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

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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 presented in the 2010 report. Survival rate in Mendocino County ranges from 60-100%, with Fox 11 having the most losses. In 2013, Bartlett yields increased 29% from 2012. Horner 4 trees were the largest and 708-36 the smallest. Horner 4 had the largest and most fruit and yielded the most. 708-36 had the lowest yield. Pyrodwarf had the highest yield efficiency. OHxF 69 had the smallest fruit and the lowest yield efficiency. Horner 4 trees average the least mid-day water stress and Pyro 2-33 the most, although OHxF 69 and 87 were the most stressed in mid-July. For Bosc, yields increased 106% from 2012; Horner 4 trees were largest and 708-36 and OHxF 87 the smallest. Horner 4 had the largest fruit and 708-36 and OHxF 87 the smallest. Pyrodwarf had the most fruit and the highest yield efficiency, while BM 2000, Horner 4, and Fox 11 had the lowest. BM 2000 and OHxF 87 had the highest soluble solids and Horner 4 the lowest. OHxF 87 fruit was firmest. 2013 was the ninth season of the 10 year trial; data collection will continue through 2014 and final report completed.

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 have only recently been re-explored. The two OHxF selections currently most offered by major wholesale nurseries are 97 and 87 (333 is generally sold to homeowners). 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

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

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., 2007; Elkins et al., 2008; Elkins and DeJong, 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. California began participating in NC-140 for apples in 1995 and peaches in 2001 and began participating actively in pears in 2005. (The 2012-2017 continuing 5-year proposal was accepted by the North Central Regional Association (NCRA) of State Agricultural Experiment Station Directors.

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 NC-140 trials are currently the only **bearing *replicated*** rootstock trials in California and the Talmage Bartlett trial is the only one planted in 2005 that includes OHxF 69. The ultimate objective of the above trials, as with all NC-140 and other rootstock trials, is to select the best potential available candidates for future increased propagation and industry use. The information they provide will contribute to future nursery and grower planting decisions, particularly for new, high density planting systems. The 2013 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.

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 2005-2013 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. 2010-2013 data also included firmness (kg) and soluble solids (°Brix). In 2013, mid-day stem water potential (MSWP) was measured weekly using a PMS Model 610 Pressure Chamber (PMS

Instrument Company, Albany, OR) to assess water relations potentially related to rootstock. Data was analyzed using ANOVA and means separated using Tukey's HSD.

RESULTS AND DISCUSSION

Results from previous years are available (Elkins, R. 2012, Elkins, R. 2011, Elkins, R. 2010, Elkins, R. and C. Ingels, 2009).

2005 Bartlett Pear Rootstock Planting

2013 results (Tables 2-4)

No trees were lost in 2013. Fruit number increased 17% and tree yield 30%. Fruit size increased 10%, although was below 200 gms. for five of the eight rootstocks. Horner 4 continued to have the most and largest fruit (252 gm. or size 80 fruit, based on a 44 lb. box) and the greatest yield (36.6 kg. or 1.8 boxes/tree). 708-36 had the least yield (13 kg.) and OHxF 69 and OHxF 87 the smallest fruit (170 and 179 gm. respectively). Trees have nearly reached full size; TCSA increased very little, 1.3% from 2012, with Horner 4 being the largest and 708-36 and OHxF 87 the smallest trees. Yield efficiency was 30% higher than 2012 due to higher yields and slightly larger fruit size. Pyrodwarf had the highest yield efficiency and OHxF 69 the lowest. There were no recorded root suckers in 2013. There were significant differences in fruit firmness with OHxF 69 having the firmest fruit and Horner 4 and Pyrodwarf the softest. There were no significant differences in soluble solids.

Water potential relationship to tree vigor and yield (Table 4) – Mid-day stem water potential (MSWP) was measured weekly from May through October in 2013 in order to assess whether and how much water stress might affect vigor and yield (crop load and fruit size), and vica versa. MSWP differed significantly among rootstocks from June through October. Unsurprisingly, Horner 4 was the least water stressed, averaging 9.7 bars over the season and 11.7 in July during the hottest time of the year. BM 2000 was the next least stressed. Pyro 2-33 and surprisingly, the mature Bartlett trees used as a comparison, averaged the most stressed, followed by OHxF 69 and 87, which were the most stressed in mid-July. All 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). 2013 measurements suggest that it will be important to consider the relationship between rootstock and water relations, particularly in high density plantings that might engender more intra-tree competition.

