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Influence of Peach Seedling Rootstocks on Growth, Yield and Survival of Peach Scion Cultivars[1]

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Abstract. **An 8-year study was made to assess the performance of Harrow Blood and Siberian C rootstock seedlings in comparison with the commercial seedling rootstocks Rutgers Red Leaf, Veteran, Halford and Bailey. Rootstocks significantly influenced tree size of 'Loring', 'Redhaven' and 'Babygold 5' peach (*Prunus persica* (L.) Batsch). Siberian C had the largest influence on size control, reducing tree volume by about 20%. Tree height and spread, trunk circumference and trunk cross-sectional areas were also influenced by rootstocks, but annual growth of terminal shoots was not. Rootstocks influenced crotch angle development of 'Loring', but had no effect on crotch angle development of 'Redhaven' or 'Babygold 5'. Cropping efficiency of 'Babygold 5' was influenced by rootstocks but cropping efficiency of 'Redhaven' and 'Loring' were not. Yields were significantly influenced by rootstocks. The highest cumulative yields of 'Loring' were on Veteran seedlings, the highest of 'Redhaven' were on Rutgers Red Leaf and the highest of 'Babygold 5' were on Halford. Yields were also a function of tree size with the highest yields being obtained on the largest trees. Trunk circumference and cross-sectional area were the only growth measurements that were significantly correlated with the yield of each cultivar. Tree survival was best on Harrow Blood and Siberian C and poorest on Rutgers Red Leaf and Veteran. Tree mortality was associated with winter injury and canker (*Leucostoma* spp.) infection but not with incompatibility.**

In North America, peaches are usually propagated on peach seedlings (5, 8). Other *Prunus* spp. find limited use for special purposes such as size control (*P. tomentosa* Thunb. and *P. besseyi* Bailey) or imperfectly drained soils (*P. insititia* L. and *P. domestica* L.). The problems and prospects of improving peach rootstocks have been reviewed recently (5, 9).

Although peach seedling rootstocks have been used for a long time, very few studies have been reported about their long term effects on peach scion cultivars. It has been generally assumed that different seedling rootstocks have similar effects on the scion. Consequently, nurserymen, growers, and researchers have given only minor consideration to the choice of peach rootstocks except where there is a need for nematode resistance. It is now apparent that the choice of rootstocks is important because of the differential effects of seedling rootstocks on the performance of peach scion cultivars (1, 2, 3, 5, 6, 7, 10, 11).

Hutchinson and Bradt (2) reported that trees of 'Golden Jubilee', 'Redhaven' and 'Veteran' were of similar size on Elberta and Lovell seedling rootstocks but were usually smaller on Rutgers Red Leaf seedlings. Cumulative yields were similarly affected by rootstocks. Tree losses which were greater on Rutgers Red Leaf than on the other two peach seedling rootstocks, were thought to be caused by incompatibility rather than cold injury or soil conditions. Similarly, Kochba et al. (3) reported that peach seedling rootstocks influenced cumulative yields as well as tree size and weight. The smallest trees with the lowest yields were on Elberta seedlings while the largest trees with the highest yields were on S-37, a nematode-resistant seedling rootstock from California. Tree losses were greatest on Shalil and Elberta rootstocks and survival was best on Baladi, an Israeli rootstock. Weaver (10, 11) reported that crotch angle development and canker (*Leucostoma* spp.) incidence were influenced by different peach seedling rootstocks.

In 1967 two cold hardy seedling rootstocks for peach, Siberian C and Harrow Blood, were released by the Harrow Research Station (4). In 1968, we initiated an experiment to compare these new rootstocks with commercial peach seedling rootstocks with respect to their long term influence on peach scion cultivars. A preliminary research report was made in 1973 (8), and it has been updated by more recent general reports (5, 6).

