IMPROVING ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY IN CALIFORNIA PEAR PRODUCTION THROUGH CHANGES IN ROOTSTOCK USE: THE 2005 NC-140 REGIONAL ROOTSTOCK PROJECT (Talmage)

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ABSTRACT

The Multi-State Research Project NC-140, "Improving Economic and Environmental Sustainability in Tree Fruit Production Through Changes in Rootstock Use", was established in the late 1980s. The first 10-year, multi-state pear trial was established in 1987 and subsequent ones in 2004-2006. Three trials were planted in California in April 2005: Bartlett in Mendocino (loam) and Sacramento (clay) Counties and 'Golden Russet' Bosc in Mendocino County (loam). Trial design was the standard NC-140 configuration of randomized complete block (RCB) with 10 single tree replicates. Rootstocks included 708-36 (United Kingdom), BM 2000 (Australia), Fox 11 (Italy), Horner 4 (Oregon), OHxF 69 (Oregon, Mendocino Bartlett only), OHxF 87 (Oregon), Pyro-233 and Pyrodwarf (both Germany). The Sacramento trial was abandoned after 2009, and the final trial data reported (Elkins 2011; Elkins et al. 2011; Elkins and Ingels 2010). Survival rate for both Mendocino County trials combined ranged from 60-100%, with Fox 11 having the most losses. In 2014, Horner 4 trees were the largest and 708-36 the smallest. Bartlett yields decreased 4% from 2013. Horner 4 had the largest and most fruit and highest total yield. Pyrodwarf and Horner 4 had the highest yield efficiency. 708-36 had the smallest fruit and the lowest yield. OHxF 69 had the lowest yield efficiency. Pyro 2-33 and OHxF 87 fruit had the highest soluble solids and OHxF 69 and Horner 4 the lowest. 708-36 fruit was firmest and Horner 4 softest. Horner 4 trees averaged the least mid-day water stress and 708-36 and Pyro 2-33 the most. For Bosc, yields decreased 25% from 2013. Horner 4 trees were the largest, followed by Fox 11 and BM 2000, with no difference among other rootstocks. There were not differences in tree survival, number of fruit, yield, or number of suckers. Horner 4 had the largest fruit and OHxF 87 and Pyrodwarf the smallest. There was a trend toward OHxF 87 having the highest and Fox 11 having the lowest yield efficiency. OHxF 87 fruit was firmest and Foxx 11 fruit softest. 2014 was the tenth season of the 10 year trial and the final year of formal data collection. After 10 years, there are very strong positive correlations between yield components, but not yield efficiency, and TCSA for Bartlett. For Bosc, yield efficiency was positively correlated with fruit number and negatively correlated with TCSA; while fruit size was positively correlated only with TCSA. Water stress status appears most positively correlated with vigor and soluble solids and fruit size (Bosc). 2015 focus will be on crop load management and water relations.

INTRODUCTION AND OBJECTIVES

There are very few commercially viable size controlling rootstocks for pear. Quince rootstock is widely used in Europe interstemmed with Old Home or Beurre Hardy, but is only being employed in the U.S. as a rootstock for Comice due to its incompatibility with other cultivars. The Old Home x Farmingdale (OHxF) (Brooks®)[1] series offers several potential options that are now becoming more widely planted. The two OHxF selections currently most offered by major wholesale nurseries are 97 and 87 (333 is generally sold to homeowners) (Elkins, R., 2006). 97 is a large tree similar to Winter Nelis, though more precocious than *P. betulaefolia*. 87 is a smaller tree, but has been shown to produce small fruit in some locations. Data from California, and more recently Washington, has suggested that OHxF 69, which has limited commercial availability, may also be promising, particularly for Bosc, but is difficult to propagate by hardwood cuttings (Elkins and DeJong 2002; Elkins et al. 2008; Elkins and DeJong 2011; Reed 2011; Elkins, Bell and Einhorn 2012).

The North Central Regional Research Project NC-140 (*www.NC140.org*) is a federally (NIFA)-supported, multi-state rootstock project focused on perennial tree fruit crops. The goal of NC-140 is to disseminate information generated from long-term (generally 10 year) trials throughout the U.S. Each participating state (as well as Canada and Mexico) establishes and evaluates similar ("uniform") trials using the same rootstocks and similar plot design so that regional differences can be determined. Researchers share progress and results at the annual meeting and via the NC-140 website. Each state representative submits an annual report which is distributed at the meeting and then compiled into a national report for USDA and posted on the NC-140 website for public use. Data is also shared with growers and nurseries who can then select rootstocks suitable to their location and customer base.

All Regional projects must be re-authorized every five years; the NC-140 2012-2017 continuing 5-year proposal was submitted and accepted by the North Central Regional Association (NCRA) of State Agricultural Experiment Station Directors (NC-140 2012).California began participating in NC-140 for apples in 1995 and peaches in 2001 and began participating actively in pears in 2005.

