Survival, Growth, and Yield of Peach Trees as Affected by Rootstocks

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Effects of 8 peach seedling rootstocks on tree growth, survival, and fruit yield of 'Redhaven' and 'Loring' peach scion cultivars were tested in Alabama, Arkansas, Georgia, North Carolina, and South Carolina. Lovell seedling rootstock was a standard for comparison. Six years of data indicated that Siberian C was not an acceptable rootstock because tree survival and fruit yield were low. Halford was equivalent to Lovell for tree growth, fruit yield, and survival. Fruit size was unaffected by rootstock. Nemaguard and 2 North Carolina selections were resistant to root-knot nematodes (*Meloidogyne* spp.) but they were not resistant to ring nematodes [*Criconemella xenoplax* (Raski) Luc and Raski]. Soil fumigation improved tree survival in nematode-infested soil.

The productive life of southeastern U.S. peach orchards has declined and often is only 7–10 years (2, 6). One factor responsible for this decline is the syndrome known as peach-tree short life (PTSL), which is a disease complex characterized by sudden death in late winter or early spring (2, 6, 27).

Peaches usually are propagated on seedling rootstocks but, until recently, little attention was given to the rootstock cultivar used or the condition of the seed trees (15, 28). Rootstock affects performance of the scion (2, 17, 21, 35) and has a major effect on scion cold hardiness (10, 18, 19, 20, 33) and resistance to bacterial canker caused by *Pseudomonas syringae* pv. *syringae* van Hall and valsa canker caused by *Cytospora* spp. (6, 9, 15, 16, 21, 30, 31). In the southeastern United States, trees on Lovell rootstock survived longer than did those on Nemaguard (27, 37).

Siberian C rootstock in Canada promoted early defoliation, enhanced early fall cold acclimation, scion and bud cold hardiness in mid-winter, bud survival and fruit set in the spring, and imparted slightly more cold hardiness to apical shoots than did other rootstocks (17, 19). Maximum cold injury in Georgia, however, was sustained by trees on Siberian C and NRL 4 rootstocks. Also, Chaplin and Schneider (4) found that New and Harrow Blood rootstocks transmitted more hardiness to scions than did Siberian C or Rutgers Red Leaf. Siberian C also has been reported to delay the completion of chilling requirement and the onset of bloom and to decrease the xylem water potential of fruiting shoots prior to bloom when compared with Lovell, Halford, and Harrow Blood rootstocks (35, 36). Lovell, Halford, and NA-8 rootstocks imparted more cold hardiness to 'Redhaven' scions than other rootstocks tested in Georgia (34).

Nematodes are a major factor in reduced growth and survival of peach trees. The ring nematode *Criconemella xenoplax* and root-knot nematodes (*Meloidogyne* spp.) are commonly associated with peach trees in the field (1). *C. xenoplax* is associated with PTSL and increases susceptibility to *P. syringae* pv. *syringae* and cold injury (1, 5, 22, 24, 25, 37). In South Carolina, 9 of 10 peach trees planted in 1.6-m-diameter microplots of soil infested with *C. xenoplax* died of PTSL within 4 years, while there was no tree loss in non-infested soil (26). The lesion nematode, *Pratylenchus vulnus* Allen and Jensen, may be important in some orchard sites (7). Siberian C rootstock is severely affected by *Pratylenchus penetrans* (Cobb) Filip. & Sch. Stekhoven (13, 17). Okinawa, S-37, and Nemaguard rootstocks are resistant to *Meloidogyne incognita* (Kofoid & White) Chitwood and *M. javanica* (Treub) Chitwood (3, 11, 14, 24, 29). All rootstocks tested by Barker and Clayton (1) were susceptible to *C. xenoplax* but it was reported (32, 37) that population densities of *C. xenoplax* are affected by rootstock. Control of *M. xenoplax* by soil fumigation prevented early development of PTSL on Lovell, but not on Elberta or Nemaguard rootstocks (27, 37). Most rootstocks also are susceptible to *P. vulnus*, but Bokhara and Yunnan may be partially resistant (7).

