HIGH DENSITY ORCHARD SYSTEMS FOR EUROPEAN PEAR: 2013 NC-140 REGIONAL ROOTSTOCK PROJECT (2020 Progress Report) I. Overall training systems, spacing, and rootstocks

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ABSTRACT

The California pear industry has shrunk considerably in the past two decades, both in number of growers and total acreage (USDA-NASS 2020 and 2014; Elkins, Bell and Einhorn 2012). Remaining growers are considering replanting options or have already replanted small acreages. In coordination with Oregon State University (OSU) and Cornell University, three replicated trials were established in Spring 2013 in Mendocino County, California (CA), Hood River, Oregon (OR), and Geneva, New York (NY) to evaluate multiple training system, spacing, and rootstock combinations for the European pear cultivars 'Bartlett' (California), 'D'Anjou' (Oregon), and 'Bosc' (New York). California treatments consisted of Tall Spindle (TS), "V" Trellis (V-T), parallel 2-leader (2- L), and nursery-formed Bi-axis (B-A) x 3', 4.5' and 6' spacings x OHxF 69, OHxF 87, and Pyro 2-33 rootstocks (36 total combinations) in a split-split plot design. Cumulative survival rate from 2013-2020 is 94.9%, with no tree death in 2020. 2020 harvested overall yield increased 36% over 2019, excluding the 27% of fruit removed pre-harvest during pruning needed to maintain a 2-dimensional canopy (6 to 52% removed annually in previous years). V-T and TS had significantly most fruit per tree (46.3 and 40.3) and 2-L and B-A the least (30.1 and 26.6). B-A and V- T had the largest fruit (219 and 218 gm), and TS the smallest (208 gm). V-T had the highest yield (9.6 kg/tree), followed by TS (8.1 kg), with 2-L and B-A the lowest (6.3 and 6.0 kg). Spacing significantly influenced fruit number and yield, but unlike 2019, not size. 6' had the most fruit (40.3/tree) and 3' the least (31.7). 6' and 4.5' had the highest yield (8.3 and 7.7 kg/tree) and 3' the least (6.5 kg). Rootstock only influenced yield, with OHxF 69 and Pyro 2-33 trees yielding most (8.1 and 7.6 kg/tree) and OHxF 87 least (6.9 kg). B-A (41.9 cm^2 based on average of two leaders), 6' (53.2 cm^2), and OHxF 69 (52.0 cm^2) trees were largest based on scion (cultivar) TCSA and 2-L (33.4 cm^2), 3' and 4.5' (45.2 and 48.3 cm^2), and OHxF 87 (45.6 cm^2) trees smallest. TS (320 cm), 3' (310 cm), and Pyro-233 and OHxF 69 (311 and 301 cm) trees were tallest. V-T trees were most efficient (0.25 kg/cm^2) and B-A least (0.08 kg/cm^2), with no efficiency differences among spacings or rootstocks. There were few root suckers, with no training or spacing differences; Pyro 2-33 had the most (0.52/tree), followed by OHxF 69 (0.37) and OHxF 87 (0.10). Harvest fruit maturity was higher in 2020 vs. 2019 (average 7.4 vs 6.8 kg force) but lower than 2015-2018 (average 8.6). Sugars were higher than in previous years (15.6 vs. 13.4 °B 2015-2019). The only interactions were for fruit size and scion TCSA (training x spacing), and root suckers (training x rootstock). Completely unpruned OHxF 69 and 87 trees adjacent to treatment trees yielded 42% more than 2019 (25.3 vs. 14.7 kg), and 70% more than pruned trees at harvest, with total fruit number approximately 67% more combining removed and harvested fruit. OHxF 69 had significantly more fruit (176 vs. 123). OHxF 69 fruit was numerically larger (181 vs.164 gm, $p = 0.25$) and yield significantly higher (31.0 vs.19.6 kg/tree) than OHxF 87. For a separate group of adjacent trees, the only significant difference between spread and unspread B-A/OHxF 87 trees was rootstock (below graft union) TCSA (76.9 cm^2 for unspread vs. 56.2 cm^2 for spread, $p = 0.03$). Overall mid-day stem water potential (MSWP) measurements from the main treatment area were equal

between rootstocks and approached baseline after irrigations. B-A trees appear to have maintained better water status, with 2-L and TS intermediate, and V-T showing the most stress. Spacing appears to have had little influence on average seasonal MSWP. Data collection will continue in 2021.

INTRODUCTION

The California pear industry has shrunk considerably in the past several decades, both in number of growers and total acreage (USDA-NASS 2020 and 2014). There are many reasons for this, which have been described (Elkins, Bell and Einhorn, 2012). Remaining growers are considering replanting older low-density orchards with high density "fruiting wall" amenable to mechanization. Formal economic evaluation and the example of one small planting in the Ukiah Valley of Mendocino County that completed its 15th year in 2020 have shown that higher density plantings can be successful (Elkins et al 2011; Elkins and DeJong, 2011; Elkins et al 2008; Elkins and DeJong, 2002; Chris Ruddick, pers. communication).

The NC140 Regional Rootstock Research Project (*www.nc140.org*) is a USDA NIFA multi-state project for perennial fruit (and nut) crops. Regional projects are resubmitted for authorization every five years; the 2017-2022 NC140 Regional Research Project Proposal may be downloaded from NC140 web site. The goal of NC- 140 is to develop and disseminate information generated from trials throughout the U.S. Each participating state establishes and evaluates similar ("uniform") trials using the same rootstocks and similar plot design so that regional differences can be determined. Progress and results are shared at an annual two-day meeting (California hosted in 2015, 2016 Pennsylvania, 2017 Washington, 2018 North Carolina, 2019 New York, 2020 (virtually) Colorado, 2021 planned for Colorado) and via the NC140 website. Each state submits an annual report which is distributed and discussed at the meeting. State reports are then compiled into a national report for USDA. California began participating in NC140 in 1995 (apples, Scott Johnson) and peaches (Johnson and Ted DeJong) were added in 1999. The first pear trial was initiated in 1987 by the late Dr. Eugene Mielke of OSU (Azarenko et al 2002), followed by the 2002, 2004, 2005, 2006, and 2013 trials. Rachel Elkins is the California voting representative for all crops (currently pear and organic apple) and leads the current trials in California, summarizing and reporting California information at the annual meeting. She also co-organizes pear data for the national trials for reporting and publications with Associate Professor Todd Einhorn (formerly of Oregon State University (OSU), now at Michigan State University (MSU), East Lansing). Her expenses to the meetings were covered through 2016 by Hatch funds through the UC Davis Department of Plant Sciences and in 2017 by industry research funds (no travel funds were expended in 2018-2020).

In coordination with OSU and Cornell University, an NC-140 project to study high density systems and management techniques was initiated in Spring 2013. Three replicated trials were established in Mendocino County, California (CA), Hood River, Oregon (OR) (removed in early 2018 due to extensive damage from winter injury and fire blight) and Geneva, New York (NY) to evaluate multiple combinations of training systems, spacings, and promising commercially-available rootstocks for the European pear cultivars 'Bartlett' (CA), 'D'Anjou' (OR), and 'Bosc' (NY). The 2013 trial succeeds the 10-year 2005 multi-state rootstock trial that was formally completed in 2014 (Elkins 2016; Elkins et al 2008).

The 2013 NC-140 trial compares 27 (OR, NY) or 36 (CA) combinations of training systems, spacings, and rootstocks. The California trial was planted May 1 - 2, 2013 in Hopland, Mendocino County, California and has completed eight growing seasons (8th leaf). Treatments consist of four (versus three in OR and NY) training systems and three spacings that have shown promise in high density plantings,

particularly apple and pear, and three commercially available rootstocks which have shown promise in previous NC- 140 trials. Similar to the 2005 NC-140 trial, the 2013 trial is the only formal, replicated pear systems trial in California to benefit future planting decisions.

OBJECTIVES

This multi-state, multi-factor trial will evaluate alternative rootstocks, planting systems, and cultivars relative to:

- Cultivar compatibility ('Bartlett; CA, 'Bosc' NY, 'D'Anjou' OR);
- Early and consistentproduction;
- Improved labor efficiency/increased attractiveness for picking crews and amenability to futuremechanization;
- Ability to apply a systems approach to canopy management;and
- Improved fruit quality (higher percentage of "target" fruit, which may or may not be accompanied by increased production peracre).

While not a specific objective of the orchard systems project, improved pesticide application efficacy (cost, coverage) will be observed and documented once trees are fully trained out.

PROCEDURES (Figure 1)

Trial locations:

1) OSU Mid-Columbia Agricultural Research and Extension Center, Hood River, OR ('D'Anjou', Todd Einhorn, PI); (REMOVED IN WINTER 2018)

2) Cornell Geneva Experiment Station, NY ('Golden Russet®' Bosc', Terence Robinson,PI);

3) Shadowbrook Farms (Kurt Ashurst), Hopland, Mendocino County, CA ('Bartlett', Rachel Elkins, PI; collaborators Bruce Lampinen, Ted DeJong, and Chuck Ingels (through 2017). Soil type is a very deep Russian loam adjacent to the east bankof the RussianRiver.

Training systems:

1) *Tall spindle* (TS) (developed by Terence Robinson for apple) (unheaded at planting);

2) *Tatura "V" trellis* (V-T) (22° at the base, planted in-line with every other tree pulled to the opposite side of thetrellis);

3) *Bi-axis* (B-A) planted parallel to the row. Developed by Dr. Stefano Musacchi, formerly of University of Bologna, Italy, now with Washington State University. B-A trees are pre-formed in the nursery; the California B-A trees were headed high to a "knip" at planting so are one year behind those left unheaded. Trees were spread into a parallel "V" after the 2013 growing season in order to more quickly fill the growing space, reduce main scaffold vigor, and hastenfruiting;

4) *2-leader* (2-L) planted parallel to the row, created by choosing two appropriately placed "feathers" just above or below the first wire (left unheaded), or if none available, heading the leader and choosing two new scaffolds.

"Feathers", i.e. branches grown in the nursery, were left on sufficiently vigorous trees unless broken and utilized to begin cropping.

In addition to the main trial block, an adjacent row of extra B-A and single leader trees was left completely unheaded and unpruned. A replicated sub-trial was initiated on one set of these extra B-A trees on OHxF 87 to compare the effect of spreading vs. not spreading on vigor and precocity. The remaining trees in the extra row were left completely unpruned. These trees were divided into two replicated sets on either OHxF 69 or OHxF 87 to be analyzed separately.

Cultivar and Rootstocks: 'Bartlett' on OHxF 69, OHxF 87, Pyro 2-33. Rootstocks were chosen based on best available data in comparison with standard size rootstocks. Micro propagated rootstock plants (North American Plant, Lafayette, Oregon) were delivered to Willow Drive Nursery (Ephrata, WA), acclimated, fall budded, grown and planted May 1-2, 2013. A total of (about) 700 trees were planted, with 540 included in the main systems trial.

Spacing: 3' (1m, 807 trees/acre), 4-5' (1.5m, 1,210 trees/acre), and 6' (2m, 605 trees/acre) in-row x 12' (4m) between rows. Final height is 10-12' (3.3- 4m) (TBD). The unreplicated "fifth" row in-row spacing is 6' (2m).

Design: Split-split plot: main plot = training system, sub-plot = spacing, sub- sub-plot = rootstock. 5 replicated blocks, each plot consisting of 27 trees (27/training system; 9/spacing; 3/rootstock) (4 treatment rows per block)[1].

Blocking is across the field with trees oriented north to south (east-west sun exposure). Approximately 2 acres of land in a high-producing orchard along the Russian River was cleared and prepared in 2012 in preparation for fumigation, however, the fumigation was unable to occur due to weather and regulatory delays[2].

[1] Data analysis is on four replicates as one replicate required re-training and is one year behind. Analysis will include all five replicates once trees are bearing equally.

[2] While *Armillaria mellea* has infected trees in the orchard, average tonnage of existing trees approached 40 tons per acre; oak root fungus has yet to affect trial results.

Data Collection

Tree training and crop load management: From 2013 through 2020 training continued to emphasize and refine leader development, proper shaping, and thinning to optimize fruiting wood distribution. 2019 completed the process started in 2017 of more intensive pruning to transform tree shape from a 3- to 2-dimentional (flat canopy) to accommodate mechanization, with less intensive "maintenance" pruning in 2020. Nearly all training was performed between the start of terminal bud growth and terminal bud set in October. Emphasis was on 1) encouraging leaders to reach the top wire by reducing the influence of competing scaffolds, 2) filling intra-row and inter-tree space along the supporting wire, and 3) ensuring ideally spaced and optimally vigorous fruiting wood development. Clothes pins and

rubber tubing tie were the main training aides, and nearly all wood removal was done by hand or by-pass pruners and loppers using thinning rather than heading cuts. Fruit was removed on weak trees but left if vigor appeared adequate. 27% of fruit was removed across all treatments in 2020, slightly less than in 2019 (28.6%), reflecting nearly finalized canopy configuration.

Tree survival, growth and vigor (2013-2020): Percent surviving trees was determined. Tree height and trunk cross-sectional area (TCSA) of both scion (cultivar) (10 cm above graft union) and rootstock (5 cm below graft union) were measured. Measuring above and below the union allowed comparing single-leader trees with the bi-axis trees which were nursery budded very low at the base. Root suckers were counted. Baseline canopy light interception was initially measured on October 19, 2013 using a Kawasaki Mule- mounted lightbar, then annually through 2016 to eventually develop a predictive model to inform future plantings. (In 2016 the new smartphone iPAR "app" was utilized instead of the large lightbar system, however measurement data was corrupted; these were resumed in 2017). From 2013-2015 four plant cameras, each focused on one training system, recorded the daily and weekly progress of tree growth (e.g. terminal height growth, number of leaves, flowers, fruit) and biotic and abiotic interactions. One photo per day at 10:00 a.m. served as a continuous recording of seasonal growth pattern.