Materials and Methods

Three experimental orchards were planted in the spring of 1968 on a well-drained Fox sandy loam soil that was fumigated the previous fall with Telone (1,3-dichloropropene and other related C_3 hydrocarbons, Dow Chemical Co.) at 333 liters/ha. The trees were planted in 3 separate blocks with 1 cultivar per block. The cultivars were 'Loring', 'Redhaven' and 'Babygold 5'. Four seedling rootstocks were common to each block: Siberian C, Harrow Blood, Rutgers Red Leaf and Veteran. Two additional seedling stocks, Bailey and Halford, were included in the 'Babygold 5' block only. The basic design of each orchard was a randomized complete block replicated 5 times in which rootstocks were the treatments. Each rootstock treatment consisted of a 3-tree subplot, and the replications were rows of trees. Trees were spaced 4.2 m within and 6.0 m between rows (14 x 20 ft) and trained to an open center. Each orchard received the same fertility program and the same mangement practice of clean cultivation until July of each year followed by a cover crop of oats (*Avena sativa* L.) or Italian rye grass (*Lolium multiflorum* Lam.). The trees were pruned lightly in the first 4 years and were moderately pruned thereafter.

Growth measurements were obtained in the fall when active growth had ceased. Measurements were made on each tree in

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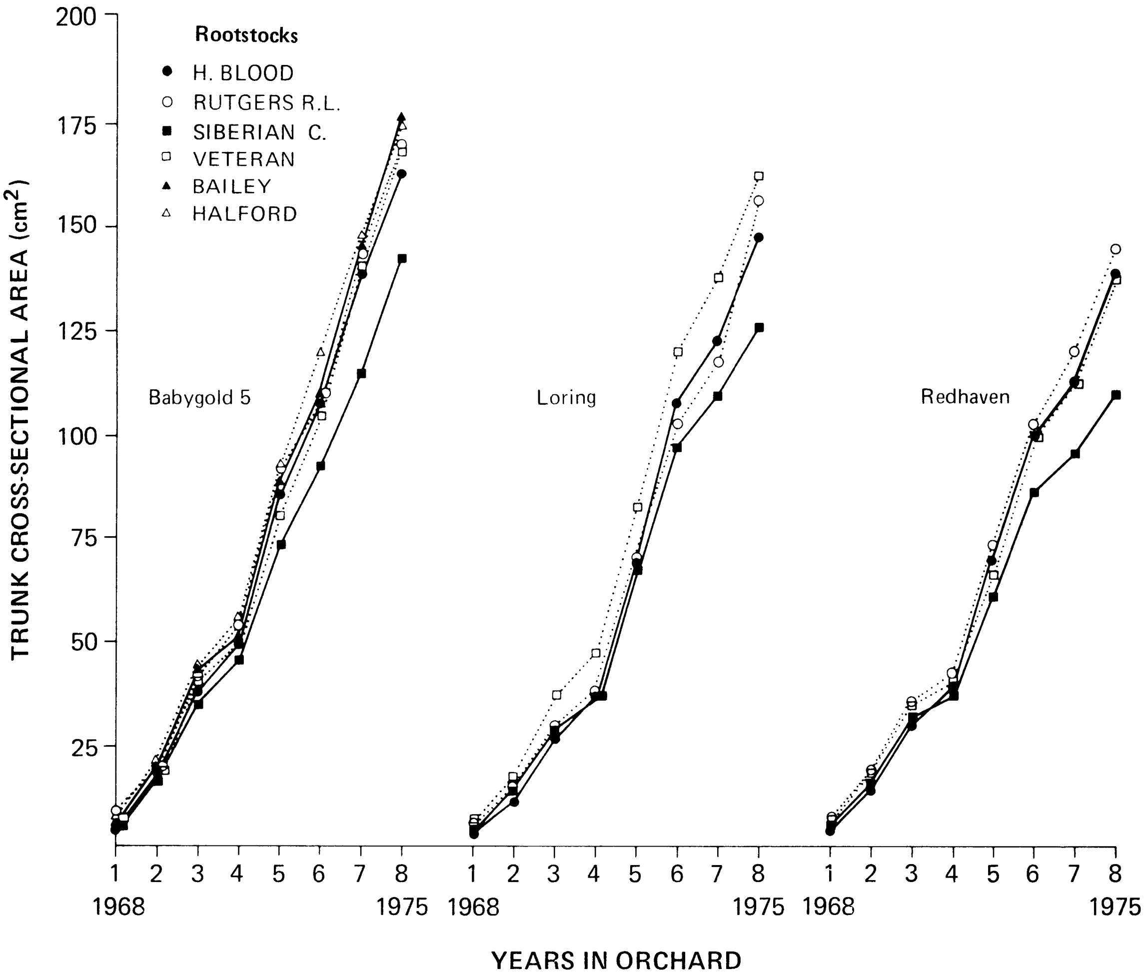

