HIGH DENSITY ORCHARD SYSTEMS FOR EUROPEAN PEAR: 2013 NC-140 REGIONAL ROOTSTOCK PROJECT (2018 Progress Report)

Rachel Elkins, University of California Cooperative Extension, Lake and Mendocino Counties
Bruce Lampinen, Department of Plant Sciences, University of California, Davis

ABSTRACT

The California pear industry has shrunk considerably in the past two decades, both in number of growers and total acreage (USDA-NASS 2014; Elkins, Bell and Einhorn 2012). Remaining California growers are considering replanting options, or have already replanted relatively 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. California 2018 overall yield increased 46% over 2017 despite removing an average of 52% of the crop prior to harvest due to restructuring trees from a 3- to 2-dimensional canopy (previous years ranged from 6-18% removed). As in 2017, V-T yielded most (5.8 kg/tree), followed by TS (4.7 kg) and 2-L and B-A least (3.1 kg each). Versus previous years, spacing yields differed significantly in 2018: 6' (4.5 kg) and 4.5' (4.3 kg) spaced trees yielded significantly more than 3' (3.7 kg). As in 2017, OHxF 87 and 69 yielded most (4.6 and 4.1 kg) and Pyro 2-33 least (3.8 kg). Completely unpruned trees in an adjacent row to treatment trees yielded 96% more at harvest (22.9 kg), and approximately 60% more combining removed and harvested fruit. Fruit size decreased from average 232 gm in 2017 to 199 gm in 2018 due to higher crop load and perhaps extended summer pruning up until harvest which decreased leaf area. B-A and 2-L fruit was largest (206 and 199 gm), followed by TS and V-T (194 and 197 gm), which had higher yields. Completely unpruned OHxF 69 and 87 fruit size was 174 and 162 gm, respectively. There were no spacing differences. Pyro 2-33 and OHxF 69 fruit (202 gm) were significantly larger than OHxF 87 (194 gm). Fruit maturity was lower in 2018 than 2017 (8.0 vs. 8.4 kg) though harvested one week later, however sugars were higher (13.3 vs. 13.0 °B). Mid-day stem water potential (MSWP) measurements were interrupted due to wildfires after July 19. As in previous years, MSWP never reached baseline. OHxF 87 exhibited slightly more stress than Pyro 2-33 (range 13-19 bars versus 14-18 bars) on June 29, the date of lowest recorded MSWP (OHxF 69 MSWP is not measured). Final MSWP on September 26 was slightly wetter (3-4 bars) than 2017 (12-14 versus 14-19 bars). OHxF 87 combinations differed significantly with TS x 3' the most stressed (and trended as such among Pyro 2-33 combinations. Cumulative from 2013-2018, survival rate is 97.2%. B-A trees were largest based on cultivar TCSA

(combined scaffolds) but second smallest based on rootstock TCSA (individual scaffolds). 2-L trees were smallest. TS, 3', Pyro-233, and OHxF69 trees were tallest. V-T and OHxF 87 trees were most efficient, while B-A and Pyro 2-33 least, with no spacing differences. There were interactions for fruit number, fruit size, yield, cultivar yield efficiency, and rootstock yield efficiency. There were no root sucker differences. For spread versus unspread B-A trees on OHxF 87 and 69, there were no significant differences though absolute fruit number, fruit size and yield were numerically larger for unspread trees. Effects of training, spacing, and rootstocks on tree growth, fruiting, harvest maturity, and suckering will continue in 2019. After three years, Bartlett on Horner 4 trees in Lake County had the largest TCSA (average about 34.67 mm, followed by OHxF 97 (31.98 mm), then OHxF 87 (28.19 mm).

INTRODUCTION

The California pear industry has shrunk considerably in the past several decades, both in number of growers and total acreage. 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 "wall type" orchards amenable to mechanization. Formal economic evaluation and the example of one small planting in the Ukiah Valley of Mendocino County that completed its 13th year in 2018 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 must be 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 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 as travel was cancelled due to wildfires).

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’ (California), ‘D’Anjou’ (Oregon), and ‘Bosc’ (New York). 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 six growing seasons (6th 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 consistent production;
- Improved labor efficiency/increased attractiveness for picking crews and amenability to future mechanization;
- 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 per acre).

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 bank of the Russian River.

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 the trellis);

3) *Bi-axis* (B-A) planted parallel to the row. Developed by Dr. Stefano Mussachi, 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 hasten fruiting;

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.

In all cases where tree vigor was adequate, “feathers”, i.e. branches grown in the nursery, were left on 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 as an unreplicated control. These trees were divided into two 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.

Micropropagated 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, of which 540 are part of the main systems trial.

Spacing: 3' (1m), 4-5' (1.5m), and 6' (2m) 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). 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[1].

[1] **While *Armillaria mellea* has infected trees in the orchard, average tonnage of existing trees approached 40 tons per acre; it is thus felt oak root fungus will not hinder trial results for the duration of the trial as long as** prudent measures are taken to manage irrigation properly.

Data Collection

Tree training and crop load management: From 2013 through 2018 training emphasized leader development, proper shaping, and thinning to optimize fruiting wood distribution. 2018 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. 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 pruning was done using thinning rather than heading cuts. Fruit was removed on weak trees but left if vigor appeared adequate. Just over 50% of total fruit was removed in 2018 due to the large number of branches removed to create a "flat" canopy and prevent upper limb breakage.

Tree survival, growth and vigor (2013-2018): Percent surviving trees was determined. Tree height and trunk cross-sectional area (TCSA) of both 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 (2014-2018) per tree were measured and both cultivar and rootstock yield efficiency (YE) calculated (see above for why rootstock TCSA was recorded). 2015-2018 data also included number of fruit removed prior to harvest (an indicator of overall vigor and result of severity of canopy modification) and firmness (kg) and soluble solids (°Brix). In 2014-2018, 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 vise versa. Measurements were taken from trees representing all training systems but only Pyro 2-33 and OHxF 87 rootstocks. MSWP measurements were interrupted from July 19 until September in 2018 due to wildfires.

Data summarization and analysis

Data was analyzed using ANOVA and means separated using Tukey HSD test, $p \leq 0.05$ (rootsuckers 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 2013-2018, there were some significant interactions among treatments, mainly training x rootstock, but also spacing x rootstock and training x spacing x rootstock (fruit number, size, and yield). For this report, only overall differences among the three main treatments are discussed (training, spacing, and rootstock); analysis for each individual combination (36 total) commenced in 2018 (data not show in the 2018 written report) but will be available prior to the 2019 season.

2017-2018 AND CUMULATIVE 2013-2018 RESULTS (Tables 1-16); (2013-2017 results summarized in Elkins and Lampinen 2017, 2016, and 2015, Elkins 2014)).

Tree survival, growth, and vigor (Tables 1-3): Only two trees have died since 2014 and one replant in 2018. 15 out of 540 trees, or 2.8%, have succumbed (data not shown): 2 2-L/Pyro 2-33, 2 2-L/OHxF 87, 5 B-A/OHxF 87, 2 B-A OHxF 69, 1 B-A/Pyro 2-33, 1 TS/OHxF 69, 1 V-T/Pyro 2-33, and 1 V-T/OHxF 69, for a total of 4 Pyro 2-33, 4 OHxF 69, and 7 OHxF 87.

2018 cultivar and rootstock TCSA increased an average of 20% from 2017, with most training systems and spacings increasing similarly. 2-L, 6', and Pyro 2-33 tree size increased the most and OHxF 87 trees least. 2-L trees had the smallest cultivar single leader TCSA with other systems being equal (averaging both B-A leaders). However, B-A and 2-L rootstock TCSAs (below graft union) were smaller than those of TS and V-T. 6' spaced trees were largest, followed by 4.5' then 3'. OHxF 69 trees were largest, with Pyro 2-33 and OHxF trees equally smaller. There were no TCSA interactions. T-S, 3', and Pyro-233 trees were tallest. There were few suckers.

Productivity (fruit number, fruit size, yield, yield efficiency) (Tables 1-3): Average harvested fruit number increased 50% and yield 46% from 2017 across all treatments (percent change not shown). B-A fruit number increased most (47%) and TS least (37%). 3' and 6' spaced (34% and 48%) and Pyro 2-33 (57%) fruit number increased most. In 2018, V-T (29.8), 4.5' and 6' (22.5 and 22.4), and OHxF 87 (24.2) had the most fruit. 2-L and B-A (15.7 and 15.0), 3' (18.8), and OHxF 69 and Pyro 2-33 rootstocks (20.7 and 18.8) had the least.