Productivity and harvest maturity: Flower clusters (2013-2015), fruit number and size, and yield (2014-2020) per tree were measured and both scion and rootstock yield efficiency (YE) calculated (see above for why rootstock TCSA was recorded). 2015-2020 data also included number of fruits removed prior to harvest (an indicator of overall vigor and result of severity of canopy modification) and firmness (kg) and soluble solids (°Brix). In 2014-2020, weekly mid-day stem water potential (MSWP) was measured from May through early October using a pressure chamber (PMS Model 610 Pressure Chamber, PMS Instrument Company, Albany, OR) to assess whether and how much water stress might affect vigor and yield (crop load and fruit size), and vice versa. Measurements were taken from trees representing all training systems but only Pyro 2- 33 and OHxF 87rootstocks.

Data summarization and analysis

Data was analyzed using ANOVA and means separated using Tukey HSD test, $p \leq 0.05$ (root suckers by Duncans MRT, $p \leq 0.10$) (Statgraphics Centurion XVII, StatPoint Technologies, Warrenton, VA). Due to unequal tree age of one of the replicates, only four replicates were utilized for most analyses, with data from the fifth replicate used as appropriate. From 2013-2020, the main significant interactions were among training x rootstock (fruit number, yield, scion yield efficiency, rootstock TCSA) and training x spacing (fruit number, scion TCSA, scion yield efficiency, rootstock yield efficiency). There were no significant training x spacing interactions, nor any related to fruit size.

2020 AND CUMULATIVE 2013-2020 RESULTS (Tables 1-19); (2013-2019 results summarized in Elkins and Lampinen 2020, 2018, 2017, 2016, and 2015, Elkins 2014)).

Tree survival, growth, and vigor (Tables 1-4; percent changes not shown in tables): No trees died in 2020. From 2014-2020, five trees have died (1.2%) and not been replaced and nine (2.1%) replanted since 2014 (data not shown): 2 x 2-L/Pyro 2-33, 2 x 2-L/OHxF 87, 5 x B-A/OHxF 87, 2 x B-A OHxF 69, 1 x B-A/Pyro 2-33, 1 x TS/OHxF 69, and 1 x V-T/OHxF 69, for a total of 3 x Pyro 2-33, 4 x OHxF 69, and 7 x OHxF 87.

2020 scion (above graft union) TCSA increase averaged 16% from 2019. B-A, 6', and OHxF 69 tree size increased most and 2-L, 3', and OHxF 87 least. B-A scion single leader TCSA was largest (41.9 cm^2 averaging both leaders), TS (40.1 cm^2) and V-T (38.2 cm^2) intermediate, and 2-L smallest (33.4 cm^2). Rootstock (below graft union) TCSA increase averaged 10%. T-S and V-T, 6' spacing, and OHxF 69 tree increased most, and 2-L, 3', and OHxF 87 least. TS and V-T rootstock TCSA was largest (56.6 and 55.6 cm^2), followed by B-A (50.7 cm^2), then 2-L (45.8 cm^2). There was a significant training x spacing interaction for scion TCSA, but not for rootstock TCSA. T-S (320 cm), 3' (294 cm), Pyro 2-33 and OHxF 69 (311 and 301 cm respectively) trees were significantly tallest; other training systems, spacings, and OHxF 87 were statistically equally shorter. All treatments averaged <1 sucker per tree; only rootstock differences were significant, with Pyro 2-33 having significantly more (0.52/tree) than either OHxF rootstock, with no interactions.

Productivity (fruit number, fruit size, yield, yield efficiency) (Tables 1-4; percent changes not shown in tables): 2020 average harvested fruit number increased 36% from 2019 across all treatments. Training system fruit number increased 34% and spacing and rootstock 36%. V-T fruit number increased most (42%), followed by B-A (36%), 2-L (27%), and TS (25%). Spacing fruit number increased 35%, with 3' increasing 21%, 4.5' 35%, and 6' 48%. Rootstock fruit number increased 35%: OHxF 69 43%, Pyro 2-33 34%, and OHxF 87 29%. Overall 2020 fruit number averaged 36.3 per tree; V-T (46.3), 6' and 4.5' (40.3 and 36.9) trees had significantly most fruit and B-A and 2-L (28.6 and 30.1) and 3' (31.7) trees least. Rootstocks averaged 36.3 fruit per tree with no difference among treatments. There were nointeractions.

2020 overall average fruit size across all treatments was 215 gm (44 lb. box size 90), the same as 2019. Fruit also averaged 215 gm within all three main treatments, despite increases in both fruit number and yield. As in 2019, there were significant training system differences, with 2-L, B-A, and V-T having equally large fruit size (range 215 - 219 gm), and TS fruit being significantly smaller (208 gm or 44 lb. box size 100). Unlike 2019, there were no spacing differences (range 213 - 216 gm), and like 2019, no rootstock (range 213 – 218 gm) differences. There was significant training x spacing interaction.

Overall yield increased 36%. B-A yield increased most (62%), followed by V-T (49%), 2-L (27%), and TS (26%). 6' spacing increased 46%, 4.5' 36%, and 3' 23%. OHxF 69 yield increased most (42%), Pyro 2-33 37%, and OHxF 87 29%. V-T yielded significantly most (9.6 kg/tree), followed by TS (8.1 kg), with 2-L and B-A least (6.3 and 6.0 kg respectively). 4.5' and 6' spacings yielded more than 3' (7.7 kg/tree and 8.3 kg vs. 6.5 kg). OHxF 69 (8.1 kg) yielded significantly more than OHxF 87 (6.9 kg/tree), with Pyro 2-33 intermediate (7.6 kg). There were no significant interactions.

2020 overall scion (above graft union) yield efficiency (YE) increased 28% from 2019. Training system scion YE increased 17%. V-T increased most (48%), followed by 2-L and B-A (30% and 25%), then TS (15%). Among spacings (overall increase 31%), 6' YE increased 42%, 4.5' 32%, and 3' 18%. Overall rootstock scion YE increased 31%, ranging from 39% for OHxF 69, 32% for Pyro 2-33, and 23% for OHxF 87. Among training systems, V-T YE was significantly highest (0.25 kg/cm^2), followed by TS and 2-L (both 0.20), and lastly B-A (0.08). There were no differences among spacings (range 0.17- 0.19 kg/cm^2) or rootstocks (range 0.17 to 0.19). There were no interactions.

Overall rootstock (below graft union) YE increased 32%. Among training systems, V-T YE increased 47%, B-A 33%, 2-L 29%, and TS 20%. Spacing rootstock YE increase averaged 33%: 6' YE increased 44%, 4.5' 33%, and 3'21%. Rootstock YE increased 30%, with OHxF 69 increasing 36%, Pyro 2-33

33%, and OHxF 87 21%. As with scion YE, V-T had the highest rootstock YE (0.17 kg/cm^2), with all other systems equal (range 0.12 - 0.15). 6' spacing YE was highest (0.16 kg/cm^2), followed by 4.5' (0.15), and 3' (0.14). There were no YE differences among rootstocks (range 0.14 - 0.15 kg/cm^2).

2013-2020 cumulative results continue to suggest consistent primary influence of training system on initial to long-term bearing. V-T and TS trees had numerically similar and statistically equal fruit numbers and yield (138 and 131/tree, 28.0 and 25.6 kg/tree), however V-T had significantly larger fruit (203 vs.193 gm). 2-L and B-A trees had statistically equal and significantly fewer (87 and 76/tree) but larger (205 and 210 gm) fruit, and corresponding lower yields (17.9 and 15.9 kg). On both a two and single leader basis, B-A trees were largest based on scion TCSA (combined leaders 83.8 cm^2, average 41.9 cm^2), followed by TS (40.1 cm^2), V-T (38.2 cm^2) and 2-L (33.4 cm^2). V-T trees had the highest scion efficiency (0.71 kg/cm^2), followed by TS (0.64 kg/cm^2), 2- L (0.53 kg/cm^2), and lastly, B-A (0.20 kg/cm^2). TS and V-T were also largest based on rootstock (below graft union) TCSA (56.6 and 55.6 cm^2), and had correspondingly highest rootstock YE (0.46 and 0.49 kg/cm^2 respectively). B-A rootstock TCSA was larger than the single leader scion TCSA, with lowest rootstock YE (50.7 cm^2 and 0.33 kg/cm^2). 2-L rootstock TCSA was smallest but rootstock YE higher than B-A (45.8 cm^2 and 0.39 kg/cm^2).

There were no cumulative differences among spacings in fruit number (range 102 - 114) or fruit size (range 200 – 204). Versus 2013-2019, there were significant yield differences among spacings, with 6' trees yielding most (23.3 kg/tree), followed by 4.5' (21.8 kg), and 3' (45.2 kg). 6' trees were largest (53.2 cm^2 scion TCSA), followed by (equally large) 4.5' and 3' (48.3 and 45.2 cm^2), but no cumulative YE differences. Rootstock (below graft union) TCSA and YE patterns were similar to scion TCSA. 6' trees had the most root suckers (1.41/tree), followed by 4.5' (1.36) and 3' (1.22).

There were numerous cumulative rootstock differences. OHxF 69 fruit number (111 vs 121), fruit size (201 vs 198 gm), and yield (22.4 vs 24.0 kg/tree) statistically equaled OHxF 87 for the first time, though OHxF 87 scion YE (0.60 vs. 0.49 kg/cm^2) was higher than OHxF 69 due to the latter's larger tree size (52.0 cm^2 vs. 45.6 cm^2 scion TCSA). Pyro 2-33 had the least number of fruit (92) and lowest yield (19.2 kg/tree) and YE (0.47 kg/cm^2). Rootstock TCSAs were numerically larger than scion TCSAs and followed the same pattern. Cumulative 2013-2020 interactions were limited to training x spacing for yield, scion TCSA and scion YE.

Pre-harvest fruit removal (Tables 5-8): An average of 13 fruit per tree was removed prior to harvest (about 27% of the total number per tree) versus 36 harvested (49 total per tree), with the same overall average number and percent across training, spacing, and rootstock. In contrast to earlier years (11.8% removed in 2015, 6.2 in 2016, 15.0% in 2017, 52% in 2018, 29% in 2019) when it was accomplished mainly to avoid overcropping, foster vigor and facilitate leader development, the number and percent of fruit removed in 2017 - 2020 reflected the pruning severity needed to restructure tree architecture from 3- to 2-dimensional requiring removing all east and west protruding branches and associated fruit. There were no differences in number removed among training systems, however percent removed differed significantly, with the most removed from B-A (41%) and least from TS (16%). There were no spacing or rootstock differences. There were no interactions.

Firmness and soluble solids (Table 9): Fruit was firmer at harvest than in 2019 (7.4 kg force/16 lbs vs. 6.8 kg force/15 lbs) but softer than 2015-2018 (8.6 /17.6). 2-L fruit was firmest (7.6 kg /16.7 lbs), followed by B-A and TS (7.4 /16) and V-T softest (7.2 /15.9). 6' spacing fruit was firmest (7.5 kg/16.5 lbs), followed by 4.5' (7.4 /16), then 3' (7.3 /16.1). There were no significant interactions. Soluble solids were also higher (15.6 vs.14.0 °Brix in 2019 and average 13.25 °Brix 2015-2018). There were no

significant training system (range 15.2 – 15.9 °Brix) or rootstock (range 15.5 – 15.8 °Brix) differences. 6’ spacing soluble solids were highest (15.9 °Brix), followed by 4.5’ (15.6), then 3’ (15.3). There were training x rootstock and training x spacing interactions.

Mid-day Stem Water Potential (MSWP) (Table 20, Figures 2-7): 2020 measurements ceased from August 31 to September 16 during harvest. There were no overall significant differences between Pyro 2-33 and OHxF 87 rootstocks, Values have remained consistently below currently accepted (preliminary) baseline in all years, but as in 2019 they approached it after each irrigation in 2020. This suggests irrigations have increasingly aligned with canopy development and size, as well as deeper rooting capacity. Initial MSWP averaged 13.1 bars on June 17, and approached baseline on July 22 (average 8.5 bars, baseline 7.2 bars) and August 5 (average 8.5 bars, baseline 6.9 bars). MSWP decreased during the harvest season in late August. The only notable difference was for B-A 6’ trees, which trended toward less stress on OHxF 87 versus Pyro 2-33. While not analyzed, average seasonal MSWP was similar for 3’ (14.1 bars, OHxF87; 14.9 bars, Pyro 2-33) and 6’ (14.9 bars, OHxF 87; 14.4 bars Pyro 2-33). MSWP was highest (least stressed) for B-A (13.5 bars, OHxF 87; 12.8 bars, Pyro 2-33) and lowest (most stressed) for V-T (15.8 bars, OHxF 87; 16.7 bars, Pyro 2- 33). 2-L (14.8 bars, OHxF 87; 14.1 bars, Pyro 2-33) and TS (14.3 bars, OHxF 87; 14.9 bars, Pyro 2-33) were intermediate and similar.

2013-2020 DISCUSSION AND 2021 PLANS

After eight growing seasons, training system continues to be the most consistent factor determining tree growth and productivity; V-T and TS continue to be the most productive systems while 2-L and B-A continue to lag, largely due to required remedial training needed to achieve a 2-dimensional canopy. Spacing has increasingly influenced productivity; 6’, and to a lesser extent, 4.5’ spaced trees have overtaken 3’ spacing in both fruit number and total yield, with no decrease in fruit size. 6’ trees are larger but equally yield efficient, suggesting increasing impact of greater bearing surface and developmental vigor as 3’ trees have filled their allotted growing space. Rootstock influenced productivity in 2020, with OHxF 69 fruit number and yield increasing, Pyro 2-33 intermediate, and OHxF 87 yield continuing to decrease. Tree water status appeared better in 2020, with MSWP values suggesting applied water is meeting tree needs during the hottest part of the year. Comparing spreading versus allowing natural upright scaffold growth (unspread) on otherwise untrained and unpruned trees, larger fruit size has been the most consistent trend favoring unspread trees from 2013-2020.

