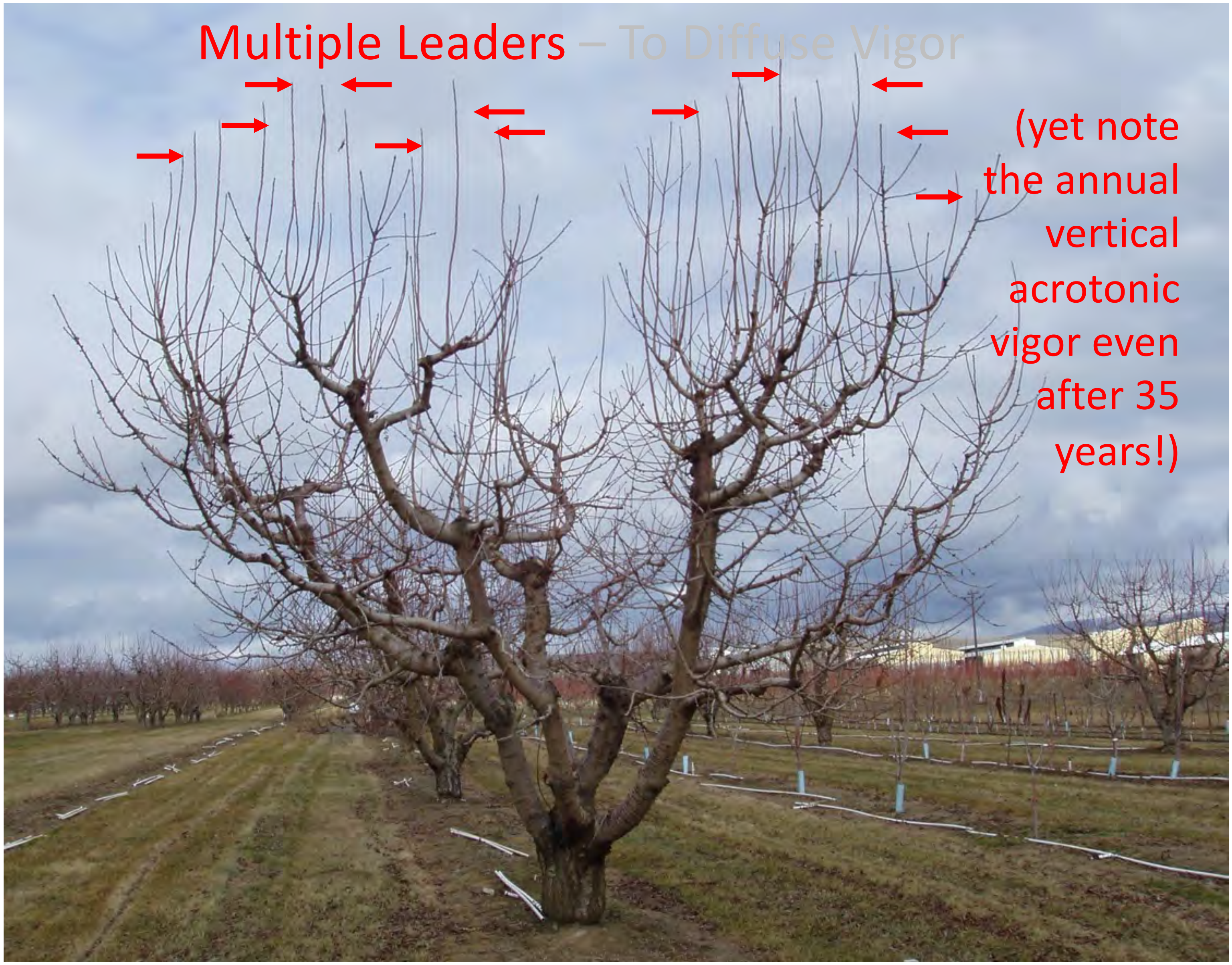
Evolutionary Traits to be Managed in the Orchard

Delayed Reproductive Maturity
(*genetic tools:* precocious rootstocks*)*

Vertical Growth and Apical Dominance
(*horticultural tools:* tying, bending, pruning, PGRs*)*

Acrotonic Vigor
(*genetic tools:* dwarfing rootstocks; *horticultural tools:* multiple leaders*)*



A 35 m tall tree is kept to 5 m by diffusing vigor into 5-6 leaders

Peach - Multiple Leader Vigor Diffusion

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As the number of leaders increases (and tree spacing is increased proportionally), *tree* vigor increases, but *leader* vigor decreases

	Trunk cross-sectional area (TCSA)							
Number of Leaders	cm^2	% single leader						
1	40.8	100						
2	48.4	119						
4	54.4	133						
6	60.4	148						
8	74.4	182						

+82%

Peach - Multiple Leader Vigor Diffusion

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As the number of leaders increases (and tree spacing is increased proportionally), *tree* vigor increases, but *leader* vigor decreases

	Trunk cross-sectional area (TCSA)		Tree (leader) height					
Number of Leaders	cm^2	% single leader	m	% single leader				
1	40.8	100	3.88	100				
2	48.4	119	3.66	94				
4	54.4	133	3.60	93				
6	60.4	148	2.98	77				
8	74.4	182	2.86	74				

+82%

-26%

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As the number of leaders increases (and tree spacing is increased proportionally), *tree* vigor increases, but *leader* vigor decreases

	Trunk cross-sectional area (TCSA)		Tree (leader) height		Leader cross-sectional area (LCSA at 1.5 m)			
Number of Leaders	cm^2	% single leader	m	% single leader	cm^2	% single leader		
1	40.8	100	3.88	100	14.7	100		
2	48.4	119	3.66	94	9.8	67		
4	54.4	133	3.60	93	7.7	52		
6	60.4	148	2.98	77	5.1	35		
8	74.4	182	2.86	74	4.4	30		

+82%

-26%

-70%

Peach - Multiple Leader Vigor Diffusion

MSU Stone Fruit Research

As the number of leaders increases (and tree spacing is increased proportionally), *tree* vigor increases, but *leader* vigor decreases

	Tree trunk cross-sectional area (TCSA at 25 cm)		Tree height		Leader cross-sectional area (LCSA at 1.5 m)		Lateral shoots per leader and canopy density	
Number of Leaders	cm^2	% single leader	m	% single leader	cm^2	% single leader	no.	no. / m of leader
1	40.8	100	3.88	100	14.7	100	72.7	18.7
2	48.4	119	3.66	94	9.8	67	71.3	19.4
4	54.4	133	3.60	93	7.7	52	60.1	16.7
6	60.4	148	2.98	77	5.1	35	50.4	16.9
8	74.4	182	2.86	74	4.4	30	45.2	15.8

+82% -26% -70%

MSU Stone Fruit Research

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2	48.4	119	3.66	94	9.8	67	71.3	19.4
4	54.4	133	3.60	93	7.7	52	[illegible]	[illegible]
6	60.4	148	2.98	77	5.1	35	[illegible]	[illegible]
8	74.4	182	2.86	74	4.4	30	45.2	15.8

+82%

-26%

-70%

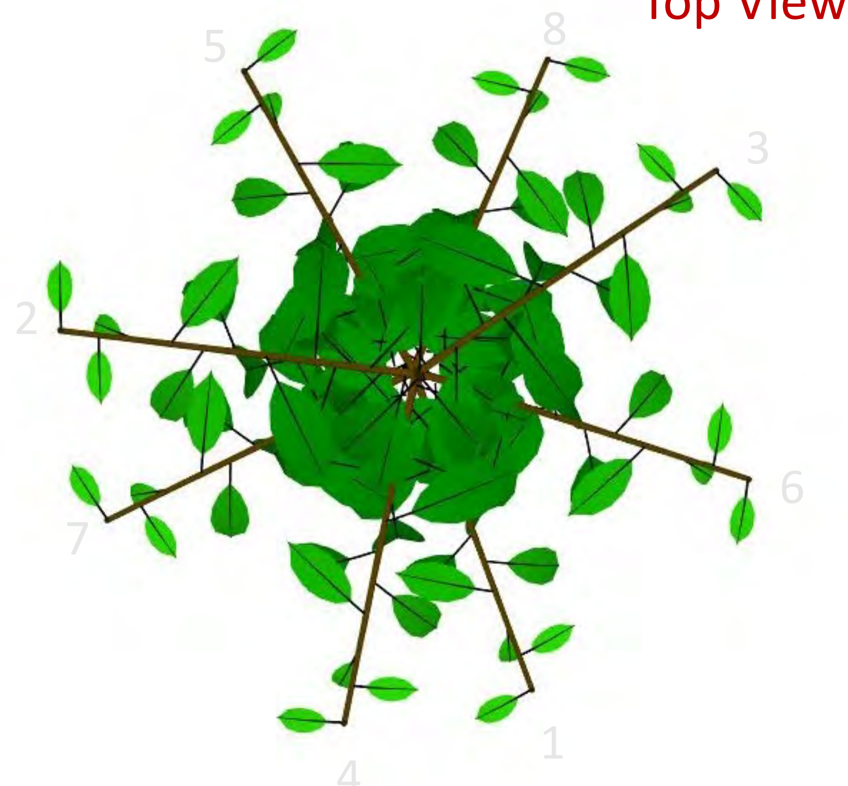
Lower density, better light, fewer suckers

