Journal of the American Pomological Society 74(1): 45-56 2020

Nine-Year Rootstock Performance of the NC-1 40 'Redhaven' Peach Trial across 13 states

G. Reighard[1], W. Bridges, jr.[1], D. Archbold[2], A. Atucha[3], W. Autio[4], T. Beckman[5], B. Black[6], D.J. Chavez[7], E. Coneva[8], K. Day[9], P. Francescatto[10], M. Kushad[11], R.S. Johnson[9], T. Lindstrom[6], J. Lordan[10], I.S. Minas[12], D. Ouellette[1], M Parker[13], R. Pokharel[14], T. Robinson[10], J. Schupp[15], M. Warmund[16], and D. Wolfe[2]

Additional index words: *Prunus persica* L., interspecific hybrids, plum, almond, *Pseudomonas syringae*

Abstract

Prunus rootstocks (13 to 18) budded with 'Redhaven' peach [*Prunus persica* (L.) Batsch] were planted at 16 locations in North America in 2009 and evaluated for nine years at all but 3 sites. Significant differences among rootstocks and sites were found for survival, root suckers, tree growth, flowering date, fruit maturity date, fruit size, cumulative yield, and yield efficiency at the remaining 13 locations in 12 states in 2017. Survival was highest for the four peach seedling rootstocks. In contrast, survival of non-peach species and hybrid rootstocks was poor to fair in Missouri (cold injury, wet feet conditions), Illinois (unknown), and in Alabama, Georgia, North Carolina, and South Carolina due to bacterial canker disease (*Pseudomonas syringae*). Rootstocks 'Krymsk® 1', 'Krymsk® 86', 'Empyrean® 2', 'Empyrean® 3', 'Controller™ 5', 'Imperial California', and 'Rootpac® R' were the most susceptible to tree death from bacterial canker in the four southeastern states. 'Fortuna' exhibited incompatibility symptoms and had very high mortality at most locations. Overall, 'Imperial California' and 'Fortuna' had the lowest survival. Rootstock suckering was excessive on *Prunus americana* seedlings, with lesser suckering noted on 'Rootpac® R', 'Krymsk® 1', 'Empyrean® 2', 'Empyrean® 3' and Guardian®. Largest trees were on *Prunus* hybrids 'Viking', 'Atlas', 'Bright's Hybrid #5' and 'Krymsk® 86', and peach seedlings Guardian® and Lovell. Fruit size varied with location and crop load (i.e., some rootstocks had few fruit). 'Atlas', 'Bright's Hybrid #5' and Guardian® produced the largest fruit across locations though all but three rootstocks produced adequate or excellent size. 'Controller™ 7' and 'Imperial California' produced slightly smaller fruit on average while 'Fortuna' had the smallest fruit across all sites. Fruit weight varied significantly among locations. South Carolina and Utah grew the largest fruit; whereas New York and Georgia recorded the smallest fruit. Cumulative yields were highest for the peach seedling rootstocks Guardian®, Lovell, KV010127, and hybrids 'Atlas' and 'Viking'. The lowest yields were from trees on plum hybrids and plum species. Cumulative yield efficiency after 9 years was highest on clonal peach rootstocks 'Controller™ 7' and 'Controller™ 8' and the plums 'Krymsk® 1' and *P. americana*. These data suggest that there was no demonstrated advantage to increase yield/ha by using clonal interspecific *Prunus* hybrids for peach production under current cultural practices, but the potential to increase productivity per ha exists with higher planting densities. Moreover, on high pH soils in Colorado and Utah, peach seedlings were not the superior rootstocks for production, so continuing evaluation of non-peach rootstocks is warranted.

[1] Clemson University, 161 Poole Ag Center, Clemson, South Carolina 29634
[2] University of Kentucky, 1205 Hopkinsville St., Princeton, Kentucky 42445
[3] University of Wisconsin, 1575 Linden Drive, Madison, Wisconsin 53706
[4] University of Massachusetts, 161 Holdsworth Way, Amherst, Massachusetts 01003
[5] USDA-ARS, 21 Dunbar Road, Byron, Georgia 31008
[6] Utah State University, 4820 Old Main Hill, Logan, Utah 84322
[7] University of Georgia, 1109 Experiment Street, Griffin, Georgia 30223
[8] Auburn University, 101 Funchess Hall, Auburn, Alabama 36849
[9] University of California Davis, 9240 S. Riverbend Ave., Parlier, California 93648
[10] Cornell University, 118 Hedrick Hall, Geneva, New York 14456
[11] University of Illinois, 1201 S. Dorner Drive, Urbana, Illinois 61801
[12] Colorado State University, 215 Shepardson, Fort Collins, Colorado 80523
[13] North Carolina State University, Box 7609, Raleigh, North Carolina 27695
[14] Maryland Dept. Agriculture, 50 Harry S. Truman Parkway, Annapolis, Maryland 21401
[15] Penn State University, P.O. Box 330, Biglerville, Pennsylvania 17307
[16] University of Missouri, 1-31 Agriculture Bldg., Columbia, Missouri 65211