While spreading tends to increase yield efficiency, larger rootstock TCSA suggests greater vigor of unspread trees, favoring larger fruit without sacrificing fruit number or total yield. Spreading in and of itself thus appears to diminish fruit size over time, though variably year to year.

Completely forgoing pruning in early years encourages early fruiting, however compromises fruit size as trees mature. The more vigorous OHxF 69 trees resulted in significantly larger fruit than OHxF 87 with equal yield efficiency.

Tree training and data collection will continue in 2021 (Year 9).

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2013 NC-140 PEAR SYSTEMS TRIAL - REP I (Rows 1-4)

Shadowbrook Farms, Hopland, Mendocino, CA. Planted May 1-2, 2013

↑ **SOUTH**

Reps II - V

BARTLETT TREES

Training	Spacing/Rootstock	
Row 1	6	2-33
BI-AXIS	6	2-33
	6	2-33
	6	87
	6	87
	6	87
	6	69
	6	69
	6	69
Buffer	PYRO 2-33	
Row 1	4.5	69
BI-AXIS	4.5	69
	4.5	69
	4.5	2-33
	4.5	2-33
	4.5	2-33
	4.5	87
	4.5	87
	4.5	87
Buffer	PYRO 2-33	
Row 1	3	2-33
BI-AXIS	3	2-33
	3	2-33
	3	87
	3	87
	3	87
	3	69
	3	69
	3	69
Buffer	PYRO 2-33	

Training	Spacing/Rootstock	
Row 2	3	69
"V" TRELLIS	3	69
	3	69
	3	2-33
	3	2-33
	3	2-33
	3	87
	3	87
	3	87
Buffer	PYRO 2-33	
Row 2	6	69
"V" TRELLIS	6	69
	6	69
	6	2-33
	6	2-33
	6	2-33
	6	87
	6	87
	6	87
Buffer	PYRO 2-33	
Row 2	4.5	2-33
"V" TRELLIS	4.5	2-33
	4.5	2-33
	4.5	87
	4.5	87
	4.5	87
	4.5	69
	4.5	69
	4.5	69
Buffer	PYRO 2-33	

Training	Spacing/Rootstock	
Row 3	4.5	2-33
2-LEADER	4.5	2-33
	4.5	2-33
	4.5	87
	4.5	87
	4.5	87
	4.5	69
	4.5	69
	4.5	69
Buffer	PYRO 2-33	
Row 3	6	87
2-LEADER	6	87
	6	87
	6	69
	6	69
	6	69
	6	2-33
	6	2-33
	6	2-33
Buffer	PYRO 2-33	
Row 3	3	2-33
2-LEADER	3	2-33
	3	2-33
	3	87
	3	87
	3	87
	3	69
	3	69
	3	69
Buffer	PYRO 2-33	

Training	Spacing/Rootstock	
Row 4	6	2-33
TALL SPINDLE	6	2-33
	6	2-33
	6	69
	6	69
	6	69
	6	87
	6	87
	6	87
Buffer	PYRO 2-33	
Row 4	4.5	87
TALL SPINDLE	4.5	87
	4.5	87
	4.5	2-33
	4.5	2-33
	4.5	2-33
	4.5	69
	4.5	69
	4.5	69
Buffer	PYRO 2-33	
Row 4	3	87
TALL SPINDLE	3	87
	3	87
	3	69
	3	69
	3	69
	3	2-33
	3	2-33
	3	2-33
Buffer	PYRO 2-33	

Row 5 - UNPRUNED BARTLETT TREES AND NEW USDA CULTIVAR SELECTIONS

BOSC TREES/RUSSIAN RIVER

NORTH END

Table 1: Effect of training system, spacing, and rootstock on number and size of fruit, yield, box size and number, tree growth, yield efficiency, root suckers and survival of 8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2020.

	Fruit No. (no./tree) 8/31,9/1&2/20	Fruit Size (g) 8/31,9/1&2/20	Yield (kg/tree) 8/31,9/1&2/20	Nearest Box Size (44 lb. box) 8/30,9/1&2/20	Average Box Number (per tree) 8/31,9/1&2/20	Cultivar TCSA[4] (cm^2) 12/1-22/2020	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[5] (cm^2) 12/1-22/2020	Rootstock Yield Efficiency (kg/cm^2)	Tree Heights[6] (cm) 12/1-22/2020	Root Suckers[7] (no./tree) 12/2020 & 1/2021	Percent Survival 1/7/2021
Training[1]												
2-Leader	30.1 b	215 ab	6.3 c	90 b	0.32 c	33.4 c	0.20 b	45.8 c	0.14 b	301 b	0.52	91 b
Bi-axis[3]	28.6 b	219 a	6.0 c	90 b	0.30 c	83.8 a	0.08 c	50.7 b	0.12 b	291 b	0.28	91 b
Tall Spindle	40.3 a	208 b	8.1 b	100 a	0.40 b	40.1 b	0.20 b	56.6 a	0.15 b	320 a	0.17	99 a
V-Trellis	46.3 a	218 a	9.6 a	90 b	0.48 a	38.2 bc	0.25 a	55.6 a	0.17 a	285 b	0.34	99 a
Spacing[1]												
3 feet	31.7 b	216	6.5 b	90	0.33 b	45.2 b	0.17	48.4 b	0.14 b	310 a	0.16	93
4.5 feet	36.9 ab	213	7.7 a	90	0.38 a	48.3 b	0.19	51.6 b	0.15 ab	295 b	0.40	98
6 feet	40.3 a	216	8.3 a	90	0.42 a	53.2 a	0.19	56.5 a	0.16 a	294 b	0.43	94
Rootstock[1]												
Pyro 2-33	35.7	218	7.6 ab	90	0.38 ab	49.1 ab	0.19	51.9 b	0.15	311 a	0.52 a	94
OHxF 69	39.6	213	8.1 a	90	0.40 a	52.0 a	0.18	56.0 a	0.14	301 a	0.37 ab	96
OHxF 87	33.7	214	6.9 b	90	0.34 b	45.6 b	0.17	48.7 b	0.14	286 b	0.10 b	95
ANOVA (*P* -values)[2]												
Training	***(<0.001)	**(0.01)	***(<0.001)	* (0.05)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.12)	***(<0.001)
Spacing	** (0.002)	NS (0.55)	***(<0.001)	NS (0.85)	***(<0.001)	***(<0.001)	NS (0.12)	***(<0.001)	* (0.05)	** (0.003)	NS (0.08)	NS (0.12)
Rootstock	NS (0.09)	NS (0.30)	* (0.03)	NS (0.14)	* (0.05)	***(0.001)	NS (0.17)	***(<0.001)	NS (0.41)	*** (<0.001)	** (0.01)	NS (0.62)
Block	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.000)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.31)
Interaction (*P* -values)[2]												
Training x Rootstock	NS (0.25)	NS (0.33)	NS (0.35)	NS (0.20)	NS (0.27)	NS (0.31)	NS (0.11)	NS (0.08)	NS (0.09)	NS (0.20)	NS (0.33)	***(<0.001)
Spacing x Rootstock	NS (0.18)	NS (0.29)	NS (0.24)	NS (0.37)	NS (0.20)	NS (0.47)	NS (0.08)	NS (0.70)	NS (0.08)	NS (0.82)	NS (0.71)	NS (0.75)
Training x Spacing	NS (0.23)	*** (0.001)	NS (0.29)	** (0.002)	NS (0.27)	* (0.03)	NS (0.19)	NS (0.65)	NS (0.31)	NS (0.28)	NS (0.13)	NS (0.10)
Training x Spacing x Rootstock	NS (0.48)	NS (0.50)	NS (0.29)	NS (0.73)	NS (0.36)	NS (0.16)	NS (0.47)	NS (0.41)	NS (0.49)	NS (0.09)	NS (0.92)	** (0.002)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$, $P < 0.10$ No. Fruit and Box No. by spacing).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, 0.001 respectively. NS indicates not significant.

[3] Total of two scaffolds.

[4] Measured 10 cm above union.

[5] Measured 5 cm below union.

[6] Tallest scaffold.

[7] Root sucker data normalized, SQRT (root suckers+1.0) for *P* -valuies.

Harvest date, 8/31, 9/1&2/2020

Table 2: Effect of training system, spacing, and rootstock on number and size of fruit, yield, box size and number, tree growth, yield efficiency and root suckers of 7th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2019.

	Fruit No. (no./tree) 8/26-28/2019	Fruit Size (g) 8/26-28/2019	Yield (kg/tree) 8/26-28/2019	Nearest Box Size (44 lb. box) 8/26-28/2019	Average Box Number (per tree) 8/26-28/2019	Scion TCSA[4] (cm^2) 10&12/2019	Scion Yield Efficiency (kg/cm^2)	Rootstock TCSA[5] (cm^2) 10&12/2019	Rootstock Yield Efficiency (kg/cm^2)	Tree Heights[6] (cm) 10/9-16/2019	Root Suckers[7] (no./tree) 10/9-16/2019
Training[1]											
2-Leader	22.1 bc	216 a	4.6 bc	90 b	0.24 b	28.2 c	0.14 b	41.7 b	0.10 ab	273 ab	0.53
Bi-axis[3]	17.3 c	220 a	3.7 c	90 b	0.19 c	69.4 a	0.06 c	46.0 ab	0.08 c	263 b	0.41
Tall Spindle	30.1 a	205 b	6.0 a	100 a	0.30 a	33.4 b	0.17 a	49.8 a	0.12 a	276 a	0.30
V-Trellis	26.7 b	220 a	4.9 b	90 b	0.25 ab	31.8 bc	0.13 b	50.5 a	0.09 bc	278 a	0.40
Spacing[1]											
3 feet	24.9 a	210 b	5.0	100 a	0.26	37.9 b	0.14 a	43.6 b	0.11 a	278 a	0.22 b
4.5 feet	23.9 ab	214 ab	4.9	100 ab	0.25	40.9 ab	0.13 a	47.9 a	0.10 ab	268 b	0.50 ab
6 feet	21.1 b	221 a	4.5	90 b	0.23	43.5 a	0.11 b	49.5 a	0.09 b	271 ab	0.51 ab
Rootstock[1]											
Pyrodwarf 2-33	23.4	218	4.8	90 b	0.25	40.0 b	0.13 a	46.9 b	0.10 a	281 a	0.59 a
OHxF 69	22.7	214	4.7	100 ab	0.24	44.0 a	0.11 b	51.1 a	0.09 b	272 ab	0.44 ab
OHxF 87	23.8	213	4.9	100 a	0.25	38.3 b	0.13 a	43.0 c	0.11 a	265 b	0.20 b
ANOVA (*P* -values)[2]											
Training	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	**(0.002)	NS (0.26)
Spacing	* (0.04)	***(0.001)	NS (0.28)	** (0.002)	NS (0.24)	***(<0.001)	***(0.001)	***(0.001)	**(0.002)	*(0.05)	* (0.04)
Rootstock	NS (0.84)	NS (0.15)	NS (0.86)	* (0.04)	NS (0.98)	***(<0.001)	**(0.004)	***(<0.001)	**(0.002)	*** (0.001)	* (0.02)
Block	***(<0.000)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.000)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)
Interaction (*P* -values)[2]											
Training x Rootstock	NS (0.41)	** (0.01)	NS (0.38)	** (0.003)	NS (0.46)	NS (0.21)	NS (0.14)	* (0.05)	NS (0.20)	NS (0.32)	NS (0.35)
Spacing x Rootstock	NS (0.90)	NS (0.23)	NS (0.91)	NS (0.17)	NS (0.84)	NS (0.27)	NS (0.69)	NS (0.52)	NS (0.76)	NS (0.49)	NS (0.58)
Training x Spacing	** (0.01)	NS (0.61)	** (0.004)	NS (0.43)	** (0.01)	* (0.04)	** (0.003)	NS (0.48)	**(0.004)	**(0.01)	* (0.02)
Training x Spacing x Rootstock	NS (0.06)	* (0.04)	NS (0.08)	* (0.04)	NS (0.12)	NS (0.39)	NS (0.45)	NS (0.28)	NS (0.39)	NS (0.19)	NS (0.44)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$, $P < 0.10$ No. Fruit and Box No. by spacing).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, 0.001 respectively. NS indicates not significant.

[3] Total of two scaffolds.

[4] Measured 10 cm above union.

[5] Measured 5 cm below union.

[6] Tallest scaffold.

[7] Root sucker data normalized, SQRT (root suckers+1.0) for *P* -valuies.

Harvest date, 8/26-8/28/2019

Table 3: Cumulative effect of training system, spacing, and rootstock on number and size of fruit, tree yield and growth, yield efficiency and root suckers of 1st to 8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2013-2020.