2005-2013 cumulative results (Table 5)

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

Fruit size – Average fruit size has been relatively small, ranging from 160-200 grams. Horner 4 has had the largest fruit thus far (200 grams average), followed by Fox 11 and BM 2000. 708-36, OHxF 69, and OHxF 87 have had the smallest fruit. Fundamentally, however, most of these rootstocks have also been selected for lower vigor and fruit

thinning (not normally practiced in California) and more intensive cultural practices may be required to enable large fruit in some cases in a high density planting with more intra tree competition.

Tree size and vigor – After nine seasons, Horner 4 trees are nearly twice as large as others, followed by BM 2000, Fox 11, OHxF 69, and Pyro 2-33 (these three are the same size), Pyrodwarf, OHxF 87, and lastly, 708-36.

Cumulative yield and yield efficiency – Horner 4 has yielded 70% 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 that some OHxF 69 trees have expressed poor vigor, bark cracking, and dieback of as-yet undefined origin at this location. Low vigor 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). 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 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. 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.

Root suckers – There have been very few root suckers at this location. Only Fox 11 and BM 2000 have had two 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).

2005 'Golden Russet' Bosc Pear Rootstock Planting

2013 results (Tables 6-7)

Overall survival is less than in the Bartlett trial with no changes in 2013. The number of fruit increased by 81% and yield increased by 106% from 2012, reflecting (finally) loss of juvenility, as well as Bosc's tendency to alternate bear. Only fruit size and trunk cross-sectional area (TCSA) differed significantly, although there were trends in yield efficiency and tree height. Overall, fruit size increased 15%. As with Bartlett, Horner 4 had the largest fruit (227 gm. or size 90 box size) and 708-36 and OHxF 87 the smallest (153 and 157 gm. respectively). Horner 4 trees were largest and 708-36 and OHxF 87 the smallest. There were few root suckers. There were significant differences in both firmness and soluble solids, with OHxF 87 having the firmest fruit and Horner 4 the softest. Soluble solids were highest for OHxF 87 and BM 2000 and lowest for Horner 4. These results are unsurprising as Horner 4 fruit are also the largest.

2005-2013 cumulative results (Table 8)

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

Fruit size – There have been no differences among rootstocks, 2013 results suggest, however, that differences among rootstocks are becoming more prominent as crop load increases and trees age. 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, 708-36 and OHxF 87 the smallest, and all others equal. Data suggests that tree vigor is correlated with fruit size and this will be analyzed in 2014 when the trial is completed. MSWP will also be measured for Bosc in 2014, and values compared to Bartlett.

Cumulative yield and yield efficiency – Overall yields have been 40% 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.

Root suckers – There have been no difference among rootstocks.

WORK PLANNED FOR 2014 (Year 10) – 2013 results were presented at the NC-140 meeting in Boise, Idaho and will be summarized for the 2014 ISHS Pear Sumposium in Leuven, Belgium in July 2014. 2014 objectives are to continue to evaluate the existing group of rootstocks for compatibility with Bartlett and Golden Russet Bosc fruit size, vigor, growth habit, productivity, susceptibility to diseases and pests, propensity to sucker, fruit quality, and water stress (Bartlett and Bosc). Efforts were initiated in 2013 to propagate a greater number of Horner 4 trees for wider testing, either by micropropagation or cuttings, and this will continue in 2014 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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LITERATURE CITED (chronological)

Postman, J.D., N.V. Bassil and D. Kim. 2013. OHxF paternity problem perplexes pear producers. *Journal of the American Pomological Society*, 67(3):157-167.

Elkins, R. 2012. Evaluation of potential new size controlling rootstocks for European pear. *2011 California Pear Research Report*, California Pear Advisory Board, p. 104-113.

Elkins, R., R. Bell, and T. Einhorn. 2012. Needs assessment for future U.S. pear rootstock research directions based on the current state of pear production and rootstock research. *Journal of the American Pomological Society*, 66(3):153-163.

Bell, R., R. Elkins and T. Einhorn. 2012. Current state of pear rootstock research: progress and priorities. Abstract. *HortScience* 47(9) (supplement):S100. ASHS, Alexandria, Virginia.

NC-140 Regional Rootstock Project. 2012. Improving Economic and Environmental Sustainability in California Pear Production Through Changes in Rootstock Use. North Central Regional Association, 21 pp. http://www.nc140.org/2012/nc1402012finalproposal.pdf (accessed January 14, 2014).

Reed, B. 2012. Improved micropropagation and rooting of dwarfing pear rootstocks. *2011 California Pear Research Report*, California Pear Advisory Board, pp. 128-140.

Elkins, R. 2011. Evaluation of potential new size controlling rootstocks for European pear. *2010 California Pear Research Report, p*p. 108-116,

Elkins, R.B., S. Castagnoli, C. Embree, R. Parra-Quezada, T.L. Robinson, T.J. Smith and C.A. Ingels. 2011. Evaluation of potential rootstocks to improve pear tree precocity and productivity. *Acta Hort* 909:183-194.