Fibonacci Arrangement of Sweet Cherry Shoot Formation:

Moving from a *2-Dimensional* to *3-Dimensional* Canopy Complexity

Side View

Top View



Each shoot follows the same efficient pattern for light interception;
Shade begins increasing due to the “3rd“ dimension of the canopy

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Fibonacci Arrangement of Sweet Cherry Shoot Formation:

Moving from a *2-Dimensional* to *3-Dimensional* Canopy Complexity

Top View

Side View

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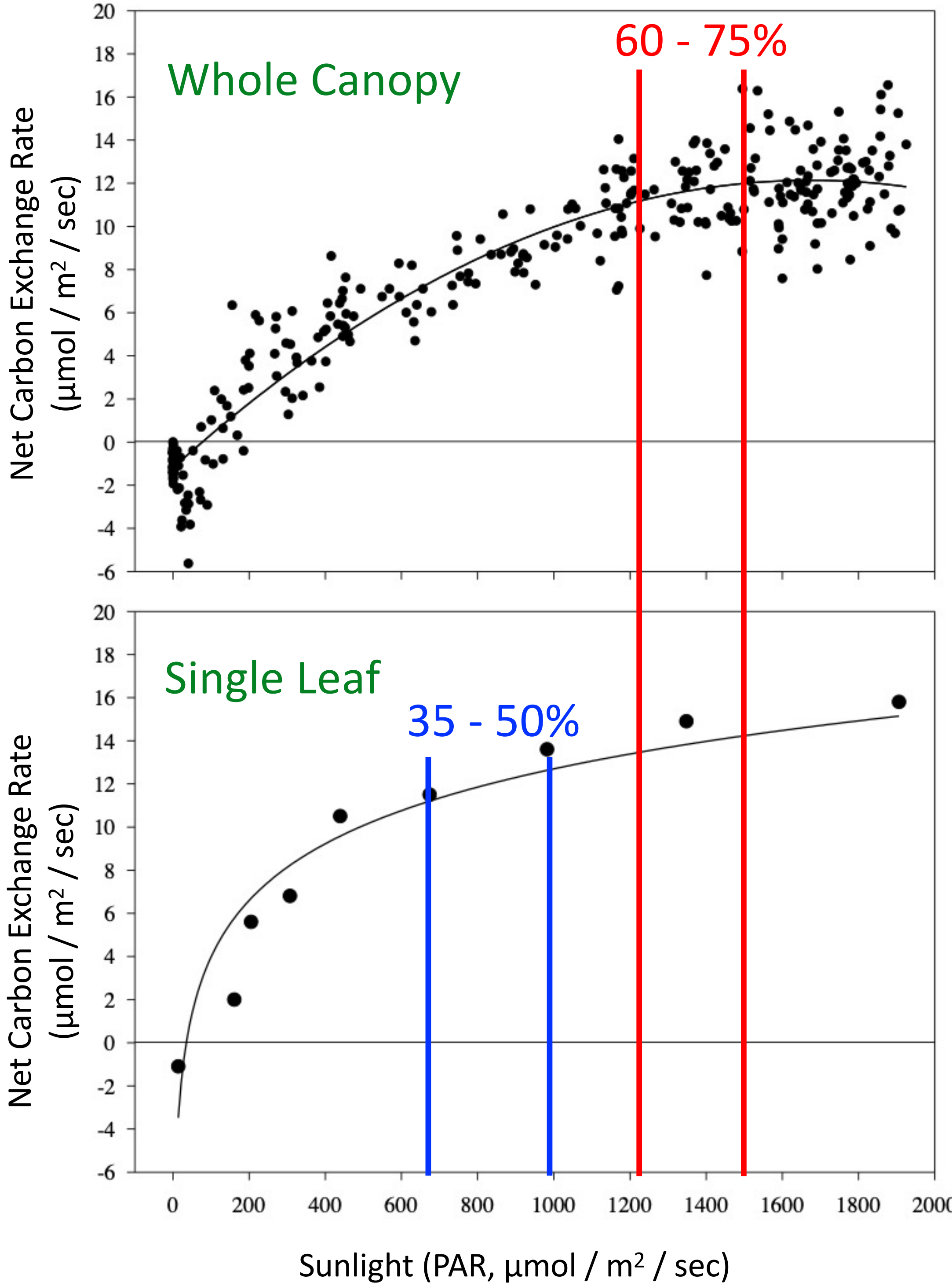
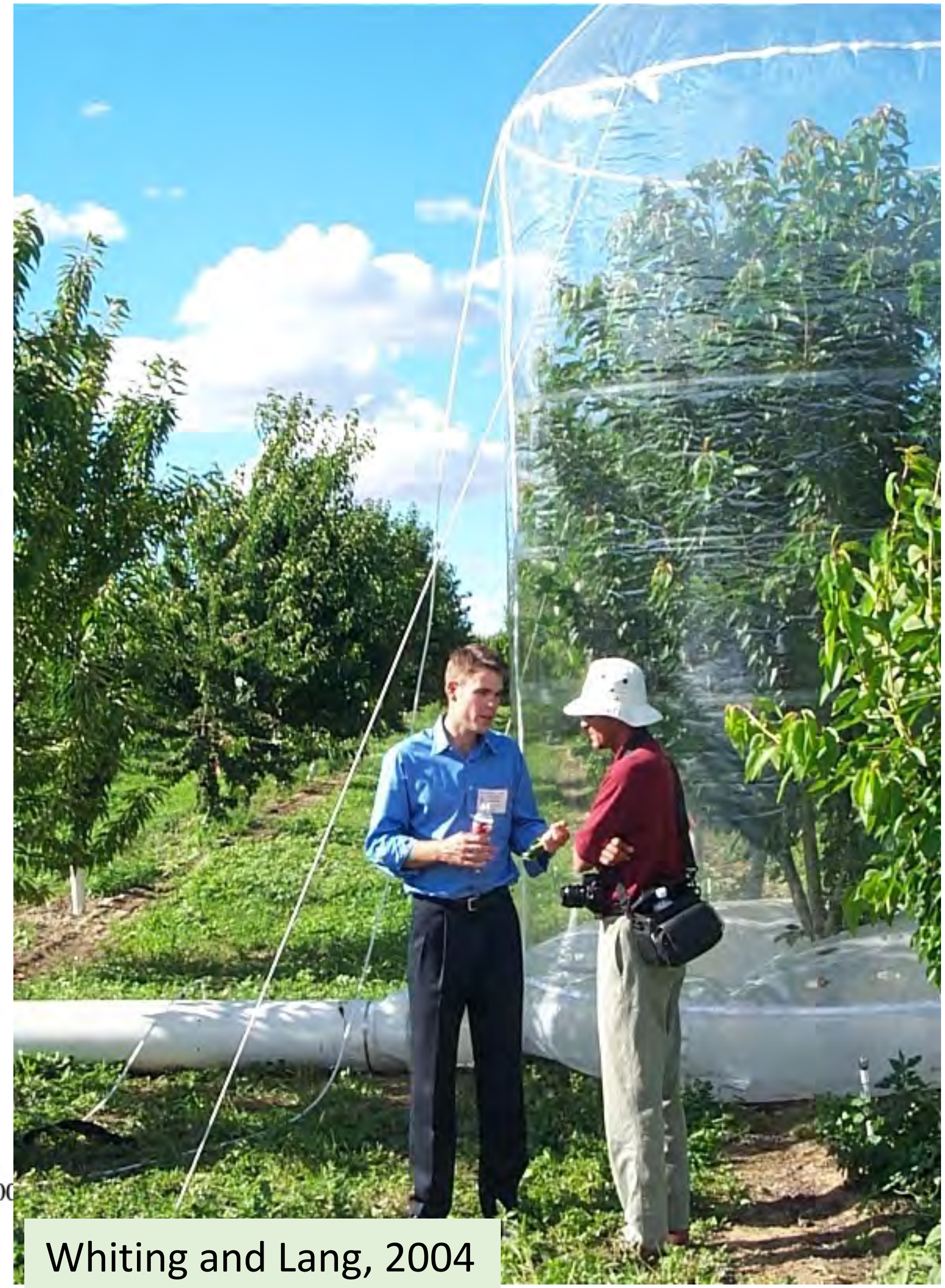
With increasing canopy complexity, the *efficiency* of light interception (and thus canopy photosynthesis) decreases, prompting the orchard management need for pruning intervention