	Average Fruit No. (per tree)	Average Fruit Size[4] (g)	Average Yield (kg/tree)	2020 Scion TCSA (cm^2)	Average Cumulative Scion Yield Efficiency[5] (kg/cm^2)	2020 Rootstock TCSA (cm^2)	Average Cumulative Rootstock Yield Efficiency[5] (kg/cm^2)	Root Suckers[6] (no/tree)
Training[1]								
2-Leader	87 b	205 ab	17.9 b	33.4 c	0.53 c	45.8 c	0.39 b	1.24 b
Bi-axis[3]	76 b	210 a	15.9 b	83.8 a	0.20 d	50.7 b	0.33 c	1.31 ab
Tall Spindle	131 a	193 c	25.6 a	40.1 b	0.64 b	56.6 a	0.46 a	1.46 a
V-Trellis	138 a	203 b	28.0 a	38.2 bc	0.71 a	55.6 a	0.49 a	1.31 ab
Spacing[1]								
3 feet	102	204	20.4 b	45.2 b	0.52	48.4 b	0.42	1.22 b
4.5 feet	108	200	21.8 ab	48.3 b	0.53	51.6 b	0.41	1.36 ab
6 feet	114	203	23.3 a	53.2 a	0.52	56.5 a	0.42	1.41 a
Rootstock[1]								
Pyrodwarf 2-33	92 b	208 a	19.2 b	49.1 ab	0.47 b	51.9 b	0.37 b	1.44 a
OHxF 69	111 a	201 b	22.4 a	52.0 a	0.49 b	56.0 a	0.39 b	1.33 ab
OHxF 87	121 a	198 b	24.0 a	45.6 b	0.60 a	48.7 b	0.48 a	1.22 b
ANOVA (*P* -values)[2]								
Training	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.06)
Spacing	NS (0.14)	NS (0.13)	* (0.04)	***(<0.001)	NS (0.87)	***(<0.001)	NS (0.97)	* (0.03)
Rootstock	***(<0.001)	***(<0.001)	***(<0.001)	***(0.001)	***(<0.001)	***(<0.001)	***(<0.001)	** (0.01)
Block	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)
Interaction (*P* -values)[2]								
Training x Rootstock	NS (0.54)	NS (0.44)	NS (0.53)	NS (0.31)	NS (0.60)	NS (0.08)	NS (0.55)	NS (0.77)
Spacing x Rootstock	NS (0.35)	NS (0.21)	NS (0.46)	NS (0.47)	NS (0.47)	NS (0.70)	NS (0.42)	NS (0.37)
Training x Spacing	NS (0.08)	NS (0.63)	* (0.05)	* (0.03)	* (0.02)	NS (0.65)	NS (0.16)	NS (0.11)
Training x Spacing x Rootstock	NS (0.11)	NS (0.23)	NS (0.09)	NS (0.16)	NS (0.34)	NS (0.41)	NS (0.24)	NS (0.90)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, 0.001 respectively. NS indicates not significant.

[3] Total of two scaffolds.

[4] Average fruit size 2014 to 2020.

[5] Based on cumulative yield (2014-20) and final TCSA (2020).

[6] Root sucker data normalized, SQRT(root suckers+1.0) for *P* -values.

Table 4: Cumulative effect of training system, spacing, and rootstock on number and size of fruit, tree yield and growth, yield efficiency and root suckers of 1st to 7th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2013-2019.

	Average Fruit No. (per tree)	Average Fruit Size[4] (g)	Average Yield (kg/tree)	2019 Scion TCSA (cm^2)	Average Cumulative Scion Yield Efficiency[5] (kg/cm^2)	2019 Rootstock TCSA (cm^2)	Average Cumulative Rootstock Yield Efficiency[5] (kg/cm^2)	Root Suckers[6] (no/tree)
Training[1]								
2-Leader	56 b	203 ab	11.4 b	28.2 c	0.40 b	41.7 b	0.27 b	1.12
Bi-axis[3]	47 b	207 a	9.8 b	69.4 a	0.15 c	46.0 ab	0.22 c	0.80
Tall Spindle	91 a	190 c	17.5 a	33.4 b	0.52 a	49.8 a	0.35 a	0.70
V-Trellis	91 a	200 b	18.4 a	31.8 bc	0.56 a	50.5 a	0.36 a	0.67
Spacing[1]								
3 feet	70	201	13.9	37.9 b	0.42	43.6 b	0.31	0.62
4.5 feet	72	198	14.2	40.9 ab	0.40	47.9 a	0.29	0.88
6 feet	73	201	14.8	43.5 a	0.40	49.5 a	0.30	0.96
Rootstock[1]								
Pyrodwarf 2-33	56 c	206 a	11.5 c	40.0 b	0.35 b	46.9 b	0.25 b	1.05 a
OHxF 69	71 b	199 b	14.3 b	44.0 a	0.40 b	51.1 a	0.27 b	0.80 ab
OHxF 87	87 a	195 b	17.1 a	38.3 b	0.50 a	43.0 c	0.39 a	0.61 b
ANOVA (*P* -values)[2]								
Training	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.20)
Spacing	NS (0.88)	NS (0.18)	NS (0.47)	***(<0.001)	NS (0.56)	***(0.001)	NS (0.06)	NS (0.09)
Rootstock	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	*(0.03)
Block	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)
Interaction (*P* -values)[2]								
Training x Rootstock	*(0.02)	NS (0.53)	*(0.04)	NS (0.21)	*(0.02)	*(0.05)	NS (0.26)	NS (0.70)
Spacing x Rootstock	NS (0.14)	NS (0.10)	NS (0.26)	NS (0.27)	NS (0.83)	NS (0.52)	NS (0.92)	NS (0.38)
Training x Spacing	*(0.04)	NS (0.58)	NS (0.20)	*(0.04)	*(0.05)	NS (0.48)	**(0.01)	NS (0.24)
Training x Spacing x Rootstock	*(0.03)	NS (0.13)	*(0.05)	NS (0.39)	NS (0.25)	NS (0.28)	NS (0.50)	NS (0.73)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, 0.001 respectively. NS indicates not significant.

[3] Total of two scaffolds.

[4] Average fruit size 2014 to 2019.

[5] Based on cumulative yield (2014-19) and final TCSA (2019).

[6] Root sucker data normalized, SQRT(root suckers+1.0) for *P* -values.

Table 5: Effect of training system, spacing, and rootstock on number of dropped fruit and % dropped or removed fruit as compared to total fruit of 8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2020.

	Average Fruit Dropped or Removed from Tree (no./tree)			
	Preharvest 6/17-8/26/2020	Harvested 8/31, 9/1&2/2020	Total Removed and Harvested	Average Percent Removed Preharvest
Training[1]				
2-Leader	16 a	30 b	47 b	32 ab
Bi-axis[#]	12 a	29 b	40 b	41 a
Tall Spindle	6 b	40 a	47 b	16 b
V-Trellis	15 a	46 a	61 a	21 b
Average	**13**	**36**	**49**	**27**
Spacing[1]				
3 feet	13	32 b	44 b	29
4.5 feet	12	37 ab	48 ab	29
6 feet	13	40 a	54 a	25
Average	**13**	**36**	**49**	**27**
Rootstock[1]				
Pyrodwarf 2-33	12	36	48	25
OHxF 69	14	40	52	33
OHxF 87	12	34	45	24
Average	**13**	**36**	**49**	**27**
ANOVA (*P* -values)[2]				
Training	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)
Spacing	NS (0.30)	** (0.002)	**(0.01)	NS (0.66)
Rootstock	NS (0.29)	NS (0.09)	NS (0.09)	NS (0.17)
Block	***(<0.001)	***(<0.001)	***(<0.001)	*(0.02)
Interaction (*P* -values)[2]				
Training x Rootstock	NS (0.71)	NS (0.25)	NS (0.42)	NS (0.13)
Spacing x Rootstock	NS (0.21)	NS (0.18)	NS (0.23)	NS (0.94)
Training x Spacing	***(<0.001)	NS (0.23)	***(<0.001)	NS (0.39)
Training x Spacing x Rootstock	*(0.05)	NS (0.48)	NS (0.36)	NS (0.91)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, 0.001 respectively. NS indicates not significant.

[#] Total of two scaffolds

Harvest date, 8/31, 9/1&2/2020

Table 6: Effect of training system, spacing, and rootstock on number of dropped fruit and % dropped or removed fruit as compared to total fruit of 7th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2019.

	Average Fruit Dropped or Removed from Tree (no./tree)			
	Preharvest 6/11-8/26/2019	Harvested 8/26-28/2019	Total Removed and Harvested	Average Percent Removed Preharvest
Training[1]				
2-Leader	10	22 bc	32 bc	31 ab
Bi-axis[#]	8	17 c	25 c	33 a
Tall Spindle	10	30 a	40 a	24 b
V-Trellis	9	24 b	33 b	26 ab
Average	**9**	**23**	**33**	**29**
Spacing[1]				
3 feet	11	25	36 a	31
4.5 feet	9	24	33 ab	27
6 feet	8	21	29 b	28
Average	**9**	**23**	**33**	**29**
Rootstock[1]				
Pyrodwarf 2-33	9	23	33	28
OHxF 69	9	23	31	30
OHxF 87	10	24	34	28
Average	**9**	**23**	**33**	**29**
ANOVA (*P* -values)[2]				
Training	NS (0.28)	***(<0.001)	***(<0.001)	**(<0.004)
Spacing	NS (0.11)	NS (0.08)	* (0.02)	NS (0.28)
Rootstock	NS (0.64)	NS (0.88)	NS (0.74)	NS (0.70)
Block	***(<0.001)	***(<0.001)	***(<0.001)	**(0.01)
Interaction (*P* -values)[2]				
Training x Rootstock	NS (0.86)	NS (0.41)	NS (0.41)	NS (0.57)
Spacing x Rootstock	NS (0.33)	NS (0.90)	NS (0.67)	NS (0.41)
Training x Spacing	* (0.02)	** (0.01)	** (0.003)	NS (0.12)
Training x Spacing x Rootstock	* (0.02)	NS (0.06)	* (0.04)	NS (0.42)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, 0.001 respectively. NS indicates not significant.

[#] Total of two scaffolds

Harvest date, 8/26-28/2019

Table 7: Effect of training system, spacing, and rootstock on the amount of fruit dropped or removed from 'Bartlett' pear 3rd to 8th leaf trees, Hopland, Mendocino County, California, 2015 to 2020.

	Percent Dropped or Removed Fruit (%/per tree)						
	6/10-11/2015	6/6 & 17/2016	6/26 & 7/6/2017	5/25-8/24/2018	6/11-8/26/2019	6/17-8/26/2020	Average % 2015-2020
Training[1]							
2-Leader	18.9 a	3.3 b	14.7 b	58.8 a	31.4 ab	31 7 ab	
Bi-axis	18.5 a	0.1 b	15.5 b	50.9 b	33.1 a	40.7 a	
Tall Spindle	4.3 b	18.5 a	23.1 a	44.2 c	24.3 b	15.6 b	
V-Trellis	5.4 b	3.0 b	6.6 c	53.4 ab	25.6 ab	21.1 b	
Average	**11.8**	**6.2**	**15.0**	**51.8**	**28.6**	**27.3**	**23.5**
Spacing[1]							
3 feet	14.4	7.2	14.4	53.3	30.8	28.5	
4.5 feet	10.0	7.0	13.6	50.3	26.7	28.8	
6 feet	11.1	4.4	17.0	52.0	28.3	24.5	
Average	**11.8**	**6.2**	**15.0**	**51.9**	**28.6**	**27.3**	**23.5**
Rootstock[1]							
Pyrodwarf 2-33	13.0	4.6	12.4 b	49.0 b	28.4	24.7	
OHxF 69	13.1	6.9	18.4 a	56.4 a	29.7	33.0	
OHxF 87	9.3	7.1	14.2 ab	50.1 b	27.6	24.1	
Average	**11.8**	**6.2**	**15.0**	**51.8**	**28.6**	**27.3**	**23.5**
ANOVA[2] **(*P* -values)**							
Training	***(<0.0001)	*** (<0.001)	*** (<0.001)	***(<0.001)	**(<0.004)	*** (<0.001)	
Spacing	NS (0.08)	NS (0.67)	NS (0.28)	NS (0.21)	NS (0.28)	NS (0.66)	
Rootstock	NS (0.13)	NS (0.83)	* (0.02)	**(0.003)	NS (0.70)	NS (0.17)	
Block	NS (0.11)	NS (0.06)	NS (0.34)	**(0.002)	**(0.01)	* (0.02)	
Interaction[2] ***P* -values**							
Training x Rootstock	NS (0.33)	NS (0.49)	* (0.05)	NS (0.84)	NS (0.57)	NS (0.13)	
Spacing x Rootstock	* (0.02)	NS (0.30)	NS (0.32)	NS (0.10)	NS (0.41)	NS (0.94)	
Training x Spacing	NS (0.19)	NS (0.67)	** (0.01)	NS (0.50)	NS (0.12)	NS (0.39)	
Training x Spacing x Rootstock	NS (0.84)	~[3]	NS (0.38)	NS (0.31)	NS (0.42)	NS (0.91)	

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively. NS indicates not significant.

[3] Insufficient replicated data.

Table 8: Effect of training system, spacing, and rootstock on the amount of fruit dropped, removed, or harvested from 'Bartlett' pear 3rd - 8th leaf trees, Hopland, Mendocino County, California, 2015-2020.

