ONTARIO APPLE GROWERS

Best Management Practices for Building Trellis Support Systems for High Density Ontario Apples

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INTRODUCTION

Apple trellis support systems have been built in Ontario for many years with little consistency in design and methods. Most commercial orchards are planted now with trellises (Figure 1) for several reasons:

- Trellises encourage trees to **direct energy to fruiting, rather than growing structural wood;**
- Trellises provide **a structural framework for tree training**, promoting more uniform trees;
- Trellis support **improves light interception** to optimize fruit quality and consistent ripening;
- Trees supported from planting time **produce earlier yields**; many growers report cropping begins Years 2 or 3 and total early yields increase 30^{+}% first 5 years;
- Trellis support **reduces labour costs**; pruning, training, thinning are all more uniform and simplified;
- **Graft union breakage and fruit bruising are reduced** as trees twist less in the wind; and
- Trellises **help us conceive orchards differently** as narrow, dense fruiting walls, more 2-D than 3-D.

Figure 1. These trees were planted one year ago. Note consistent growth. In-line posts are 16 feet tall with 4 ft in ground and 12 ft above to accommodate a future hail netting structure. *(Photo: Hugh Fraser)*

WHY ARE STRONG TRELLISES IMPORTANT?

Strong trellises are required to support the high yields that modern high density orchards produce. A trellis collapse with a full crop can be financially devastating since the trellis often takes down many, many trees with it.

Trellises are expensive. A 2014 installation cost \$0.82/ft of trellis for posts, wires, anchors and hardware (Balsillie, 2015). Trellises are difficult to repair or improve, so they must be built properly. Common trellis *failures* are:

- **Posts leaning** from shallow installation. Install posts 1/4 of their length deep in ground, not less than 2.75 ft;
- **Posts breaking** just above the ground from wind loads, or poor quality wood;
- **Anchors bending, or pulling** from ground (Figure 2);
- **Wires breaking** because of strain or damage;
- **Leaders snapping** above the top wire from lack of support above it;
- **Limbs breaking** from snow drifting, crusting, melting and sagging, pulling tree limbs with it; and
- **Staples pulling out** from poor installation.

Figure 2. Steel anchors bend above ground when not in line with the pull of the wire. Plan ahead to install steel anchors properly into undisturbed soil. *(Photo: Hugh Fraser)*

LOCAL CONDITIONS AFFECT TRELLISES

There are unique conditions in all Ontario orchards; soils, drainage, topography, winds, snow loads and expected yields. Some sites have more challenging conditions that affect trellis strength requirements (Table 1).

Table 1. Farm conditions and their effect on trellis strength.

Worse (need more strength)	Better (need less strength)
Lighter, sandy soil	Heavier, clay soil
Wetter, untiled, soils	Drier, tiled soils
Rolling topography	Flat topography
High apple yields	Low apple yields
High wind speeds	Low wind speeds
Heavy snow drifting	Light snow drifting
Stony or shallow bedrock subsoil	Stone or bedrock-free subsoil

ORCHARD LAY-OUT AND DESIGN

No two apple orchards are identical, so all trellis designs will benefit from local adaptation. Many factors determine the optimum layout and design:

- **Row spacing and tree spacing:** determines the total number of trees/acre (Table 2);

- **Ideal tree height vs. row spacing**: Row spacing determines the optimum tree height to maximize daily sunlight interception (Figure 3);

- **Row length**: 500’ rows are ideal to reduce end post loads and simplify field work travel;

- **Topography:** Rolling land requires posts closer together, and staples angled differently (Figure 13) vs. flat land due to more vertical pull up or down on wires;

- **In-line posts/row:** Assuming headlands not included; *Number of in-line posts per row = [Row length (ft) – {2 x End Brace Length (ft)}] ÷ Post spacing (ft);*

  Eg. [408 ft row–{2 x 9 ft end brace length}] ÷ 30 ft post spacing] = 13 in-line posts (1st post should be 15 ft after each end brace assembly, 30 ft spacing for rest);

- **Wind speeds and loads:** Ontario apple growing regions experience wind loads ranging from 0.25 to 0.45 kPa (1 in 10 year design). Proximity to the Great Lakes generally means higher winds. Localized winds can vary greatly depending on exposure. OMAFRA Publication 819 *Farm Building Standards* indicates design wind loads for many Ontario areas. Most climate change forecasts suggest frequency and intensity of wind gust events will significantly increase in future, so the need for strong trellises is even more imperative. Remember, orchards can last more than 20 years, so heavy winds are likely to occur; and

- **Local subsoil conditions:** Consult local builders, tile drainage contractors and farmers to determine underlying stone or bedrock challenges. This may impact the type of installation of posts and anchors.