In coordination with Oregon, Washington, New York, and Chihuahua, Mexico, three NC-140 trials were established in California in spring 2005: two in Talmage, Mendocino County (Bartlett and ‘Golden Russet’ Bosc, 5' x 10' spacing), and one in Courtland, Sacramento County (Bartlett, 9' x 15' spacing). Rootstock liners were propagated by Meadow Lake Nursery, McMinnville, Oregon then budded and grown by Fowler Nurseries, Inc., Newcastle, California. The Courtland trial was abandoned after 2009, leaving the two Mendocino County trials in place. Rootstock and cultivar selections for the existing 2005 NC-140 pear plantings are shown in Table 1.

The 2005 NC-140 trials were the only **bearing *replicated*** rootstock trials in California until the successor systems trial was planted in Hopland in 2013 (Elkins, et al 2014) and the Talmage Bartlett trial is the only one planted in 2005 to include OHxF 69. The ultimate objective of the above trials, as with all NC-140 and other rootstock trials, was to ind[illegible] nursery and grower planting decisions, particularly for new, high density planting systems. The 2014 final year continuing objective of the Talmage NC-140 trial was to evaluate rootstocks for size, vigor, growth habit, productivity, compatibility with major varieties, susceptibility to diseases and pests, propensity to sucker, etc.

[1]The male parent of this series has now been shown to be Bartlett (Postman et al. 2013).

PROCEDURES

Two trials were planted in Talmage (Ukiah Valley), Mendocino County, California in April 2005. Design was randomized complete block, with 10 single tree replicates per rootstock. Data collection and calculation from 2005-2014 included number of flower clusters (2005-2010), number of fruit, tree height, trunk cross sectional area (TCSA), yield, yield efficiency, number of root suckers, and % survival. 2010-2014 data also included firmness (kg) and soluble solids (°Brix). In 2013 and 2014, weekly mid-day stem water potential (MSWP) was measured using a pressure chamber (PMS Model 610 Pressure Chamber, PMS Instrument Company, Albany, OR) from May through early October to assess whether and how much water stress might affect vigor and yield (crop load and fruit size), and vise versa. Data was analyzed using ANOVA (including means separation using Tukey's HSD) and simple regression analysis run to obtain correlation coefficients (r values) among variables for each trial year and for cumulative (2008-2014) cropping years (Statgraphics Centurion XVII, Statpoint Technologies, Warrenton, VA). In 2014, the decision was made to remove two "outlier" trees from the statistical analysis for the Bosc trial based on field observations, one "runt" Horner 4 (kept survival data only), and one BM 2000 that had rootstock fruit.

RESULTS AND DISCUSSION

Results from previous years are available (Elkins. 2014, 2013, 2012, 2011; Elkins 2010, Elkins and Ingels, 2010 and 2009).

2005 Bartlett Pear Rootstock Planting

2014 results (Tables 2-5)

Tree growth and productivity – No trees were lost in 2014. Fruit number increased 19% although tree yield decreased by 4%. Fruit size decreased 21% and was less than 200 grams for all rootstocks. Horner 4 continued to have the most and largest fruit (183 g. or size 110 fruit, based on a 44 lb. box) and the greatest yield (41 kg. or 2 boxes/tree). 708-36 had the least yield (11.8 kg.) and the smallest fruit (131 g.). Trees are at full height, although TCSA increased 25% from 2013, with Horner 4 being the largest and

708-36 the smallest trees. Yield efficiency was 24% lower than 2013 due to lower yields and smaller fruit size. Pyrodwarf and Horner 4 had the highest yield efficiency and OHxF 69 the lowest. There were few root suckers in 2014. There were significant differences in fruit firmness with 708-36 having the firmest fruit and Horner 4 the softest. Soluble solids were highest for Pyro 2-33 and OHxF 87 and lowest for Horner 4 and OHxF 69.

Water potential relationship to tree vigor and yield – MSWP differed significantly among rootstocks from May through early October. Rootstocks, including (non-replicated) standard sized mature Bartlett trees on Winter Nelis never attained the values of -6 - -8 bars, the suggested baseline for fully-watered trees (Shackel 2007). Unsurprisingly, however, Horner 4 was the least water stressed, averaging -10.7 bars (baseline -7.2) over the season and -12.3 (baseline -8.0) in July during the hottest time of the year. BM 2000 was the next least stressed. 708-36 averaged the most stressed (-14.1), followed by Pyro 2-33 and OHxF 69, which were the most stressed in mid- to late-July. MSWP was very significantly and positively correlated with every individual growth and productivity factor except yield efficiency and soluble solids.

2005-2014 cumulative results (Tables 5,10,12)

Tree survival – There were no significant differences in tree survival.

Fruit size – Average fruit size has been relatively small, ranging from 156 -197 grams. Horner 4 has consistently had the largest fruit (197 grams average), followed by Pyro 2-33 and BM 2000. 708-36, OHxF 69, and OHxF 87 have had the smallest fruit. It is important to note that most of these rootstocks were selected for lower vigor and fruit thinning (not normally practiced in California and not done in this trial) and more intensive cultural practices may be required to enable production of large fruit in a high density planting with more intra tree competition, and particularly in warm climates with higher evapotranspiration rates.

Tree size and vigor – After ten seasons, Horner 4 trees were nearly twice as large as others, followed by BM 2000, Fox 11, OHxF 69, Pyro 2-33, Pyrodwarf, OHxF 87, and lastly, 708-36.