Methods

Plantings. Trees were planted between Dec. 1975 and Mar. 1976, depending on location. 'Loring' and 'Redhaven' cultivars on NC NRL-4, NC 152-AI-2, NA-8, Lovell, Halford, Siberian C, Harrow W208, and Nemaguard were compared in the cooperating states of Alabama, Arkansas, Georgia, North Carolina, and South Carolina. Lovell was the standard rootstock for comparison. The plantings were established in a randomized complete block design with 4 replications of 4 to 8 trees per plot 4.6 m (15 ft) in the row with rows 6.1 m (20 ft) apart. The soil type for each planting site was: Ruston fine sandy loam (Alabama), Saffel-Dirks gravelly sandy loam (Arkansas), Faceville fine sandy loam (Georgia), Wagram fine sand (North Carolina), and Lakeland fine sand (South Carolina). Trees for all plantings were propagated by the North Carolina Agricultural Research Service in cooperation with the North Carolina Foundation Seed Producers, Inc. The "10 point program" for orchard maintenance and short life management (2) was followed for site preparation and postplanting care. Fertilizer practices generally recommended in the respective locations were followed. Overhead irrigation was applied sparingly or not at all. Recommended herbicides were applied in the row for weed control, with sod or natural vegetation growing between the rows.

Soil fumigation and nematode control. Soil fumigation practices differed at all 5 loca-

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Fig. 1. The effect of rootstock and scion cultivar on survival of peach trees in the Alabama location after 6 years. In the orchard, all 6 trees in each replication were dead 6 years after planting as follows: (**A**) 'Loring' on Siberian C; (**B**) Redhaven on NA8; and (**C**) and (**D**) Redhaven on Siberian C. The vigor and productivity of other rootstock-scion combinations are apparent in adjacent trees.

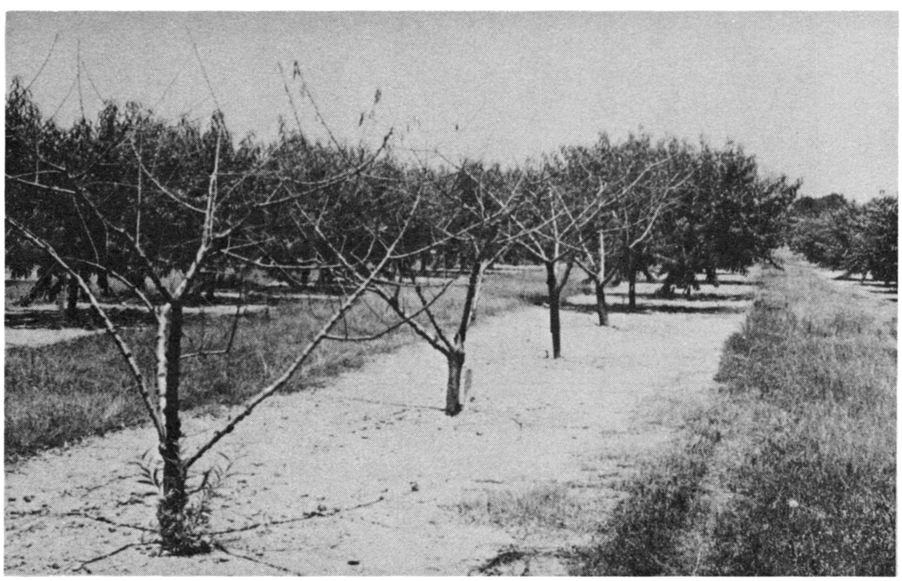

Fig. 2. At the Arkansas location, all trees in the replication of Siberian C under the Redhaven cultivar were dead in 1980. Trees in back and on right of same row are on Lovell rootstock.

tions according to the needs of the individual sites and the capabilities to apply a nematicide and assay nematode populations. No nematicide was applied at the Arkansas location. Methyl bromide at 460 kg/ha was applied preplant and DBCP (1,2-dibromo-3-chloropropane) at 40 kg/ha postplant in Georgia, and D-D (Shell Chemical Co.) at 467 liters/ha was applied preplant in North Carolina. DBCP 12.1 EC at 45 liters/ha was applied preplant in South Carolina and Alabama. Eight trees per replicate were planted at the South Carolina site. Four received no nematicide and 4 received DBCP preplant in 1976, and again in 1979. DBCP was applied postplant in Alabama in 1977 and 1978, and in 1978 in Georgia and North Carolina.

Measurements. When trees died, an attempt was made to determine the cause of death. Cold injury following low temperatures in late winter and early spring (31) was measured by the degree of trunk cambial browning according to measurements developed for this purpose (S.L. Doud and U.L. Yadava, unpublished). Fruit weight per tree and size of fruit were determined in 1978–1980 in all locations and in 1981 at the Georgia, North Carolina, and Alabama locations. Tree growth was measured each fall by tree spread, height, shoot length, and trunk circumference.