Fig. 1. Peach seedling rootstock influence on trunk cross-sectional area (1968 to 1975).

a plot but only if alive and vigorous. Plot means, therefore, were an average of 1 to 3 trees. There were no missing plots. Measurements of trunk circumference were made annually about 20 cm above the soil surface. Measurements of maximum height and spread of trees were made annually (1970 to 1975) and measurements of annual shoot growth were made (1971 to 1975) by randomly selecting 5 terminal shoots per tree. Crotch angles were measured only in 1968 and 1970 using a bevel T-square fitted with a protractor (11). Fruit yields were weighed and recorded on a per tree basis from 1971 to 1975, but the data for 1972 were not included because severe cold injury to flower buds resulted in almost complete crop failure. A count was made in the 8th year (1975) of the no. of trees alive in each plot and a general assessment of their health and vigor was made.

The data from each scion cultivar were treated as a separate study and analyzed using a computerized analysis of variance program with rootstocks as the treatments. Trunk cross-sectional area (A) from which growth curves were plotted was obtained by the formula $A=C^2/4^\pi$ where C=trunk circumference. Since the trees were nearly spheroidal in shape, their volumes (V) in the 8th year (1975) were calculated using the formula $V=4/3\ (a^2b)$, where a=½ the spread and b=½ the height (12). A correlation analysis was performed on the 1975 data in which each parameter of scion growth was compared with fruit yield. Previous work by Kochba et al. (3) showed that yield was more closely related to trunk cross-sectional area than either tree weight or tree volume. Accordingly, the ratio of yield to trunk area in 1975 was calculated to obtain a measure of cropping efficiency of each scion/rootstock combination.

Results

Rootstock influence on trunk cross-sectional area. The data on trunk circumference were converted to trunk cross-sectional area and appear in Fig. 1. Analysis of variance was also per-

Table 1. Peach seedling rootstock influence on tree size in the 8th year.

Rootstocks	Mean maximum tree size (m)					
	Loring		Redhaven		Babygold 5	
	Height	Spread	Height	Spread	Height	Spread
Siberian C	3.5a[z]	5.4a	3.6a	5.9a	4.1a	6.0a
Harrow Blood	3.8b	5.7a	3.8ab	6.4a	4.5c	6.4ab
Rutgers Red Leaf	3.5a	5.5a	3.9b	6.2a	4.6c	6.3ab
Veteran	3.7ab	5.8a	4.0b	6.2a	4.2ab	6.6b
Bailey					4.4bc	6.5ab
Halford					4.5c	6.5ab

[z]Mean separation within columns by Duncan's multiple range test, 5%.

Table 2. Peach seedling rootstock influence on tree volume in the 8th year.

Rootstocks	Tree volume in 1975 (m^3)		
	Loring	Redhaven	Babygold 5
Siberian C	53.4a[z]	64.5a	79.0a
Harrow Blood	66.8a	82.0b	96.5ab
Rutgers Red Leaf	54.4a	77.8ab	96.2ab
Veteran	65.2a	80.4ab	98.3ab
Bailey			91.3ab
Halford			100.6b
Mean	59.9	76.1	93.7

[z]Mean separation within columns by Duncan's multiple range test, 5%.

Table 3. Peach seedling rootstock influence on crotch angle of 'Loring' in the 1st and 3rd year.