Cumulative yield and yield efficiency – Horner 4 has yielded 41% or more than the next highest yielding rootstocks, BM 2000 and Pyrodwarf. 708-36 has yielded the least and all others equally. There are fewer differences in yield efficiency, with Pyrodwarf having numerically the highest and OHxF 69 numerically the lowest. Results with OHxF 69 are due to poor yields relative to tree size, in contrast with past results with ‘Golden Russet’ Bosc (Elkins and DeJong 2011) and data from other locations (Auvil, 2005) and may be related to scion selection or to some OHxF 69 trees began expressing poor vigor, bark cracking, and dieback of as-yet undefined origin soon after planting at this location. Low vigor of OHxF 69 due to lack of juvenility, a known characteristic attributed to some clonal rootstocks, is one possible cause being currently being addressed by

industry-supported research on improving micropropagated rooting and growth (Reed 2012, 2013, 2014). OHxF 69 liners readily flower soon after planting in the nursery, suggesting lack of juvenility, which may in turn, reduce grafted tree vigor. OHxF 69 has also exhibited strong early flowering in the Bartlett orchard systems trial planted in Hopland in May 2013; this new trial offers another opportunity to observe its performance in a high density orchard setting (Elkins 2014). Interestingly however, OHxF 69 yield and fruit size have equaled OHxF 87 in the NC-140 trial, and OHxF 69 trees are larger than OHxF 87.

Relationships among productivity factors – Simple linear regression analysis of the average of 10 replicate trees over the years 2008-2014 revealed very highly significant relationships (r=.90-.100) between yield and fruit number, yield and TCSA, and fruit number and TCSA. Relationships between yield and fruit size, fruit size and fruit number, and fruit size and TCSA were also highly significant. There was no **direct** significant correlation between yield efficiency and any individual variable.

Including all the annual averages for each rootstock ("scattergram") revealed numerous significant non-linear, but generally weaker, relationships, the strongest being between yield and both fruit number and TCSA.

While yield efficiency could not be directly correlated with any given factor overall, there was weak ($p \leq .10$) positive correlation with yield and fruit number in some years, and hence significant non-linear correlation. This suggests that some rootstocks may tend toward very high or low efficiency, primarily based on fruit number, in some years. It is interesting that yield efficiency correlated with yield every other year from 2008-2014, suggesting somewhat of an alternate bearing pattern.

Yield began to be correlated with fruit size only in the fourth bearing year (2011), suggesting that as trees matured, differences in vigor became apparent. This parallels a similar trend between TCSA and both fruit number and fruit size, in which correlations dramatically increased in 2011.

Root suckers – There have been very few root suckers at this location. Only Fox 11 and BM 2000 have had three or more, although OHxF 69 had 1.9. Neither Pyrodwarf nor Pyro 2-33 have suckered, in contrast with profuse suckering of Pyrodwarf in other locations (Washington, New York).

Mid-day stem water potential (MSWP) (2013-2014 only) – Positive (increasing) MSWP was significantly and positively correlated with TCSA, yield efficiency, firmness, and soluble solids. Because 2014 results differed from those in 2013, more years of data will be needed to determine true relationships (planned for 2015).

2005 'Golden Russet' Bosc Pear Rootstock Planting

2014 results (Tables 6-8)

Tree growth and productivity – Overall survival was less than in the Bartlett trial with no changes in 2014. There were few root suckers.
The number of fruit increased by 5% while yield decreased by 25% from 2013. Only fruit size (and concurrent box size) and trunk cross-sectional area (TCSA) differed significantly, although there were trends in yield efficiency. Overall, similar to Bartlett, fruit size decreased 27%. As with Bartlett, Horner 4 had the largest fruit (167 g. or size 120 box size) and OHxF 87 and Pyrodwarf the smallest (123 and 126 g. respectively). Horner 4 trees were largest, followed by Fox 11 and BM 2000, with no differences among other rootstocks. There were trends toward OHxF 87 having higher yield efficiency and Fox 11 having the lowest. and toward OHxF 87 and 708-36 having the firmest fruit and Fox 11 the softest. There were no diffierences in soluble solids.
Water potential relationship to tree vigor and yield – MSWP differed significantly among rootstocks throughout the season. Horner 4 was the least water stressed, averaging -9.3 bars over the season and -10.6 in July during the hottest time of the year. Fox 11 was the next least stressed. OHxF 87 averaged the most stressed, followed by Pyro 2-33 and 707-36, which were the most stressed during the hottest weeks of mid to late-July. During May and September Horner 4 and Fox 11 rootstocks attained the values of -6 - -8 bars, the suggested baseline for fully-watered trees (Shackel 2007). Increasing (positive) MSWP was significantly and positively correlated with fruit size, TCSA, and yield efficiency, but not firmness or soluble solids. More years of data are needed to clarify the relationship between MSWP and growth and productivity.

2005-2014 cumulative results (Table 9)

Tree survival – Horner 4 is the only selection with 100% survival, although there were no statistical differences among rootstocks.