Table 2. Tree density at various row and tree spacings for planted area. Remember to exclude headlands in your calculations. *(eg. An orchard planted at 3 ft x 11 ft spacing: Calculate density as 43,560 sq.ft/acre ÷ 3 ft/tree ÷ 11 ft/ row = 1320 trees/acre)*

	Tree Spacing (feet)			
Row Spacing (feet)	2	2.5	3	3.5
10	2178	1742	1452	1245
11	1980	1584	1320	1131
12	1815	1452	1210	1037
13	1675	1340	1117	957

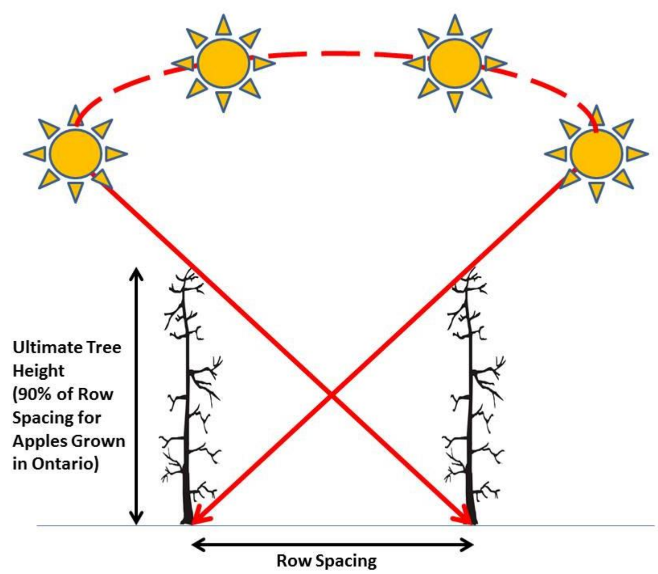

Figure 3. North-south tree rows are recommended for Ontario (42° - 45° latitude) to maximize sunlight interception. Tree height should be a maximum 90% of the row spacing.
(Schematic: Hugh Fraser) 10 ft rows = 9 ft trees
11 ft rows = 10 ft trees
12 ft rows = 11 ft trees

END-OF-ROW ANCHOR SYSTEMS

End of row anchor systems keep rows stabilized in one direction. Two main systems are common in Ontario:

- ***Angled-Brace***
- ***H-Brace***

Regardless of system, end posts should be a size larger diameter than in-line posts. So, 4-5" end posts if using 3-4" in-line posts; 5-6" end posts if using 4-5" in-line posts.

1. *Angled-Brace, End-of-Row Anchors*

A study commissioned by the *Tug of War International Federation* (University of Pretoria, 2002) discovered the most proficient eight person tug of war teams had mean body angles 46.9°-71.3° starting from No. 1 position (front) to No. 8 (anchor). Mean angle for all 8 positions was 58.1° (Figure 4). This indicates people instinctively anchor at the strongest orientation – equilateral triangle with 60° corners!

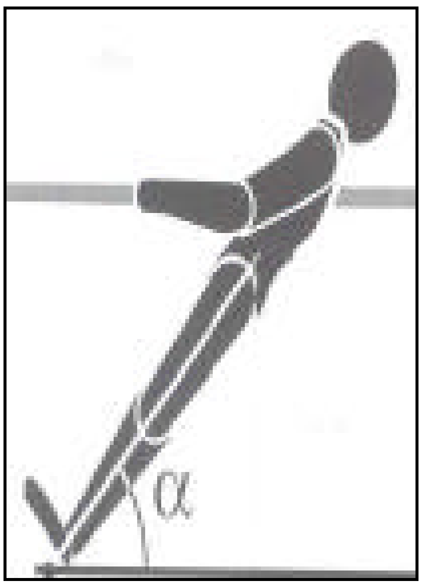

Figure 4. A study commissioned by the *Tug of War International Federation* (University of Pretoria, 2002) found most proficient eight person teams had mean body angles of 58.1, with the 'anchor' No. 8 position having a body angle of 71.3°. ***(Schematic courtesy of University of Pretoria)***