	Total Number of Fruit Dropped, Removed, or Harvested (per tree)						
	6/10-11/2015	6/6 & 17/2016	6/26 & 7/6/2017	5/25-8/24/2018	6/11-8/26/2019	6/17-9/1/2020	Average No. Fruit 2015-2020
Training[1]							
2-Leader	9 b	2 bc	11 b	41 bc	32 bc	47 b	
Bi-axis	7 b	1 c	9 b	34 c	25 c	40 b	
Tall Spindle	18 a	2 ab	20 a	46 b	40 a	47 b	
V-Trellis	15 a	3 a	19 a	72 a	33 b	61 a	
Average	**12**	**2**	**15**	**48**	**33**	**49**	**27**
Spacing[1]							
3 feet	12	2	14 ab	44 b	36 a	44 b	
4.5 feet	12	2	14 b	50 ab	33 ab	48 ab	
6 feet	13	3	17 a	51 a	29 b	54 a	
Average	**12**	**2**	**15**	**48**	**33**	**49**	**27**
Rootstock[1]							
Pyrodwarf 2-33	5 c	1 c	9 c	40 b	33	48	
OHxF 69	14 b	2 b	14 b	51 a	31	52	
OHxF 87	18 a	3 a	21 a	53 a	34	45	
Average	**12**	**2**	**15**	**48**	**33**	**49**	**27**
ANOVA[2] **(*P* -values)**							
Training	***(<0.0001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	
Spacing	NS (0.40)	*(0.04)	**(0.002)	** (0.01)	* (0.02)	** (0.01)	
Rootstock	***(<0.0001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.74)	NS (0.09)	
Block	***(<0.0001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	
Interaction[2] ***P* -values**							
Training x Rootstock	***(<0.0001)	*(0.02)	**(0.01)	NS (0.19)	NS (0.41)	NS (0.42)	
Spacing x Rootstock	*(0.04)	NS (0.38)	NS (0.15)	NS (0.06)	NS (0.67)	NS (0.23)	
Training x Spacing	NS (0.50)	NS (0.22)	**(0.01)	NS (0.66)	** (0.003)	***(<0.001)	
Training x Spacing x Rootstock	NS (0.23)	NS (0.29)	**(0.002)	NS (0.22)	* (0.04)	NS (0.36)	

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively. NS indicates not significant.

Table 9: Effect of training system, spacing, and rootstock on firmness and soluble solids of 3rd-8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2015-2020.

	Firmness (kg. force)						Soluble Solids (°Brix)					
	8/12-13/2015	8/8/2016	8/26-27/2017	8/31-9/1/2018	8/26-28/2019	8/31-9/2/2020	8/12-13/2015	8/8/2016	8/26-27/2017	8/31-9/1/2018	8/26-28/2019	8/31-9/2/2020
Training[1]												
2-Leader	9.4 ab	8.8	8.6 a	7.9 bc	6.7 ab	7.6 a	14.1	12.9 a	13.1 ab	13.3	14.0	15.2
Bi-axis	9.5 a	8.7	8.5 a	8.4 a	7.0 a	7.4 ab	13.9	12.2 b	12.7 b	13.3	14.1	15.7
Tall Spindle	9.4 ab	8.5	8.4 a	8.3 ab	6.7 b	7.4 ab	14.0	12.5 ab	12.8 b	13.4	13.8	15.9
V-Trellis	9.1 b	8.6	7.9 b	7.6 c	6.8 ab	7.2 b	14.1	12.8 a	13.2 a	13.5	14.1	15.5
Average	**9.4**	**8.7**	**8.4**	**8.1**	**6.8**	**7.4**	**14.0**	**12.6**	**13.0**	**13.4**	**14.0**	**15.6**
Spacing[1]												
3 feet	9.4	8.6	8.3	8.0	6.7	7.3 b	13.9	12.6 ab	13.0	13.4	14.1	15.3 b
4.5 feet	9.3	8.6	8.3	8.0	6.8	7.4 ab	14.1	12.4 b	12.9	13.4	13.9	15.6 ab
6 feet	9.4	8.7	8.5	8.0	6.9	7.5 a	14.1	12.9 a	13.0	13.3	13.9	15.9 a
Average	**9.4**	**8.6**	**8.4**	**8.0**	**6.8**	**7.4**	**14.0**	**12.6**	**13.0**	**13.4**	**14.0**	**15.6**
Rootstock[1]												
Pyrodwarf 2-33	9.5	8.7	8.5	8.1	6.8	7.3	13.7 b	12.3 b	12.8 b	13.3	14.1	15.5
OHxF 69	9.3	8.6	8.4	8.1	6.8	7.4	14.0 ab	12.6 ab	13.0 ab	13.2	13.8	15.4
OHxF 87	9.2	8.7	8.3	7.9	6.7	7.4	14.4 a	12.9 a	13.2 a	13.5	14.0	15.8
Average	**9.3**	**8.7**	**8.4**	**8.0**	**6.8**	**7.4**	**14.0**	**12.6**	**13.0**	**13.3**	**14.0**	**15.6**
ANOVA[2] **(*P* -values)**												
Training	*(0.02)	NS (0.24)	*** (<0.001)	*** (<0.001)	* (0.04)	*** (0.001)	NS (0.53)	** (0.002)	** (0.01)	NS (0.61)	NS (0.32)	NS (0.16)
Spacing	NS (0.82)	NS (0.44)	NS (0.56)	NS (0.96)	NS (0.12)	NS (0.66)	NS (0.64)	** (0.01)	NS (0.91)	NS (0.24)	NS (0.20)	* (0.05)
Rootstock	NS (0.19)	NS (0.85)	NS (0.15)	NS (0.09)	NS (0.36)	NS (0.84)	**(0.01)	*** (0.001)	** (0.01)	NS (0.06)	NS (0.15)	NS (0.69)
Block	*(0.03)	*(0.04)	NS (0.40)	NS (0.10)	** (0.01)	* (0.05)	*(0.03)	NS (0.36)	* (0.02)	** (0.002)	*** (0.001)	NS (0.16)
Interaction[2] ***P* -values**												
Training x Rootstock	NS (0.54)	NS (0.07)	NS (0.47)	NS (0.61)	NS (0.27)	NS (0.22)	**(0.01)	NS (0.39)	NS (0.90)	NS (0.61)	NS (0.54)	* (0.05)
Spacing x Rootstock	NS (0.56)	NS (0.15)	NS (0.82)	NS (0.40)	NS (0.90)	NS (0.78)	NS (0.18)	NS (0.91)	NS (0.18)	NS (0.15)	NS (0.35)	NS (0.51)
Training x Spacing	NS (0.28)	NS (0.92)	*** (<0.001)	NS (0.07)	NS (0.55)	NS (0.24)	NS (0.13)	NS (0.23)	NS (0.97)	NS (0.51)	NS (0.94)	** (0.01)
Training x Spacing x Rootstock	NS (0.43)	~[3]	NS (0.51)	NS (0.12)	NS (1.00)	NS (0.69)	NS (0.18)	~[3]	NS (0.67)	NS (0.83)	NS (0.16)	NS (0.54)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **,*** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively. NS indicates not significant.

[3] Insufficient data for interaction.

Table 10: Effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2020.

Treatment[1]	Fruit No. (no./tree) 9/2/2020	Fruit Size (g) 9/2/2020	Yield (kg/tree) 9/2/2020	Cultivar TCSA[3] (cm^2) 12/22/2020	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[4] (cm^2) 12/22/2020	Rootstock Yield Efficiency (kg/cm^2)	Tree Heights (cm) 1/7/2021	Root Suckers (no./tree) 1/7/2021
OHxF 69	176 a	181	31.0 a	46.6 a	0.66	76.3 a	0.41 a	269 a	0.0
OHxF87	123 b	164	19.6 b	38.8 b	0.53	62.9 b	0.32 b	240 b	0.0
ANOVA (*P* -values)[2]									
Treatment	* (0.03)	NS (0.25)	** (0.005)	* (0.03)	NS (0.06)	* (0.03)	* (0.04)	* (0.02)	~
Block	NS (0.50)	NS (0.15)	NS (0.11)	NS (0.13)	** (0.002)	NS (0.21)	** (0.002)	** (0.01)	~

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, ** Indicate significance at $P \leq 0.05$ and 0.01 respectively. NS indicates not significant.

[3] Measured 10 cm above union.

[4] Measured 5 cm below union.

Harvest date: 9/2/2020

Table 11: Effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 7th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2019.

Treatment[1]	Fruit No. (no./tree) 8/28/2019	Fruit Size (g) 8/28/2019	Yield (kg/tree) 8/28/2019	Cultivar TCSA[3] (cm^2) 10 & 12/2019	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[4] (cm^2) 10 & 12/2019	Rootstock Yield Efficiency (kg/cm^2)	Tree Heights (cm) 10/9-16/2019	Root Suckers (no./tree) 10/9-16/2019
OHxF 69	88	196	15.3	43.3 a	0.35	73.7 a	0.20	264 a	0.0
OHxF87	83	184	14.2	35.5 b	0.40	60.1 b	0.24	233 b	0.0
ANOVA (*P* -values)[2]									
Treatment	NS (0.77)	NS (0.10)	NS (0.59)	* (0.02)	NS (0.24)	* (0.03)	NS (0.18)	** (0.004)	~
Block	*** (<0.001)	*** (<0.001)	*** (<0.001)	NS (0.17)	*** (<0.001)	NS (0.21)	*** (0.001)	** (0.01)	~

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01 and 0.001 respectively. NS indicates not significant.

[3] Measured 10 cm above union.

[4] Measured 5 cm below union.

Harvest date: 8/28/2019

Table 12: Cumulative effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 2nd to 8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2013-2020.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Cumulative Yield (kg)	2020 Cultivar TCSA (cm^2)	Cultivar Yield Efficiency[4] (kg/cm^2)	2020 Rootstock TCSA (cm^2)	Rootstock Yield Efficiency[4] (kg/cm^2)	Root Suckers (no./tree)
OHxF 69	533	183 a	94.4 a	46.6 a	2.01	76.3 a	1.24	0.0
OHxF87	455	168 b	75.6 b	38.8 b	1.99	62.9 b	1.21	0.0
ANOVA (*P* -values)[2]								
Treatment	NS (0.16)	* (0.03)	* (0.05)	* (0.03)	NS (0.89)	* (0.03)	NS (0.73)	~
Block	NS (0.85)	* (0.03)	NS (0.90)	NS (0.13)	* (0.03)	NS (0.21)	NS (0.06)	~

[1] Within columns, treatment means significantly different (Duncan Multiple Range test, $P \leq 0.05$).

[2] * Indicates significance at $P \leq 0.05$. NS indicates not significant.

[3] Based on fruiting years 2014-2020.

[4] Based on cumulative yield (2014-2020) and final TCSA (2020).

Table 13: Cumulative effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 2nd to 7th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2013-2019.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Cumulative Yield (kg)	2019 Scion TCSA (cm^2)	Scion Yield Efficiency[4] (kg/cm^2)	2019 Rootstock TCSA (cm^2)	Rootstock Yield Efficiency[4] (kg/cm^2)	Root Suckers (no./tree)
OHxF 69	356	183 a	63.4	43.3 a	1.45	73.7 a	0.86	0.0
OHxF87	333	169 b	56.0	35.5 b	1.61	60.1 b	0.94	0.0
ANOVA (*P* -values)[2]								
Treatment	NS (0.47)	* (0.04)	NS (0.23)	* (0.02)	NS (0.18)	* (0.03)	NS (0.23)	~
Block	NS (0.23)	* (0.04)	NS (0.78)	NS (0.17)	NS (0.42)	NS (0.21)	NS (0.58)	~

[1] Within columns, treatment means significantly different (Duncan Multiple Range test, $P \leq 0.05$).

[2] * Indicates significance at $P \leq 0.05$. NS indicates not significant.

[3] Based on fruiting years 2014-2019.

[4] Based on cumulative yield (2014-2019) and final TCSA (2019).

Table 14: Effect of rootstock on firmness and soluble solids of completely unpruned 3rd to 8th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2015-2020.

	Firmness (kg force)						Soluble Solids (° Brix)					
Treatment[1]	2015[3]	2016[4]	2017[5]	2018[6]	2019[7]	2020[8]	2015[3]	2016[4]	2017[5]	2018[6]	2019[7]	2020[8]
OHxF 69	9.2	8.1	7.7	6.3	6.5 b	6.9 b	14.1	14.1	13.6 b	14.0	13.6 b	14.4
OHxF87	9.4	8.3	7.9	6.7	6.8 a	7.9 a	14.5	14.5	14.2 a	14.2	14.8 a	14.7
ANOVA (*P* -values)[2]												
Treatment	NS (0.52)	NS (0.53)	NS (0.12)	NS (0.16)	* (0.05)	** (0.002)	NS (0.07)	NS (0.07)	** (0.01)	NS (0.36)	** (0.003)	NS (0.32)
Block	NS (0.20)	NS (0.24)	NS (0.51)	NS (0.21)	NS (0.18)	NS (0.49)	** (0.01)	* (0.03)	** (0.01)	* (0.02)	** (0.002)	** (0.002)

[1] Within columns, treatment means significantly different (Tukey HSD test, $P \leq 0.05$).

[2] *, ** Indicates significance at $P \leq 0.05$ and 0.01 respectively. NS indicates not significant.

[3] Samples collected at harvest : 8/12/15, measured 8/26, 28, 31/15.

[4] Samples collected at harvest : 8/8/16, measured 8/9, 10, 12/16.

[5] Samples collected at harvest : 8/26/17, measured 8/28, 30, 31/17.

[6] Samples collected at harvest : 9/1/18, measured 9/5, 13/18.

[7] Samples collected at harvest : 8/28/19, measured 8/31/19.

[8] Samples collected at harvest : 9/2/20, measured 9/9 & 10/20.

Table 15: Effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, tree height, and root suckers of 8th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2020

Treatment[1]	Fruit No. (per tree)	Fruit Size (g)	Yield (kg/tree)	Cultivar TCSA[3] (cm2)	Cultivar Yield Efficiency (kg/cm2)	Rootstock TCSA (cm2)	Rootstock Yield Efficiency (kg/cm2)	Tree Height (cm)	Root Suckers (per tree)
Spreading	187	136	24.4	94.9	0.26	56.2	0.44	256	0.0
No Spreading	231	142	31.2	115.5	0.27	76.9	0.40	260	0.0
P -value[2]	NS (0.46)	NS (0.79)	NS (0.28)	NS (0.23)	NS (0.73)	* (0.03)	NS (0.59)	NS (0.89)	~

[1] Means analyzed by T-test, $P \leq 0.05$).