Prunus interspecific hybrids and plum species have become the primary focus of private and public rootstock breeding programs in Europe and North and South America. New interspecific rootstock cultivars have replaced peach seedlings as preferred rootstocks for peach cultivars in Europe and are becoming more important in some areas of North and South America. Peach is partially to completely graft compatible with several species within its taxonomic Section *Euamygdalus* Schne *Microcerasus*. When breeding new rootstocks for peach from intra- and interspecific crosses, field-testing of budded peach scion cultivars to ascertain good graft compatibility for tree nutrition, growth, fruit quality, and survival under normal orchard conditions is necessary before commercialization (Zarrouk et al., 2006; Reighard and Loreti, 2008; DeJong et al., 2014). In addition, evaluation of adaptation or tolerance to different soils, climates, pests, and diseases is also important.

Peach has been budded with many species from Section *Euprunus*. Compatibility has been good with some rootstock selections from *P. insititia* L. (damson plum), *P. spinosa* L. (sloe plum), *P. domestica* L. (European plum), *P. salicina* Lindl. (Japanese plum), and *P. cerasifera* Ehrh. (myrobalan or cherry plum). Myrobalan plums are often more compatible when they are first hybridized with other plums. Several early examples were commercially available selections of *P. americana* Marshall, *P. insititia* ('Adesoto 101'), *P. domestica* ('Damas C'), and *P. pumila* L. ('Pumiselect®') that were mostly to completely compatible with peach cultivars, but tended to be dwarfing, sucker prone and/or less productive.

The objective of this study was to evaluate the compatibility and performance of newly

Table 1. State locations for the 2009 NC-140 peach rootstock trial.

State	Location	Cooperator
Alabama	Clanton	Auburn University
California	Parlier	Univ. of California at Davis
Colorado	Grand Junction	Colorado State University
Georgia	Byron	University of Georgia, USDA
Illinois	Champaign	University of Illinois
Kentucky	Princeton	University of Kentucky
Massachusetts	Belchertown	University of Massachusetts
Missouri	New Franklin	University of Missouri
New York	Geneva	Cornell University
North Carolina	Jackson Springs	North Carolina University
Pennsylvania	Biglerville	Penn State University
South Carolina	Seneca	Clemson University
Utah	Kaysville	Utah State University
Utah	West Payson	Utah State University

commercialized *Prunus sp.* rootstocks for peach using 'Redhaven' as the scion cultivar at multiple peach growing locations throughout North America as part of the NC-140 Regional Project.

Materials and Methods

'Redhaven' peach was grafted to a total of 18 rootstocks and planted in 16 replicated orchard trials across the USA (13 states) and in Mexico (Chihuahua) (Table 1). These trials were planted in 2009 in the following states: Alabama, California, Colorado, Georgia, Illinois, Kentucky, Massachusetts, Missouri, New York (2 sites), North Carolina, Pennsylvania, South Carolina, and Utah (2 sites). No initial data were provided by Mexico and one New York location and these were dropped from the study. Data collection was discontinued from California in 2013 and Alabama and Missouri in 2016. The rootstock cultivars included eight interspecific *Prunus* hybrids and three *Prunus* species with semi-dwarfing rootstocks estimated to be 10-30% smaller and dwarfing rootstocks >30% smaller than Lovell peach rootstock in trunk cross-sectional area (Table 2).

Each trial was planted as a randomized

Table 2. Rootstock cultivars in the 2009 NC-140 trial and their reported species composition and tree size relative to peach seedling Lovell.