Fruit size –Horner 4 has had the largest fruit (183 g.), 708-36 the smallest (147 g.), and all others equal. Average fruit size has been small, suggesting overall low vigor, likely for the same reasons as described above for Bartlett.

Tree size and vigor – Overall tree size (TCSA) is about 50% larger than Bartlett. As with Bartlett, Horner 4 trees are the largest followed by Fox 11 and BM 2000, with all others being equal.

Cumulative yield and yield efficiency – Overall yields have been 48% those of Bartlett and there are no significant differences among rootstocks. OHxF 69 was not included in the Bosc trial so cultivar performance cannot be compared with Bartlett. There were very highly significant differences in yield efficiency, with OHxF 87 having the highest and Fox 11 and Horner 4 the lowest.

Relationship among productivity factors – There were fewer significant, and more negative, correlations for Bosc. Using yearly bearing year data for the average of 10 trees from 2008-2014, there were moderately strong (>.70) significant positive

correlations between yield efficiency and fruit number and fruit size and TCSA. There was a strong negative correlation between yield efficiency and TCSA (versus Bartlett with no correlation between yield efficiency and TCSA). However, there was no correlation between yield and TCSA except for compiled individual yearly data. Data for cumulative averages reflected the pattern for individual years, but less so than for Bartlett, as annual data varied more year to year. Using individual yearly data resulted in more significant correlations (only yield efficiency and fruit number and yield and fruit number were >.70). Also, in contrast to Bartlett, the larger sample size revealed significant negative correlations among rootstocks between yield efficiency and fruit size, and fruit size and fruit number (2009-2014).

Root suckers – There have been no difference among rootstocks.

Relationships among productivity factors (Tables 10-13)

Relationships differed between Bartlett and Bosc and between cumulative results derived from 10-tree averages and those derived from including all yearly averages ("scattergram") (data not shown).

Bartlett versus Bosc – Results were more consistent for Bartlett, both among factors and across years; relationships were also all positive. Trends were firmly established as early as 2008, and at the latest in 2011 (fruit size and yield, TCSA and fruit number). Interestingly, based on average data, yield efficiency was not significantly **directly** related to any individual factor, on a cumulative tree average basis, but yield showed the strongest relationship, and it in turn was strongly correlated with TCSA, fruit size, and fruit number. Scattergram results suggest potential ability to predict yield efficiency based on yield, and **perhaps** TCSA and fruit number, but not fruit size, which appears unrelated to yield efficiency.

In contrast to Bartlett, Bosc yield efficiency was more directly related to several factors, particularly fruit number and TCSA, but also to lesser extent, total yield (which was mainly correlated with fruit number). Correlation with yield was significant during early bearing, suggesting rootstock differences in precocity, but abruptly became insignificant in 2011 when it appears alternate beating set in. Also in contrast to Bartlett, yield efficiency was significantly and negatively correlated to TCSA in the later bearing years, suggesting that the combination of a vigorous, non-precocious cultivar on either an excessively vigorous cultivar or excessively vigorous rootstock can reduce efficiency by reducing early yield (fruit number). Fruit size, however, was generally positively correlated with TCSA and more negatively correlated with fruit number, suggesting a more delicate economic balance between yield and fruit size with Bosc. As with Bartlett, aggregate results using individual years might provide a means to select rootstocks within optimal ranges of fruit number and fruit size. In summary, utilizing yield efficiency, while important, should be considered within context of individual cultivars with different bearing habits, as well as the economic balance between yield and fruit size.

Two years of mid-day stem water potential data has begun to elucidate relationships between MSWP and vigor and productivity factors. As with productivity correlations, using data for individual years suggests differences among rootstocks and years, though least between MSWP and yield efficiency and less for Bosc than Bartlett.

WORK PLANNED FOR 2015 (Year 11) – 2014 results were presented at the NC-140 meeting in Clemson, South Carolina and at the 2014 ISHS Pear Symposium in Leuven, Belgium in July 2014. 2014 was the final formal reporting year of the trial, however, the existing trees will be utilized to study the effect of fruit thinning on vigor, fruit size, and water relations. Efforts to propagate a greater number of Horner 4 trees for wider testing, either by micro-propagation or cuttings, will continue in 2015 in collaboration with OSU, USDA, and commercial nurseries. It is also hoped that additional sites to test Horner 4 under varying grower conditions (soil type, nutritional challenges, microclimates) will be located. Final 2014 results will be summarized for publication and for multiple research meetings. The NC-140 Pear Committee is planning to establish a trial comparing selections of quince (*Cydonia sp.*) at 10 locations in the U.S., Canada, and Mexico in 2016.

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Table 1: Locations and included rootstocks, current 2005 NC140 Bartlett and Bosc[1] pear rootstock trials.