Elkins, R.B. and T.M. DeJong. 2011. Performance of 'Golden Russet Bosc' on five training systems and nine rootstocks. *Acta Hort* 903:689-694.

Elkins, R. and C. Ingels. 2010. Evaluation of potential new size controlling rootstocks for European pear. *2009 California Pear Research Report, p*p. 149-156.

Elkins, R. and C. Ingels. 2009. Evaluation of potential new size controlling rootstocks for European pear (NC140 Project). *2008 California Pear Research Report,* California Pear Advisory Board, pp. 83-90.

Elkins, R.B., K. Klonsky, R. DeMoura and T.M. DeJong. 2008. Economic evaluation of high density versus standard orchard configurations; case study using performance data for 'Golden Russet Bosc' pears. *Acta Hort* 800:739-746.

Elkins, R.B., K. Klonsky and R. DeMoura. Revised 2007. Sample Costs to Establish and Produce Specialty Pears; High Density Planting with Standard Trees, North Coast Region – Lake and Mendocino Counties. PR-NC-06-3-R. Univ. of Calif. Coop. Ext. *http://coststudies.ucdavis.edu/files/pearnc063r.pdf* (accessed December 17, 2009).

Shackel, K.A. 2007. Water Relations. In: Mitcham, E.J. and R.B. Elkins (eds). Pear Production and Handling Manual. Oakland: University of California Agriculture and Natural Resources Publication 3483, pp. 97-100.

Auvil, T. 2005. Pear rootstock and deficit irrigation trial. Northwest Pear Research Review 2005, p.8. http://jenny.tfrec.wsu.edu/wtfrc/PDFfinalReports/2005FinalReports/Pear/WTFRCCashmere2005.pdf. (accessed December 21, 2011).

Elkins, R.B. and T.M. DeJong. 2002. Effect of training system and rootstock on growth and productivity of 'Golden Russet® Bosc' pear trees. *Acta Hort* 596:603-606.

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 of Lake.
[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 8-year-old (9th leaf) 'Bartlett' pear trees, Talmage, Mendocino County, California, 2013.

	Tree Survival 8/19/13 (%/10 trees)	No. Fruit 8/19/13 (no./tree)	Fruit Size 8/19/13 (g/fruit)	Yield 8/19/13 (kg/tree)	TCSA 10/21/13 (cm^2)	Yield Efficiency 10/21/13 (kg/cm^2)	Tree Height 10/21/13 (cm)	Root Suckers[3] 10/21/13 (no./tree)	Average Box Size 8/19/13 (44 lb. box)	Average No. boxes 8/19/13 (per tree)
ROOTSTOCK[1]										
708-36	90	75 b	185 cd	13.0 c	20.6 d	0.56 ab	219 b	~	110 bcd	0.6 c
BM 2000	100	112 ab	225 ab	24.8 b	40.2 b	0.63 ab	243 ab	~	90 ab	1.2 b
Horner 4	100	148 a	252 a	36.6 a	59.7 a	0.62 ab	249 a	~	80 a	1.8 a
Fox 11	80	77 b	220 abc	16.7 bc	33.4 bc	0.52 ab	236 ab	~	90 ab	0.8 bc
OHxF 69	90	101 ab	170 d	17.1 bc	32.8 bc	0.51 b	225 ab	~	120 c	0.9 bc
OHxF 87	100	92 b	179 d	15.8 bc	25.9 cd	0.61 ab	226 ab	~	120 c	0.8 bc
Pyrodwarf	90	124 ab	191 bcd	23.6 b	29.1 cd	0.81 a	228 ab	~	110 bc	1.2 b
Pyro 2-33	70	116 ab	192 bcd	22.0 bc	32.2 bc	0.67 ab	234 ab	~	110 bc	1.1 bc
ANOVA[2]										
Rootstock	~	** (<0.003)	** (<0.001)	*** (<0.001)	*** (<0.001	NS (0.06)	* (0.03)	~	(<0.001)	(<0.001)
Block	~	NS (0.20)	NS (0.90)	NS (0.18)	NS (0.10)	NS (0.40)	NS (0.25)	~	NS (0.97)	NS (0.18)

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

Table 3. Effects of 2005 NC-140 rootstock planting on firmness and soluble solids among 8-year-old (9th leaf) 'Bartlett' pear trees, Talmage, Mendocino County, California, 2013.