Overall average fruit size decreased 14% from 2017 to 2018 (average 232 to 199 gm) unsurprising given the large increase in fruit number and severe summer pruning undertaken to transform canopy architecture. V-T and 2L decreased most (average 19%) and TS least (12%). 3' spacing decreased most (18%) and others about 15%. Rootstock differences were most apparent, with OHxF 69 size decreasing 20%, Pyro 2-33 and OHxF 87 14%. B-A and 2-L systems (206 and 199 gm), and Pyro 2-33 and OHxF 69 rootstocks (202 gm each) had statistically larger fruit than other treatments; there were no spacing differences.

Average yield for all treatments increased 46%. BA increased most (39%) and VT least (26%). 4.5' spacing increased most (41%), Pyro 2-33 increased the most (53%) and OHxF 87 the least (13%). V-T yielded most (5.8 kg), followed by TS (4.7 kg) then 2-L and B-A (3.1 kg each). 4.5' and 6' yielded significantly more (4.4 and 4.5 kg respectively) then 3' (3.7 kg). OHxF 87 yielded most (4.6 kg), followed by OHxF 69 (4.1 kg) then Pyro 2-33 (3.8 kg).

Overall training 2018 system and spacing cultivar YE increased about 25% from 2017 (percent change data not shown). For training and spacing, 2-L system increased most (30%) and V-T least (18%), 4.5' (40%) increased most and the others 17-18%. Rootstock YE change varied greatly, ranging from 62% for Pyro-233, 33% for OHxF 69, and only 7% for OHxF 87, the latter reflecting more limited bearing capacity on smaller trees at this site. Versus 2017, when both increased, overall cultivar (above graft union) YE increased 24% while rootstock YE actually decreased 9%, reflecting enlarging below-graft union growth. 4.5' spacing YE increased more than twice that of others (40% vs. 17-18%). Rootstock YE increases varied greatly, averaging 7% (OHxF 87), 33% (OHxF 69), and 62% (Pyro 2-33). On a single leader basis 2-L YE was less than other training systems (20 vs. 25 kg/cm^2). Spacing YE was highest for 6' (.12) followed by 3' (.11) then 4.5' (.10). OHxF 87 YE (.15) was about one-third higher than OHxF 69 or Pyro 2-33 (.09 and .08, respectively). Rootstock YE pattern was similar to cultivar YE.

2013-2018 cumulative results were more similar to 2017. V-T and TS trees had statistically equal fruit numbers, however V-T had larger fruit (199 gm) and thus higher total yield (13.5 kg). V-T and TS trees were equally large (28.3 and 29.8 cm^2), thus V-T trees were more efficient (0.46 vs.39 kg/cm^2), followed by 2-L (.28 kg/cm^2) and lastly, B-A (.11 kg/cm^2). There were no spacing differences in fruit number, but 3' spacing fruit were largest (200 gm), followed by 6' (196 gm), then 4.5' (194 gm). OHxF87 trees were the same size as Pyro 2-33 (33.9 and 34.9 cm^2), had the most fruit (64/tree), highest yield (12.3 kg), and highest YE (0.42 kg/, cm^2), but numerically smallest fruit (192 gm). OHxF 69 trees were largest (39.4 cm^2), had fruit size statistically equal to OHxF 87 (196 gm), and intermediate fruit number (49), yield (9.6 kg), and YE (.28 kg/cm^2). Pyro 2-33 had the least fruit (33), largest fruit (203 gm), lowest yield (6.7 kg), and despite being relatively small trees, lowest YE (0.23 kg/cm^2). There were few training and rootstock interactions, mainly training x rootstock (fruit number, yield, yield efficiency) and training x spacing x rootstock (fruit number, fruit size, yield).

Pre-harvest fruit removal (Tables 4-5): An average of 27 fruit per tree was removed prior to harvest (about 52% of the total number of fruit per tree) versus about 21 harvested, with the same overall average number and percent across training, spacing, and rootstock. In contrast to previous years (11.8% removed in 2015, 6.2 in 2016, and 15.0% in 2017) when it was accomplished mainly to avoid overcropping, foster vigor and facilitate leader development, the number and percent of fruit removed in 2018 reflected the pruning severity needed to complete restructuring tree architecture from 3- to 2-dimensional that began in 2017, which required removing all east and west protruding branches and associated fruit. Among training systems, the most fruit removed pre-harvest was from V-T (42, 53.4%). Fewer but larger percentage of fruit was removed from 2-L (26, 58.8%). B-A and TS had the statistically equal number (19 and 21) but significantly lower percentage (50.9, 44.2) removed as 2-L. There were no spacing differences. Among rootstocks, both numerically most and highest percentage was removed from OHxF 69 (31, 56.4%). An equal statistical number but significantly less percentage was removed from OHxF 87 (29, 50.1%). The least and lowest percentage was removed from Pyro 2-33 (50.1 and 49.0%).

Firmness and soluble solids (Tables 6-7): Firmness was lower in 2018 versus 2017 (about 8.0 vs. 8.4 kg force) while soluble solids were higher (13.4 vs. 13.0). Similar to 2017, the only statistical difference was for firmness among training system. B-A fruit was firmest (8.4 kg force), followed by TS (8.3), 2-L (7.9) and V-T (7.6). V-T fruit was also the least in 2017 (as well as sweetest), suggesting an earlier potential harvest date. There were no significant interactions.

Completely unpruned OHxF 69 and 87 trees averaged 108 more fruit at harvest (135 vs. 27) and 87 more fruit including fruit removed pre- and at harvest. Total yield averaged 22.9 vs. 4.3 kg/tree at harvest, however, fruit averaged 30 grams less (168 vs. 198 gm). There were no significant productivity differences between the two rootstocks in 2018, however there was a trend toward larger OHxF 69 fruit size (p = 0.13; 174 vs. 162) and total yield (p = 0.15; 25.7 vs. 20.1 kg/tree). While OHxF 69 trees were significantly larger than OHxF 87 (39.0 vs. 31.3 cm^2 TCSA, 278 vs. 241 cm tall), yield efficiencies were similar. There was a trend (p = 0.16) toward lower soluble solids for OHxF 69. Cumulative 2013-2018 results resembled 2018, and a non-significant but clear recent trend of larger fruit, higher cumulative yield and cultivar YE for OHxF 69, despite being larger trees. This suggests that the weaker OHxF 87 trees are less able to carry an increasing crop load as trees mature (Tables 8-11).

Spread versus unspread Bi-Axis/OHxF 87 (Tables 12-16): There were no statistical differences in spread versus unspread trees in 2018, though unspread trees trended toward having a larger rootstock (below graft union) TCSA (61.2 vs 46.4 cm^2). There were also no differences in firmness and soluble solids. Cumulatively from 2013-2018, cultivar YE trended higher for spread trees (.70 vs .57) and rootstock YE was significantly higher as well (1.12 vs 0.84). While no individual YE component differed significantly, the combination of numerically more (but smaller) fruit, somewhat more yield, and smaller tree size suggests variability among trees over the years may have preclude a more definitive conclusion.

Mid-day Stem Water Potential (MSWP) (Table 17, Figures 2-7): 2018 measurements ceased from July 19 - September 26 due to wildfire activity. Overall from 2014 through 2018 both OHxF 87 trees appeared most stressed in 2017, with apparent recovery in 2018, perhaps due to cooler temperatures due to a continuous smoke blanket from mid-July through post-harvest . There were no differences among treatments for Pyro 2-33 in any year. For OHxF 87, TS x 3' trees were significantly more stressed in 2018 while V-T x 3' and 2-L x 3' and were least stressed in 2018, the status of 2-L x 3' in previous years, as well. Values were consistently below baseline in all years. Maximum stress occurred in late-June in both 2017 and 2018 (for measured MSWP readings) versus mid-August in 2016. OHxF 87 exhibited slightly more stress than Pyro 2-33 (range 13-19 bars versus 14-18 bars) on June 29, 2018, the date of lowest recorded MSWP.

2013-2018 DISCUSSION AND 2019 PLANS

After six growing seasons, training and rootstock continue to be the most important factors in determining early tree growth and productivity, however spacing significantly influenced fruit number for the first time in 2018, but not fruit size. V-T is the most productive training system to date followed by TS then 2-L and B-A. Spacing differences were more pronounced in 2018 as trees with more bearing surface filled their space. Differences among rootstocks are narrowing. While OHxF 87 continues to bear more fruit, total relative yield has trended down due to a trend toward significantly smaller fruit versus OHxF 69 and Pyro 2-33, translating into very little increase in yield efficiency versus 2017. While still lagging behind, Pyro-233 fruit number and total yield have trended closer to those of the OHxF rootstocks. Versus 2017 V-T significantly more fruit removal to promote leader development and restructure than other systems while OHxF 87 required more fruit removal to prevent overcropping and maintain tree vigor. Tree water status was better in 2018 than 2017, perhaps due to cooler temperatures created by the smoke “blanket” during the hottest part of the season.