Nematode assays. Populations of ring and root-knot nematodes were determined in the South Carolina, North Carolina, and Georgia plantings once each year, either in the fall or early spring. Root galls induced by root-knot nematodes were indexed in the South Carolina planting in 1979, based on a scale of 0–10, where 0 = no galls; 1 = 10% of roots galled; 2 = 20% galled, etc. (8). In Georgia, two 2.1-cm-diameter soil cores up to 30 cm deep were taken from under the tree canopy, composited for each plot, passed through a 4-mesh sieve, and a 150-cm^3 subsample was assayed for nematodes by the sugar-centrifugation method (12). Nematodes were identified and counted. Similar methods were used in North Carolina and South Carolina.

Statistical analyses. Yearly measurements of yield, fruit size, tree growth, survival, and nematode populations at each location were subjected to analyses of variance. Least significant differences (LSD) for each scion were determined by comparing rootstocks with Lovell, the standard rootstock.

Results

Survival. Peach trees were examined in the spring each year for symptoms of bacterial canker or cold injury, which are responsible for tree death in the PTSL complex (27). Tree losses from other problems (e.g., Clitocybe root rot or phony peach) were determined but not included in the data.

Tree survival during the first 6 years after planting was not satisfactory on Siberian C rootstock, with or without soil fumigation, except where 'Loring' was the scion cultivar in North Carolina and the 2 South Carolina sites (Table 1). When DBCP was used before and after planting, tree mortality was low for trees on other rootstocks except 'Redhaven' on Nemaguard, NC NRL-4, and NC 152 AI-2 in North Carolina and NA-8 in Alabama. PTSL was extensive without soil fumigation (in Arkansas and part of the South Carolina experiment). In Arkansas, only trees on Halford rootstock survived as well as did trees on Lovell. Tree losses on Siberian C were especially severe (Fig . 1 and 2). Tree losses were less severe in South Carolina, but trees on Siberian C, NC NRL-4, and Harrow W208 did not survive well.

There was a tendency for 'Redhaven' trees to be more susceptible to PTSL than 'Loring', especially at the Alabama and South Carolina test sites,where differences were significant (P = 5%).

Fruit yield and size. Fruit yield was recorded at each of the 5 locations in 1978 and 1979, and in Georgia, North Carolina, and Alabama in 1980 and 1981. Yield measure-

Table 1. Survival of 'Loring' and 'Redhaven' peach trees on 8 rootstocks during the first 6 years after orchard establishment.[z]

Rootstock	Alabama[y] Loring	Alabama[y] Redhaven	Arkansas[x,w] Loring	Arkansas[x,w] Redhaven	Georgia[y] Loring	Georgia[y] Redhaven	N. Carolina[y] Loring	N. Carolina[y] Redhaven	S. Carolina[y] Loring	S. Carolina[y] Redhaven	S. Carolina[x,w] Loring	S. Carolina[x,w] Redhaven
	Survival (%)											
Nemaguard	100	100	29	67	100	92	100	69	100	88	100	75
Halford	96	96	83	92	100	96	100	100	100	100	81	94
NC NRL-4	83	100	50	38	92	96	81	81	94	88	69	56
NC 152 AI-2	100	96	46	54	96	96	94	75	100	100	81	94
NA-8	96	62	63	63	100	100	94	100	100	100	100	75
Harrow W208	96	---	46	63	92	96	94	100	100	100	75	81
Lovell	96	96	67	92	100	100	100	100	100	94	100	81
Siberian C	62	44	8	12	42	17	87	75	88	69	88	56
LSD 50%	18	28	28	38	11	11	14	25	NS	19	NS	NS

[z]Cold injury, bacterial canker, or both were the major causes of death. Tree losses due to root rot or phony peach are excluded.
[y]Fumigated before and after planting with DBCP 45 L/ha.
[x]Not fumigated before or after planting.
[w]Scions were significantly different ($P = 5\%$) in the Alabama and South Carolina (nonfumigated) plots.
[NS]Nonsignificant.

Table 2. Fruit yield of 'Redhaven' and 'Loring' peach trees in the 4th and 6th years of growth as related to rootstock in 5 test locations, 1979–1981.