Rootstock	Origin	CA1[2]	CA2[3]	CH (MX)	NY	WA
708-36	United Kingdom	Bart, Bosc	Bart	-	Bart, Bosc	-
BM 2000	France	Bart, Bosc	Bart	Bart	Bart	Bosc
Fox 11	France	Bart, Bosc	Bart	-	Bart	-
Horner 4	Oregon	Bart, Bosc	Bart	-	Bart, Bosc	Bosc
OHxF 69	Australia	Bart	-	-	-	-
OHxF 87	Germany	Bart, Bosc	Bart	Bart	Bart	Bosc
OHxF 97	Germany	-	-	-	-	-
Pyrodwarf	Italy	Bart, Bosc	Bart	Bart	Bart, Bosc	Bosc
Pyro 2-33	Hood River, OR	Bart, Bosc	Bart	-	Bart	Bosc
Winter Nelis	Oregon	-	Bart	-	-	-
BU-3	Oregon	-	-	-	-	Bosc

[1] Three Anjou trials in Oregon and Washington are not included in this table.
[2] CA1 is in Talmage, Mendocino County.
[3] CA2 was disbanded in 2009 and was in Courtland, Sacramento County.

Table 2: Effects of the 2005 NC-140 rootstock planting on tree survival, number and size of fruit, tree yield, tree growth, yield efficiency, root suckers, box size and number of boxes per tree on 9-year-old (10th leaf) 'Bartlett' pear trees, Talmage, Mendocino County, California, 2014.

	Tree Survival 8/14/14 (%/10 trees)	No. Fruit 8/14/14 (no./tree)	Fruit Size 8/14/14 (g/fruit)	Yield 8/14/14 (kg/tree)	TCSA 10/13/14 (cm^2)	Yield Efficiency 10/13/14 (kg/cm^2)	Root Suckers 10/13/14 (no./tree)	Aver Box S 8/14 (44 lb.
ROOTSTOCK[1]								
708-36	90	88.6 bc	131 d	11.8 b	25.8 e	0.44 ab	0.0	150
BM 2000	100	139.0 b	174 ab	24.1 b	48.8 b	0.50 ab	0.4	110
Horner 4	100	225.7 a	183 a	40.8 a	77.4 a	0.53 a	0.1	110
Fox 11	80	131.1 bc	152 bcd	19.7 ab	42.4 bc	0.47 ab	0.4	135
OHxF 69	90	105.0 bc	151 cd	15.6 b	41.4 bcd	0.36 b	0.0	135
OHxF 87	100	87.2 c	166 abc	14.2 b	31.4 de	0.45 ab	0.2	120
Pyrodwarf	90	120.8 bc	159 bc	19.0 ab	35.6 cde	0.54 a	0.0	135
Pyro 2-33	70	106.3 bc	164 abc	17.4 ab	39.7 bcd	0.44 ab	0.3	120
ANOVA[2]								
Rootstock	NS (0.32)	*** (<0.001)	*** (<0.001)	*** (<0.001)	*** (<0.001))	NS (0.09)	NS (0.32)	*** (<0
Block	NS (0.56)	NS (0.10)	** (<0.01)	* (0.03)	* (0.03)	NS (0.22)	NS (0.44)	** (<0

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, $P \leq 0.05$ and 0.1 for yield efficiency). Root sucker data normalized using SQRT (root sucker +1) for *P*-value.

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

Harvest date: 8/14/2014.

Table 3. Effects of 2005 NC-140 rootstock planting on firmness and soluble solids among 9-year-old (10th leaf) 'Bartlett' pear trees, Talmage, Mendocino County, California, 2014.

	Firmness 8/14/14 (kg of force)	Soluble Solids 8/14/14 (ºBrix)
ROOTSTOCK[1]		
708-36	9.2 a	11.8 ab
BM 2000	8.2 bc	11.6 ab
Horner 4	7.7 c	10.6 b
Fox 11	8.7 ab	11.7 ab
OHxF 69	8.9 ab	10.5 b
OHxF 87	8.5 abc	12.1 a
Pyrodwarf	9.0 ab	11.3 ab
Pyro 2-33	8.8 ab	12.3 a
ANOVA[2]		
Rootstock	*** (<0.001)	* (0.05)
Block	NS(0.98)	NS (0.78)

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, $P \leq 0.5$ for Firmness, Duncan MRT, $P<0.05$, for Brix).
[2] *, *** Indicates significance at $P \leq 0.05$ and 0.001. NS indicates not significant.

Table 4: Comparison of monthly mid-day stem water potential (MSWP), baseline -6 - -8 (bars) among 9-year-old (10th leaf) Bartlett pear trees, Ruddick Ranch, Talmage, Mendocino County, California, 2014

	5/21[4]	6/18	7/24	8/20	9/10	10/8	Average
ROOTSTOCK[1]							
708-36	10.5 b	15.4 c	20.7 c	11.1 ab	14.1 ab	12.9	14.1
BM 2000	9.5 b	12.2 b	15.3 ab	10.5 ab	13.6 ab	12.5	12.3
Horner 4	9.5 a	9.7 a	12.8 a	9.5 a	11.6 a	11.1	10.7
Fox 11	10.3 b	13.2 bc	16.4 abc	10.9 ab	13.6 ab	12.0	12.7
OHxF 69	9.7 b	13.0 b	19.4 bc	11.8 b	13.5 ab	12.1	13.3
OHxF 87	9.6 b	12.9 b	17.0 abc	10.4 ab	12.4 ab	11.3	12.3
Pyrodwarf	10.2 b	13.8 bc	16.9 abc	11.3 ab	13.8 ab	11.5	12.9
Pyro 2-33	10.6 b	14.4 bc	16.0 abc	11.0 ab	15.0 b	12.7	13.3
Big Trees[3]	9.9	14.2	~	11.4	15.6	15.2	13.3
Baseline	**7.7**	**6.7**	**8.0**	**6.7**	**7.0**	**7.3**	**7.2**
ANOVA[2]							
Rootstock	*** (<0.001)	***(<0.001)	*** (<0.001)	* (0.05)	* (0.04)	NS (0.44)	
Block	* (0.02)	NS (0.52)	**(0.01)	NS (0.10)	NS (0.42)	NS (0.39)	