From 2013-2018 there has been no consistent effect of spreading alone on B-A trees. Completely forgoing pruning in early years appears to encourage early fruiting however may compromise fruit size as trees mature.

Tree training and data collection will continue in 2019 (Year 7).

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↑ SOUTH
Reps II - V

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	

BARTLETT TREES

Row 5 - UNPRUNED BARTLETT TREES AND NEW USDA CULTIVAR SELECTION

BOSC TREES/RUSSIAN RIVER

NORTH END

Figure 1: 2013 NC-140 PEAR SYSTEMS TRIAL - REP I (Rows 1-4), Shadowbrook Farms, Hopland, Mendocino, CA. Planted May 1-2, 2013.

Table 1: 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 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2018.

	Fruit No. (no./tree) 8/31-9/1/2018	Fruit Size (g) 8/31-9/1/2018	Yield (kg/tree) 8/31-9/1/2018	Mean Box Size (44 lb. box) 8/31-9/1/2018	Average Box Number (per tree) 8/31-9/1/2018	Cultivar TCSA[4] (cm^2) 11/20-12/3/2018	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[5] (cm^2) 11/20-12/3/2018	Rootstock Yield Efficiency (kg/cm^2)	Tree Heights[6] (cm) 10/18-24/2018	Root Suckers[7] (no./tree) 10/18-24/2018
Training[1]											
2-Leader	15.7 c	199 ab	3.1 c	102 ab	0.16 c	24.5 c	0.13 c	36.0 b	0.09 c	286 b	0.12
Bi-axis[3]	15.0 c	206 a	3.1 c	99 b	0.15 c	61.7 a	0.05 d	38.6 b	0.08 c	272 b	0.12
Tall Spindle	24.4 b	194 b	4.7 b	105 a	0.23 b	29.8 b	0.16 b	44.7 a	0.11 b	310 a	0.17
V-Trellis	29.8 a	197 b	5.8 a	105 a	0.29 a	28.3 b	0.20 a	43.4 a	0.13 a	282 b	0.04
Spacing[1]											
3 feet	18.8 b	198	3.7 b	103	0.19 b	34.2 b	0.13	38.2 b	0.10	301 a	0.06
4.5 feet	22.4 a	198	4.3 a	103	0.22 a	36.0 ab	0.14	40.8 ab	0.10	284 b	0.15
6 feet	22.4 a	202	4.5 a	101	0.22 a	38.1 a	0.14	43.1 a	0.10	278 b	0.13
Rootstock[1]											
Pyrodwarf 2-33	18.8 b	202 a	3.8 b	101 b	0.19 b	34.9 b	0.13 b	39.8 b	0.09 b	298 a	0.14
OHxF 69	20.7 b	202 a	4.1 ab	101 b	0.21 ab	39.4 a	0.12 b	44.2 a	0.09 b	288 ab	0.13
OHxF 87	24.2 a	194 b	4.6 a	106 a	0.23 a	33.9 b	0.16 a	38.1 b	0.12 a	277 b	0.06
ANOVA (*P* -values)[2]											
Training	***(<0.001)	***(<0.001)	***(<0.001)	**(0.003)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.22)
Spacing	* (0.02)	NS (0.11)	**(0.01)	NS (0.44)	** (0.01)	***(<0.001)	NS (0.51)	***(<0.001)	NS (0.51)	***(<0.001)	NS (0.18)
Rootstock	***(0.001)	**(0.002)	**(0.01)	***(<0.001)	** (0.01)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.26)
Block	**(0.003)	***(<0.001)	**(0.002)	***(<0.001)	**(0.003)	***(<0.001)	***(<0.001)	***(<0.001)	**(0.002)	***(<0.001)	NS (0.31)
Interaction (*P* -values)[2]											
Training x Rootstock	NS (0.47)	NS (0.47)	NS (0.55)	NS (0.82)	NS (0.57)	NS (0.33)	NS (0.84)	NS (0.06)	NS (0.67)	NS (0.36)	NS (0.56)
Spacing x Rootstock	NS (0.27)	NS (0.18)	NS (0.56)	NS (0.44)	NS (0.55)	NS (0.33)	NS (0.36)	NS (0.27)	NS (0.34)	NS (0.14)	NS (0.17)
Training x Spacing	NS (0.22)	* (0.04)	NS (0.19)	NS (0.06)	NS (0.19)	NS (0.36)	NS (0.81)	NS (0.69)	NS (0.36)	***(<0.001)	NS (0.79)
Training x Spacing x Rootstock	NS (0.19)	* (0.05)	NS (0.33)	* (0.05)	NS (0.33)	NS (0.19)	NS (0.21)	NS (0.10)	NS (0.56)	NS (0.23)	NS (0.71)

[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] 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, 8/31-9/1/2018

Table 2: Effect of training system, spacing, and rootstock on number and size of fruit, tree yield and growth, yield efficiency and root suckers of 5th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2017.

	No. Fruit (no./tree) 8/26-27/2017	Fruit Size (g) 8/26-27/2017	Yield (kg/tree) 8/26-27/2017	Cultivar TCSA[3] (cm^2) 10/27,11/1-2/2017	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[4] (cm^2) 10/27,11/1-2/2017	Rootstock Yield Efficiency (kg/cm^2)	Root Suckers[5] (no./tree) 11/3/2017
Training[1]								
2-Leader	9.3 b	229 ab	2.1 c	19.9 c	0.10 c	29.9 b	0.07 bc	0.13
Bi-axis[#]	7.9 b	238 a	1.9 c	51.7 a	0.04 d	32.8 b	0.06 c	0.08
Tall Spindle	15.3 a	218 b	3.3 b	25.0 b	0.13 b	39.3 a	0.08 b	0.08
V-Trellis	18.3 a	240 a	4.3 a	24.0 b	0.17 a	39.2 a	0.11 a	0.03
Spacing[1]								
3 feet	12.4	234	2.9	28.8 b	0.11 ab	33.7 b	0.08 ab	0.14
4.5 feet	11.8	228	2.6	30.5 ab	0.10 b	35.5 ab	0.07 b	0.03
6 feet	13.8	233	3.2	31.2 a	0.12 a	36.6 a	0.08 ab	0.08
Rootstock[1]								
Pyrodwarf 2-33	8.1 c	231 ab	1.8 c	27.7 b	0.08 b	32.9 b	0.05 c	0.11
OHxF 69	11.9 b	242 a	2.8 b	33.3 a	0.09 b	39.2 a	0.07 b	0.06
OHxF 87	18.0 a	222 b	4.0 a	29.4 b	0.15 a	33.8 b	0.11 a	0.08
ANOVA (*P* -values)[2]								
Training	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.61)
Spacing	NS (0.06)	NS (0.39)	* (0.02)	** (0.01)	* (0.02)	* (0.02)	** (0.004)	NS (0.30)
Rootstock	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.87)
Block	***(<0.001)	NS(0.22)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	* (0.04)
Interaction (*P* -values)[2]								
Training x Rootstock	NS (0.38)	NS(0.45)	NS(0.35)	NS (0.35)	* (0.03)	**(0.004)	NS (0.37)	NS (0.08)
Spacing x Rootstock	NS (0.34)	NS (0.08)	NS (0.45)	NS (0.45)	NS (0.78)	NS (0.10)	NS (0.73)	NS (0.67)
Training x Spacing	NS (0.62)	NS (0.47)	NS (0.30)	NS (0.35)	* (0.04)	NS (0.55)	NS (0.10)	NS (0.79)
Training x Spacing x Rootstock	* (0.04)	NS (0.54)	* (0.04)	NS (0.42)	NS (0.21)	NS (0.26)	NS (0.23)	NS (0.08)

[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, 8/26-27/2017

[3] Measured 10 cm above union.

[4] Measured 5 cm below union.

[5] Root sucker data normalized, SQRT(value+1) for *P* -value.

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 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2013-2018.