Sunlight, Photosynthesis, and Tree Canopy Design

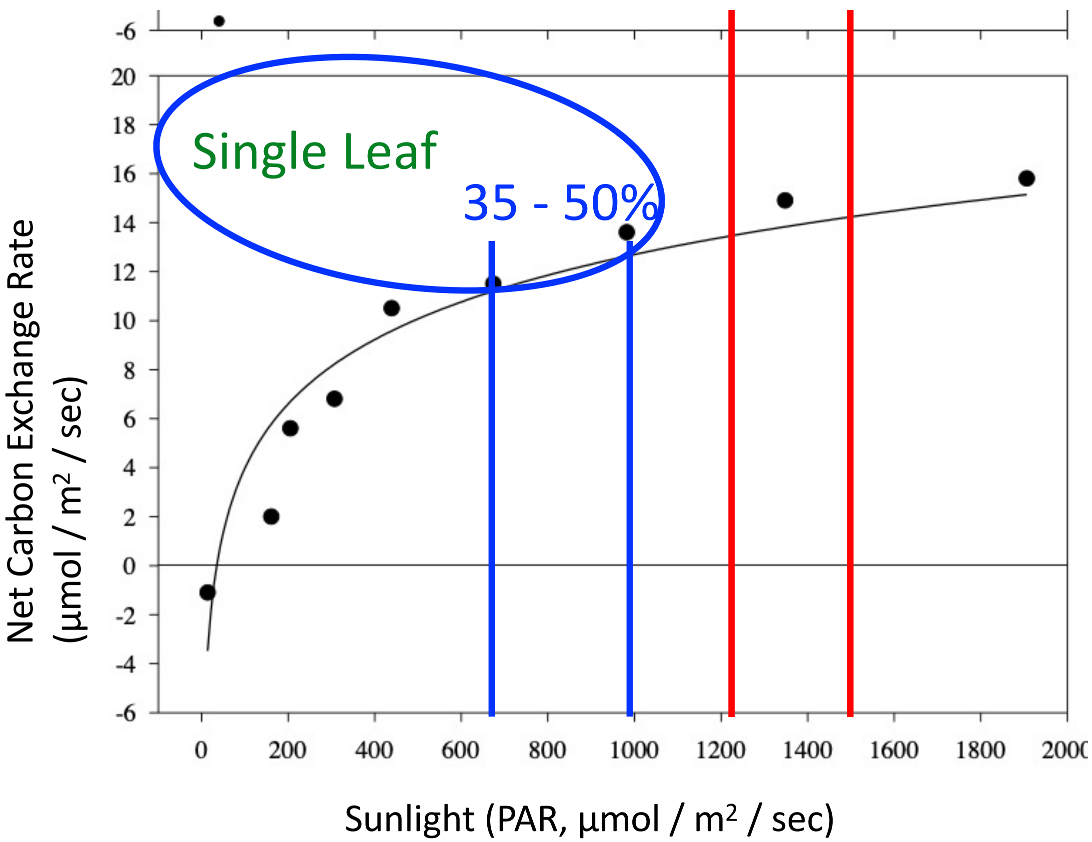




Whiting and Lang, 2004

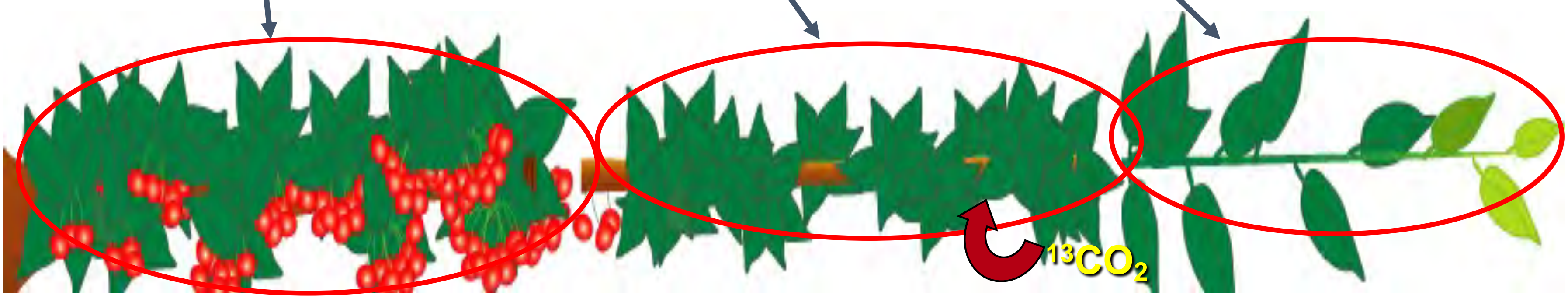
Sunlight, Photosynthesis, and Tree Canopy Design

Sun-lit single leaves are much more efficient than a whole 3-D canopy; Consequently, narrow 2-D canopy photosynthesis is more like a single leaf, optimizing overall canopy photosynthesis at lower levels of sunlight (e.g., under netting)



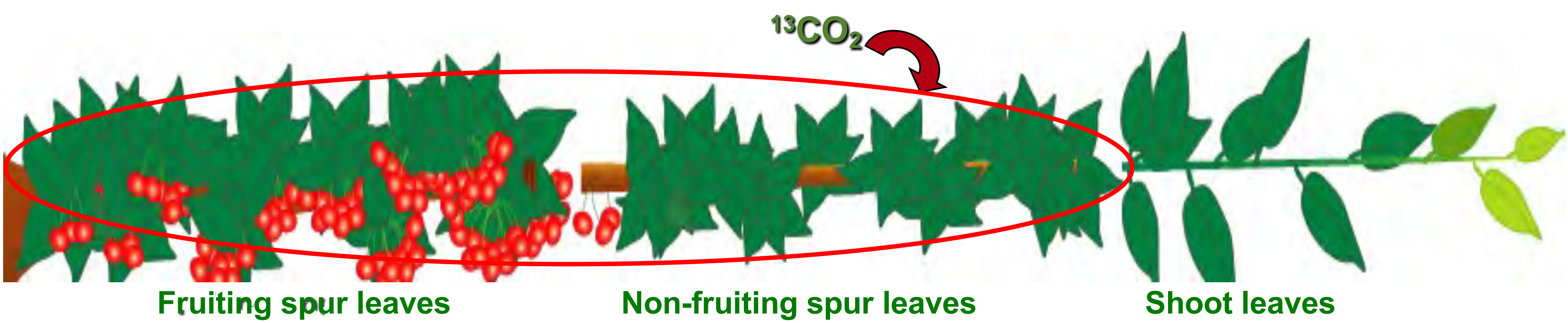
$^{13}CO_2$ Photosynthesis (Are All Leaves Created Equal?)

Marlene Ayala



What Is the Relative Ps Contribution of Each Leaf Population to Fruit?