Scion cultivar Rootstock	Alabama 1979	Alabama 1980	Alabama 1981	Arkansas 1979	Arkansas 1980	Georgia 1979	Georgia 1980	Georgia 1981	N. Carolina 1979	N. Carolina 1980	N. Carolina 1981	S. Carolina 1979
	Fruit yield (kg/tree)											
Redhaven												
Nemaguard	43	69	66	12	7	32	57	37	22	38	29	60
Halford	34	54	52	13	6	32	47	33	15	26	18	47
NC NRL-4	46	65	69	19	4	26	37	31	18	37	25	53
NC 152 AI-2	39	64	58	8	4	31	56	33	15	30	19	51
NA-8	40	65	71	10	6	31	61	33	17	31	19	40
Harrow W208	---	---	---	14	7	28	45	37	17	30	26	50
Lovell	36	68	59	12	6	27	56	35	14	28	19	48
Siberian C	31	54	---	12	6	12	17	33	15	23	11	40
LSD 5%	NS	NS	10	7	3	13	10	NS	6	9	8	15
Loring												
Nemaguard	58	20	106	12	3	30	37	54	20	19	65	27
Halford	52	18	102	14	5	23	28	50	17	16	43	24
NC NRL-4	49	15	104	15	4	36	33	58	17	20	49	27
NC 152 AI-2	52	19	84	11	2	22	35	54	19	16	37	26
NA-8	55	23	97	12	3	25	37	48	21	23	45	23
Harrow W208	54	18	117	16	4	35	37	56	21	19	55	32
Lovell	49	16	93	15	5	25	44	56	14	12	37	24
Siberian C	49	29	100	9	4	20	26	30	19	12	32	21
LSD 5%	NS	8	21	5	2	11	10	11	5	5	10	6

[NS]Nonsignificant.

Table 3. Growth as measured by trunk circumference of 4-year-old 'Redhaven' and 'Loring' peach trees on 8 rootstocks at 5 locations in 1980.

Rootstock	Alabama Loring	Alabama Redhaven	Arkansas Loring	Arkansas Redhaven	Georgia Loring	Georgia Redhaven	N. Carolina Loring	N. Carolina Redhaven	S. Carolina Loring	S. Carolina Redhaven	Avg all locations Loring	Avg all locations Redhaven
	Trunk circumf (cm)											
Nemaguard	37	32	24	25	36	32	28	25	41	37	33	30
Halford	34	28	27	24	34	29	24	20	37	35	31	27
NC NRL-4	34	29	27	24	33	29	25	23	40	35	32	28
NC 152 AI-2	34	30	26	22	33	31	25	21	40	34	32	28
NA-8	39	31	28	22	35	33	26	23	40	36	34	29
Harrow W208	36	23	29	26	32	32	26	25	40	36	33	28
Lovell	37	30	29	26	35	33	22	21	40	34	33	29
Siberian C	34	28	29	25	34	29	22	21	36	32	31	27
LSD 5%	3.5	2.6	2.1	2.6	2.9	3.1	2.8	2.5	2.2	2.2	1.2	1.1

ments in Arkansas were discontinued after 1980 due to severe tree loss.

Fruit yield in North Carolina often was higher for trees on Nemaguard, NC NRL-4, or Harrow W208 than for trees on Lovell (Table 2). Similar yields for trees on these rootstocks were recorded in some other locations, but trees on NC NRL-4 in Georgia yielded less in 1980 than those on Lovell. Other rootstocks were comparable to Lovell, but trees on Siberian C sometimes yielded less.

Fruit size was determined in the South Carolina, North Carolina, and Alabama locations. Fruit size on 'Loring' trees averaged 6.2 to 6.8 cm (2.4–2.7 inches) diameter at each of the 3 locations. 'Redhaven' fruits averaged about 6.2 cm (2.5 inches) diameter and were slightly larger (6.2–6.8 cm) in South Carolina and slightly smaller (5–5.6 cm) in North Carolina in 1979. There was no detectable influence of rootstock on fruit size or quality at any of the 3 locations. Differences in yield described in the preceding paragraph reflect differences in numbers of fruit not differences in size.

Growth. Tree spread, height, and shoot length were measured at several locations and trunk circumference was measured at all locations. The average trunk circumference for all experiments 4 years after planting (Table 3) was slightly less than Lovell when trees were on Halford or Siberian C rootstocks. This trend was not evident in all sites, however, and there were many site-to-site differences in growth response. Overall growth was slower in North Carolina and Arkansas than in the other locations. Trees on Lovell rootstock were of the same circumference as Siberian C and Halford in these 2 sites. Smaller tree size was an important factor in the lower yields recorded at these 2 sites.