	Average Fruit No. (per tree)	Average Fruit Size[3] (g)	Average Yield (kg/tree)	2018 Cultivar TCSA (cm^2)	Average Cumulative Cultivar Yield Efficiency[4] (kg/cm^2)	2018 Rootstock TCSA (cm^2)	Average Cumulative Rootstock Yield Efficiency[4] (kg/cm^2)	Root Suckers[5] (no/tree)
Training[1]								
2-Leader	34 b	200 ab	6.8 c	24.5 c	0.28 c	36.0 b	0.19 c	0.59
Bi-axis[3]	31 b	206 a	6.3 c	61.7 a	0.11 d	38.6 b	0.17 c	0.39
Tall Spindle	61 a	186 c	11.5 b	29.8 b	0.39 b	44.7 a	0.26 b	0.40
V-Trellis	68 a	196 b	13.5 a	28.3 b	0.46 a	43.4 a	0.30 a	0.27
Spacing[1]								
3 feet	45	200 a	8.9 b	34.2 b	0.31	38.2 b	0.23	0.40
4.5 feet	48	194 b	9.3 ab	36.0 ab	0.30	40.8 ab	0.22	0.38
6 feet	52	196 ab	10.3 a	38.1 a	0.32	43.1 a	0.24	0.45
Rootstock[1]								
Pyrodwarf 2-33	33 c	203 a	6.7 c	34.9 b	0.23 c	39.8 b	0.17 c	0.45
OHxF 69	49 b	196 b	9.6 b	39.4 a	0.28 b	44.2 a	0.21 b	0.37
OHxF 87	64 a	192 b	12.3 a	33.9 b	0.42 a	38.1 b	0.31 a	0.41
ANOVA (*P* -values)[2]								
Training	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.29)
Spacing	NS (0.10)	*(0.05)	*(0.03)	***(<0.001)	NS (0.46)	***(0.001)	NS (0.31)	NS (0.60)
Rootstock	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	NS (0.63)
Block	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	***(<0.001)	* (0.04)
Interaction (*P* -values)[2]								
Training x Rootstock	** (0.004)	NS (0.79)	* (0.02)	NS (0.33)	***(<0.001)	NS (0.06)	* (0.04)	NS (0.46)
Spacing x Rootstock	NS (0.06)	NS (0.10)	NS (0.16)	NS (0.33)	NS (0.59)	NS (0.27)	NS (0.77)	NS (0.36)
Training x Spacing	NS (0.30)	NS (0.51)	NS (0.20)	NS (0.36)	NS (0.94)	NS (0.69)	NS (0.26)	NS (0.70)
Training x Spacing x Rootstock	** (0.01)	* (0.05)	* (0.03)	NS (0.19)	NS (0.73)	NS (0.10)	NS (0.27)	NS (0.74)

[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] Average fruit size 2014 to 2018.

[4] Based on cumulative yield (2014-18) and final TCSA (2018).

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

Table 4: Effect of training system, spacing, and rootstock on dropped or removed fruit number and % dropped or removed fruit as compared to total harvested fruit number of 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2018.

	Dropped or Removed Fruit No. (per tree) 5/25-8/24/2018	Total Dropped or Removed and Harvest Fruit No. (per tree)	% Dropped or Removed Fruit No. (per tree) 5/25-8/24/2018
Training[1]			
2-Leader	26 b	41 bc	58.8 a
Bi-axis[#]	19 b	34 c	50.9 b
Tall Spindle	21 b	46 b	44.2 c
V-Trellis	42 a	72 a	53.4 ab
Spacing[1]			
3 feet	25	44 b	53.3
4.5 feet	27	50 ab	50.3
6 feet	29	51 a	52.0
Rootstock[1]			
Pyrodwarf 2-33	22 b	40 b	49.0 b
OHxF 69	31 a	51 a	56.4 a
OHxF 87	29 a	53 a	50.1 b
ANOVA (*P* -values)[2]			
Training	***(<0.001)	***(<0.001)	***(<0.001)
Spacing	NS (0.20)	** (0.01)	NS (0.21)
Rootstock	***(<0.001)	***(<0.001)	**(0.003)
Block	***(<0.001)	***(<0.001)	**(0.002)
Interaction (*P* -values)[2]			
Training x Rootstock	NS (0.35)	NS (0.19)	NS (0.84)
Spacing x Rootstock	NS (0.10)	NS (0.06)	NS (0.10)
Training x Spacing	NS (0.46)	NS (0.66)	NS (0.50)
Training x Spacing x Rootstock	NS (0.33)	NS (0.22)	NS (0.31)

[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: 8/31-9/1/2018

Table 5: Effect of training system, spacing, and rootstock on the amount of fruit dropped or removed from 'Bartlett' pear 3rd, 4th, 5th, and 6th leaf trees, Hopland, Mendocino County, California, 2015-2018.

	Dropped and Removed Fruit (% / per tree)			
	6/10-11/2015	6/6 & 17/2016	6/26 & 7/6/2017	5/25-8/24/2018
Training[1]				
2-Leader	18.9 a	3.3 b	14.7 b	58.8 a
Bi-axis	18.5 a	0.1 b	15.5 b	50.9 b
Tall Spindle	4.3 b	18.5 a	23.1 a	44.2 c
V-Trellis	5.4 b	3.0 b	6.6 c	53.4 ab
Spacing[1]				
3 feet	14.4	7.2	14.4	53.3
4.5 feet	10.0	7.0	13.6	50.3
6 feet	11.1	4.4	17.0	52.0
Rootstock[1]				
Pyrodwarf 2-33	13.0	4.6	12.4 b	49.0 b
OHxF 69	13.1	6.9	18.4 a	56.4 a
OHxF 87	9.3	7.1	14.2 ab	50.1 b
ANOVA[2] **(*P* -values)**				
Training	***(<0.0001)	*** (<0.001)	*** (<0.001)	***(<0.001)
Spacing	NS (0.08)	NS (0.67)	NS (0.28)	NS (0.21)
Rootstock	NS (0.13)	NS (0.83)	* (0.02)	**(0.003)
Block	NS (0.11)	NS (0.06)	NS (0.34)	**(0.002)
Interaction[2] ***P* -values**				
Training x Rootstock	NS (0.33)	NS (0.49)	* (0.05)	NS (0.84)
Spacing x Rootstock	* (0.02)	NS (0.30)	NS (0.32)	NS (0.10)
Training x Spacing	NS (0.19)	NS (0.67)	** (0.01)	NS (0.50)
Training x Spacing x Rootstock	NS (0.84)	~[3]	NS (0.38)	NS (0.31)

[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 6: Effect of training system, spacing, and rootstock on firmness and soluble solids of 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2018.

	Firmness (kg. of force)	Soluble Solids (°Brix)
Training[1]		
2-Leader	7.9 bc	13.3
Bi-axis[#]	8.4 a	13.3
Tall Spindle	8.6 ab	13.4
V-Trellis	7.6 c	13.5
Average	**8.1**	**13.4**
Spacing[1]		
3 feet	8.0	13.4
4.5 feet	8.0	13.4
6 feet	8.0	13.3
Average	**8.0**	**13.4**
Rootstock[1]		
Pyrodwarf 2-33	8.1	13.3
OHxF 69	8.1	13.2
OHxF 87	7.9	13.5
Average	**8.0**	**13.3**
ANOVA (*P* -values)[2]		
Training	*** (<0.001)	NS (0.24)
Spacing	NS (0.96)	NS (0.24)
Rootstock	NS (0.09)	NS (0.06)
Block	NS (0.10)	** (0.002)
Interaction (*P* -values)[2]		
Training x Rootstock	NS (0.61)	NS (0.61)
Spacing x Rootstock	NS (0.40)	NS (0.15)
Training x Spacing	NS (0.07)	NS (0.51)
Training x Spacing x Rootstock	NS (0.12)	NS (0.83)

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

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

[#] Total of two scaffolds

Harvest date, 8/31-9/1/2018

Table 7: Effect of training system, spacing, and rootstock on firmness and soluble solids of 3rd-6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2015-2018.