[2] * Indicates significance at P<0.05. NS indicates not significant.

[3] Total of two scaffolds.

Harvest Date - 9/2/2020

Table 16: Effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, tree height and root suckers of 7th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2019.

Treatment[1]	Fruit No. (per tree)	Fruit Size (g)	Yield (kg/tree)	Scion TCSA[3] (cm^2)	Scion Yield Efficiency (kg/cm^2)	Rootstock TCSA (cm^2)	Rootstock Yield Efficiency	Tree Height (cm)	Root Suckers (per tree)
Spreading	141.4	126.2	17.7	86.1	0.20	48.5	0.36	243	0.0
No Spreading	108.8	178.2	19.0	104.5	0.18	73.7	0.26	242	0.0
P -value[2]	NS (0.27)	* (0.02)	NS (0.76)	NS (0.26)	NS (0.62)	* (0.03)	NS (0.11)	NS (0.99)	~

[1] Means analyzed by T-test, $P \leq 0.05$).

[2] * Indicates significance at P<0.05. NS indicates not significant.

[3] Total of two scaffolds.

Harvest Date - 8/28/2019

Table 17 : Cumulative effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, and root suckers of 2nd-8th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2013-2020.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Yield (kg)	2020 Cultivar TCSA[3] (cm^2)	Cultivar Yield Efficiency (kg/cm^2)	2020 Rootstock TCSA (cm^2)	Rootstock Yield Efficiency (kg/cm^2)	Root Suckers (per tree)
Spreading	645	158	93.6	94.9	0.98	56.2	1.66	0.0
No Spreading	629	175	102.3	115.5	0.89	76.9	1.31	0.0
P -value[2]	NS (0.90)	NS (0.14)	NS (0.64)	NS (0.23)	NS (0.25)	* (0.03)	NS (0.06)	~

[1] Means analyzed by T-test, $P \leq 0.05$).

[2] * Indicates significance at P<0.05. NS indicates not significant.

[3] Total of two scaffolds.

Table 18: Cumulative effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, and root suckers of 2nd-7th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2013-2019.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Yield (kg)	2019 Cultivar TCSA[3] (cm^2)	Cultivar Yield Efficiency (kg/cm^2)	2019 Rootstock TCSA (cm^2)	Rootstock Yield Efficiency (kg/cm^2)	Root Suckers (per tree)
Spreading	457	162	69.3	86.1	0.81	48.5	1.43	0.0
No Spreading	398	181	71.1	104.5	0.68	73.7	0.96	0.0
P -value[2]	NS (0.48)	NS (0.10)	NS (0.89)	NS (0.26)	NS (0.15)	* (0.03)	** (0.003)	~

[1] Means analyzed by T-test, $P \leq 0.05$).

[2] *, ** Indicates significance at P<0.05 and 0.01 respectively. NS indicates not significant.

[3] Total of two scaffolds.

Table 19: Effect of scaffold spreading on firmness and soluble solids on Bi-axis trained 3rd to 8th leaf 'Bartlett' pear trees on OHxF 87 rootstock Hopland, Mendocino County, California, 2015-2020.

	Firmness (kg of force)						Soluble Solids (° Brix)					
Treatment[1]	2015[3]	2016[4]	2017[5]	2018[6]	2019[7]	2020[8]	2015[3]	2016[4]	2017[5]	2018[6]	2019[7]	2020[8]
Spreading	8.7	8.2	6.9	6.3	6.4	7.8	14.4	31.1	13.6	14.1	13.9	14.9
No Spreading	8.7	8.3	7.1	6.2	6.4	7.9	14.3	13.1	14.2	13.9	14.1	14.8
P -value[2]	NS (1.00)	NS (0.84)	NS (0.76)	NS (0.70)	NS (0.68)	NS (0.82)	NS (0.73)	NS (0.86)	NS (0.22)	NS (0.50)	NS (0.63)	NS (0.85)

[1] Means analyzed by T-test, $P \leq 0.05$).

[2] NS indicates not significant.

[3] Samples collected at harvest : 8/12/15, measured 8/26, 28, 31/15.

[4] Samples collected at harvest : 8/8/16, measured 8/9, 10, 12/16.

[5] Samples collected at harvest : 8/26/17, measured 8/28, 30, 31/17.

[6] Samples collected at harvest : 9/1/18, measured 9/5, 13/18.

[7] Samples collected at harvest : 8/28/19, measured 10/31/19.

[8] Samples collected at harvest : 9/2/2020, measured 9/9&10/2020.

Table 20: Comparison of average mid-day stem water potential (negative bars) for OHxF 87 and Pyro 2-33 rootstocks by training and spacing for 'Bartlett' pear trees, Hopland, Mendocino County, California, 2014-2020.

	2014[4] (n=5)			2015[4] (n=10)			2016[4] (n=14)		
Treatment[1]	OHxF 87	Pyro 2-33	*P* -value[2]	OHxF 87	Pyro 2-33	*P* -value[2]	OHxF 87	Pyro 2-33	*P* -value[2]
Bi-axis x 3 ft.	14.4	14.2	NS (0.84)	18.2	17.4	NS (0.61)	16.3	16.8	NS (0.80)
Bi-axis x 6 ft.	14.9	15.0	NS (0.94)	18.2	17.7	NS (0.72)	16.9	15.7	NS (0.52)
V-Trellis x 3ft.	14.4	15.5	NS (0.53)	17.9	18.7	NS (0.60)	16.2	17.0	NS (0.67)
V-Trellis x 6ft.	14.5	14.7	NS (0.93)	18.9	18.8	NS (0.95)	17.2	16.7	NS (0.82)
2-Leader x 3 ft.	12.2	13.7	NS (0.20)	17.0	17.3	NS (0.87)	15.8	16.4	NS (0.75)
2-Leader x 6 ft.	14.8	14.5	NS (0.88)	17.9	17.9	NS (0.98)	17.9	16.9	NS (0.62)
Tall Spindle x 3 ft.	13.5	14.4	NS (0.42)	18.7	17.8	NS (0.62)	16.8	16.6	NS (0.92)
Tall Spindle x 6 ft.	15.0	15.2	NS (0.88)	19.1	18.4	NS (0.66)	16.9	16.4	NS (0.80)
Baseline[3]	7.7			7.7			7.6		

	2017[4] (n=9)			2018[4] (n=8)			2019[4] (n=8)		
Treatment[1]	OHxF 87	Pyro 2-33	*P* -value[2]	OHxF 87	Pyro 2-33	*P* -value[2]	OHxF 87	Pyro 2-33	*P* -value[2]
Bi-axis x 3 ft.	17.7	15.9	* (0.03)	14.2	13.8	NS (0.52)	14.1	13.9	NS (0.92)
Bi-axis x 6 ft.	16.6	15.2	NS (0.18)	13.8	13.4	NS (0.68)	13.3	13.4	NS (0.92)
V-Trellis x 3ft.	18.6	17.7	NS (0.51)	12.9	14.6	NS (0.13)	13.2	14.7	NS (0.44)
V-Trellis x 6ft.	18.6	17.6	NS (0.41)	14.2	14.1	NS (0.89)	13.8	13.6	NS (0.91)
2-Leader x 3 ft.	16.6	18.4	NS (0.12)	12.9	14.2	NS (0.21)	12.9	15.0	NS (0.25)
2-Leader x 6 ft.	19.0	17.7	NS (0.30)	14.9	13.9	NS (0.40)	13.8	14.4	NS (0.79)
Tall Spindle x 3 ft.	17.9	18.2	NS (0.85)	15.1	15.3	NS (0.84)	15.8	14.7	NS (0.51)
Tall Spindle x 6 ft.	18.3	18.9	NS (0.73)	13.5	14.6	NS (0.20)	13.2	14.4	NS (0.55)
Baseline[3]	8.1			7.7			7.6		

	2020[4] (n=12)		
Treatment[1]	OHxF 87	Pyro 2-33	*P* -value[2]
Bi-axis x 3 ft.	12.4	13.9	NS (0.36)
Bi-axis x 6 ft.	14.6	11.7	NS (0.12)
V-Trellis x 3ft.	15.0	16.4	NS (0.46)
V-Trellis x 6ft.	16.6	17.1	NS (0.80)
2-Leader x 3 ft.	13.2	13.8	NS (0.75)
2-Leader x 6 ft.	16.5	14.4	NS (0.32)
Tall Spindle x 3 ft.	16.0	15.5	NS (0.80)
Tall Spindle x 6 ft.	12.6	14.3	NS (0.29)
Baseline[3]	7.8		

[1] Means analyzed by T-test, $P \leq 0.05$).

[2] * Indicates significance at $P \leq 0.05$. NS indicates not significant.

[4] Monitor period: 2014: 6/3-10/6, 2015: 6/4-10/1, 2016: 6/23-9/26, 2017: 6/2-9/27, 2018: 6/14-10/18, 2019: 6/12-10/14, 2020: 6/17-9/24.

	2014	2015	2016	2017	2018	2019	2020
Bi-axis x 3 ft.	-14.4	-17.4	-16.8	-17.1	-13.7	-13.9	-14.3
Bi-axis x 6 ft.	-15.1	-17.7	-15.7	-16.1	-13.5	-13.1	-12.1
V-Trellis x 3ft.	-15.9	-18.6	-17	-18.7	-14.8	-14.3	-15.8
V-Trellis x 6ft.	-15.1	-18.8	-16.8	-19.1	-14	-14.2	-16.4
2-Leader x 3 ft.	-14.2	-17.3	-16.4	-19.4	-14.4	-15.0	-14.1
2-Leader x 6 ft.	-15.1	-17.9	-17.7	-18.9	-14.7	-14.3	-13.9
Tall Spindle x 3 f	-14.8	-17.8	-16.6	-19.3	-15.3	-14.7	-15.4
Tall Spindle x 6 f	-15.4	-18.4	-16.4	-19.7	-14.6	-14.4	-14.3
Baseline	-7.8	-7.7	-7.6	-8.1	-7.7	-7.6	-7.8

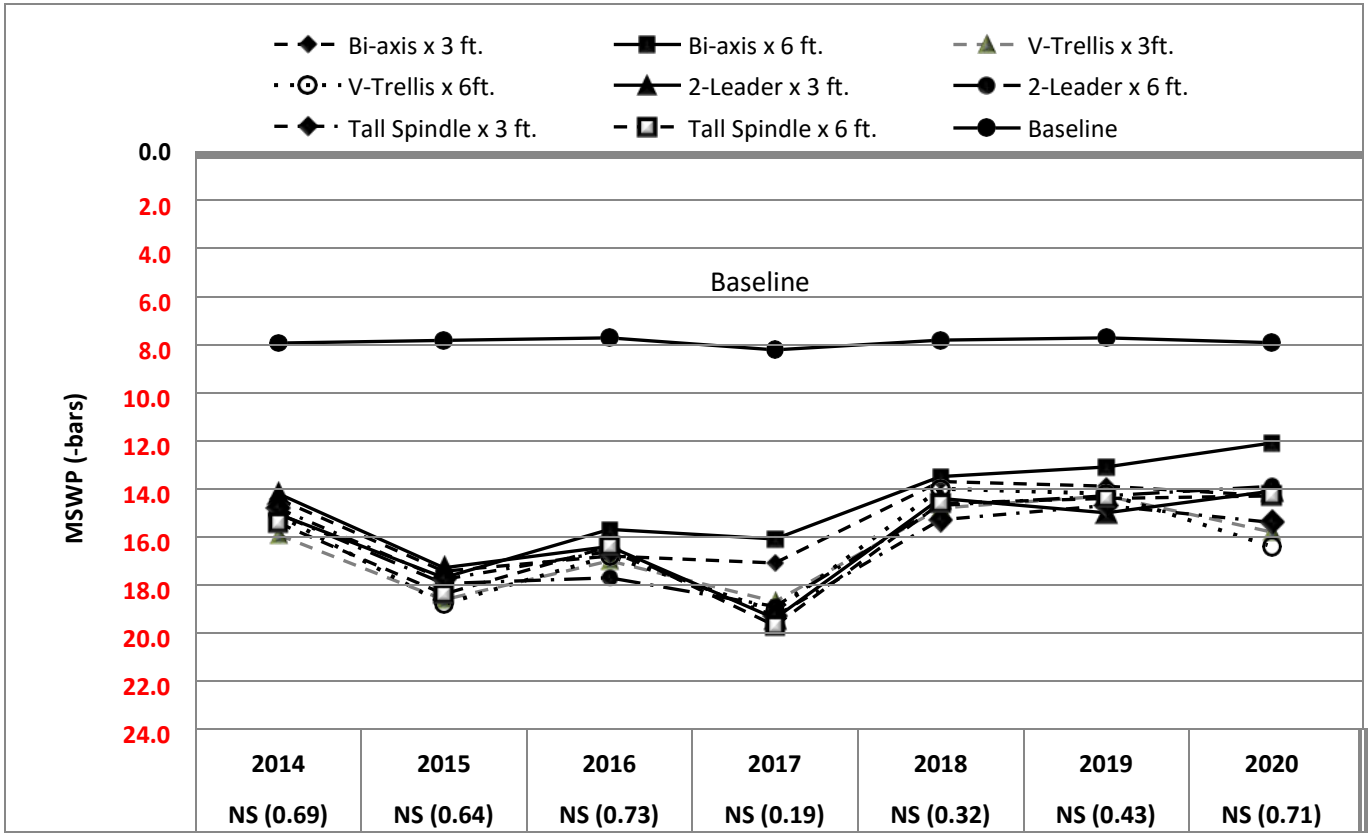


Figure 2: Effect of training system and spacing on seasonal average mid-day stem water potential (MSWP) of 2nd-8th leaf "Bartlett" pear trees on Pyro 2-33 rootstock, Hopland, Mendocino County, California, 2014-2020.