See Figure 5 for an example of an ideal end-of-row anchor formed by an equilateral triangle between post, wire and ground. This can be challenging so some growers prefer to use steeper angles. As in the tug of war analogy, increasing the post angle up to 70° is acceptable, but not any steeper.

Figure 5. Angled-brace, end-of-row anchor system. Note the 60° angles between the post, wire and ground, forming an equilateral triangle for maximum strength. The end post should be pounded, or vibrated in at least 3-4 ft into undisturbed soil. This installation uses a shorter tie-back wire 7 ft off the ground, instead of from the top of the post, to minimize space. This trellis uses 16 ft posts with 3.75 ft in ground to accommodate future hail nets. This requires longer and heavier anchors. ***(Photo: Hugh Fraser)***

Post-type anchors (Figure 6) should be pounded or vibrated in at least 4 ft deep for sufficient anchorage. Augering posts in is not recommended because the disturbed soil reduces the post anchorage and may result in posts leaning.

Figure 6. This post-type anchor has been pounded vertically, but if it was installed with about a 10° *lean* against the pull (in the same direction as the angled end post) it would strengthen the entire assembly. *(Photo: Hugh Fraser)*

Screw-in, auger-type anchors (Figure 7) need to be very strong and deeply anchored. This means augers at least 48" long, with at least a ¾" inch diameter shaft, heavy eye ring on one end to attach the wire, and a helix screw at the other end at least 6" in diameter. The weaker the soil and the longer the tree row, the stronger the anchor must be. For best anchorage, auger-type anchors should be installed into undisturbed soil in line with their tie-back wire. Clearly, this is challenging, so most growers install anchors vertical, or almost vertical. However, bending can result (Figure 2).

Figure 7. Screw-in, auger-type anchor; 68" long, 3/4" diameter shaft, heavy eye ring and 6" diameter helix screw. Note eye ring sticking out of soil on left. ***(Photo: Hugh Fraser)***

Gripple™ has developed an anchor that is easy to install and is designed to avoid the problems of anchor angles and bending (Figure 8). They are quick to install, work in most soils and disturb little soil underground during installation to provide good anchorage.

Figure 8. New *Gripple™* soil anchor. See website for instructional video. ***(Photo courtesy of Gripple™ website)***

The tie-back wire remains exposed to damage during machine work in angled-brace systems. Some growers plant two or three trees between the end post and anchor to provide a visual flag and produce more fruit (Figures 1, 15).

Be cautious about end-posts that are 'shorter' than in-line posts. This design puts strain lengthwise on this section of trellis. Remember this is one part of the trellis that needs the best support. Uniform post height avoids the top wire angling down to the end-post from the first in-line post.

2. *H-Brace, End-of-Row Anchors*

H-Brace anchor systems consist of two heavy posts pounded or vibrated in at least 3 to 4 ft in undisturbed soil (Figure 9). A horizontal brace is installed at a point about ¾ of the height of the top wire, often coinciding with the height of the second highest wire. A tie-back brace wire is installed from the intersection of second post/horizontal brace to near the ground on the end post. Horizontal braces should be 10-12 ft long. Avoid shorter ones because it puts the brace wire at too steep an angle, risking 'ratcheting' of the end post out of the ground. Avoid notching the brace into the vertical posts because this weakens those posts and may introduce rot. Instead, toe-nail or toe-screw the brace into the vertical posts. When the wires are tightened, the horizontal brace will become tightly held in place.

This system avoids the problem of the top wire angling down as described above for angled-brace systems, but the first in-line post should still be placed a 'half-space' from the H-brace assembly as subsequent ones.

Some growers have attempted to combine angled-brace and H-Brace systems by installing a brace from the bottom of the second post to the top of the first end post. Do not do this as it can 'ratchet-jack' the end post out of the ground.