[1] Within columns, rootstock 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] Established trees used for comparison only (statistical analysis not run).
[4] All data negative (below 0.0 bars

Table 5: Cumulative effects of 2005 NC-140 rootstock planting on tree survival, average fruit size, average cumulative yield, trunk cross-sectional area, yield efficiency, root suckers, box size, and number of boxes on 9-year-old (10th leaf) Bartlett pear trees, Talmage, Mendocino County, California, 2005-2014.

	Tree Survival	Average Fruit Size[3]	Average Cumulative Yield	2014 TCSA	Average Cumulative Yield Efficiency[4]	Root Suckers[3] (Cum.	Averag
	(%)	(g)	(kg/tree)	(cm^2)	(kg/cm^2)	No/tree)	(44 lb. bo
ROOTSTOCK[1]							
708-36	90	156 d	60.9 d	25.8 e	2.28 ab	0.4 ab	135 c
BM 2000	100	181 b	113.2 b	48.8 b	2.36 ab	3.1 ab	110 ab
Horner 4	100	197 a	191.9 a	77.4 a	2.50 ab	0.3 ab	100 a
Fox 11	80	180 abc	91.9 bcd	42.4 bc	2.20 b	3.5 a	110 ab
OHxF 69	90	158 d	82.0 cd	41.4 bcd	1.93 b	1.9 ab	135 a
OHxF 87	100	164 cd	81.1 cd	31.4 de	2.58 ab	0.5 ab	120 bc
Pyrodwarf	90	166 bcd	104.1 bc	35.6 cde	2.98 a	0.0 b	120 bc
Pyro 2-33	70	183 ab	93.7 bcd	39.7 bcd	2.36 ab	0.0 b	110 ab
ANOVA[2]							
Rootstock	NS (0.28)	*** (<0.001)	*** (<0.001)	*** (<0.001)	** (<0.01)	** (0.01)	*** (<0.00
Block	NS (0.56)	** (<0.01)	**(<0.01)	* (0.03)	* (0.05)	NS (0.23)	NS (0.0

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, $P \leq 0.05$).
Root sucker data normalized SQRT (root sucker + 1), $P \leq 0.05$); Duncan multiple range test, $P < 0.05$.).
[2] *, **, *** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively. NS indicates not significant.
[3] Average fruit size based on fruiting years – 2008-2014.
[4] Based on cumulative yield (2005-14) and final TCSA (2014).

Table 6. Effects of 2005 NC-140 rootstock planting on tree survival, number and size of fruit, tree yield, trunk cross-sectional area, yield efficiency, tree height, root suckers, box size, and number of boxes per tree among 9-year-old (10th leaf) 'Golden Russet' Bosc pear trees, Talmage, Mendocino County, California, 2014.

	Tree Survival 8/29/14 (%/10 trees)	No. Fruit 8/29/14 (no./tree)	Fruit Size 8/29/14 (g/fruit)	Yield 8/29/14 (kg/tree)	TCSA 10/13/14 (cm^2)	Yield Efficiency 10/13/14 kg/cm^2)	Root Suckers[3] 10/13/14 (no./tree)	Average Box Size 8/29/14 (44 lb. box)
ROOTSTOCK[1]								
708-36	80	80	135 ab	9.8	48.8 b	0.22 abc	0.3	150 a
BM 2000	60	100	142 ab	13.6	68.8 ab	0.21 abc	0.1	120 a
Horner 4	100	86	167 a	13.6	96.8 a	0.14 abc	0.0	120 b
Fox 11	60	61	154 ab	9.1	76.1 ab	0.13 c	0.1	135 ab
OHxF 87	80	116	123 b	14.0	51.9 b	).26 a	0.1	135 ab
Pyrodwarf	90	125	126 b	15.1	65.4 b	).24 ab	0.4	165 b
Pyro 2-33	80	115	140 ab	15.3	66.9 b	0.23 abc	0.1	120 ab
ANOVA[2]								
Rootstock	NS (0.26)	NS (0.46)	**(0.01)	NS (0.58)	***(0.001)	NS (0.09)	NS (0.56)	NS(0.28)
Block	NS (0.30)	NS (0.84)	*(0.03)	NS (0.88)	*(0.04)	NS (0.49)	NS (0.59)	NS (0.23)

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, $P \leq 0.05$); no. of fruit and yield efficiency means,
(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] Root sucker data normalized SQRT (root sucker + 1), $P \leq 0.05$. (Duncan Multiple Range Test).
Harvest date: 8/28/2014