	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19	8/26	9/3	9/9	9/16	9/24
Bi-axis x 3 ft.	-13.1	-15.6			-11.9	-8.7	-13.5	-8.7	-12.7	-15.5	-17.0	-11.63		-19.1	-19.8
Bi-axis x 6 ft.	-10.9	-14.9			-10.4	-7.0	-11.1	-7.0	-10.1	-14.8	-12.3	-7.73		-15.3	-16.8
V-Trellis x 3 ft.	-15.2	-16.9			-14.2	-10.0	-16.2	-10.0	-12.3	-17.8	-21.4	-15.53		-23.2	-23.2
V-Trellis x 6 ft.	-14.7	-16.0			-13.4	-9.6	-18.3	-9.6	-15.0	-20.0	-22.9	-16.70		-24.2	-24.0
2-Leader x 3 ft.	-12.9	-15.4			-12.4	-7.8	-13.3	-7.8	-10.1	-14.9	-15.8	-12.73		-18.6	-22.5
2-Leader x 6 ft.	-12.4	-13.3			-11.6	-8.0	-13.8	-8.0	-10.2	-18.4	-17.4	-14.27		-20.9	-22.7
Tall Spindle x 3 ft.	-12.6	-15.1			-10.8	-8.3	-13.4	-8.3	-10.8	-18.4	-19.0	-16.07		-24.4	-26.2
Tall Spindle x 6 ft.	-13.0	-14.3			-11.2	-8.4	-13.5	-8.4	-12.3	-14.1	-18.4	-13.07		-20.4	-23.7
Baseline	-8.0	-8.1			-8.0	-7.2	-8.0	-6.9	-7.7	-9.2	-8.1	-6.8		-7.8	-7.3

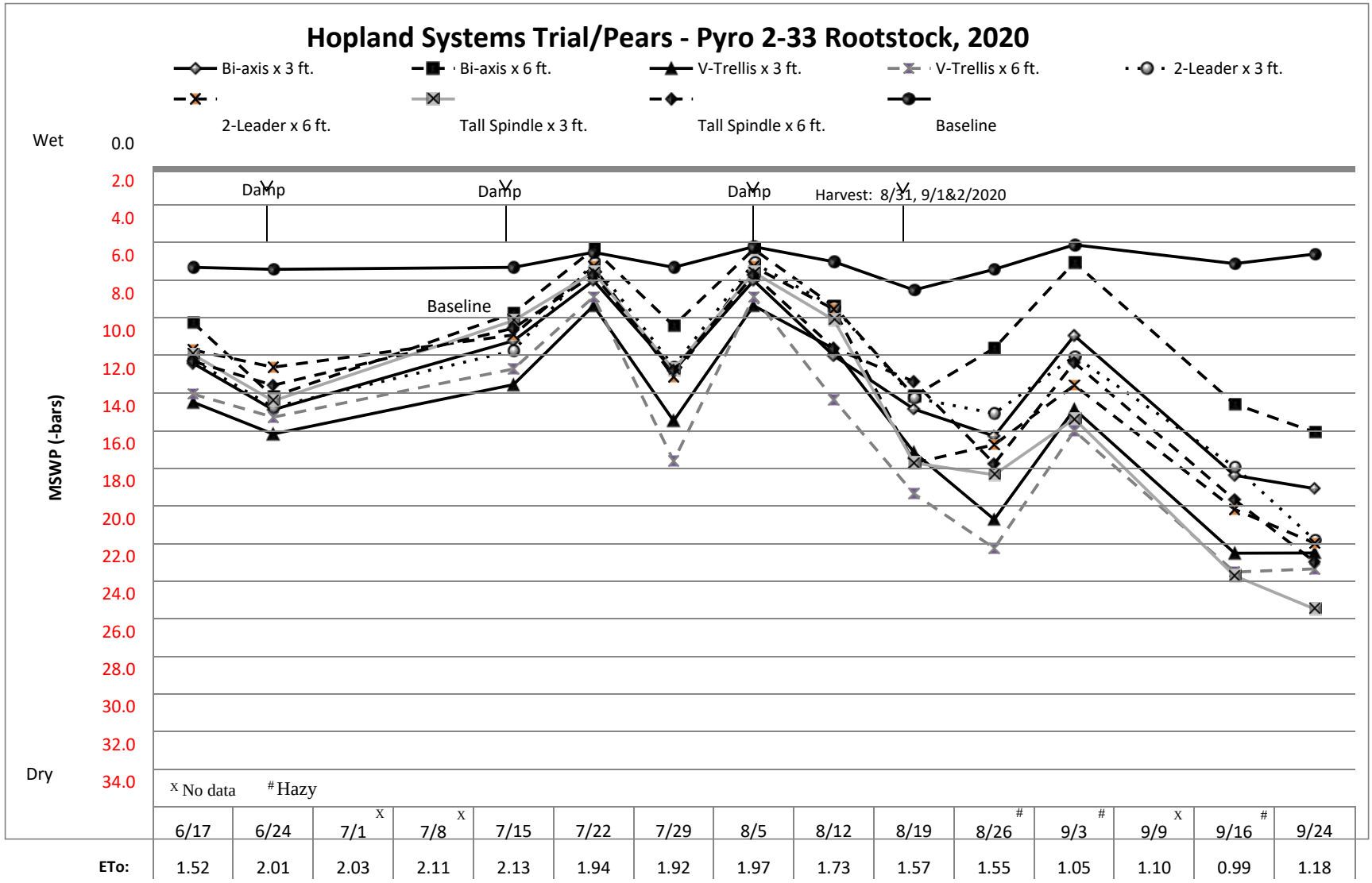
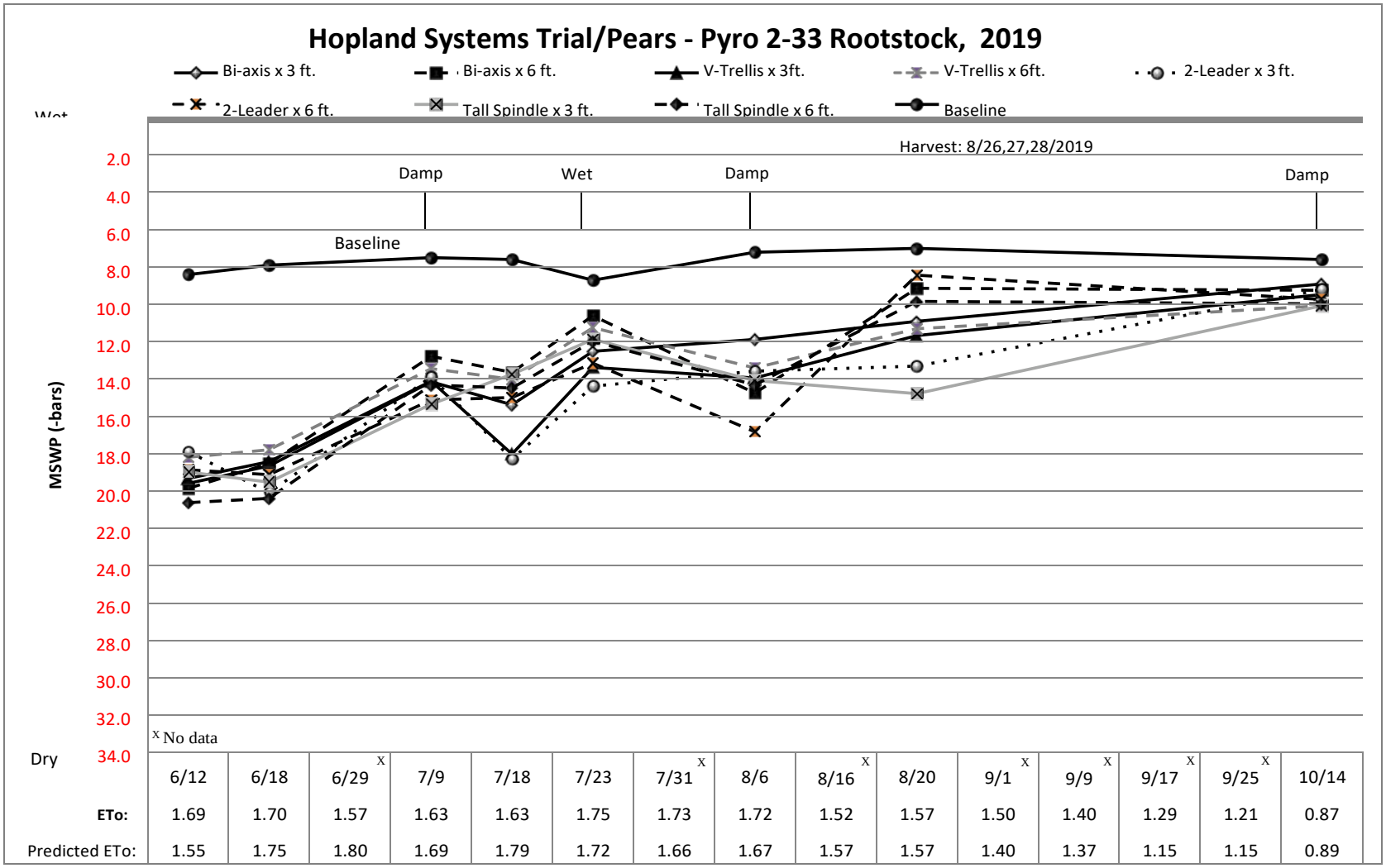


Figure 3. Comparison of mid-day stem water potential (MSWP) and baseline (-7 to-10 bars) among Pyro 2-33 rootstock, 8th-leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2020.

	6/12	6/18	6/29	7/9	7/18	7/23	7/31	8/6	8/16	8/20	9/1	9/9	9/17	9/25	10/14
Bi-axis x 3 ft.	-19.5	-18.5		-14.0	-15.3	-12.4		-11.8		-10.8					-8.8
Bi-axis x 6 ft.	-19.7	-18.4		-12.7	-13.5	-10.5		-14.6		-9.0					-9.1
V-Trellis x 3ft.	-19.2	-18.3		-14.0	-17.9	-13.3		-13.8		-11.6					-9.4
V-Trellis x 6ft.	-18.1	-17.7		-13.3	-13.9	-11.1		-13.3		-11.2					-10.0
2-Leader x 3 ft.	-17.8	-20.0		-13.8	-18.2	-14.3		-13.5		-13.2					-9.1
2-Leader x 6 ft.	-18.7	-19.0		-15.0	-14.9	-13.0		-16.7		-8.3					-9.6
Tall Spindle x 3 ft.	-18.9	-19.4		-15.2	-13.6	-11.8		-14.0		-14.7					-10.0
Tall Spindle x 6 ft.	-20.5	-20.3		-14.2	-14.4	-11.9		-14.2		-9.7					-9.9
Baseline	-8.3	-7.8		-7.4	-7.5	-8.6		-7.1		-6.9					-7.5



	6/12	6/18	6/29 x	7/9	7/18	7/23	7/31 x	8/6	8/16 x	8/20	9/1 x	9/9 x	9/17 x	9/25 x	10/14
ETo:	1.69	1.70	1.57	1.63	1.63	1.75	1.73	1.72	1.52	1.57	1.50	1.40	1.29	1.21	0.87
Predicted ETo:	1.55	1.75	1.80	1.69	1.79	1.72	1.66	1.67	1.57	1.57	1.40	1.37	1.15	1.15	0.89

Figure 4. Comparison of mid-day stem water potential (MSWP) and baseline (-7 to-9 bars) among Pyro 2-33 rootstock, 7th-leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2019.

	2014	2015	2016	2017	2018	2019	2020
Bi-axis x 3 ft.	-14.3	-14.3	-16.3	-19.0	-14.2	-13.4	-12.5
Bi-axis x 6 ft.	-14.9	-14.9	-16.9	-17.5	-13.7	-13.2	-14.7
V-Trellis x 3ft.	-14.6	-14.6	-16.2	-19.2	-12.9	-13.1	-13.7
V-Trellis x 6ft.	-14.8	-14.8	-17.2	-19.2	-14.4	-13.8	-15.3
2-Leader x 3 ft.	-12.8	-12.8	-15.8	-17.8	-13.0	-12.9	-14.5
2-Leader x 6 ft.	-14.4	-14.4	-17.9	-19.9	-14.9	-13.9	-17.8
Tall Spindle x 3 ft.	-13.7	-13.7	-16.8	-18.9	-15.0	-14.8	-16.0
Tall Spindle x 6 ft.	-15.1	-15.1	-16.9	-19.6	-13.5	-14.1	-12.6
Baseline	-7.8	-6.9	-7.6	-8.1	-7.7	-7.6	-7.8