Rootstock cultivar	Country origin	Species	Tree size (% of Lovell)[z]
Lovell	U.S.A.	*Prunus persica*	100
Guardian®	U.S.A.	*P. persica*	110
KV-010123	U.S.A.	*P. persica*	100
KV-010127	U.S.A.	*P. persica*	100
Controller™ 8 (HBOK 10)	U.S.A.	*P. persica*	90
Controller™ 7 (HBOK 32)	U.S.A.	*P. persica*	80
Bright's Hybrid #5 (BH-5)	U.S.A.	*P. dulcis x P. persica*	110
Prunus americana	U.S.A.	*P. americana*	60
Empyrean® 2 (Penta)	Italy	*P. domestica*	80
Empyrean® 3 (Tetra)	Italy	*P. domestica*	70
Imperial California	Italy	*P. domestica*	70
Rootpac® R (Replantpac)	Spain	*P. cerasifera x P. dulcis*	110
Fortuna	Russia	*P. cerasifera x P. persica*	70
Krymsk® 86 (Kuban 86)	Russia	*P. cerasifera x P. persica*	100
Krymsk® 1 (VVA-1)	Russia	*P. tomentosa x P. cerasifera*	50
Controller™ 5 (K146-43)	U.S.A.	*P. salicina x P. persica*	60
Viking	U.S.A.	*P. persica x (P. dulcis x (P. cerasifera x P. mume))*	110
Atlas	U.S.A.	*P. persica x (P. dulcis x (P. cerasifera x P. mume))*	120

[z] Tree size compared to Lovell is an estimate based on published rootstock trials and personal observations by the senior author.

complete-block design with eight replicates of single-tree plots of each rootstock. Some rootstocks, such as 'Empyrean® 3', 'Imperial California' and 'Fortuna', were either only planted at a few sites and/or had high early mortality, and thus there were significant missing data for these rootstocks. Orchards received standard cultural practices for each location and were irrigated according to local conditions. Thinning and optimum crop load was determined by each cooperator for their location. Annual survival, tree circumference (TC), root sucker counts (up to 20/tree), 90% bloom date, 10% maturity date, yield/tree and mean fruit weight were recorded. Tree width (parallel plus perpendicular row widths divided by 2) was also recorded in October 2017. Trunk cross-sectional area (TCA) was calculated from the 2017 TC. To measure long-term productivity, cumulative yield efficiency (total fruit yield in kg per tree divided by final trunk cross-sectional area in cm^2) was calculated.

A statistical model was developed that related the response variables of interest to the effect of rootstock while adjusting for the additional random effects of locations, replications within locations, and rootstock and location interactions. Analyses of variance (ANOVA) techniques were used to statistically test the effects. When a significant effect of rootstock was detected, least-square means among rootstocks were separated by Tukey's Studentized range test (HSD), $P < 0.05$. Three different versions of the model were actually analyzed. For the first analysis, all rootstocks were included to provide an overall comparison of the rootstock performance. The second analysis only included rootstocks (total of 13) that were common to all locations. This analysis is not presented, but was used to confirm the comparisons of the rootstocks and provide the best test of the rootstock and location interaction (which was significant for all variables). The third analysis was by location (the model only included rootstocks and replications). This analysis was used to determine any rootstocks that performed very differently across the locations. These differences in performance across locations added to the discussion of the overall performance of rootstocks. All statistical computations were preformed using PROC MIXED (SAS, Cary, NC), and statistical significance was based on $P < 0.05$.

Results and Discussion

Nine-year survival, TC, tree height, and average tree width in October 2017 for 'Redhaven' on each rootstock are given in Table 3. Rootstocks with poor or below average survival and performance were 'Empyrean® 3' (unknown), 'Imperial California' (bacterial canker from *Pseudomonas syringae*), 'Fortuna' (graft incompatibility), and Krymsk®1 (bacterial canker). All other rootstocks had scion survival rates of 69 to 93% for those planted at multiple sites. Survival was lowest in North Carolina, Georgia, and Alabama all primarily due to bacterial canker, and Missouri (waterlogging, wind damage) and Illinois (unknown) (Tables 4, 5).