Figure 9. H-Brace, end-of-row anchor systems are often chosen for stony soils. ***(Photo: Leslie Huffman)***

POST MATERIALS

Sourcing good quality wood posts is difficult. You must order trellis posts at least a year in advance so the trellis can be installed *immediately* after planting. Three main types of wood posts are used for Ontario trellises (Hedges, 2015).

Southern Yellow Pines have the highest dry densities (36-42 lbs/ft^3) and are unevenly grained (The Wood Database, 2015). These posts are the heaviest, strongest and longest lasting due to their cell structure, allowing chemicals to permeate the entire post during pressure treatment. They are the most costly, but trellises must last at least 20 years. Europeans build trellises using concrete posts that remain in the ground for the next orchard. Imagine if Ontario growers did this with their wood posts for two crops of trees!

Western Yellow Pines have lighter dry densities (28-29 lbs/ft^3) and a more even grain (The Wood Database, 2015). Lodgepole Pine is commonly used for trellises. These trees grow slowly, giving good quality and are tall and straight with few knots. They are mostly in 10-12 ft lengths.

Red pines have a dry density between the other two pines (34 lbs/ft^3) but because of their structure, are not as long-lasting as other woods and are less costly. They have more knots than the other woods (The Wood Database, 2015).

- Strength against bending is related to the post radius squared; so 5" diameter posts (2.5" radius^2 = 6.25) are over 50% stronger than 4" posts (2" radius^2 = 4);
- Driven posts are 50% stronger in anchorage than augered posts; increasing post depth 33% increases overturning resistance 100% (Van Dalfsen, 1989);
- 12 ft posts are commonly used in Ontario, but should never be installed with less than 30" depth;
- Marking posts ahead helps ensure proper set depth; be aware that all posts may not be the same length;
- One quarter of a post's length should be in ground, but never less than 2.75 ft;
- Sort out the best quality posts for end posts; and
- 16 ft posts are needed to install hail netting over the orchard; with up to 4 ft in ground, 12 ft above.

WIRE AND INDIVIDUAL TREE SUPPORTS

Wires carry the weight of the crop, transferring it to staples, to in-line posts and ultimately to the ground. Suppose a mature orchard of *Galas* planted at 3 x 11 ft tree density yields 50 bins/ac, a good, achievable yield for Ontario. At 20 bu/bin and 42 lbs/bu, this is 32 lbs/tree. With in-line post spacing of 30 ft, each in-line post and the wires connected to it carries apple load from 10 trees, or 320 lbs. Add in wind loads and it is clear strong trellises are required.

Wire and spacing

Orchard trellis wire should be:

- Highest, *Class 3* galvanizing, referring to highest level of zinc added to wire surfaces for long life
- *12.5 gauge* wire, referring to the thickness or diameter of wire (0.1 inch)
- *High tensile* wire, referring to the tensile strength of wire, which has improved over the years, now up to 200,000 psi through some suppliers

See suppliers for wire dispensing tools, in-line winders, tensioning tools and *Gripples*™. High tensile wire tension should be 250 lbs (Brown, 1996). Although with experience, one might be able to 'feel' the proper tension, only by using a measuring device can one be sure of the actual tension. A torq tensioning tool with a measurement option is offered by *Gripple*™ (Figure 10). Check wire tension after the crop is off and retighten where necessary.

Figure 10. A Torq Tensioning Tool by *Gripple™* permits users to set the tension they want by sliding a bar to the desired degree of torq. The tool clicks when the desired tension is reached. ***(Photo: Leslie Huffman)***

Across Ontario, there are as many combinations of number, wire spacing, and tree attachment to wire methods as growers! However, there are some consistent principles:

- Leaders should not be permitted to grow taller than 1 ft above the top wire as winds and crop load can cause breakage which affects tree structure and performance;
- Each year, remove large side branches near the leader to avoid heavy crop loads above the top wire; the majority of crop should be in the bottom 2/3 of the tree;
- Trees should be supported at least every 2 to 2.5 ft starting from planting; further spacing does not provide enough support, while closer spacing is not warranted;
- Support wires should be on windward sides of posts for support in windy conditions, but there is no agreement on which side to plant trees; trees on the windward side have more tree support and tree connectors do not have to be perfect; trees on the leeward side have less trunk bruising for potential injury and disease entry; and
- Outside rows are exposed to prevailing winds and should have tighter wires.