	Leaf Populations		
Fruit Growth Stage	Fruit Spurs	Non-Fruit Spurs	Shoots
Stage I (25 DAFB)	49%	41%	90%
Stage II (40 DAFB)	51	30	
Stage III (44 DAFB)	54	31	80-85%
Stage III (56 DAFB)	44	38	
Stage III (75 DAFB)	47	28	



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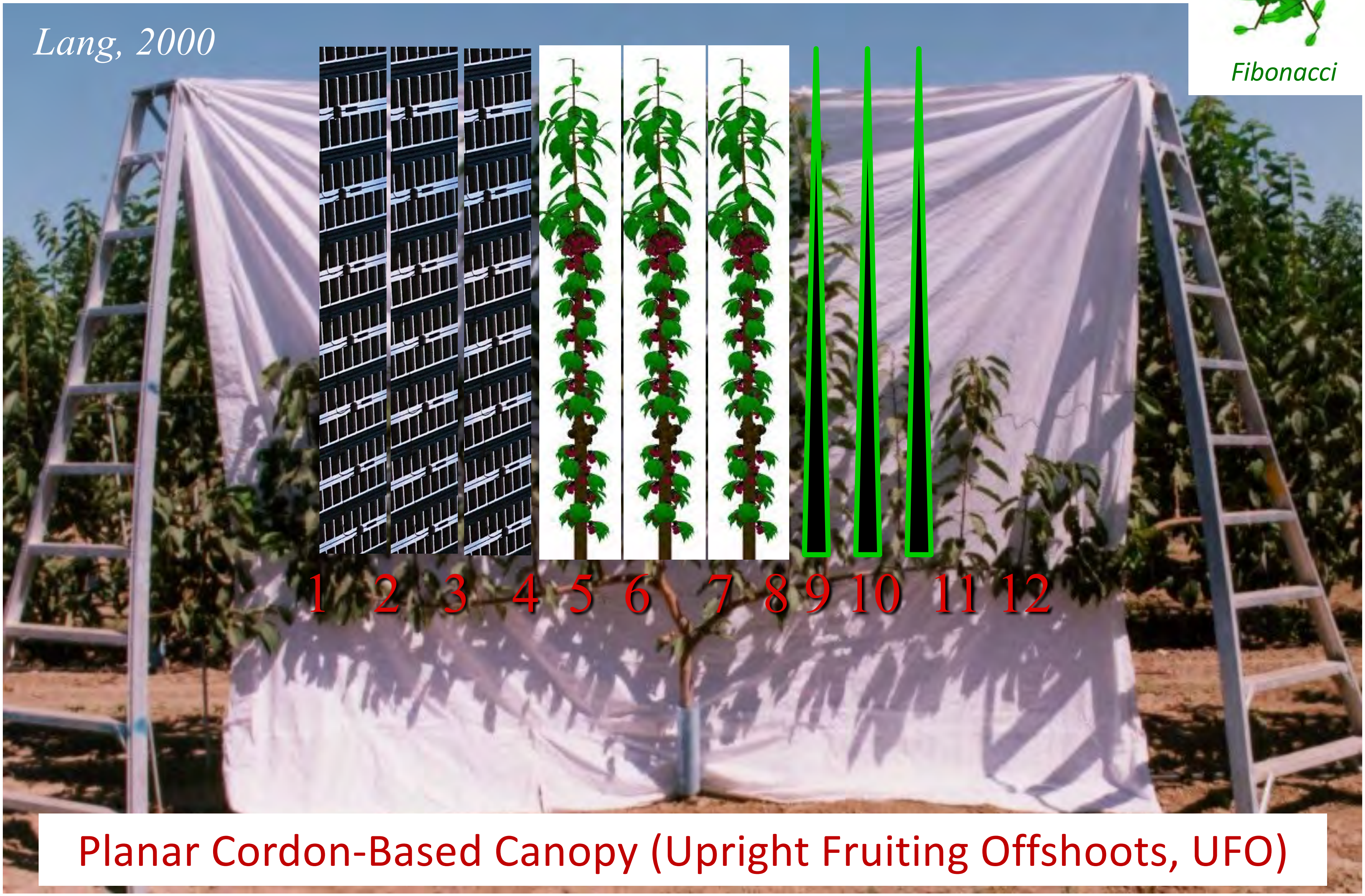
Fruit Growth Stage	*Leaf Populations* Fruit Spurs	Non-Fruit Spurs	Shoots
Stage I (25 DAFB)	49	41	10%
Stage II (40 DAFB)	51	30	19
Stage III (44 DAFB)	54	31	15
Stage III (56 DAFB)	44	38	18
Stage III (75 DAFB)	47	28	25

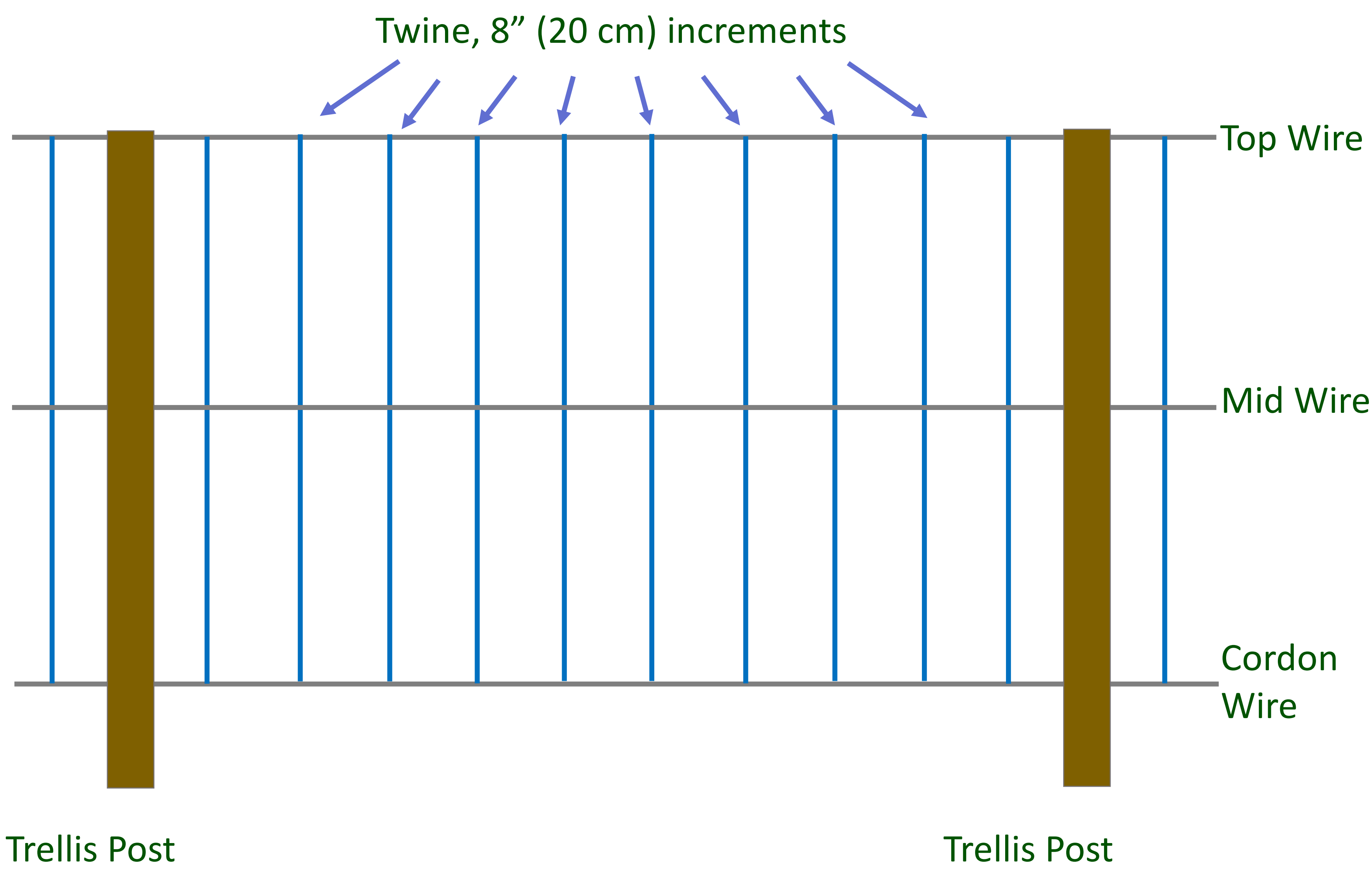
Optimize Light Interception Efficiency (minimize shade) and Light Distribution Uniformity to Spur Leaves