Rootstock	Mean crotch angle (°)	
	1968	1970
Harrow Blood	45.7a[z]	44.9a
Siberian C	46.4a	46.9a
Rutgers Red Leaf	52.2b	52.5b
Veteran	47.4a	44.4a

[z]Mean separation within columns by Duncan's multiple range test, 5%.

formed on converted data. Trunk area was affected by both scions and rootstocks. 'Babygold 5' attained greater size than either 'Loring' or 'Redhaven'. 'Loring' trunks were intermediate in size between those of 'Babygold 5' and 'Redhaven'. The growth of each cultivar was also affected by rootstocks with Siberian C having the most consistent influence on trunk growth. The overall rootstock influence on trunk cross-sectional area was significant in the 1st, 2nd, and 6th years for 'Babygold 5'; the 1st, 2nd, 3rd and 8th years for 'Loring'; and the 1st, 2nd, 7th and 8th years for 'Redhaven', respectively.

Rootstock influence on tree height and spread. Annual measurements were made from 1970 to 1975 when trees were in their 3rd to 8th year, respectively. Only the data for 1975 are presented (Table 1). The height of 'Loring' was not significantly influenced by rootstocks from the 3rd to the 6th years, but differences were significant in the 7th and 8th years. The spread of 'Loring' was influenced by rootstocks in the 3rd and 4th years but not in subsequent years. The height of 'Redhaven' was influenced by rootstocks in the 6th year when trees on Siberian C were shorter than on the other 3 rootstocks and the same trend held to the 8th year. The spread of 'Redhaven' trees was not significantly influenced by rootstocks in any of the 6 years. Tree height of 'Babygold5' was significantly influenced by rootstocks in the 4th, 5th and 8th years while tree spread was similarly influenced in the 6th, 7th and 8th years, respectively. The shortest trees were consistently on Siberian C from the 3rd to the 8th year, and those with the least spread were also on Siberian C from the 6th to the 8th year.

Rootstock influence on tree volume in the eighth year. Tree volume in the 8th year was influenced by scions and by rootstocks (Table 2). 'Babygold 5' trees occupied the most space (93.7 m^3), 'Redhaven' trees were intermediate (76.1 m^3), and 'Loring' trees were smallest (59.9 m^3). Because of cultivar differences in tree volume, it appeared that trees of 'Redhaven' and 'Loring' could be planted 19% and 36% closer, respectively, than those of 'Babygold 5'. In addition, tree volumes of 'Redhaven' and 'Babygold 5' were also influenced by rootstocks. Trees with the smallest volumes were on Siberian C, while those with the largest were on Harrow Blood and Halford for 'Redhaven' and 'Babygold 5', respectively. The volume of 'Loring' trees was not influenced by rootstocks. It might be possible to plant trees of 'Redhaven' and 'Babygold 5' about 20% closer on Siberian C than on Harrow Blood or Halford, respectively.

Table 4. Peach seedling rootstock influence on yield of 'Loring' from the 4th to the 8th year.

Rootstock	Mean fruit yield (kg/tree)					
	1971	1973	1974	1975	Total	Mean
Harrow Blood	17.4a[z]	76.6a	78.8ab	73.1a	245.9	61.5
Siberian C	23.0b	66.3a	66.0a	69.1a	224.4	56.1
Rutgers Red Leaf	20.3ab	65.0a	63.7a	72.0a	221.0	55.3
Veteran	23.1b	74.5a	83.7b	77.8a	259.1	64.8
Mean	21.0	70.6	73.1	73.0		59.4

[z]Mean separation within columns by Duncan's multiple range test, 5%.

Table 5. Peach seedling rootstock influence on yield of 'Redhaven' from the 4th to the 8th year.

Rootstock	Mean fruit yield (kg/tree)					
	1971	1973	1974	1975	Total	Mean
Harrow Blood	23.6a[z]	66.9a	58.1a	83.8ab	232.4	58.1
Siberian C	26.1a	64.0a	52.5a	74.0a	216.6	54.2
Rutgers Red Leaf	26.6a	60.4a	64.4a	95.1b	246.5	61.6
Veteran	22.0a	55.0a	58.6a	91.2ab	226.8	56.7
Mean	24.6	61.6	58.4	86.0		57.7

[z]Mean separation within columns by Duncan's multiple range test, 5%.