Some growers prefer the 'lowest' wire be at least 6 ft off the ground to provide an 'escape route' between rows for field work. Some growers attach drip irrigation on the bottom wire. This reduces animal damage, protects it from equipment and allows visual inspection.

Staples

Use longer 2", double-barbed, slashed-ended, Class 3 galvanized (Figure 11). Cheaper ones do not grip the post properly. The difference in cost for better staples is minor. Staples should never be 'clinched' tightly against the wire. Leaving a space allows wires to slide freely and more evenly distribute loads along the trellis, flex to help absorb wind loads, and help protect wires against nicking during installation which weakens them. Wires should be held against the post by the installer when hammering, not allowing the staple to 'pull' the wire to the post, as this damages it. Do not hit the wire with hammer as it chips off the precious galvanizing zinc.

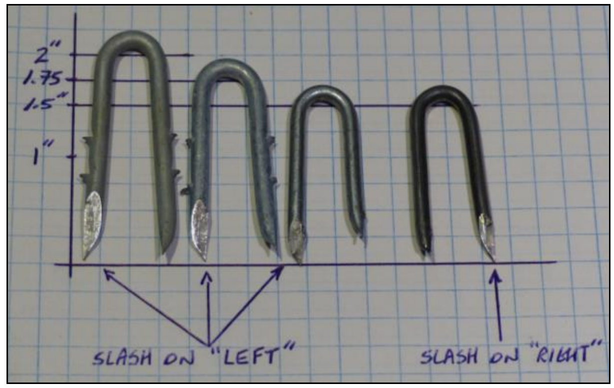

Figure 11. Use the staple on left; 2" long (measured from inside curve); double-barbed both legs to grip wood like a fish hook; slash cut ends which 'rotate' legs away from slash points; and Class 3 galvanizing for long life. Difference in cost between 2" and 1-3/4" staples is minor. The two right staples are too short and have no barbs. The staple on extreme right is opposite the others as its slashed ends are on 'right'. Staples like this seem to be less common, and should be installed differently than shown in Figure 12. ***(Photo: Hugh Fraser)***

Staples with slashed end points like the one on the left in Figure 11 should be positioned as in Figure 12 (Pratt, 1989). This does two things. First, it ensures the staple is not aligned with the grain of the wood, helping prevent splitting and loosening of the staple. Second, the flat surfaces of the slash points act like wedges when they enter the wood, forcing the staple legs to rotate away from those flat surfaces. Legs spread out as they penetrate the wood, helping keep the staple rigidly fixed in place (Figure 13).

Figure 12. Staples **with slashed end points like the one on the left in Figure 11 should be positioned at 20-30° off vertical to the 'right' over the wire (1 o'clock) as shown above. This** helps reduce wood splitting and forces the staple legs to rotate away from the flat slash face of the staple. Staples with slashes like the one on the right in Figure 11 should be installed at 20-30° off vertical, to the 'left' (11 o'clock) over the trellis wire. Fortunately, when you buy a box of staples, they are all alike. ***(Photo: Hugh Fraser)***

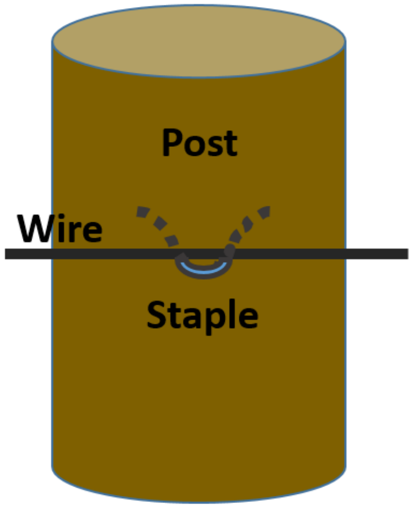

Figure 13. When installed as in Figure 12, staples with slashed end points as shown will spread out inside the wood helping keep staples rigidly in place. **(Schematic: Hugh Fraser)**

Some growers prefer to install wires through drilled holes in the posts, negating the need for staples altogether. This works much better on flatter land. Be sure to drill the holes horizontally level to avoid bending the wires.