	Firmness (kg. force)				Soluble Solids (°Brix)			
	8/12-13/2015	8/8/2016	8/26-27/2017	8/31-9/1/2018	8/12-13/2015	8/8/2016	8/26-27/2017	8/31-9/1/2018
Training[1]								
2-Leader	9.4 ab	8.8	8.6 a	7.9 bc	14.1	12.9 a	13.1 ab	13.3
Bi-axis	9.5 a	8.7	8.5 a	8.4 a	13.9	12.2 b	12.7 b	13.3
Tall Spindle	9.4 ab	8.5	8.4 a	8.3 ab	14	12.5 ab	12.8 b	13.4
V-Trellis	9.1 b	8.6	7.9 b	7.6 c	14.1	12.8 a	13.2 a	13.5
Spacing[1]								
3 feet	9.4	8.6	8.3	8.0	13.9	12.6 ab	13.0	13.4
4.5 feet	9.3	8.6	8.3	8.0	14.1	12.4 b	12.9	13.4
6 feet	9.4	8.7	8.5	8.0	14.1	12.9 a	13.0	13.3
Rootstock[1]								
Pyrodwarf 2-33	9.5	8.7	8.5	8.1	13.7 b	12.3 b	12.8 b	13.3
OHxF 69	9.3	8.6	8.4	8.1	14.0 ab	12.6 ab	13.0 ab	13.2
OHxF 87	9.2	8.7	8.3	7.9	14.4 a	12.9 a	13.2 a	13.5
ANOVA[2] **(*P* -values)**								
Training	*(0.02)	NS (0.24)	*** (<0.001)	*** (<0.001)	NS (0.53)	** (0.002)	** (0.01)	NS (0.61)
Spacing	NS (0.82)	NS (0.44)	NS (0.56)	NS (0.96)	NS (0.64)	** (0.01)	NS (0.91)	NS (0.24)
Rootstock	NS (0.19)	NS (0.85)	NS (0.15)	NS (0.09)	**(0.01)	*** (0.001)	** (0.01)	NS (0.06)
Block	*(0.03)	*(0.04)	NS (0.40)	NS (0.10)	*(0.03)	NS (0.36)	* (0.02)	** (0.002)
Interaction[2] ***P* -values**								
Training x Rootstock	NS (0.54)	NS (0.07)	NS (0.47)	NS (0.61)	**(0.01)	NS (0.39)	NS (0.90)	NS (0.61)
Spacing x Rootstock	NS (0.56)	NS (0.15)	NS (0.82)	NS (0.40)	NS (0.18)	NS (0.91)	NS (0.18)	NS (0.15)
Training x Spacing	NS (0.28)	NS (0.92)	*** (<0.001)	NS (0.07)	NS (0.13)	NS (0.23)	NS (0.97)	NS (0.51)
Training x Spacing x Rootstock	NS (0.43)	~[3]	NS (0.51)	NS (0.12)	NS (0.18)	~[3]	NS (0.67)	NS (0.83)

[1] Within columns, treatment means significantly different (Tukey HSD test, *P* ≤0.05).

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

[3] Insufficiendt data for interaction.

Table 8: Effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 3rd to 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2018.

Treatment[1]	Fruit No. (no./tree) 8/31-9/1/18	Fruit Size (g) 8/31-9/1/18	Yield (kg/tree) 8/31-9/1/18	Cultivar TCSA[3] (cm^2) 12/3/18	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[4] (cm^2) 12/3/18	Rootstock Yield Efficiency (kg/cm^2)	Tree Heights (cm) 10/23/18	Root Suckers (no./tree) 10/23/18
OHxF 69	145	174	25.7	39.0 a	0.63	60.0 a	0.41	278 a	0.0
OHxF87	126	162	20.1	31.3 b	0.66	50.4 b	0.40	241 b	0.0
ANOVA (*P* -values)[2]									
Treatment	NS (0.33)	NS (0.13)	NS (0.15)	** (0.01)	NS (0.66)	* (0.02)	NS (0.89)	** (0.01)	~
Block	NS (0.43)	NS (0.09)	NS (0.31)	* (0.04)	*** (0.001)	* (0.02)	** (0.002)	** (0.01)	~

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

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

[3] Measured 10 cm above union.

[4] Measured 5 cm below union.

Harvest date: 9/1-4/18

Table 9: Effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 3rd to 5th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2017.

Treatment[1]	No. Fruit (no./tree) 8/26/17	Fruit Size (g) 8/26/17	Yield (kg/tree) 8/26/17	Cultivar TCSA[3] (cm^2) 11/1/2017	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA[4] (cm^2) 11/1/2017	Rootstock Yield Efficiency (kg/cm^2)	Root Suckers (no./tree) 11/1/2017
OHxF 69	59	213 a	12.4	32.1 a	0.38	54.6 a	0.23 a	0.0
OHxF87	65	191 b	12.2	26.9 b	0.46	43.2 b	0.28 b	0.0
ANOVA (*P* -values)[2]								
Treatment	NS (0.48)	* (0.02)	NS (0.89)	* (0.03)	NS (0.11)	** (0.01)	* (0.04)	~
Block	NS (0.10)	* (0.02)	NS (0.64)	NS (0.14)	NS (0.66)	NS (0.40)	NS (0.60)	~

[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: 8/26/17

Table 10: Cumulative effect of rootstock on fruit number and size, tree vigor, yield efficiency and root suckers of completely unpruned 3rd to 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2013-2018.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Cumulative Yield (kg)	2018 Cultivar TCSA (cm^2)	Cultivar Yield Efficiency[4] (kg/cm^2)	Rootstock TCSA (cm^2)	Rootstock Yield Efficiency[4] (kg/cm^2)	Root Suckers (no./tree)
OHxF 69	268	181	48.0	39.0 a	1.62	60.0 a	0.81	0.0
OHxF87	249	166	41.8	31.3 b	1.18	50.4 b	0.84	0.0
ANOVA (*P* -values)[2]								
Treatment	NS (0.47)	NS (0.08)	NS (0.20)	** (0.01)	NS (0.16)	* (0.02)	NS (0.54)	~
Block	NS (0.56)	NS (0.41)	NS (0.38)	* (0.04)	*** (<0.001)	* (0.02)	*** (<0.001)	~

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

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

[3] Based on fruiting years 2014-2018.

[4] Based on cumulative yield (2014-2018) and final TCSA (2018).

Table 11: Effect of rootstock on firmness and soluble solids of completely unpruned 3rd to 6th leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2015-2018.

	Firmness (kg force)				Soluble Solids (° Brix)			
Treatment[1]	2015[3]	2016[4]	2017[5]	2018[6]	2015[3]	2016[4]	2017[5]	2018[6]
OHxF 69	9.2	8.1	7.7	6.3	14.1	14.1	13.6 b	14.0
OHxF87	9.4	8.3	7.9	6.7	14.5	14.5	14.2 a	14.2
ANOVA (*P* -values)[2]								
Treatment	NS (0.52)	NS (0.53)	NS (0.12)	NS (0.16)	NS (0.07)	NS (0.07)	** (0.01)	NS (0.36)
Block	NS (0.20)	NS (0.24)	NS (0.51)	NS (0.21)	** (0.01)	* (0.03)	** (0.01)	* (0.02)

[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.

Table 12: Cumulative effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, and root suckers of 5th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2013-2018.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Yield (kg)	2018 Cultivar TCSA[3] (cm2)	Cultivar Yield Efficiency (kg/cm2)	2018 Rootstock TCSA (cm2)	Rootstock Yield Efficiency (kg/cm2)	Root Suckers (per tree)
Spreading	316	169	51.6	74.6	0.70	46.4	1.12	0.0
No Spreading	289	182	52.1	91.1	0.57	61.2	0.84	0.0
***P* -value**[2]	NS (0.68)	NS (0.23)	NS (0.96)	NS (0.26)	NS (0.06)	NS (0.09)	** (0.01)	~

Table 13: Effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, and root suckers of 5th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2018.

Treatment[1]	Fruitno. (per tree)	Fruit Size (g)	Yield (kg/tree)	Cultivar TCSA[3] (cm^2)	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA (cm^2)	Rootstock Yield Efficiency	Tree Heights (cm)	Root Suckers (per tree)
Spreading	141.4	163.2	22.8	74.6	0.30	46.4	0.49	267	0.0
No Spreading	160.2	175.4	27.6	91.1	0.30	61.2	0.45	269	0.0
***P* -value**[2]	NS (0.60)	NS (0.35)	NS (0.36)	NS (0.26)	NS (0.85)	NS (0.09)	NS (0.44)	NS (0.96)	~

[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 14: Cumulative effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, and root suckers of 4th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2013-2017*.

Treatment[1]	Average Fruit No. (per tree)	Average Fruit Size (g)	Average Yield (kg)	2017 Cultivar TCSA[3] (cm2)	Cultivar Yield Efficiency (kg/cm2)	2016 Rootstock TCSA (cm2)	Rootstock Yield Efficiency (kg/cm2)	Root Suckers (per tree)
Spreading	174	170	28.8	66.6	0.44	45.5	0.63	0.0
No Spreading	129	183	24.5	77.0	0.31	50.0	0.49	0.0
***P* -value**[2]	NS (0.51)	NS (0.24)	NS (0.37)	NS (0.35)	* (0.02)	NS (0.50)	NS (0.07)	~

* Data begins with fruiting year 2014.

Table 15: Effect of scaffold spreading on number and size of fruit, tree yield and growth, yield efficiency, and root suckers of 4th leaf Bi-axis-trained 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2017.

Treatment[1]	No. Fruit (per tree)	Fruit Size (g)	Yield (kg/tree)	Cultivar TCSA[3] (cm^2)	Cultivar Yield Efficiency (kg/cm^2)	Rootstock TCSA (cm^2)	Rootstock Yield Efficiency	Root Suckers (per tree)
Spreading	91.4	175	15.7	66.6	0.24	45.5	0.35	0.0
No Spreading	56.4	213	11.9	77.0	0.15	50.0	0.23	0.0
***P* -value**[2]	NS (0.07)	* (0.04)	NS (0.28)	NS (0.35)	* (0.03)	NS (0.50)	* (0.04)	~

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

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

[3] Average of two scaffolds.