Tree growth was significantly influenced by rootstock and location (Tables 3, 4, 6). Peach seedlings, peach-almond hybrids, and 'Krymsk® 86' were the most vigorous rootstocks for trees having fair to excellent survival (>66% alive). 'Empyrean® 2', 'Controller™ 8', and 'Controller™ 7' were semi-dwarfing rootstocks (70-75% TCA of Lovell), while *P. americana*, 'Krymsk® 1', and 'Controller™ 5' were dwarfing rootstocks that were <60% the TCA of Lovell. The largest trees were in California after 5 years before that trial was prematurely removed (Reighard et al., 2018). After 9 years, South Carolina and Alabama had the largest trees; whereas, the smallest trees were in Colorado and the West Payson planting in Utah, where both sites had high pH soils (8.3-8.5) and the highest elevations (~1450 m). *P. americana* seedling rootstock produced significantly more root suckers (> 8/tree) with lesser suckering (< 3/tree) noted on Guardian®, 'Empyrean® 2', 'Empyrean® 3',

Table 3. Mean survival trunk cross-sectional area and tree canopy size of nine-year-old 'Redhaven' peach trees on each rootstock across 13 locations.

Rootstock cultivar	Survival[z] (%) Oct. 2017		Trunk cross-sectional area (cm^2) Oct. 2017		Tree height (m) Oct. 2017		Mean tree width (m) Oct. 2017	
Viking	74	a	229	a	3.37	ab	4.89	ab
Atlas	72	ab	229	a	3.47	a	5.12	a
Bright's Hybrid #5	67	ab	221	a	3.38	ab	5.03	ab
Rootpac® R	80	a	218	a	3.23	ab	4.58	bcd
Guardian®	93	a	231	a	3.38	a	4.93	ab
Lovell	91	a	225	a	3.37	ab	4.83	abc
KV-010123	91	a	197	abc	3.26	ab	4.78	abc
KV-010127	90	a	209	ab	3.43	a	4.90	ab
Krymsk® 86	78	a	225	a	3.35	ab	4.76	abc
Empyrean® 2	70	ab	162	bcd	3.16	abc	4.36	cdef
Empyrean® 3	26	c	108	de	2.70	de	3.22	g
Imperial California	26	c	202	abc	3.23	abc	4.51	bcde
Controller™ 8	82	a	157	cd	3.08	bcd	4.42	cde
Controller™ 7	69	ab	167	bcd	3.29	ab	4.61	bcd
Prunus americana	72	ab	130	de	2.78	d	4.10	ef
Fortuna	26	c	170	abcd	2.67	de	3.67	fg
Krymsk®1	44	bc	98	e	2.36	e	3.47	g
Controller™ 5	69	ab	134	de	2.88	cd	4.18	def

[z] LS means separation within columns by Tukey's HSD (P=0.05)

'Rootpac® R', and 'Krymsk® 1' rootstocks (data not presented).

Bloom date was only recorded at 10 locations (Table 4), but was affected little by rootstock (< 1.5 days among all rootstocks except for 3.5 days later for semi-incompatible 'Fortuna') (data not shown). As expected, bloom dates were significantly different between locations, with a mean difference of 39 days between South Carolina and New York (Table 4). There were also large differences within and between years for bloom date. In the first 5 years, flower phenology varied as much as 24 to 64 days within a year among locations and as much as 35 days between years for New York (Reighard et al., 2018). Therefore, climate not genetics was the important factor affecting 'Redhaven' bloom date.

Rootstock cultivar significantly influenced

Table 4. Mean survival, trunk cross-sectional area, tree canopy size and bloom date of 'Redhaven' peach trees on 13 rootstocks common to the 13 locations.

Location	Survival (%)[z] Oct.2017		Trunk cross-sectional area (cm^2) Oct. 2017[y]		Tree height (m)[x] Oct. 2017		Mean tree width (m) Oct. 2017		Full bloom (days post Jan. 1) 2011-2017	
New York-Geneva	90	ab	238	abc	3.83	a	4.93	c	116.6	a
Kentucky	85	ab	168	def	3.67	a	5.05	bc	90.5	d
North Carolina	66	abc	137	fg	2.99	b	3.48	f	83.0	e
Alabama	48	c	271	ab	3.05	b	5.45	a	80.2	f
South Carolina	79	ab	284	a	3.73	a	5.84	a	77.5	g
Georgia	62	bc	223	bc	2.88	b	5.02	bc	79.9	f
Massachusetts	95	a	200	cde	2.73	b	4.38	d	NA	--
Utah-Kaysville	91	a	159	ef	3.88	a	4.85	c	93.4	c
Utah-West Payson	83	ab	87	g	3.04	b	3.73	ef	NA	--
Colorado	79	ab	90	g	2.96	b	4.05	de	89.6	d
Pennsylvania	86	ab	221	bcd	2.97	b	4.99	bc	NA	--
Illinois	70	abc	228	bc	2.93	b	4.07	de	98.1	b
Missouri	68	abc	233	abc	NA	--	NA	--	94.4	c