Table 7. Effects of 2005 NC-140 rootstock planting on firmness and soluble solids among 9-year-old (10th leaf) 'Golden Russet' Bosc pear trees, Talmage, Mendocino County, California, 2014

	Firmness 8/29/14 (kg of force)	Soluble Solids 8/29/14 (ºBrix)
ROOTSTOCK[1]		
708-36	9.2 ab	14.6 ab
BM 2000	9.3 ab	14.4 ab
Horner 4	8.5 ab	14.0 ab
Fox 11	6.9 b	14.9 a
OHxF 87	9.4 a	14.5 ab
Pyrodwarf	8.9 ab	13.6 b
Pyro 2-33	8.6 ab	14.6 ab
ANOVA[2]		
Rootstock	NS (0.10)	NS (0.28)
Block	NS (0.60)	NS (0.06)

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, P≤0.1 for firmness, Duncan MRT, P<0.05 for brix).
[2] NS indicates not significant.

Table 8: Comparison of monthly mid-day stem water potential (MSWP), baseline -6 - -8 (bars) among 9-year-old (10th leaf) Bosc pear trees, Ruddick Ranch, Talmage, Mendocino County, California, 2014

	5/20[3]	6/17	7/22	8/19	9/16	10/7	Average
ROOTSTOCK[1]							
708-36	9.6 b	11.5 bc	15.1 b	12.1 ab	8.4 ab	12.2 ab	12.4 b
BM 2000	9.4 ab	10.6 abc	12.9 ab	12.4 ab	9.4 ab	12.6 ab	12.0 b
Horner 4	7.0 a	9.2 a	9.8 a	8.7 a	7.7 a	9.5 a	9.2 a
Fox 11	7.8 ab	9.4 ab	12.2 ab	10.5 ab	7.8 ab	11.4 ab	10.6 ab
OHxF 87	9.4 b	11.7 c	15.1 b	13.7 b	9.5 ab	13.8 b	13.1 b
Pyrodwarf	9.5 b	11.8 c	13.8 b	12.5 b	10.1 b	13.5 b	12.4 b
Pyro 2-33	9.3 b	12.0 c	14.8 b	13.7 b	10.0 b	14.5 b	13.0 b
Baseline	**7.0**	**7.2**	**6.7**	**6.7**	**7.0**	**7.5**	**7.0**
ANOVA[2]							
Rootstock	** (0.004)	*** (<0.001)	*** (<0.001)	** (0.002)	** (0.01)	** (0.004)	***(<0.001)
Block	NS (0.60)	*** (<0.001)	*** (<0.001)	NS (0.28)	NS (0.69)	** (0.01)	NS (0.69)

[1] Within columns, rootstock 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.
[3] All data negative (below 0.0 bars).

Table 9. Cumulative effects of 2005 NC-140 rootstock planting on tree survival, average fruit size, tree yield, trunk cross-sectional area, yield efficiency, root suckers, box size, and number of boxes per tree on 9-year-old (10th leaf) 'Golden Russet' Bosc pear trees, Talmage, Mendocino County, California, 2005-2014.

	Tree Survival (%/10 trees)	Average Fruit Size[3] (g/fruit)	Average Cumulative Yield (kg)	2014 TCSA (cm^2)	Average Cumulative Yield Efficiency[4] (kg/cm^2)	Root Suckers[5] (cum.no./tree)	Aver Box (44 lb
ROOTSTOCK[1]							
708-36	80	147 b	59.8	48.8 b	1.18 ab	1.0	150 b
BM 2000	60	149 ab	55.4	68.8 ab	0.86 ab	2.3	150 ab
Horner 4	100	183 a	69.8	96.8 a	0.74 b	1.7	110 a
Fox 11	60	167 ab	54.4	76.1 ab	0.73 b	0.3	120 ab
OHxF 87	80	158 ab	73.4	51.9 b	1.35 a	0.2	135 ab
Pyrodwarf	90	162 ab	72.4	65.4 b	1.12 ab	0.3	120 ab
Pyro 2-33	80	152 ab	62.9	66.9 b	0.97 ab	0.0	135 ab
ANOVA[2]							
Rootstock	NS (0.26)	* (0.02)	NS (0.61)	*** (0.001)	*** (<0.001)	NS (0.54)	NS (0
Block	NS (0.30)	* (0.05)	NS (0.37)	* (0.04)	NS (0.53)	NS (0.72)	NS (0

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, $P \leq 0.05$), fruit size means by Duncan MRT, $P \leq 0.05$). Root sucker data normalized SQRT (root sucker + 1), (Duncan MRT, $P \leq 0.05$).

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

[3] Based on cumulative yield (2005-14) and final TCSA (2014).

[4] Based on cumulative yield (2005-2014) and final TCSA (2014).

Table 10. Correlation coefficients for factors related to cumulative performance of 'Bartlett' pear on seven rootstocks, Talmage, Mendocino County, California, 2008-2014.