Few orchards are flat though and changes in elevation put more vertical pull on wires. When wires want to pull 'down' on a rise post, angle staples downward into the post and use two staples on very steep rises. When wires want to pull 'up' on a dip post, angle staples upward into the post and use two staples on very steep dips (Brown, 1996). This puts the staple leg that is being 'pulled', in either case, deeper into the post. For extreme changes in elevations, some growers cut small notches in their posts to hold wires in place; notched 'up' for dip posts; 'down' for rise posts. Exercise caution with this approach as it weakens the post, damages the pressure treating, and could result in splitting. Continually check for staples that have loosened and add new ones, especially at grade changes in the orchard.

Wire and Individual Tree Supports

There are various methods to attach trees to the trellis. It is important to support the tree at planting time because it will grow more and begin cropping significantly sooner. ***Supporting as soon as possible cannot be stressed enough!***

Growers have had success with bamboo stakes, metal rods, twines, and for taller nursery trees, attaching them directly to the bottom wires. Be sure to monitor and adjust the ties to avoid girdling the trees as they grow.

Figures 14 and 15 show details for options on wire spacing, with 4 support wires, plus a 5th lower irrigation wire.

High tensile wire can be difficult and dangerous to work with. Be sure work crews understand how to work safely with wires, posts and installation equipment. ***Always use safe practices, proper safety gloves, safety glasses and other protective equipment when installing trellises.***

THE FUTURE FOR APPLE TRELLIS SYSTEMS

Climate change experts predict future crops are expected to endure more frequent, intense and unpredictable weather. Trellises can play an important role in future success of apple orchards to mitigate these risks:

- ***Drought:*** Trellises are ideally suited for attaching drip irrigation lines on wires
- ***Rain:*** Orchards with trellises plus drainage tiles in the middle of rows will control wheel traffic and isolate and confine soil compaction away from tree roots
- ***Wind:*** Winds are expected to be more unpredictable
- ***Frost:*** High density tree plantings help justify more late spring or early fall frost mitigation technology such as wind machines. In future, trellises might support new mitigation methods such as sprinklers
- ***Hail:*** Trellises can be a support system for hail netting
- ***Sunburn and heat stress:*** Trellises with hail netting can provide shading and reduce heat build up
- ***Pest management:*** The apple pest complex will continue to evolve with climate change and trellises may provide the skeleton for monitoring and innovative application technologies
- ***Monitoring:*** Sensor placement on trellises for climate, crop/yield monitoring and video surveillance