[z] LS means separation within columns by Tukey's HSD (P=0.05).
[y] Alabama and Missouri ended data collection in Fall 2016.
[x] NA=data were not recorded at a location.

cumulative yields and fruit weight (Table 7). Generally, vigorous rootstocks had high yields, and low vigor rootstocks had low yields. Not unexpected, four high vigor rootstocks 'Viking', 'Bright's Hybrid #5', 'Rootpac® R', and 'Krymsk® 86' had lower cumulative yield efficiencies. Most semi-dwarf and dwarfing rootstocks were equal to or better than the peach seedling rootstocks in yield efficiency with 'Controller™ 7', 'Controller™ 8', 'Krymsk® 1' and *P. americana* being the most efficient. Yields were also significantly different across locations (Tables 8 and 9). South Carolina and Missouri had the highest cumulative yields. Colorado had the lowest yields partly due to cold damage and high pH soil (pH=8.3). Though some rootstocks produced large yields per tree (e.g., 'Viking' and 'Atlas') they also had higher mortality at some sites (e.g., Alabama and Missouri) so survival needs to be weighed when assessing productivity for each rootstock at each location (Tables 5 and 9). Cumulative yield efficiency was highest in South Carolina, Utah, and Missouri, which were also statistically higher than all of the other locations with the lowest ranking states being Alabama, Georgia, Illinois, and Massachusetts (Table 8). This calculated measure of yield efficiency when greater than 1.4 was

Table 5. Percent survival for each rootstock at each location in 2017.

	Trial locations												
Rootstock	AL^{zy}	CO	GA	IL	KY	MA	MO	NC	NY	PA	SC	UTK	UTP
Viking	38	50	50	100	75	100	38	88	100	75	75	88	88
Atlas	25	75	50	63	100	100	13	88	100	88	63	88	88
BH #5	63	63	63	38	50	100	38	75	63	88	50	88	100
Rootpac® R	0	88	75	75	100	100	100	13	100	100	88	100	100
Guardian®	88	75	100	88	100	100	88	100	86	100	100	100	88
Lovell	88	88	88	88	100	100	75	75	100	100	100	100	88
KV-010123	88	75	75	88	88	88	88	100	100	100	100	100	100
KV-010127	75	88	75	88	100	100	75	100	83	100	100	100	88
Krymsk®86	25	75	63	63	100	100	88	25	100	88	88	100	100
Empyrean® 2	13	88	38	---	---	100	66	13	100	88	63	100	100
Empyrean® 3	---	---	---	---	---	---	---	---	---	---	25	---	---
Imperial CA	---	88	0	---	---	---	---	0	33	0	0	75	---
Controller™8	38	88	75	50	100	100	63	75	100	100	88	88	100
Controller™7	13	88	25	75	88	100	50	88	100	88	88	100	0
P. americana	---	88	0	88	75	88	---	63	100	75	75	88	100
Fortuna	---	38	---	---	---	---	---	13	29	63	0	---	---
Krymsk®1	0	88	0	25	25	88	63	13	63	13	25	75	100
Controller™5	13	88	38	50	100	100	88	0	100	100	75	100	50

[z] Locations are represented by the state abbreviations except for UTK and UTP which represent Kaysville, Utah and West Payson, Utah, respectively.
[y] Missing rootstocks at a location listed as ---.

positively associated with locations (except one) that had consistently high yields, which might be partly attributed to a favorable environment for peach trees and/or timely horticultural practices.

Fruit weight was affected by both rootstock and location (Tables 7 and 8). Only three rootstocks, 'Controller™7', 'Imperial California' and 'Fortuna', produced fruit significantly smaller (Table 7). However, location had a very large effect on fruit size. South Carolina (198 g) and one Utah site (Kaysville, 204 g) consistently produced the largest fruit (Table 8), though the Kaysville site produced about half the cumulative yield as South Carolina. New York (146 g) and

Table 6. Mean trunk cross-sectional area (TCA) in cm² for each rootstock at each location in 2017.