Fibonacci

Planar Cordon-Based Canopy (Upright Fruiting Offshoots, UFO)

Solar-Optimized Planar Canopy Training



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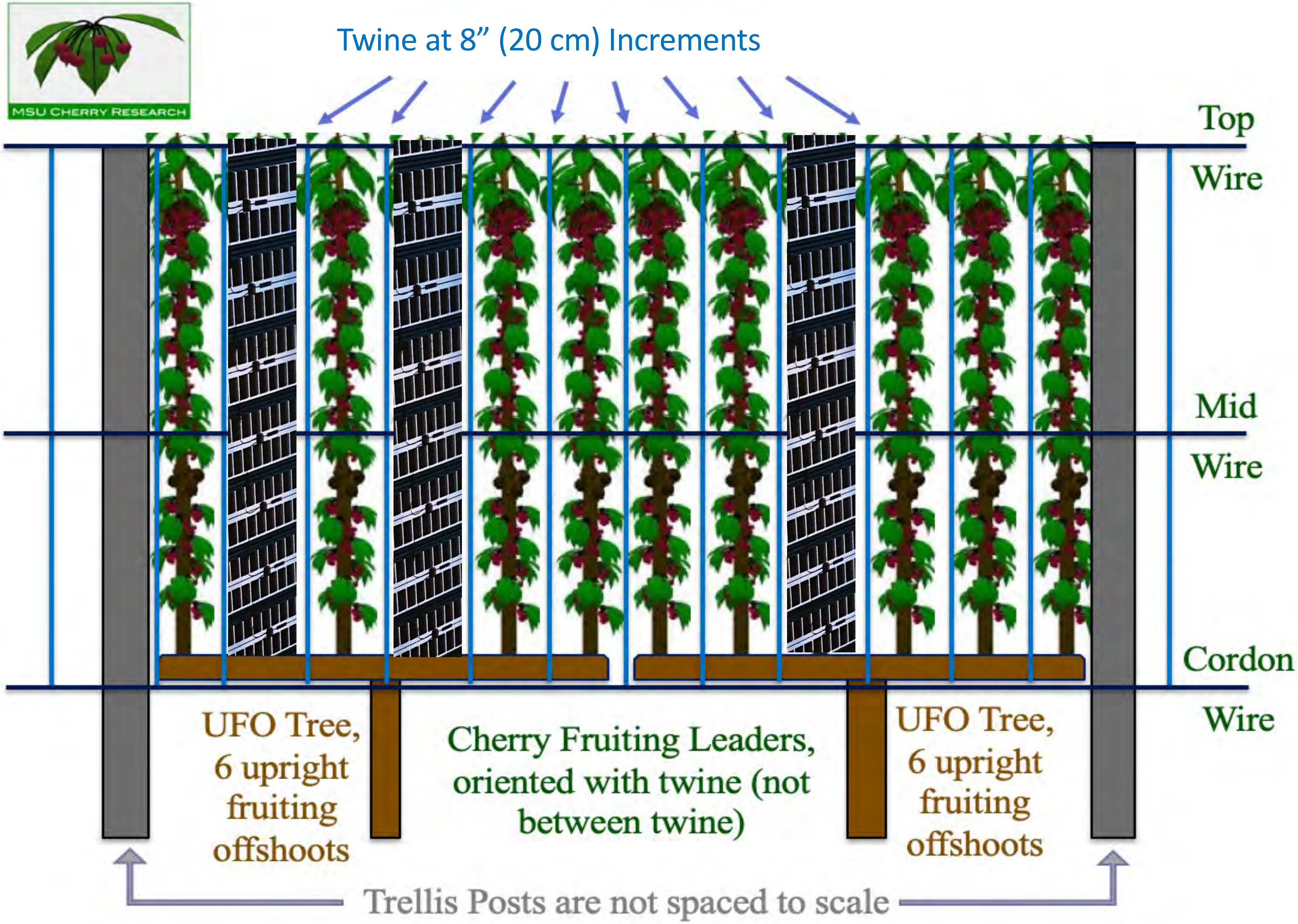


Narrow Planar (UFO) Sweet Cherry, *Michigan, USA*

Planar (UFO) Sweet Cherries, *Michigan, USA*

Planar (UFO) Sweet Cherries, *Michigan, USA*

UFO-style Planar Cordon-Trained (Guyot) Apples, Italy


Narrow Planar (UFO) Peaches, *Michigan, USA*

UFO-style Planar Cordon-Trained Pears (FOPS), New Zealand


Planar Dual Angled (V-UFO) Sweet Cherries, *Michigan, USA*

Planar (UFO) Sweet Cherries, *Washington, USA*

Planar Dual Angled (V-UFO) Sweet Cherries, *Washington, USA*

Planar Dual Angled (Y-UFO) Plums, Chile

Planar Dual Angled (Y-UFO) and Single UFO Sweet Cherries, *Chile*

Planar (UFO) Sweet Cherries, *New Zealand*

Planar (UFO) Peaches, *Tatura, Australia*

Planar Cordon-Trained (FOPS) Apples, New Zealand

Planar (UFO) Sweet Cherries, *British Columbia, Canada*

Dual Angled Planar (Y-UFO) Sweet Cherries, *British Columbia, Canada*

Planar (Espalier) Sweet Cherries, *New Zealand*

Planar Dual Angled (V-Espalier) Sweet Cherries, *Washington, USA*

Planar Dual Angled (V-Espalier) Sweet Cherries, *British Columbia, Canada*

Planar Dual Angled (V-Espalier) Apples, *Washington, USA*

Planar (Espalier) Apples, *New Zealand*

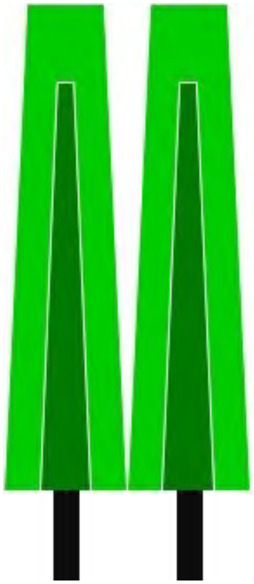
Planar (Bi-Axis SSA) Sweet Cherries, Italy

Mazzoni photo

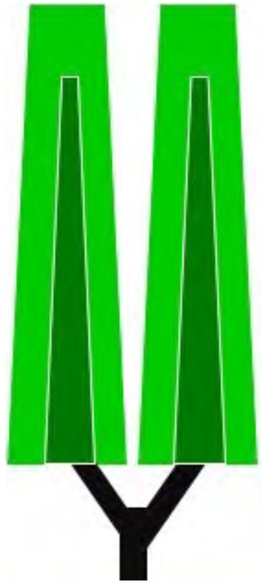
Planar (Bi-Axis SSA) Cherries, *Switzerland*

Mazzoni photo

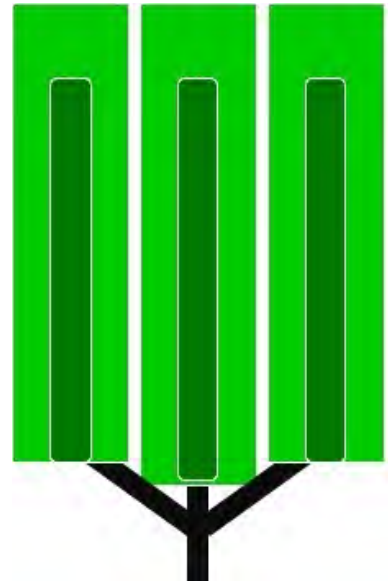
Planar Tree Fruit Canopies and Rootstock Guidelines