Table 16: Effect of scaffold spreading on firmness and soluble solids on Bi-axis trained 3rd to 6th leaf 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2015-2018.

	Firmness (kg force)				Soluble Solids (° Brix)			
Treatment[1]	2015[3]	2016[4]	2017[5]	2018[6]	2015[3]	2016[4]	2017[5]	2018[6]
Spreading	8.7	8.2	6.9	6.3	14.4	31.1	13.6	14.1
No Spreading	8.7	8.3	7.1	6.2	14.3	13.1	14.2	13.9
P -value[2]	NS (1.00)	NS (0.84)	NS (0.76)	NS (0.70)	NS (0.73)	NS (0.86)	NS (0.22)	NS (0.50)

[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.

Table 17: 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, Californis, 2014-2018.

	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)		
Treatment[1]	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)
Bi-axis x 6 ft.	16.6	15.2	NS (0.18)	13.8	13.4	NS (0.68)
V-Trellis x 3ft.	18.6	17.7	NS (0.51)	12.9	14.6	NS (0.13)
V-Trellis x 6ft.	18.6	17.6	NS (0.41)	14.2	14.1	NS (0.89)
2-Leader x 3 ft.	16.6	18.4	NS (0.12)	12.9	14.2	NS (0.21)
2-Leader x 6 ft.	19.0	17.7	NS (0.30)	14.9	13.9	NS (0.40)
Tall Spindle x 3 ft.	17.9	18.2	NS (0.85)	15.1	15.3	NS (0.84)
Tall Spindle x 6 ft.	18.3	18.9	NS (0.73)	13.5	14.6	NS (0.20)
Baseline[3]	8.1			7.7		

[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.

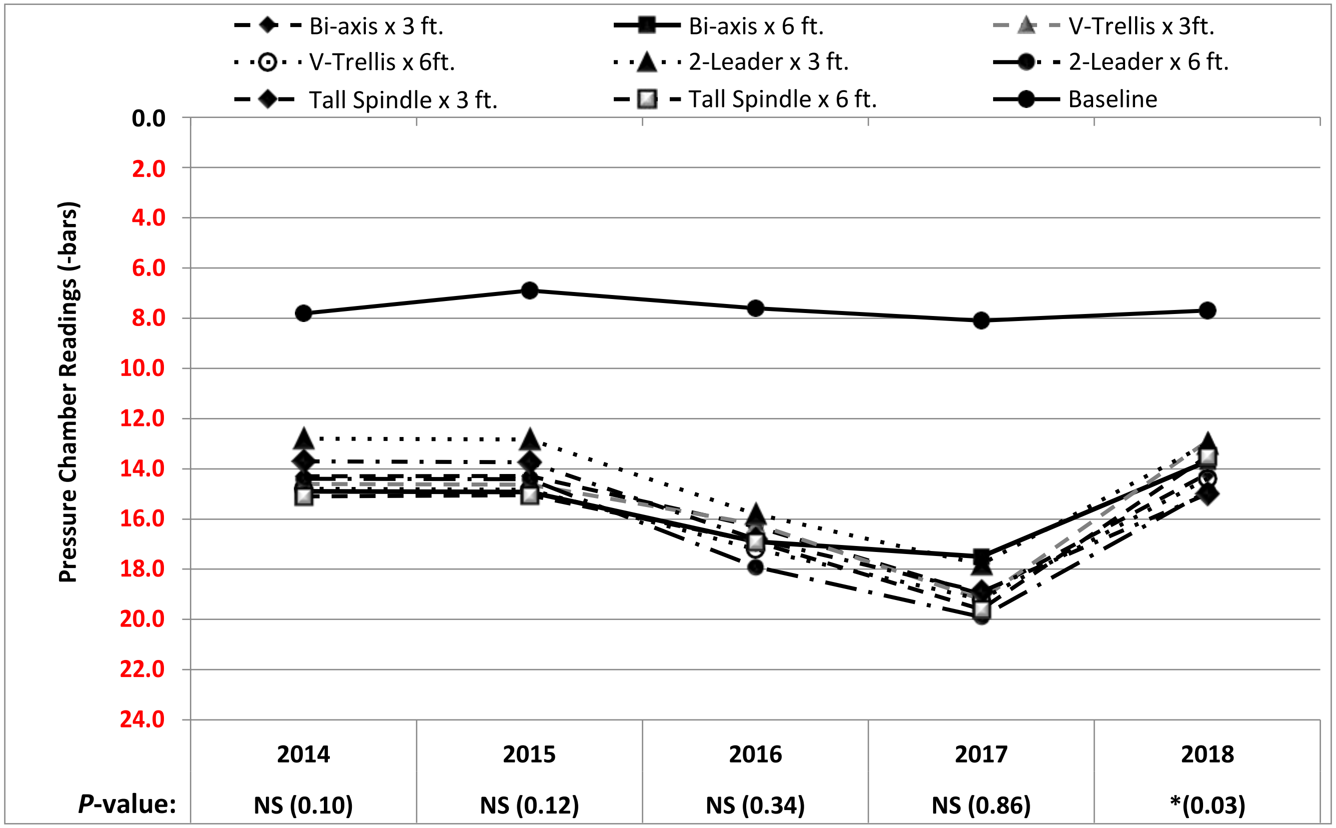


Figure 2: Effect of training system and spacing on seasonal average mid-day stem water potential (MSWP) of 2nd-6th leaf "Bartlett" pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2014-2018.