	Firmness 8/19/13 (kg of force)	Soluble Solids 8/19/13 (ºBrix)
ROOTSTOCK[1]		
708-36	7.9 ab	13.4
BM 2000	7.6 ab	12.9
Horner 4	7.2 b	12.6
Fox 11	7.7 ab	13.5
OHxF 69	8.2 a	13.0
OHxF 87	7.4 ab	13.2
Pyrodwarf	7.2 b	13.2
Pyro 2-33	7.2 ab	13.3
ANOVA[2]		
Rootstock	* (0.04)	NS (0.65)
Block	NS(0.42)	NS (0.82)

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, P≤0.1).
[2] * Indicates significance at P≤0.05. NS indicates not significant.

Table 4: Comparison of monthly mid-day stem water potential (MSWP), baseline -6 - 8 (bars) among 8-year-old (9th leaf) Bartlett pear trees, Ruddick Ranch, Talmage, Mendocino County, California, 2013

	5/22[4]	6/19	7/18	8/14	9/18	10/16	Average
ROOTSTOCK[1]							
708-36	11.6	10.7 bc	15.9 bc	14.4 ab	11.5 ab	6.8 a	11.9
BM 2000	9.1	9.3 ab	12.3 ab	14.5 ab	10.3 ab	7.3 a	10.2
Horner 4	8.1	8.4 a	11.7 a	13.4 a	9.8 a	6.9 a	9.7
Fox 11	9.5	10.3 bc	14.6 abc	15.7 ab	11.1 ab	7.9 ab	11.6
OHxF 69	9.4	11.3 c	17.4 c	17.6 b	10.7 ab	8.2 ab	12.3
OHxF 87	10.3	10.0 bc	17.4 c	16.7 ab	9.8 a	8.4 ab	12.0
Pyrodwarf	10.4	10.6 bc	14.0 abc	17.2 ab	9.1 a	7.0 a	11.3
Pyro 2-33	10.8	11.2 c	16.5 c	18.0 b	13.0 b	9.3 b	13.1
Big Trees[3]	~	10.0	15.6	13.6	12.5	10.6	12.7
Baseline	**6.4**	**6.7**	**7.5**	**7.8**	**7.0**	**6.9**	**7.1**
ANOVA[2]							
Rootstock	NS (0.28)	*** (<0.001)	*** (<0.001)	*** (<0.001)	** (0.01)	** (0.01)	
Block	NS (0.56)	** (0.01)	**(<0.01)	NS (0.10)	* (0.03)	NS (0.24)	

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, P≤0.05).
(Duncan multiple range test, P≤0.05, for 10/16 pressure bomb data.)
[2] **, *** Indicate significance at P<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 8-year-old (9th leaf) Bartlett pear trees, Talmage, Mendocino County, California, 2005-2013.

	Tree Survival (%)	Average Fruit Size[3] (g)	Average Cumulative Yield (kg/tree)	2013 TCSA (cm^2)	Average Cumulative Yield Efficiency[4] (kg/cm^2)	Root Suckers[3] (Cum. No/tree)	Average Box Size (44 lb. box)	Average No. of boxes (per tree)
ROOTSTOCK[1]								
708-36	90	160 d	49.1 c	20.6 d	2.41 ab	0.3 ab	120 d	2.4 c
BM 2000	100	182 abc	89.3 b	40.2 b	2.25 ab	2.7 ab	110 abc	4.5 b
Horner 4	100	200 a	151.0 a	59.7 a	2.55 ab	0.2 ab	100 a	7.6 a
Fox 11	80	185 ab	72.2 bc	33.4 bc	2.22 ab	3.1 a	110 abc	3.6 bc
OHxF 69	90	160 d	66.4 bc	32.8 bc	1.99 b	1.9 ab	120 d	3.3 bc
OHxF 87	100	164 cd	67.0 bc	25.9 cd	2.60 ab	0.3 ab	120 cd	3.3 bc
Pyrodwarf	90	167 bcd	85.1 b	29.1 cd	2.93 a	0.0 b	120 bcd	4.3 b
Pyro 2-33	70	186 ab	76.3 bc	32.2 bc	2.36 ab	0.0 b	110 ab	3.8 bc
ANOVA[2]								
Rootstock	NS (0.28)	*** (<0.001)	*** (<0.001)	*** (<0.001)	** (0.01)	** (0.01)	*** (<0.001)	*** (<0.001)
Block	NS (0.56)	** (0.01)	**(<0.01)	NS (0.10)	* (0.03)	NS (0.24)	* (0.03)	** (<0.01)

[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.

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

[3] Based on cumulative yield (2005-13) and final TCSA (2013).

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 8-year-old (9th leaf) 'Golden Russet' Bosc pear trees, Talmage, Mendocino County, California, 2013.