Average rootstocks/scion effects in the 8th year. Eighth year measurements were used to calculate grand means for rootstocks averaged over the 3 scion cultivars to show the cumulative effects of the 4 common rootstocks on scion growth. Similarly, grand means were calculated for each cultivar averaged over the 4 common rootstocks to show the overall growth differences among cultivars. 'Babygold 5' trees were tallest (4.33 m), 'Redhaven' trees were intermediate (3.81 m) and those of 'Loring' were shortest (3.61 m). Similarly, trees of 'Babygold 5' had the widest spread (6.35 m), those of 'Redhaven' were intermediate (6.16 m) and those of 'Loring' were narrowest (5.59 m). Tree volumes were already shown in Table 2. By comparing the effects of the 4 common rootstocks on average tree size, the tallest trees were on Harrow Blood (4.0 m) and the shortest were on Siberian C (3.7 m), the widest were on Veteran (6.2 m), and the narrowest were on Siberian C (5.8 m). Trees on Harrow Blood occupied the most space (81.8 m^3) while those on Siberian C occupied the least (65.6 m^3). In fact, trees on Harrow Blood occupied 24.6% more space than those on Siberian C, while those on Veteran and Rutgers Red Leaf occupied 23.9% and 16.0% more space, respectively.

Rootstock influence on annual shoot growth. Shoot growth of 'Loring' was not significantly influenced by rootstocks in any of the 5 years tested. Shoot growth of 'Redhaven' was significantly affected by rootstocks only in the 6th year when growth on Veteran was significantly greater than on any of the other 3 rootstocks. Shoot growth of 'Babygold 5' was significantly influenced by rootstocks only in the 4th year when shoot growth was least on Siberian C (32 cm) and the greatest on Bailey (39 cm).

Rootstock influence on crotch angle. Measurements were made in 1968 and 1970. Crotch angle development of 'Loring' was significantly wider in both years (Table 3) on Rutgers Red Leaf than on each of the other 3 rootstocks. Crotch angle development of 'Redhaven' and 'Babygold 5' was not influenced by rootstocks in either year, however.

Peach seedling rootstock influence on yield. The yield of 'Loring' (Table 4) was influenced by rootstocks only in the 4th and 7th years. There was no yield in 1972 due to complete winter kill of flower buds. In the 4th year yields were higher on Veteran and Siberian C than on Harrow Blood, but were not

Table 6. Peach seedling rootstock influence on yield of 'Babygold 5' from the 4th to the 8th year.

Rootstock	Mean fruit yield (kg/tree)					
	1971	1973	1974	1975	Total	Mean
Harrow Blood	18.9a[z]	79.9a	79.7a	81.2abc	259.7	64.9
Siberian C	17.6a	70.7a	67.7a	68.4a	224.4	56.1
Rutgers Red Leaf	20.0a	87.3a	72.1a	78.9ab	258.3	64.6
Veteran	19.2a	72.2a	68.2a	94.2c	253.8	63.5
Bailey	18.9a	81.3a	73.1a	86.8bc	260.1	65.0
Halford	21.8a	81.3a	72.4a	91.2bc	266.7	66.7
Mean	19.4	78.8	72.2	83.5		63.5

[z]Mean separation within columns by Duncan's multiple range test, 5%.

Table 7. Rootstock influence on the ratio of fruit yield (Y) to trunk cross-sectional area (A) in the 8th year.

Rootstocks	Loring Y/A[z]	Redhaven Y/A[z]	Babygold 5 Y/A[z]	Mean
Harrow Blood	.50a[y]	.61a	.50ab	.54
Siberian C	.54a	.68a	.48ab	.57
Rutgers Red Leaf	.46a	.66a	.46a	.53
Veteran	.49a	.67a	.57b	.58
Bailey			.49ab	–
Halford			.52ab	–

[z]Yield in kg per cm^2 of trunk cross-sectional area.

[y]Mean separation within columns by Duncan's multiple range test, 5%.

different from those on Rutgers Red Leaf. In the 7th year yields were higher on Veteran than on Siberian C or Rutgers Red Leaf but were similar to those on Harrow Blood. Cumulative yields of 'Loring' were highest on Veteran followed by those on Harrow Blood, Siberian C and Rutgers Red Leaf.