	Trial locations												
Rootstock	AL[zyx]	CO	GA	IL	KY	MA	MO	NC	NY	PA	SC	UTK	UTP
Viking	336	115	232	224	192	222	319	176	252	266	341	215	109
Atlas	330	134	261	225	178	228	189	158	308	276	345	176	124
BH #5	309	125	208	242	165	202	248	173	279	224	321	207	156
Rootpac®R	---	64	299	258	211	205	279	189	229	212	409	105	114
Guardian®	390	119	261	234	209	275	242	176	277	223	331	180	80
Lovell	299	87	245	337	188	239	235	184	312	254	304	185	66
KV-010123	293	70	225	234	172	210	249	146	188	247	316	160	58
KV-010127	266	95	252	259	185	220	242	148	222	256	318	178	78
Krymsk®86	211	90	289	282	184	229	296	148	304	251	305	191	99
Empyrean®2	---	79	149	---	---	203	200	84	200	184	173	150	104
Empyrean®3	---	---	---	---	---	---	---	---	---	---	186	---	---
Imperial CA	---	106	---	---	---	---	---	---	219	---	---	179	---
Controller™8	186	66	117	167	149	193	219	85	232	180	240	155	47
Controller™7	179	83	183	232	150	191	202	87	246	195	176	146	---
P. americana	---	49	---	133	104	113	---	72	198	162	158	105	70
Fortuna	---	70	---	---	---	---	---	122	240	178	---	---	---
Krymsk®1	---	35	---	151	68	100	80	32	145	110	75	76	58
Controller™5	229	43	225	129	124	92	220	---	111	177	199	86	51

[z] Locations are represented by the state abbreviations except for UTK and UTP which represent Kaysville, Utah and West Payson, Utah, respectively.
[y] Rootstocks missing or having 100% mortality have data listed as ---.
[x] 0 data for AL and MO were from 2016.

Georgia (140 g) had the smallest fruit. These differences among locations could be partially attributed to local climate (e.g., shorter growing season) or soil conditions (e.g., high pH) and also to cultural management such as timing of thinning and irrigation frequency.

Excluding three plum/plum hybrid rootstocks ('Empyrean® 3', 'Imperial California', and 'Fortuna') with limited representation, ripening date was advanced by some plum and plum hybrid rootstocks (e.g., 'Krymsk® 1', 'Controller™ 5', and *P. americana*) as much as 3 days on average in some years when compared to Lovell (data not

Table 7. Mean canopy size, fruit weight, cumulative yield and cumulative yield efficiency of 'Redhaven' peach trees on each rootstock across 13 locations.

Rootstock cultivar	Mean fruit wt.[zyx] (g) (2011-2017)		Cumulative yield (kg)/tree (live + dead)[w] (2011-2017)		Cumulative yield (kg)/tree (live trees)[v] (2011-2017)		Cumulative yield efficiency (kg/cm^2) (2011-2017)	
Viking	176.4	ab	180	abcd	208	ab	0.92	bcd
Atlas	180.7	a	176	abcd	214	a	0.99	abcd
Bright's Hybrid #5	179.8	a	144	abcde	177	abc	0.82	d
Rootpac® R	172.4	ab	167	abcd	187	abc	0.91	bcd
Guardian®	178.0	a	209	a	213	a	0.99	abcd
Lovell	172.5	ab	209	a	214	a	1.04	abcd
KV-010123	176.5	ab	190	abc	195	abc	1.04	abcd
KV-010127	172.6	ab	205	ab	211	ab	1.04	abcd
Krymsk® 86	175.0	ab	178	abcd	192	abc	0.89	cd
Empyrean® 2	176.1	ab	129	bcdef	148	cd	0.96	abcd
Empyrean® 3	180.3	a	--		--		--	
Imperial California	162.7	bc	37	f	141	cd	0.66	d
Controller™ 8	174.3	ab	165	abcd	176	abc	1.18	a
Controller™ 7	166.6	b	156	abcd	182	abc	1.15	ab
Prunus americana	171.9	ab	120	cdef	141	cd	1.15	abc
Fortuna	148.8	c	47	f	128	cd	0.76	d
Krymsk® 1	171.5	ab	66	f	90	d	1.13	abc
Controller™ 5	170.2	ab	108	def	123	d	1.02	abcd

[z] LS means separation within columns by Tukey's HSD (P=0.05).
[y] Twenty fruit were randomly collected to determine average fruit weights.
[x] Empyrean® 2 fruit data based on one location and two surviving trees.
[w] Includes yield data from trees that died before 2017.
[v] Includes yield data only from trees alive in 2017.

Table 8. Mean fruit maturity date, fruit weight, and cumulative yield/yield efficiency of 'Redhaven' peach trees on each 13 rootstocks common to the 13 locations.