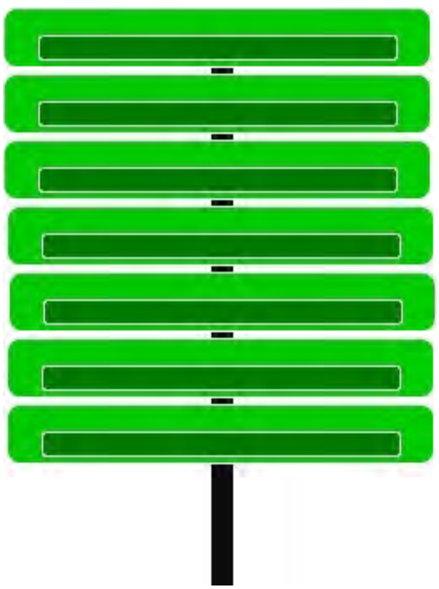
Single Leader, Dwarfing



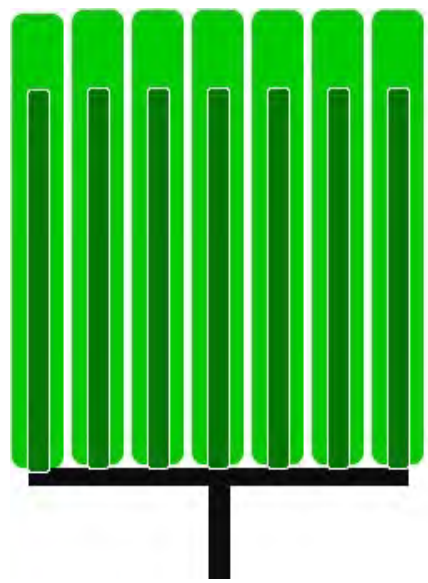
Dual Leader, Dwarfing to Semi-Dwarfing



3-4 Leaders, Semi-Dwarfing to Semi-Vigorous



Single Leader Espalier, Dwarfing to Semi-Vigorous



Multiple Leader Cordon (UFO), Dwarfing to Vigorous

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For near-term success:

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3) Physiological understanding, and horticultural manipulation, of fruit tree growth and fruiting habits

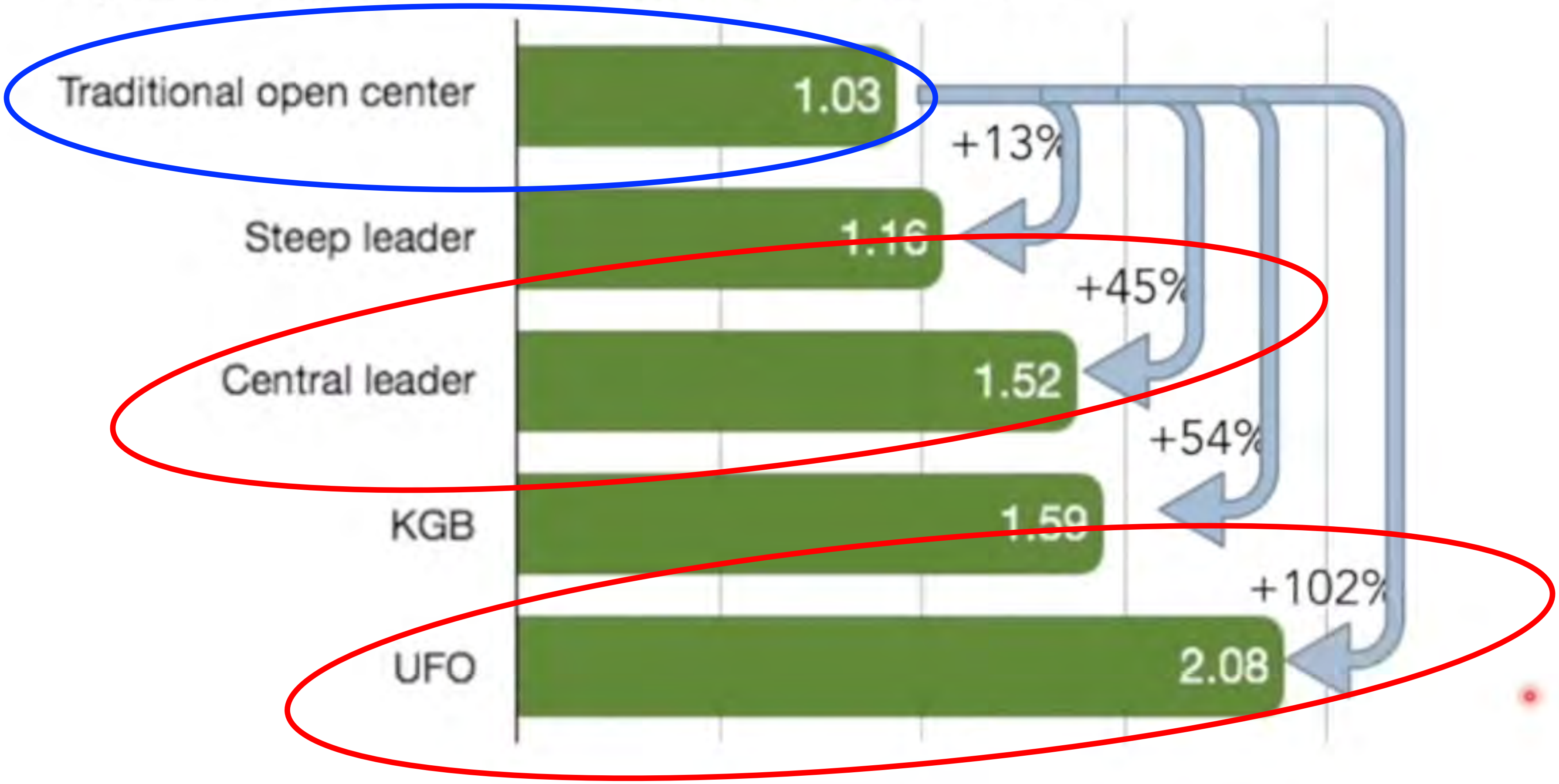
For long-term success, anticipation of:

4) Future labor costs, availability, and skills

Harvest efficiency (lbs/min)

- Same 4 pickers harvesting in 5 different commercial orchards

Ampatzidis Y. and M. Whiting, HortScience. 2013. 547-555.



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5) The potential impacts of climatic changes and extremes

Rain-covered UFO Cherries, *New Zealand*

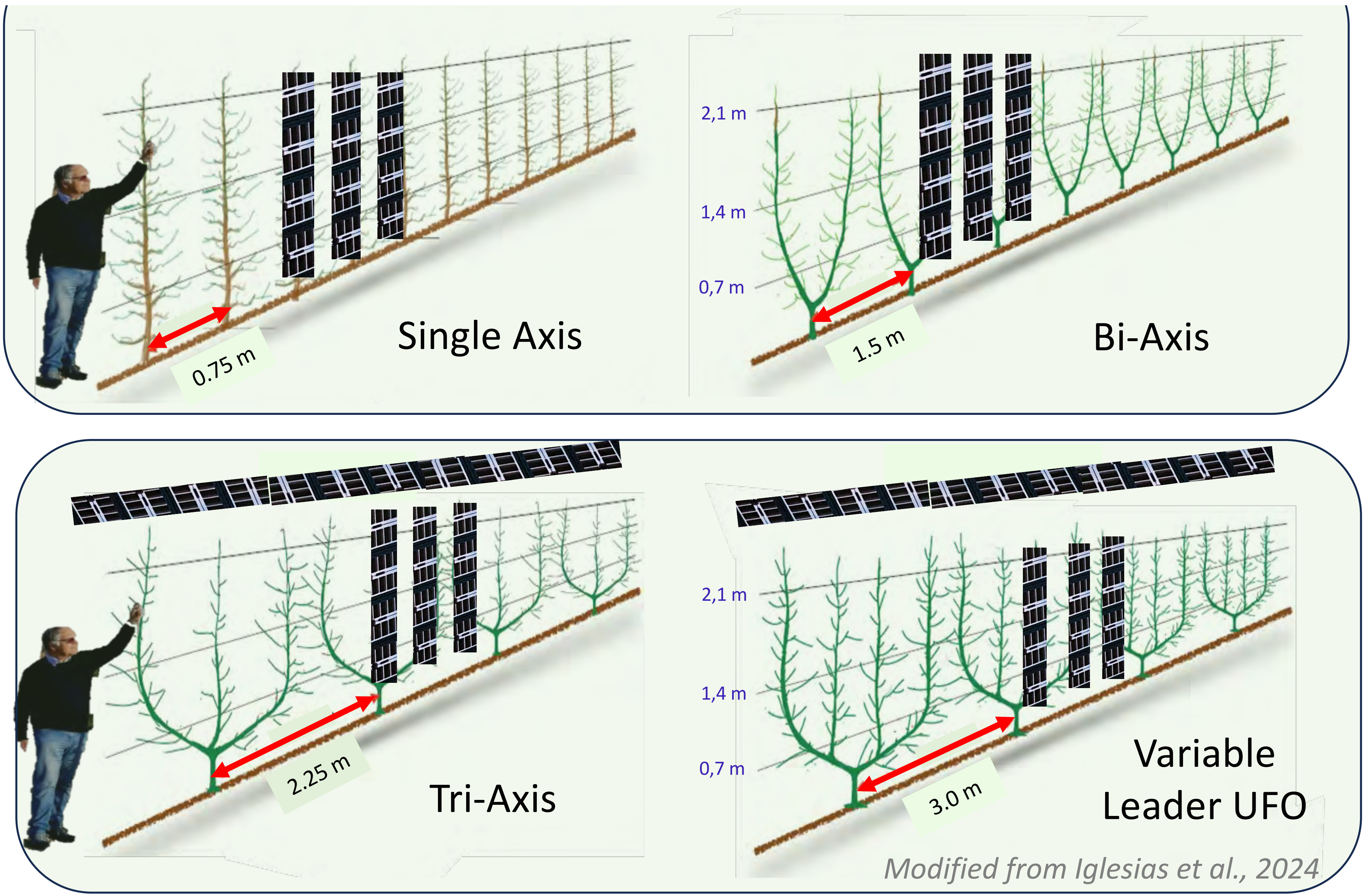
Rain-covered + Insect-netted SSA Cherries, *Italy*