The yield of 'Redhaven' was significantly influenced by rootstocks only in the 8th year when yields on Rutgers Red Leaf were higher than on Siberian C but were intermediate on Harrow Blood and Veteran (Table 5). Cumulative yields of 'Redhaven' for the 4 years were highest on Rutgers Red Leaf followed by Harrow Blood, Veteran and Siberian C.

The yield of 'Babygold 5' was also influenced by rootstocks especially in the 8th year (Table 6). Highest yields were recorded on Veteran which exceeded those on Rutgers Red Leaf or Siberian C, but were not different from those on Halford, Bailey or Harrow Blood. Cumulative yields were highest on Halford followed by those on Bailey, Harrow Blood, Rutgers Red Leaf, Veteran and Siberian C.

Rootstock influence on cropping efficiency. Cropping efficiency was calculated as the ratio of fruit yield to trunk cross-sectional area in the eighth year (Table 7). There was no significant rootstock influence on the cropping efficiency of 'Loring' or 'Redhaven', whereas the cropping efficiency of 'Babygold 5' was higher on Veteran than on Rutgers Red Leaf rootstocks. When the ratios were averaged over the 3 scions for the 4 common rootstocks, the highest cropping efficiency was associated with Veteran and Siberian C, and the lowest with Harrow Blood and Rutgers Red Leaf.

Correlation of growth with yield in the 8th year. Tree height had the poorest relationship with yield of the growth parameters studied because it was correlated with the yield of 'Redhaven' only (Table 8). Tree spread was better since it was correlated with yield of 'Loring' and 'Babygold 5' although not with yield of 'Redhaven'. Trunk circumference was the best of the direct measurements since it was correlated with the yield of each scion cultivar. Tree volume was not as reliable as trunk cross-sectional area in its relationship with yield. Tree volume was correlated with the yield of only 2 scion cultivars whereas trunk cross-sectional area was correlated with the yield of all 3 cultivars.

Rootstocks influence on tree survival. A count was made in the 8th year to determine tree survival in relation to rootstocks (Table 9). Survival of 'Redhaven' was significantly greater on Harrow Blood, Siberian C and Rutgers Red Leaf than on Veteran. Survival of 'Babygold 5' was significantly greater on Halford and Harrow Blood than on Rutgers Red Leaf or Veteran while survival on Siberian C and Bailey was intermediate. Overall scion survival on the 4 common rootstocks was greatest on Harrow Blood and Siberian C and was least on Rutgers Red Leaf and Veteran. Tree mortality appeared to be caused from a combination of winter injury and canker (*Leucostoma* spp.) infection, but not from incompatibility.

Table 8. Correlation coefficients for yield with various growth parameters in the 8th year.

Growth parameters vs. yield	Loring[z]	Redhaven[z]	Babygold 5[y]
Tree height	.038	.600**	.101
Tree spread	.615**	.335	.580**
Trunk circumference	.490*	.517*	.566**
Tree volume	.405	.504*	.514**
Trunk cross-sectional area	.500*	.517*	.559**

[z]Correlation coefficients based on 20 pairs.

[y]Correlation coefficients based on 30 pairs.

Table 9. Peach seedling rootstock influence on scion survival to the 8th year.

Rootstock	No. of trees alive (Max = 15) Loring	Redhaven	Babygold 5	Mean
Harrow Blood	14a[z]	15b	15b	14.7
Siberian C	14a	15b	14ab	14.3
Rutgers Red Leaf	11a	12b	12a	11.7
Veteran	14a	8a	12a	11.3
Bailey			13ab	–
Halford			15b	–
Mean	13.3	12.5	13.5	

[z]Mean separation within columns by Duncan's multiple range test, 5%.