Location	Mean fruit maturity date[z] (days post Jan. 1) (2011-2017)		Mean fruit wt.[y] (g) (2011-2017)		Cumulative yield (kg)/tree (live + dead)[x] (2011-2017)		Cumulative yield (kg)/tree (live trees)[w] (2011-2017)		Cumulative yield efficiency (kg/cm^2)	
New York-Geneva	221	a	146	e	193.3	cd	200.0	cd	0.88	cd
Kentucky	183	g	176	d	187.9	cd	193.5	cd	1.16	b
North Carolina	173	h	168	d	99.4	f	115.4	fg	0.90	bc
Alabama	168	i	169	d	107.1	ef	145.0	def	0.59	de
South Carolina	173	h	198	ab	378.2	a	430.4	a	1.55	a
Georgia	173	h	140	e	112.6	ef	136.1	ef	0.64	cde
Massachusetts	217	b	190	bc	124.8	def	125.9	fg	0.68	cde
Illinois	191	f	182	cd	88.5	f	96.4	fg	0.45	e
Utah-Kaysville	210	d	204	a	219.2	c	223.7	c	1.46	a
Utah-West Payson	214	c	170	d	115.1	ef	128.9	efg	1.60	a
Colorado	210	d	177	cd	64.6	f	75.4	g	0.88	cd
Pennsylvania	NA	--	174	d	172.7	cde	181.6	cde	0.85	cd
Missouri	195	e	173	d	291.5	b	329.2	b	1.49	a

[z] LS means separation within columns by Tukey's HSD (*P*=0.05), NA=no data
[y] Twenty fruit were randomly collected to determine average fruit weights.
[x] Includes yield data from trees that died before 2017.
[w] Includes yield data only from trees alive in 2017.

shown), which consistently has ripened fruit slightly later than average in rootstock trials (Reighard, personal observation). Significant differences in 'Redhaven' fruit maturity date due to rootstock cultivar were observed in Georgia, Kentucky, Massachusetts, New York, South Carolina and Utah. Overall, maturity dates were significantly influenced by locations (Table 8) with Alabama, Georgia, North Carolina, and South Carolina having the earliest maturity dates (i.e., 168 – 173 days from Jan. 1) and New York, Massachusetts, Utah, and Colorado the latest fruit maturities at 221, 217, 214, and 210 days from Jan. 1, respectively. There was an average of a 53-day difference between the earliest and latest locations for the 'Redhaven' ripening date.

Conclusions

Results from this study concur with previous NC-140 peach rootstock trials that show productivity usually does not change much in relative ranking among rootstocks after

Table 9. Mean cumulative yield (kg/tree) of alive trees on each rootstock at each location through 2017.

	Trial locations												
Rootstock	AL[zyx]	CO	GA	IL	KY	MA	MO	NC	NY	PA	SC	UTK	UTP
Viking	213	105	118	82	212	139	372	148	153	209	526	278	158
Atlas	198	108	168	102	266	122	287	150	239	205	479	255	176
BH #5	130	100	105	88	172	121	333	129	190	164	318	243	194
Rootpac®R	---	56	151	100	176	124	363	98	203	177	506	159	167
Guardian®	213	95	158	103	236	134	360	157	223	191	531	248	112
Lovell	176	73	186	118	258	139	360	161	238	211	501	251	112
KV-010123	167	62	169	93	224	134	378	136	180	200	487	227	81
KV-010127	160	88	172	120	212	132	388	129	204	195	544	271	120
Krymsk®86	155	78	167	97	180	118	316	135	246	188	457	224	140
Empyrean®2	86	65	102	---	---	113	282	---	194	141	328	193	136
Empyrean®3	---	---	---	---	---	---	---	---	---	---	159	---	---
Imperial CA	---	75	---	---	---	---	---	---	149	---	---	152	---
Controller™8	123	64	80	111	190	135	322	73	200	195	439	241	105
Controller™7	62	64	148	130	194	140	334	94	227	192	388	237	---
P. americana	---	40	---	111	115	145	---	37	158	166	274	186	115
Fortuna	---	38	---	---	---	---	---	15	139	147	---	---	---
Krymsk®1	---	39	---	49	50	122	151	3	153	86	111	130	101
Controller™5	62	34	92	46	149	73	298	---	131	149	268	155	79

[z] Locations are represented by the state abbreviations except for UTK and UTP which represent Kaysville, Utah and West Payson, Utah, respectively.
[y] Rootstocks missing or having 100% mortality have data listed as ---.
[x] Cumulative yield data for AL and MO were through 2016.