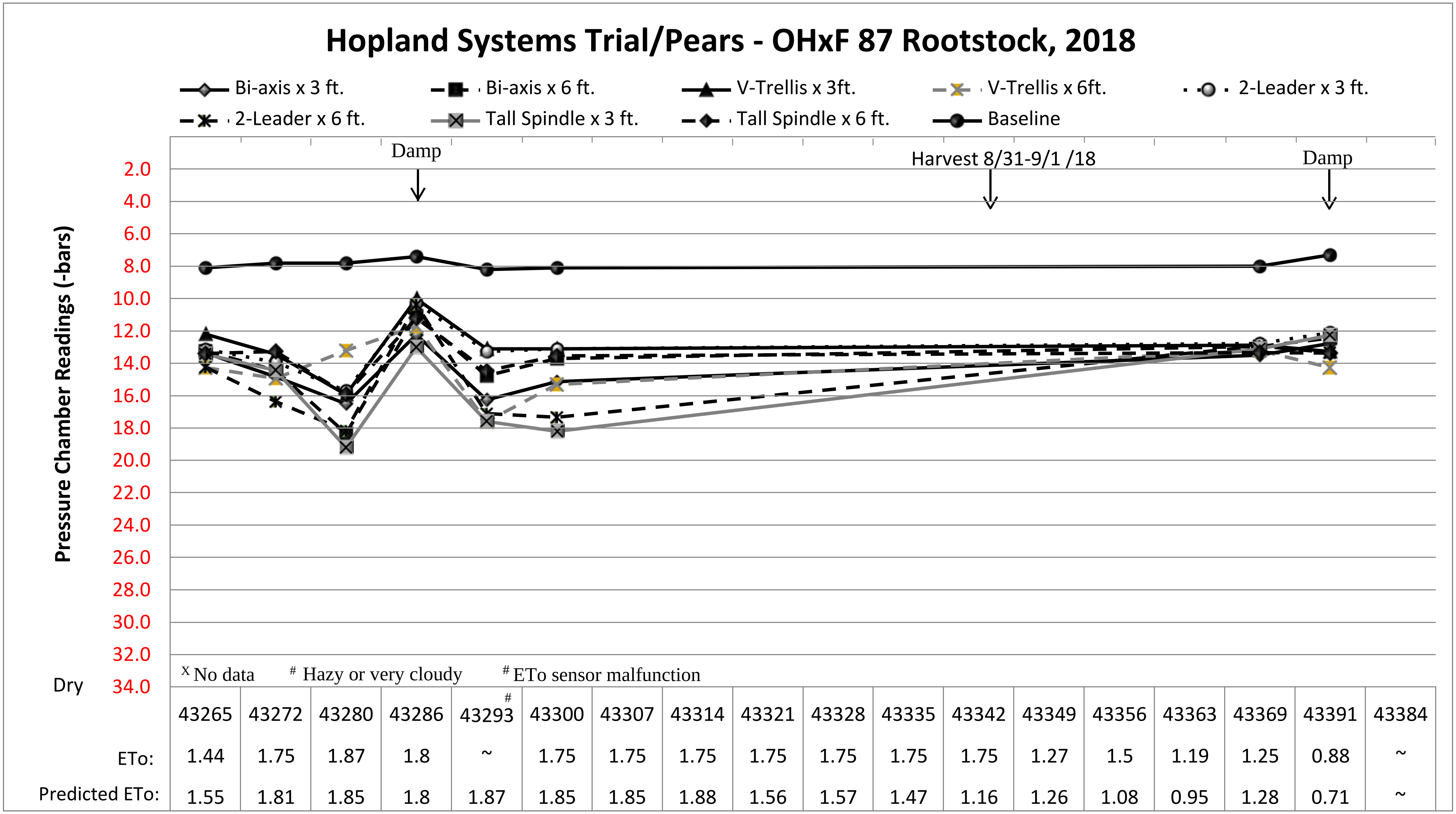
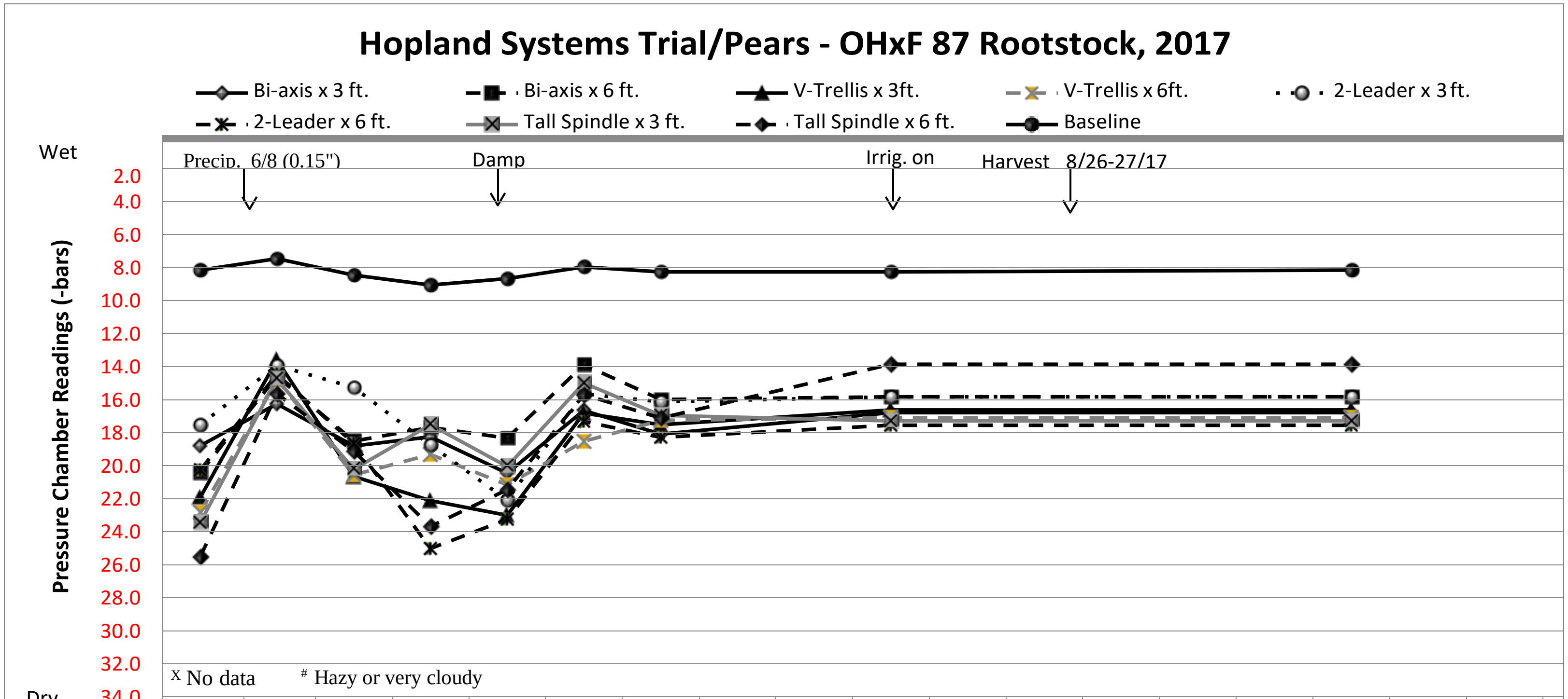


Figure 3: Effect of training system and spacing on weekly mid-day stem water potential (MSWP) of 6th-leaf 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2018.



	6/2	6/13	6/22	6/29	7/6	7/13	7/20	7/28 X	8/4 X	8/11 #	8/18 X	8/25 X	9/1 X	9/8 X	9/15 X	9/27	10/4	10/7
ETo:	1.44	1.14	1.88	1.75	1.86	1.91	1.92	1.8	1.61	1.57	1.54	1.38	1.56	1.18	1.18	1.02	~	~
Predicted ETo:	~	1.26	1.95	1.96	1.8	1.85	1.75	1.91	1.91	1.6	1.54	1.45	1.54	1.52	1.24	1	0.85	~

Figure 4: Effect of training system and spacing on weekly mid-day stem water potential (MSWP) of 5th-leaf 'Bartlett' pear trees on OHxF 87 rootstock, Hopland, Mendocino County, California, 2017.

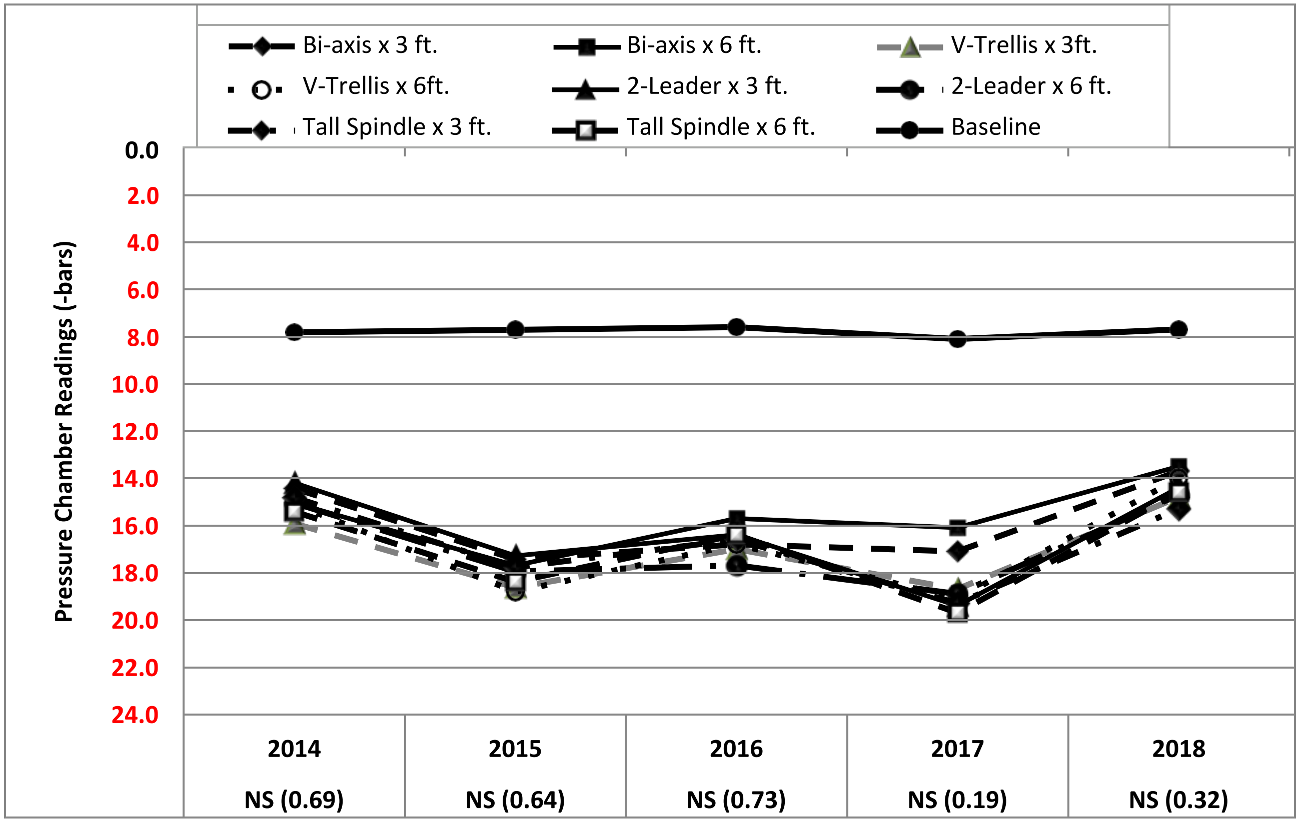


Figure 5: Effect of training system and spacing on seasonal average mid-day stem water potential (MSWP) of 2nd-6th leaf "Bartlett" pear trees on Pyro 2-33 rootstock, Hopland, Mendocino County, California, 2014-2018.