Bird-netted UFO Cherries, *New Zealand*

Integrating fruit trees (nature's solar collectors that generate fruit) with agrivoltaics (solar panels that generate electricity)

Solar-Optimized Planar Canopy Training

Leader number/ha and row spacing are ***optimized and standardized***;
leader number/tree and tree spacing ***vary proportionally*** to rootstock-imparted vigor



Modified from Iglesias et al., 2024

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5) The potential impacts of climatic changes and extremes
6) Potential advances in orchard technologies


Mechanization of Summer
Pruning / Hedging

Mechanized Platforms - Safer, More Efficient for Labor


WSU Electrostatic Pollination
Photo Courtesy of Matt Whiting

Orchard Imaging/Data Acquisition Canopy Mapping Technologies

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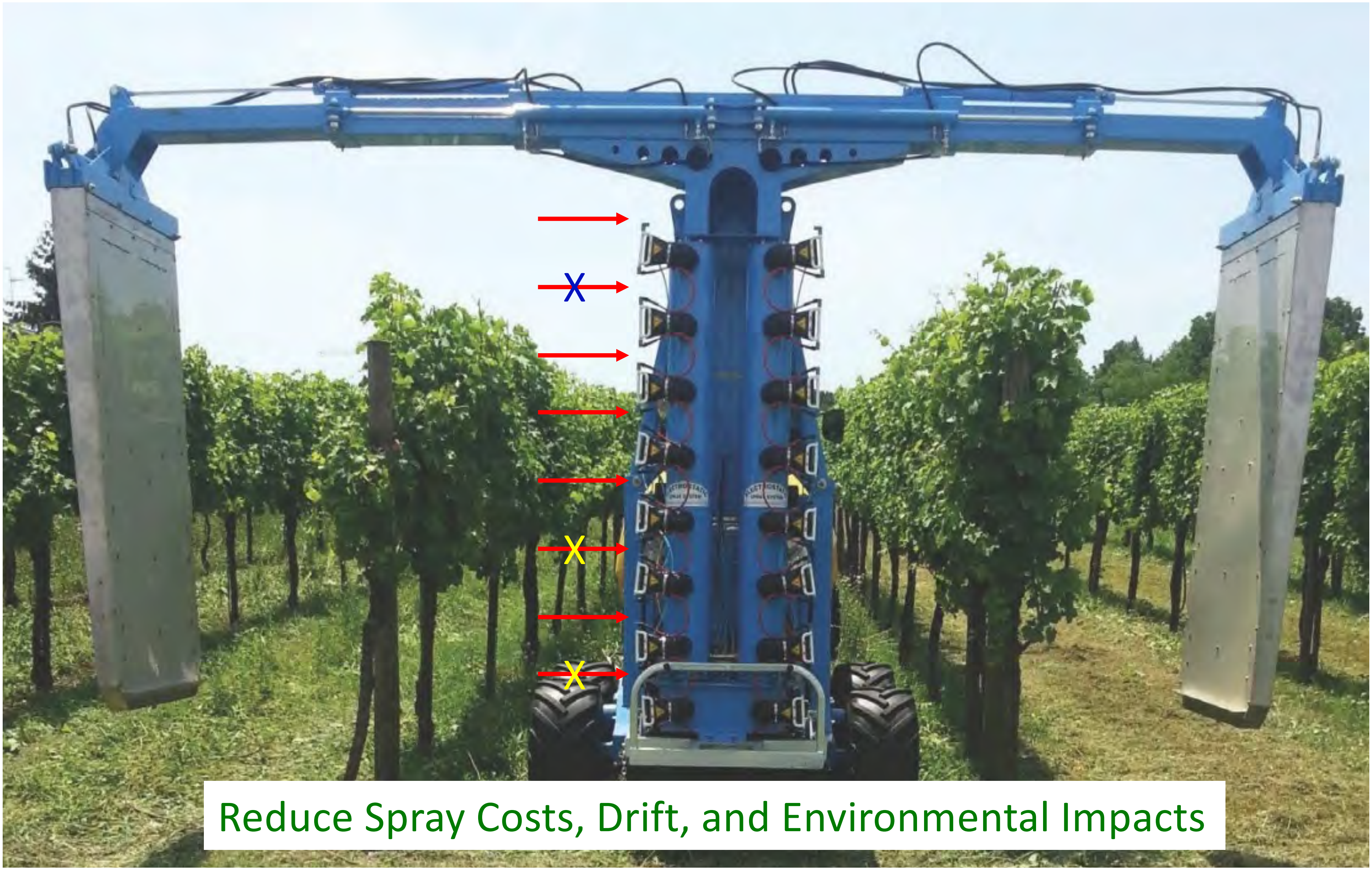
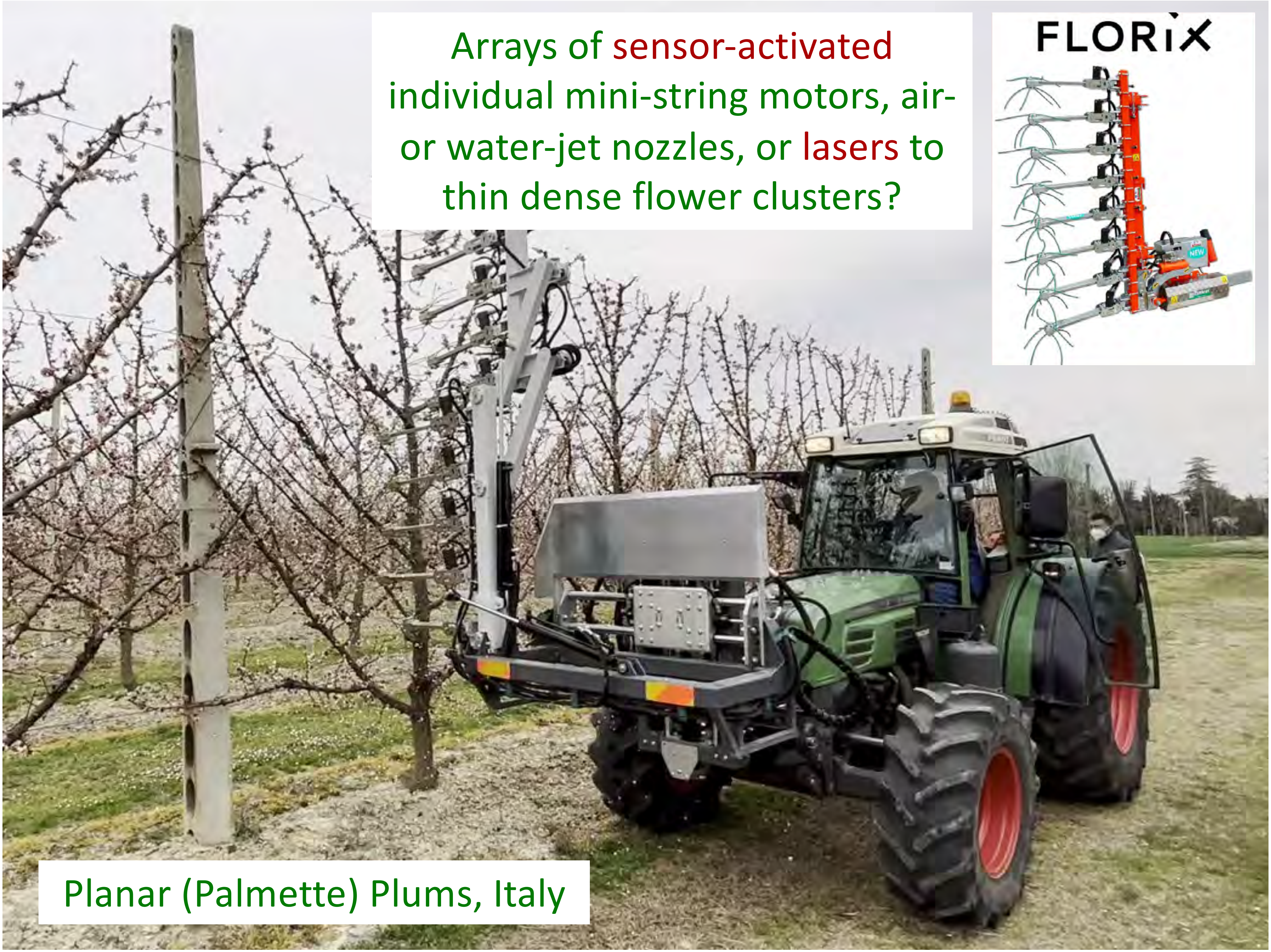
Precision Data-Mapped Canopy for Sensor-Activated Sprayer Efficiencies