3 years of bearing (Reighard et al., 2004) if survival and tree health are not significantly impacted. This seemed to be supported when growth and yield data from 2013 (5 years) and 2015 (7 years) (Reighard et al., 2018) for the same trial were compared to these 2017 data. However, survival and thus orchard productivity among rootstocks did eventually change in this trial after 5 years at some locations. The primary reason was due to increasing tree mortality near peak orchard life that affected performance rankings. Therefore, field testing for disease resistance, especially in the southeastern U.S., should be for more than 5 years and closer to 10 years before releasing an untested rootstock cultivar commercially. In other peach regions where no serious biotic tree pathogen (i.e., nematode, bacterial, fungal) or abiotic factor (i.e., climate, soils) would significantly influence

survival and productivity, then 5 years of testing might give an accurate indication of the potential productivity of each rootstock/scion combination at that location.

Additionally, the results suggest that high pH soils (> 8.0) and regions with fewer growing degree heat units (i.e., Utah at West Payson, Colorado) may limit growth potential and yield, especially on peach (*P. persica*) roots. Thus, peach cultivars would perform better with interspecific *Prunus sp*. hybrid rootstocks that are adapted to calcareous soils and induce more vigor. Moreover, this trial showed that 'Fortuna' was potentially incompatible with peach, and 'Imperial California', 'Krymsk® 1', and 'Rootpac® R' rootstocks were susceptible to bacterial canker at the four southeastern U.S. locations. Lastly, vigorous *P. persica* rootstocks were the most productive at all locations except Colorado and Utah-West Payson, but size controlling rootstocks with good survival and yield efficiency such as 'Controller™ 7' and 'Controller™ 8' have potential for higher density plantings in the future.

Acknowledgements

The authors thank the International Fruit Tree Association, Bailey Nurseries, Inc. (Newport, Minnesota), and Fowler Nursery (Newcastle, California) for providing funding and/or propagating trees. We also thank each State's Agricultural Experiment Station and USDA/NIFA (Washington, D.C.) for funding through the Multi-State NC-140 project "Improving Economic and Environmental Sustainability in Tree-Fruit Production Through Changes in Rootstock Use". This paper is Technical Contribution No. 6700 of the Clemson University Agricultural Experiment Station, Publication No. 9154 of the Utah Agricultural Experiment Station and is supported by NIFA/USDA, under project number SC-1700545.

Literature Cited

DeJong, T.M., L. Grace, A. Almehdi, R.S. Johnson, and K.R. Day. 2014. Performance and physiology of the Controller™ series of peach rootstocks. Acta Hort. 1058:523-529.

Reighard, G., R. Andersen, J. Anderson, W. Autio, T. Beckman, T. Baker, R. Belding, G. Brown, P. Byers, W. Cowgill, D. Deyton, E. Durner, A. Erb, D. Ferree, A. Gaus, R. Godin, R. Hayden, P. Hirst, P. Kadir, M. Kaps, H. Larsen, T. Lindstrom, N. Miles, F. Morrison, S. Myers, D. Ouellette, C. Rom, W. Shane, B. Taylor, K. Taylor, C. Walsh, and M. Warmund. 2004. Growth and yield of Redhaven peach on 19 rootstocks at 20 North American locations. J. Amer. Pomol. Soc. 58(4):174-202.

Reighard, G.L. and F. Loreti. 2008. Rootstock development. In: Layne, D.R. and D. Bassi (Eds.) The Peach: Botany, Production and Uses. CAB International, Wallingford, U.K., pp. 193-220.

Reighard, G.L., W. Bridges, Jr., D. Archbold, A. Atucha, W. Autio, T. Beckman, B. Black, D. Chavez, E. Coneva, K. Day, M. Kushad, R.S. Johnson, T. Lindstrom, J. Lordan, I. Minas, D. Ouellette, M. Parker, R. Pokharel, T. Robinson, J. Schupp, M. Warmund, and D. Wolfe. 2018. Rootstock performance in the 2009 NC-140 peach trial across 11 states. Acta Hort. 1228:181-186.

Zarrouk, O., J. Aparicio, Y. Gogorcena, and M.A. Moreno. 2006. Graft compatibility for new peach rootstocks in nursery. Acta Hort. 713:327-329.