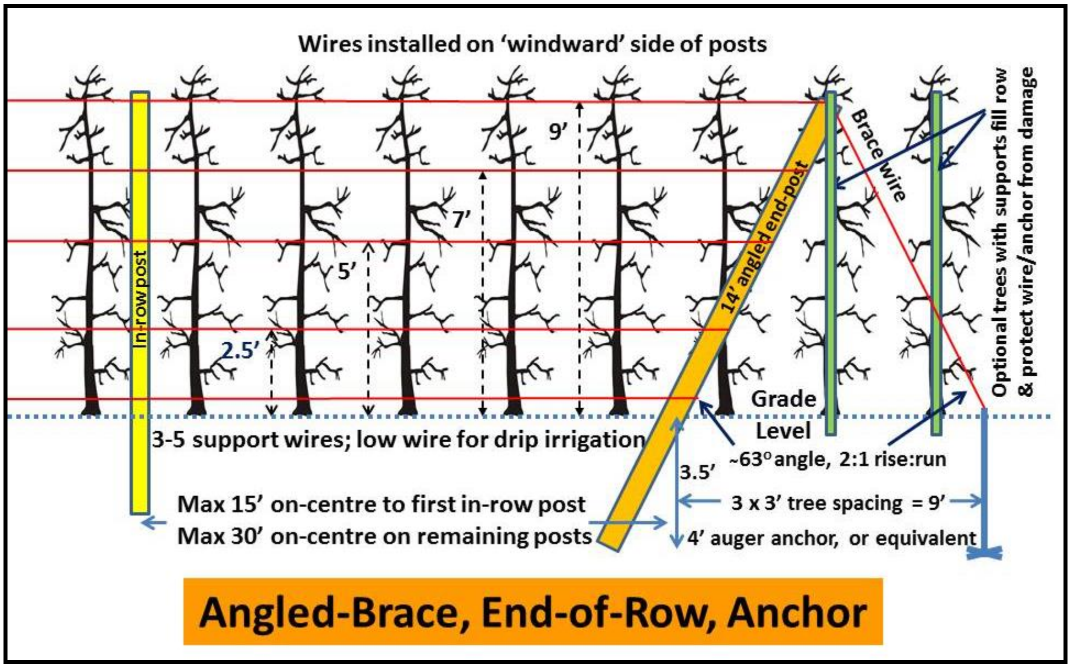

Figure 14. The ideal configuration in an angled-brace system is an equilateral triangle with 60° angles between post, wire and ground. Note the end-post is shown as 14 ft long to provide further anchorage and to provide enough height for the top wire. Also, the distance from the base of the post to the soil anchor is 9 ft. Two additional trees are planted with post supports at the end of the row to protect the tie-back wire system. (Note the optimum tree height of 10 ft with a 9 ft high wire for rows 11 ft apart). ***(Schematic: Hugh Fraser)***

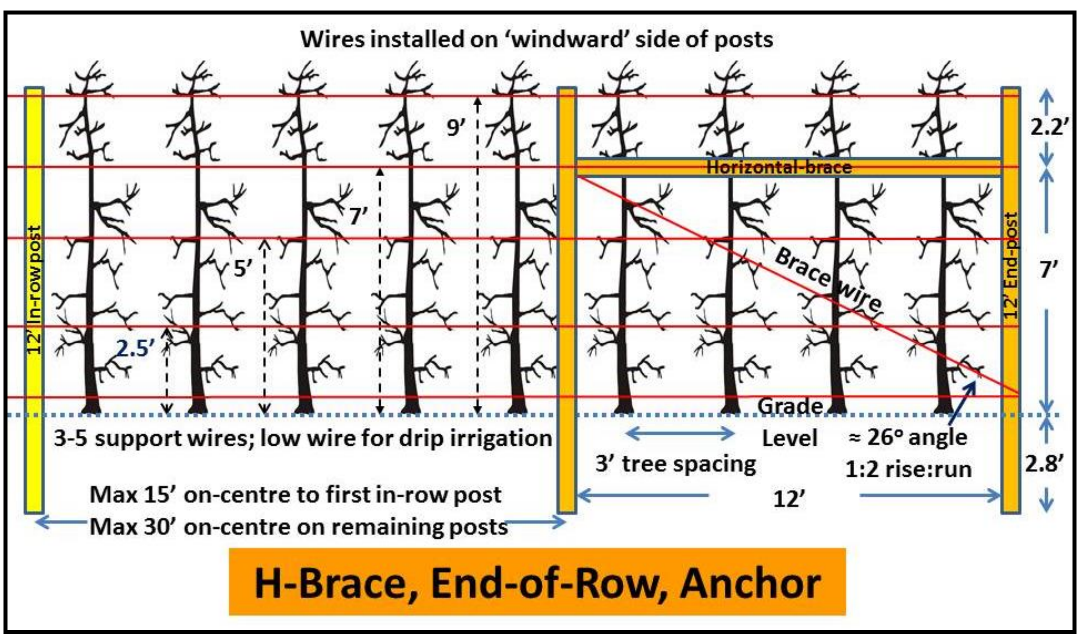

Figure 15. The 12 ft distance between the end posts provides a smaller angle for the brace wire and trees can be planted in this space. The schematic shows ultimate tree height of 10 ft with 9 ft high wire for rows 11 ft apart. ***(Schematic: Hugh Fraser)***

CONCLUSIONS

In Ontario, we have learned trellised orchards are much more uniform, simpler to manage and easier to harvest. The future looks bright for trellis support systems. Concrete posts, used in Europe, are likely to come to Ontario. Precision crop management, already in use with other crops can be assisted by trellises. GPS-guided, robotic and autonomous equipment can also be assisted by trellises. This future, though, will depend on strong trellis design and installation to provide the critical support needed to produce high yields and quality.

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