Last 15 Years: Non-Selective Mechanical (Darwin) Thinning

Next 10 Years: Imaging/Sensor Data-Driven Precision



Arrays of sensor-activated individual mini-string motors, air- or water-jet nozzles, or lasers to thin dense flower clusters?

Planar (Palmette) Plums, Italy


MADE IN THE USA
DESIGNED IN SEATTLE, WA
BUILT IN DETROIT,MI
LASERWEEDER

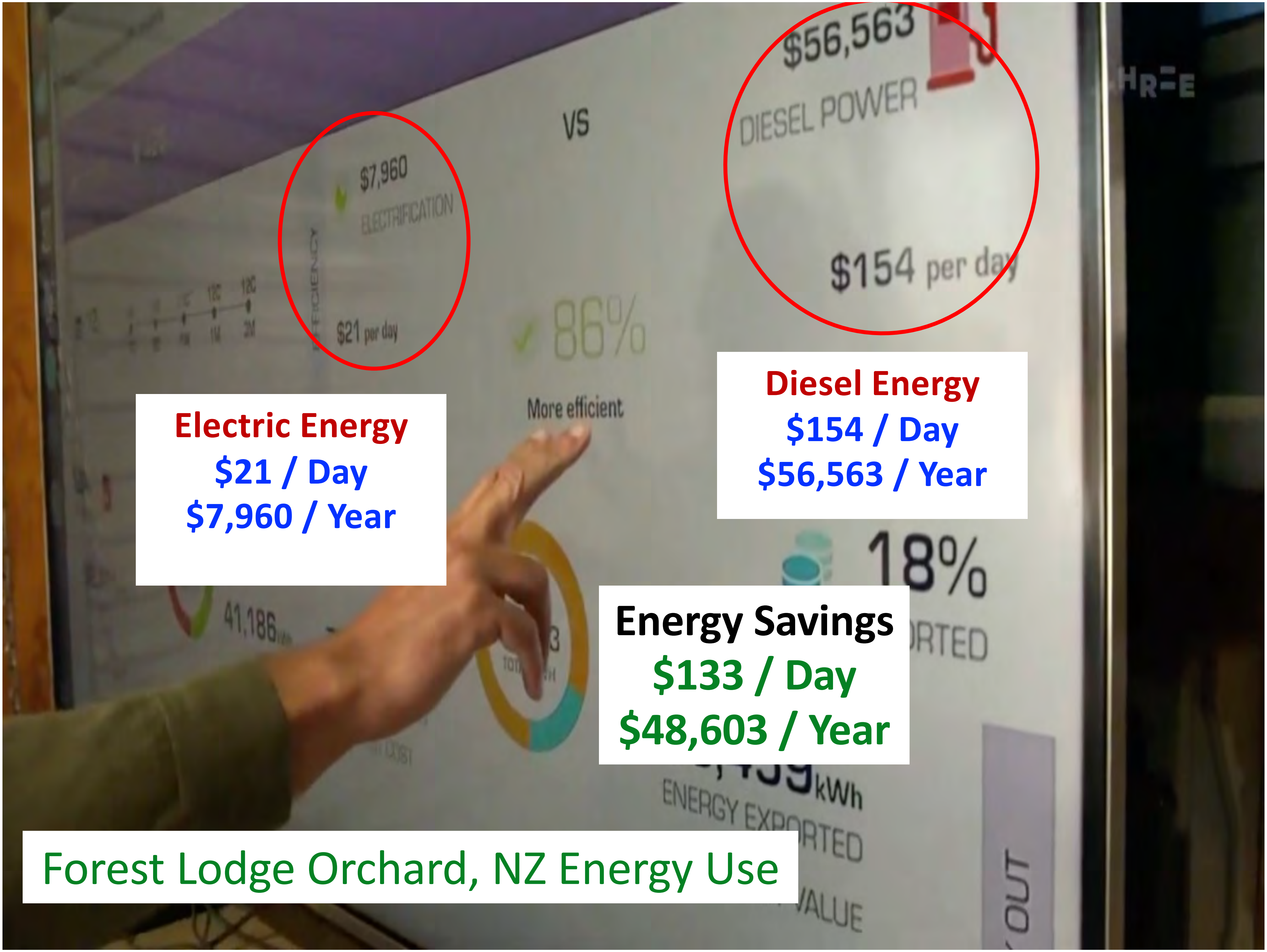
New Technologies: Autonomous Ultraviolet-C Light

Non-chemical fungal control in table-top strawberries and wine grapes – adaptable to any vertical planar canopy


advanced farm
TX Robotic Strawberry Harvester

World's First 100% Electric Orchard (45°S New Zealand) - Solar & Battery-Powered


Forest Lodge Orchard, NZ
Note this efficiency-focused orchard is planar (UFO)


$56,563
DIESEL POWER
$154 per day
$7,960
ELECTRIFICATION
$21 per day
VS
86%
More efficient
18%
kWh
ENERGY EXPORTED
Electric Energy
$21 / Day
$7,960 / Year
Diesel Energy
$154 / Day
$56,563 / Year
Energy Savings
$133 / Day
$48,603 / Year
Forest Lodge Orchard, NZ Energy Use

Conclusions: To Be Competitive in 2034 (and Still Competitive in 2044), The Orchard You Plant Today Must Create a Planar Fruiting Wall

Planar Fruiting Wall Orchards:

- Optimize light harvest efficiency
- Produce competitive yields
- Optimize fruit flavor and firmness
- Simplify crop load management
- Optimize worker efficiency
- Optimize worker safety
- Reduce some pesticide environmental impacts
- Facilitate orchard row covering systems
- Facilitate imaging/sensing/robotic technologies

MSU CHERRY RESEARCH

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IFTA INTERNATIONAL FRUIT TREE ASSOCIATION

USDA United States Department of Agriculture

National Institute of Food and Agriculture