								Cumula	
	2008	2009	2010	2011	2012	2013	2014	All years combined 2008-2014 (n=8)	200
Yield efficiency vs.									
Fruit no.	.87**	.62	.62	.37	.69(*)[2]	.57	.60	.32	.77*
Fruit size	.16	-.27	.40	.20	.29	.03	.52	.12	.13
Yield	.78*	.47	.62(*)	.33	.66(*)[2]	.40	.61(*)[2]	.27	.72*
TCSA	.07	.15	.14	.02	.48	.02	.43	-.00	.40*
Yield vs.									
Fruit no.	.95***	.97***	.99***	.99***	.99***	.93***	99***	.99***	.97*
Fruit size	.37	.48	.29	.89**	.71*	.78*	.76*	.83**	.40*
TCSA	.63(*)[2]	.89**	.86**	.95***	.97***	.92***	.98***	.96***	.90*
Fruit size vs.									
Fruit no.	.11	.28	.16	.83**	.64	.51	.68	.77*	.20
TCSA	.44	.71*	.07	.87**	.79*	.85**	.76*	.83**	.40*
Fruit no. vs.									
TCSA	.42	.78*	.84**	.93***	.95***	.77*	.97***	.94***	.86*

[1] *,**,*** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively, absence of "*" indicates not significant.
[2] ($p \leq 0.10$)
[3] Relatively week=0.01-0.50, moderately strong=0.51-0.89, relatively strong=0.90-1.00

Table 11. Correlation coefficients among factors related to cumulative performance of 'Golden Russet Bosc' pear on seven rootstocks, Talmage, Mendocino County, California, 2008-2014.

								Cumulative	
	2008	2009	2010	2011	2012	2013	2014	All years combined 2008-2014 (n=7)	Inc 2008-2 (n=
Yield efficiency vs.									
Fruit no.	.92**	.98***	.93**	.49	.92**	.94***	.42	.86**	.78***
Fruit size	.65	.11	-.16	-.36	-.66	-.89**	-.84*	-.51	-.21
Yield	.98***	.97***	.95***	.22	.63	.67	.05	.53	.63***
TCSA	.27	.09	-.47	-.55	-.98***	-.66(*)[2]	-.86**	-.85**	.59***
Yield vs.									
Fruit no.	.95***	1.00***	.99***	.82*	.68	.85**	.90**	.87**	.96***
Fruit size	.54	.58	-.13	.44	-.10	-.30	-.29	.37	.27(*)[2]
TCSA	.28	.33	-.24	.62	-.50	.11	.10	-.01	.66***
Fruit size									
Fruit no.	.38	.14	-.22	-.11	-.79*	-.75*	-.67	-.08	.11
TCSA	.60	.07	.60	.87**	.66	.91**	.88**	.83*	.32*
Fruit no.									
TCSA	.08	.29	-.27	.13	-.85*	-.41	-.31	-.49	-.65***

[1] *,**,*** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively, absence of "*" indicates not significant.
[2] ($p \leq 0.10$)
[3] Relatively week=0.01-0.50, moderately strong=0.51-0.89, relatively stong=0.90-1.00

Table 12. Correlation coefficients of the average for all replicates[1,2] for increasing (positive) mid-day stem water potential (MSWP) and growth and productivity factors of 9-year-old, (10th leaf) 'Bartlett' and "Golden Russet" 'Bosc' pear trees, 2005 NC-140 rootstock trial, Talmage, Mendocino County, California, 2013-2014.

	2013		2014		2013 - 2014	
MSWP vs.	Bartlett (n=8)	Bosc	Bartlett (n=8)	Bosc (n=7)	Bartlett (n=16)	Bosc
No. Fruit	.12	~	.86 **	.63	.48	~
Fruit Size	.74 *	~	.85 **	.91 *	.25	~
Yield	.41	~	.90 **	.34	.30	~
TCSA	.51	~	.89 **	.88 **	.61 **	~
Yield efficiency	.22	~	.52	.73*	.58 *	~
Firmness (kg of force)	.01	~	.96***	.55	.51*	~
Soluble Solids (degrees brix)	.42	~	.47	.12	.81***	~

[1] *,**,*** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively, absence of "*" indicates not significant.
[2] ($p \leq 0.10$)
[3] Relatively week=0.01-0.50, moderately strong=0.51-0.89, relatively stong=0.90-1.00

Table 13. Correlation coefficients of individual tree replicates[1] for mid-day stem water (MSWP) potential cumulative effects and growth and productivity factors of 9-year-old, (10th leaf) 'Bartlett' and "Golden Russet" 'Bosc' pear trees, Talmage, Mendocino County, California, 2013-2014.

	Bartlett	Bosc
MSWP vs.	(n=72)	(n=54)
No. Fruit (per tree)	.52 ***	.00
Fruit Size (g)	.44 ***	.65 ***
Yield (kg/tree)	.58 ***	.30 *
TCSA (2014)	.52 ***	.79 ***
Yield Efficiency (kg/cm^2)	.21	.32 **

[1] *,**,*** Indicate significance at $P \leq 0.05$, 0.01, and 0.001 respectively, absence of "*" indicates not significant.
[2] ($p \leq 0.10$)

[3] Relatively week=0.01-0.50, moderately strong=0.51-0.89, relatively stong=0.90-1.00