	Tree Survival 9/4/13 (%/10 trees)	No. Fruit 9/4/13 (no./tree)	Fruit Size 9/4/13 (g/fruit)	Yield 9/4/13 (kg/tree)	TCSA 10/21/13 (cm^2)	Yield Efficiency 10/21/13 kg/cm^2)	Tree Height 10/21/13 (cm)	Root Suckers[3] 10/21/13 (no./tree)	Average Box Size 9/4/13 (44 lb. box)	Average No. Boxes (per tree)
ROOTSTOCK[1]										
708-36	80	112 ab	153 c	16.9	34.7 b	0.43 ab	240	0.1	135 c	0.8
BM 2000	70	61 b	215 ab	13.2	51.1 ab	0.28 b	240	0.1	100 ab	0.7
Horner 4	100	85 ab	227 a	18.4	68.6 a	0.27 b	240	0.0	90 a	0.9
Fox 11	60	68 b	216 ab	15.2	57.5 ab	0.27 b	241	0.1	90 ab	0.8
OHxF 87	80	114 ab	157 c	17.9	40.3 b	0.41 ab	235	0.0	135 c	0.9
Pyrodwarf	90	129 a	177 bc	22.7	50.1 ab	0.46 a	237	0.1	110 bc	1.1
Pyro 2-33	80	88 ab	192 abc	16.6	48.6 ab	0.35 ab	246	0.0	110 abc	0.8
ANOVA[2]										
Rootstock	NS (0.41)	NS (0.16)	***(<0.001)	NS (0.58)	***(0.001)	NS (0.09)	NS (0.11)	NS (0.75)	***(<0.001)	NS (0.58)
Block	NS (0.43)	NS (0.16)	*(0.02)	NS (0.32)	*(0.04)	NS (0.14)	NS (0.32)	NS (0.23)	NS (0.06)	NS (0.33)

[1] Within columns, rootstock treatment means significantly different (Tukey HSD test, $P \leq 0.05$); no. of fruit and yield efficiency means by Duncan Multiple Range Test, $P \leq 0.05$.
[2] *, *** Indicate significance at $P \leq 0.05$ 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).

Table 7. Effects of 2005 NC-140 rootstock planting on firmness and soluble solids among 8-year-old (9th leaf) 'Golden Russet' Bosc pear trees, Talmage, Mendocino County, California, 2013

	Firmness 9/11/13 (kg of force)	Soluble Solids 9/11/13 (ºBrix)
ROOTSTOCK[1]		
708-36	8.6 ab	15.2 ab
BM 2000	7.5 ab	15.5 a
Horner 4	7.0 b	13.7 b
Fox 11	7.1 ab	13.9 ab
OHxF 87	8.7 a	15.6 a
Pyrodwarf	7.3 ab	14.8 ab
Pyro 2-33	7.0 b	14.9 ab
ANOVA[2]		
Rootstock	* (0.03)	** (0.01)
Block	NS (0.40)	** (<0.01)

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

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

Table 8. 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 8-year-old (9th leaf) 'Golden Russet' Bosc pear trees, Talmage, Mendocino County, California, 2005-2013.

	Tree Survival (%/10 trees)	Average Fruit Size[3] (g/fruit)	Average Cumulative Yield (kg)	2013 TCSA (cm^2)	Average Cumulative Yield Efficiency[4] (kg/cm^2)	Root Suckers[5] (cum.no./tree)	Average Box Size (44 lb. box)	Average No. of Boxes (per tree)
ROOTSTOCK[1]								
708-36	80	150	42.8	34.7 b	1.16	0.5	135	2.1
BM 2000	70	154	30.5	51.1 ab	0.61	1.4	135	1.5
Horner 4	100	179	37.9	68.6 a	0.67	1.5	110	1.9
Fox 11	60	166	38.0	57.5 ab	0.77	0.4	120	1.9
OHxF 87	80	168	50.2	40.3 b	1.20	0.1	120	2.5
Pyrodwarf	90	173	45.5	50.1 ab	0.92	0.1	120	2.3
Pyro 2-33	80	155	34.6	48.6 ab	0.68	0.0	135	1.7
ANOVA[2]								
Rootstock	NS (0.41)	NS (0.25)	NS (0.21)	** (0.001)	NS (0.30)	NS (0.53)	NS (0.40)	NS (0.52)
Block	NS (0.43)	NS (0.08)	NS (0.71)	* (0.04)	NS (0.60)	NS (0.69)	NS (0.52)	NS (0.33)

[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.

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

[3] Based on cumulative yield (2005-13) and final TCSA (2013).