Discussion

In this study we showed that orchard performance of peach cultivars was significantly influenced by rootstocks. Scion responses such as trunk growth, tree size, crotch angle, yield, cropping efficiency and survival were affected differently by different rootstocks. Other workers reported similar results with different scion/rootstock combinations on different soil types and in different climatic zones (1, 2, 3, 8). The rootstock influence on peach scion cultivars, therefore, is more extensive than previously thought and if properly manipulated, could have important and far reaching benefits for the peach industry. However, because of the paucity of information on the comparative attributes of different peach seedling rootstocks for various soil types and climatic zones, further studies are needed to establish their range of adaptation and to determine the scion/rootstock combinations that are optimum for different regions. Properly designed field experiments are necessary to elucidate differences due to rootstocks since the effects on the scion are usually small and difficult to discriminate. Research workers conducting or planning experiments with peaches propagated on seedling rootstocks should ensure that all rootstock seedlings are obtained from the same seed parent. If different seedling rootstock cultivars are used, they should be considered as one of the factors in the experiment in order to avoid scion responses to a given treatment being confounded by different rootstock effects.

The growth curves we obtained (Fig. 1) were similar to those previously reported (2) although different scion/rootstock combinations and soil types were involved. In this study we found that during the vegetative growth phase of the first 3 years the smallest trees were on Harrow Blood, but in later years, especially the 6th, 7th and 8th, the smallest were on Siberian C. Siberian C induces earlier bearing of peach scions than Harrow Blood or the other rootstocks studied (6). Precocity in itself has a dwarfing tendency and may account in part for the reduction of scion growth rate on Siberian C during the fruiting phase.

Orchard performance of seedlings of Harrow Blood rootstock was among the best of those studied when all factors were considered. However, nursery problems associated with their slow growth, lack of uniformity and the need for special handling limit their commercial use (6). However, because of their root hardiness (5, 6), apparent tolerance to root lesion nematode (*Pratylenchus penetrans* (Cobb) Filip. and Stekh.) (6), scion compatibility (6), and their ability to enhance scion hardiness (1) and reduce canker incidence (7), further research should be undertaken with Harrow Blood seedlings and clonal propagation should be tried. Harrow Blood should be valuable as a genetic stock in rootstock breeding.

Orchard performance of seedlings of Siberian C rootstock was good for 'Redhaven' and 'Loring' scions and satisfactory for 'Babygold 5'. Because of their unusual root hardiness (5, 6), scion compatibility (6), and their ability to induce precocity (6), enhance flower bud hardiness (6, 8), and reduce tree size; Siberian C has great potential as a rootstock seed source, especially in regions where cold injury to scions and roots is a problem. Because of the susceptibility of Siberian C seedlings to nematodes (6), however, cultivars on these seedlings should be planted on fumigated soils.

The performance of seedlings of the Halford cultivar was good for 'Babygold 5' but untested for 'Loring' and 'Redhaven'. Trees of 'Babygold 5' were generally larger, had higher cumulative yields and survived better on Halford than on seedlings of Veteran or Rutgers Red leaf. Halford seedlings were easily managed in the nursery but their roots were less cold hardy than those of Siberian C, Harrow Blood or Bailey (5, 6).

The performance of seedlings of Bailey rootstock was satisfactory for 'Babygold 5' but untested for 'Loring' or 'Redhaven'. Trees on these seedlings were of intermediate size, had yields that were similar to those on Halford seedlings, but cropping efficiency and scion survival were similar to those obtained with Siberian C seedlings. Bailey seedlings were easily handled in the nursery and their roots were comparable in hardiness with those of Harrow Blood, but were less hardy than those of Siberian C (5, 6).

Veteran seedlings were unsatisfactory for 'Redhaven' because of high scion mortality on these seedlings. Rutgers Red Leaf seedlings were unsatisfactory for 'Babygold 5' for the same reason, although the effect was less pronounced. In each case canker incidence and severity (*Leucostoma* spp.) was greater among surviving trees on these than on the other rootstocks (7). No obvious signs of rootstock-scion incompatibility were observed with any of the scion-rootstock combinations.

Trunk cross-sectional area was a more useful measure of tree size than height, spread or volume and correlated best with yield. Other workers (2, 3) have also found it to be a useful measure of tree size for peach. In addition, it can be used with yield data to estimate cropping efficiency of different rootstocks (3).

The conclusions drawn on the relative status of the seedling rootstocks studied are tentative and may change as additional data are accumulated. At least 4 more years of data will be required before their relative merits on scion growth, yield, cropping efficiency and survival can be conclusively assessed.

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