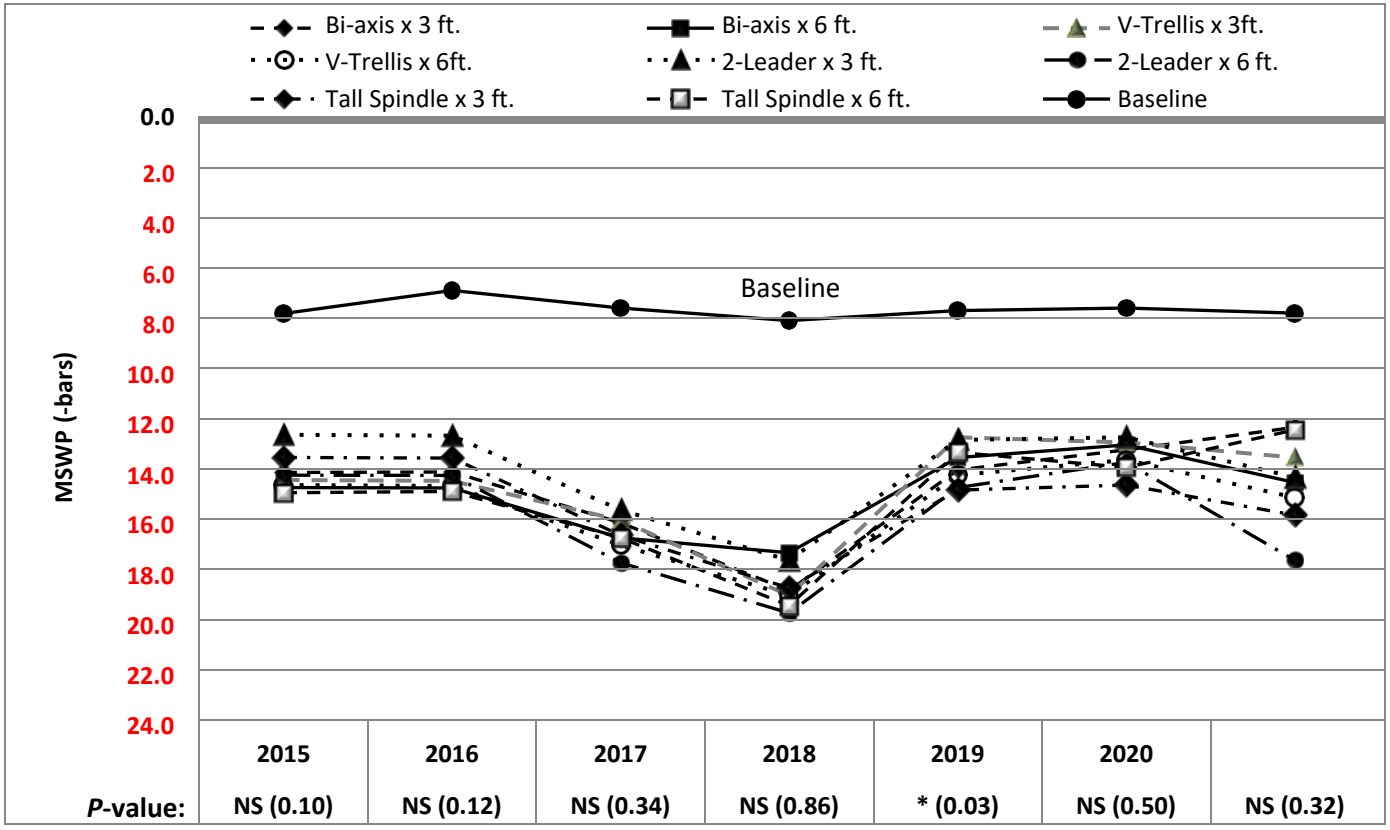


Figure 5: Effect of training system and spacing on seasonal average mid-day stem water potential (MSWP) of 2nd-8th leaf "Bartlett" pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2014-2020.

	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19	8/26	9/3	9/9	9/16	9/24
Bi-axis x 3 ft.	-12.40	-12.7			-10.6	-6.9	-9.9	-7.6	-9.7	-14.5	-15.4	-10.5		-19.6	-19.3
Bi-axis x 6 ft.	-11.20	-13.9			-11.7	-7.6	-13.0	-8.5	-11.3	-18.0	-20.3	-13.6		-22.4	-23.4
V-Trellis x 3 ft.	-12.90	-14.3			-12.8	-8.3	-14.7	-8.9	-13.3	-19.4	-17.3	-14.9		-20.7	-23.0
V-Trellis x 6 ft.	-14.43	-13.9			-17.0	-10.1	-17.5	-10.5	-15.0	-19.7	-20.0	-14.6		-23.3	-22.6
2-Leader x 3 ft.	-13.17	-11.2			-10.9	-8.2	-13.4	-7.9	-9.1	-15.5	-15.9	-13.3		-19.7	-20.3
2-Leader x 6 ft.	-13.60	-13.9			-11.7	-8.6	-21.1	-9.3	-13.3	-20.5	-22.9	-16.2		-23.5	-23.5
Tall Spindle x 3 ft.	-13.67	-13.9			-11.8	-9.1	-14.7	-9.7	-13.0	-20.9	-20.1	-17.0		-22.2	-26.1
Tall Spindle x 6 ft.	-11.03	-15.4			-11.0	-7.1	-10.4	-7.9	-9.7	-14.9	-14.6	-11.9		-17.8	-18.9
Baseline	-8.0	-8.1			-8.0	-7.2	-8.0	-6.9	-7.7	-9.2	-8.1	-6.8		-7.8	-7.3

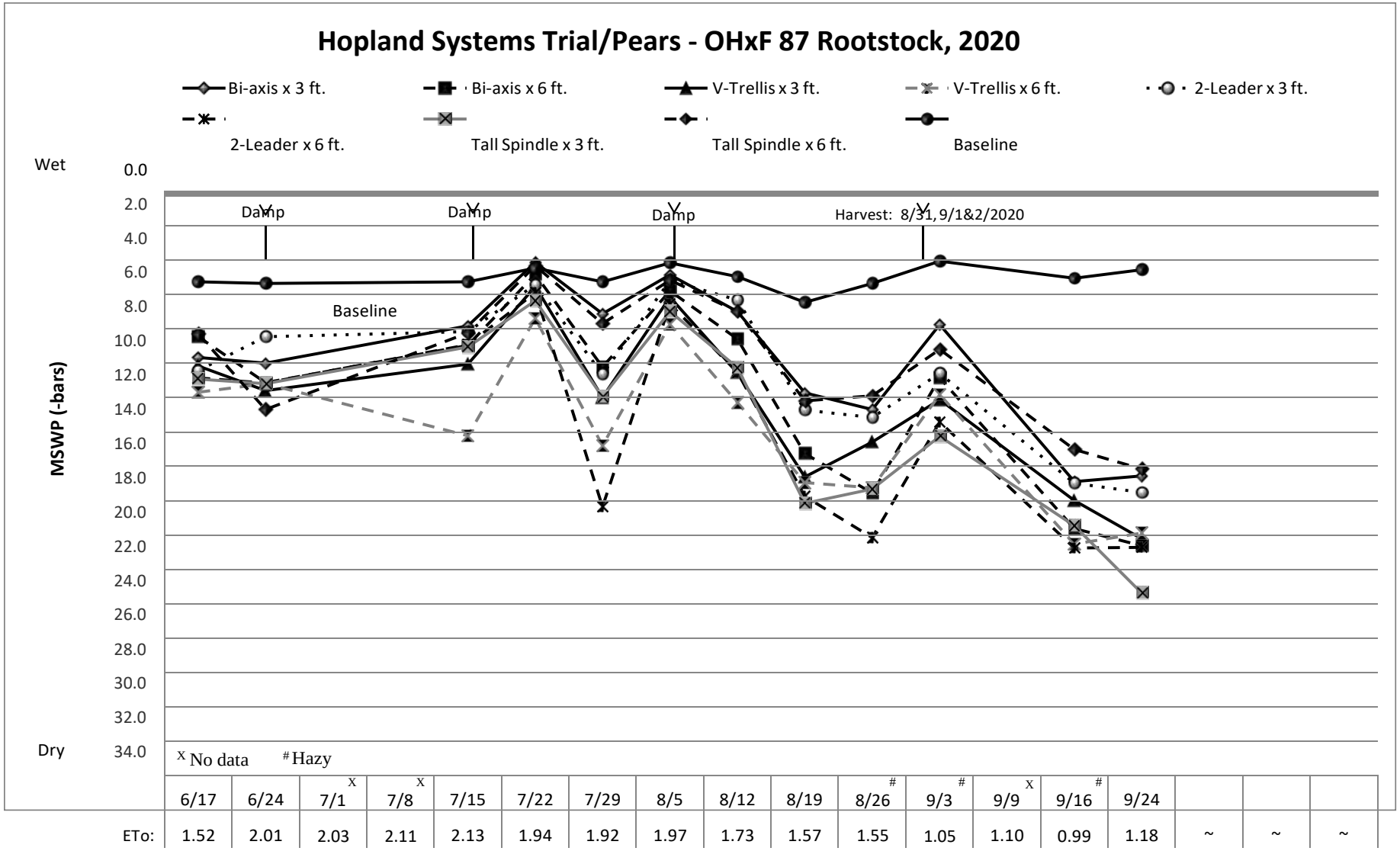


Figure 6. Comparison of mid-day stem water potential (MSWP) and baseline (-7 to-10 bars) among OHxF 87 rootstock, 8th-leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2020.

	6/12	6/18	6/29	7/9	7/18	7/23	7/31	8/6	8/16	8/20	9/1	9/9	9/17	9/25	10/14
Bi-axis x 3 ft.	-19.1	-19.7		-13.5	-15.2	-11.3		-15.2		-9.2					-9.4
Bi-axis x 6 ft.	-18.3	-17.6		-11.1	-12.5	-12.5		-14.0		-11.5					-8.5
V-Trellis x 3ft.	-18.8	-19.3		-12.0	-14.3	-10.8		-11.5		-9.3					-9.6
V-Trellis x 6ft.	-18.7	-17.8		-15.8	-14.1	-11.0		-11.9		-10.7					-10.0
2-Leader x 3 ft.	-17.7	-17.1		-14.8	-13.3	-11.3		-10.8		-9.5					-9.0
2-Leader x 6 ft.	-21.1	-19.3		-13.1	-13.5	-9.8		-12.9		-10.8					-10.2
Tall Spindle x 3 ft.	-19.1	-18.1		-16.3	-17.9	-15.7		-16.5		-12.9					-9.7
Tall Spindle x 6 ft.	-19.7	-18.9		-12.6	-12.8	-11.5		-11.0		-9.2					-9.5
Baseline	-8.3	-7.8		-7.4	-7.5	-8.6		-7.1		-6.9					-7.5

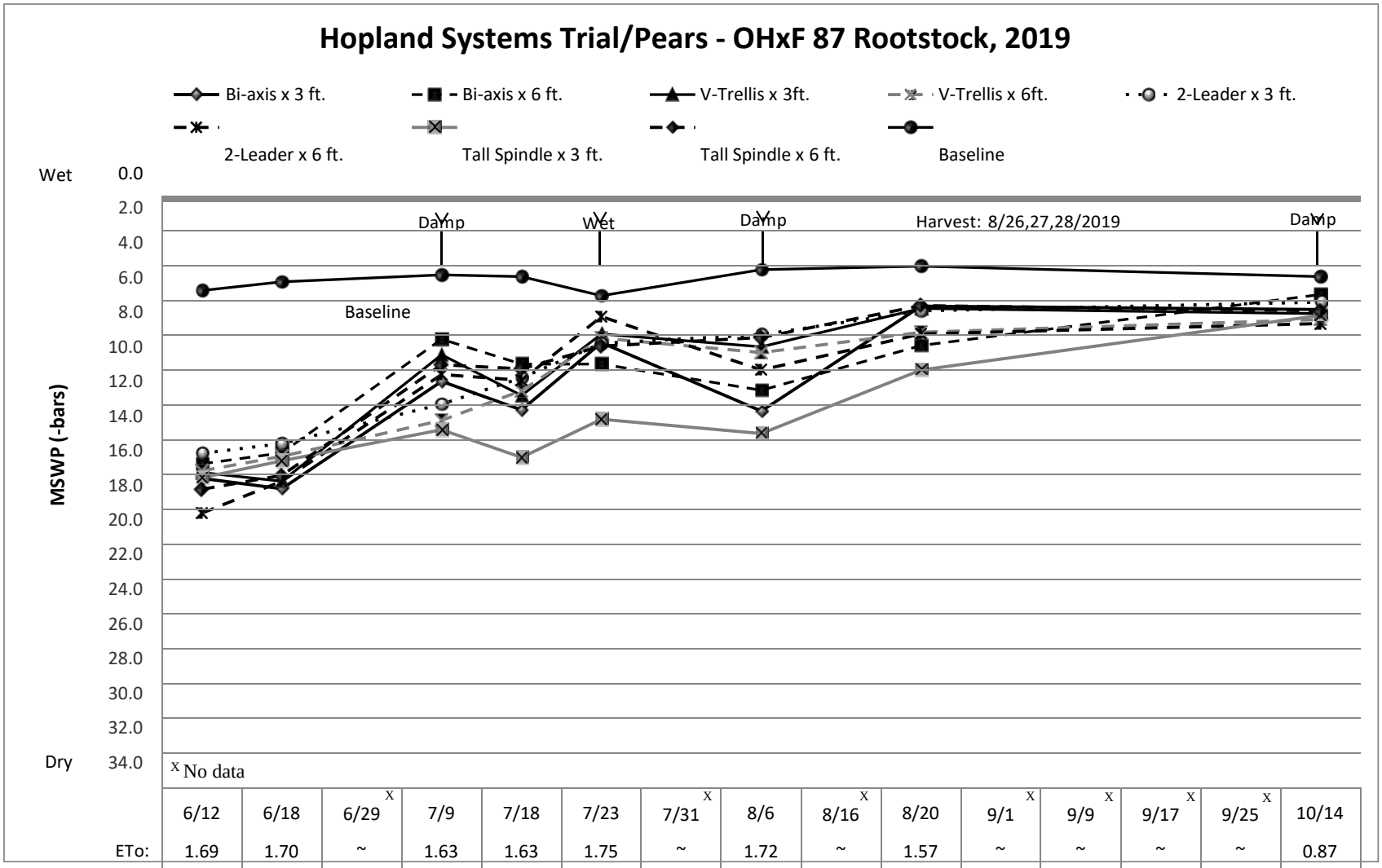


Figure 7. Effect of training system and spacing on weekly mid-day stem water potential (MSWP) of 7th-leaf 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2019.