Nematode resistance. Ring and root-knot nematodes were monitored in the North Carolina and South Carolina orchards (Tables 4 and 5). Root-knot became severe during the 3rd year of growth in portions of the South Carolina planting (Table 5). Most of the tree mortality in this orchard (Table 1) coincided with the distribution of root-knot and ring nematodes in the site.

All rootstocks were susceptible to ring nematodes, but populations usually were lower when Lovell was the host (Table 4), as others have reported (32, 37). However, populations associated with the other rootstocks generally were not significantly different from those on Lovell.

Lovell was very susceptible to root-knot nematodes (Table 5), as others have reported (1, 4). Siberian C, Halford, and NA-8 also were severely infected and the highest number of *Meloidogyne* larvae were associated with NA-8 roots. Nemaguard, NC 152 AI-2, and Harrow W208 were resistant, while NC NRL-4 appeared to be partially resistant. The pattern of infection with NC NRL-4 suggested that NC NRL-4 seeds may segregate for resistance to root-knot.

Table 4. Ring nematodes (*Criconemella xenoplax*) associated with roots of 8 peach rootstocks in the North Carolina and South Carolina locations, 1979–1981.

	Nematodes/100 cm^3 of soil					
	North Carolina			South Carolina		
Rootstock	1979	1980	1981	1979	1980	1981
Nemaguard	113	253	232	31	122	36
Halford	121	177	186	22	204	8
NC NRL-4	143	294	374	70	80	78
NC 152 AI-2	134	303	286	41	24	140
NA-8	148	230	167	12	48	33
Harrow W208	183	301	392	32	162	56
Lovell	93	201	162	26	78	15
Siberian C	100	204	156	31	130	19
LSD 5%	75	116	101	37	136	109

Table 5. Root-knot nematode (*Meloidogyne* sp.) determinations for 8 peach rootstocks at North Carolina and South Carolina locations, 1979–1981.

	North Carolina			South Carolina			
	Nematode larvae/100cm^3 soil			Nematode larvae/100cm^3 soil			Gall index[z]
Rootstock	1979	1980	1982	1979	1980	1981	1979
Nemaguard	2	0	1	3	2	0	0
Halford	6	10	21	96	27	10	3
NC NRL-4	6	5	2	40	6	10	1
NC 152 AI-2	1	1	1	9	0	0	0
NA-8	22	29	53	96	56	16	3
Harrow W208	4	1	0	12	0	0	0
Lovell	5	13	19	137	22	15	3
Siberian C	6	14	41	92	34	11	4
LSD 5%	6	9	32	132	33	16	2

[z]Gall index based on 0 = no galls; 1 = 10% of roots galled; 2 = 20% galled, etc.

Conclusions

It is difficult to generalize about the performance of the rootstocks tested in these experiments because soil and climatic conditions differed considerably. Although each experimental site was maintained according to recommended cultural practices for the area, expertise for nematode control and regular nematode assays were not always available. The possible involvment of nematodes in reduced growth and high mortality in Arkansas has not been determined. Spring frosts sometimes reduced crop yield and often were responsible for the large differences in yield between 'Loring' and 'Redhaven' cultivars. Lack of rainfall in the absence of irrigation was harmful to growth and yield in Arkansas and North Carolina.

The influence of rootstocks upon tree mortality deserves particular attention, because premature tree death is widespread in the Central South and Southeast. The PTSL syndrome appeared in all test plots. Due to severe tree loss in most sites, Siberian C was no an acceptable rootstock in most of the experimental orchards. Substantial tree mortality occurred in all sites by the 6th year (Table 1) and in some locations losses were high by the 4th year.

The use of Nemaguard rootstock presents a problem for peach production in the South. Nemaguard promotes rapid growth and prolific fruit production. It is resistant to the root-knot nematode species common in southern states, but it is very susceptible to ring nematodes. Tree death from cold injury and bacterial canker associated with ring nematode infestations has been severe (5, 22, 23, 25, 26, 37). Ring nematodes are prevalent in many areas where peaches are grown. Prudence suggests the use of Nemaguard only in areas where ring nematode infestations do not occur and where protection from root-knot is essential.

Halford rootstock, which is being used in some orchards that are prone to PTSL, appears to be equivalent to Lovell by the criteria measured, but tree size may be reduced in some locations if Halford is used. The use of Halford requires effective nematode control because it is susceptible to both ring and root-knot nematodes. We conclude from this data that Lovell and Halford are the best available rootstocks for use in replanting southern orchards that are prone to PTSL.

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