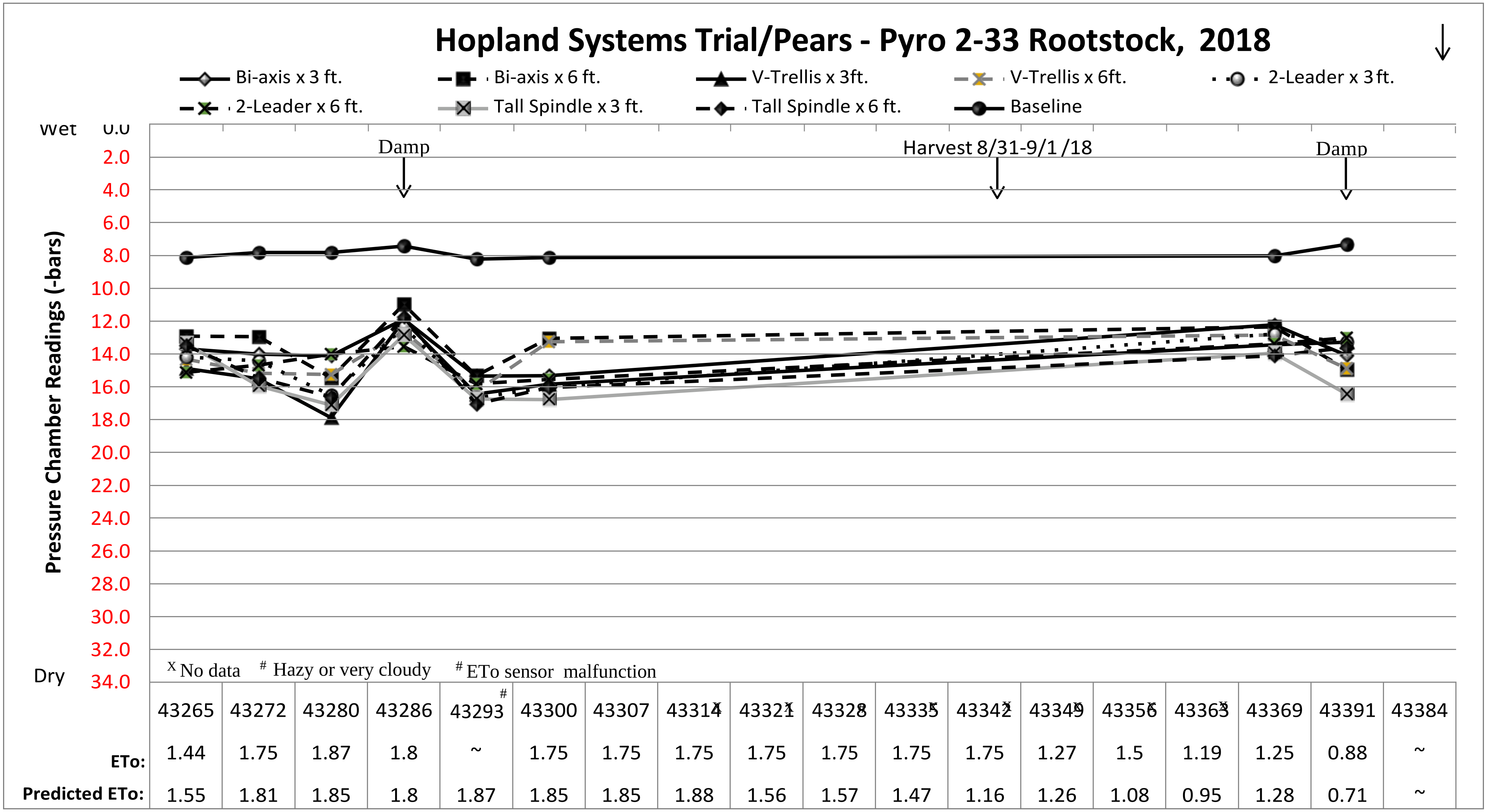
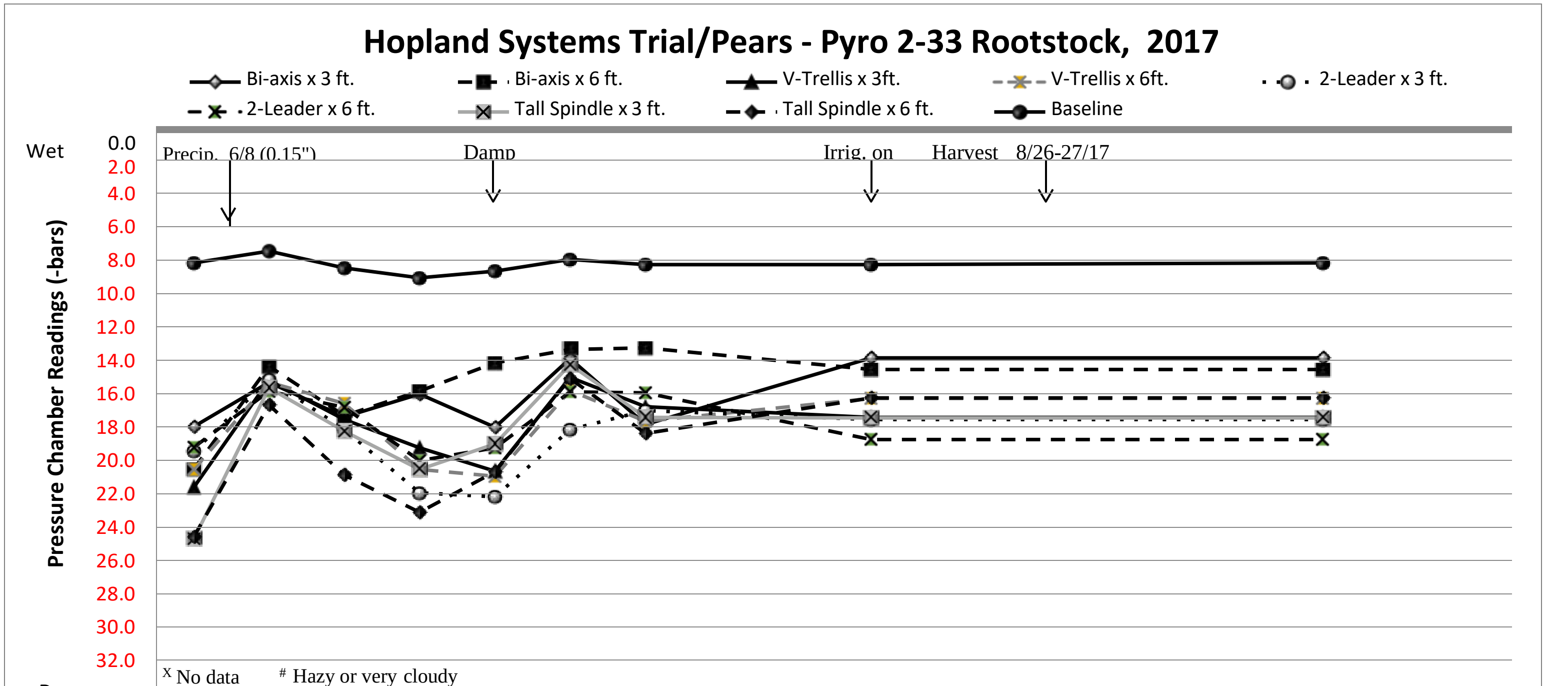


Figure 6. Comparison of mid-day stem water potential (MSWP) and baseline (-7 to-9 bars) among Pyro 2-33 rootstock, 6th-leaf 'Bartlett' pear trees, Hopland, Mendocino County, California, 2018.



	6/2	6/13	6/22	6/29	7/6	7/13	7/20	7/28 X	8/4 X	8/11 #	8/18 X	8/25 X	9/1 X	9/8 X	9/15 X	9/27	10/4	10/7
ETo:	1.44	1.14	1.88	1.75	1.86	1.91	1.92	1.8	1.61	1.57	1.54	1.38	1.56	1.18	1.18	1.02	~	~
Predicted ETo:	~	1.26	1.95	1.96	1.8	1.85	1.75	1.91	1.91	1.6	1.54	1.45	1.54	1.52	1.24	1	0.85	~

Figure 7. Effect of training system and spacing on weekly mid-day stem water potential (MSWP) of 5th-leaf 'Bartlett' pear trees on Pyro 2-33 rootstock, Hopland, Mendocino County, California, 2017.