Decline of affected trees often begins at 15 to 20 years of age. Dying tree in center of photo is a 22-year-old Frost nucellar navel on Pomeroy rootstock.

Decline of navel orange trees with trifoliate orange rootstocks

Henry Schneider □ John E. Pehrson, Jr.

Disorganized tissue that girdles the tree may be responsible

Trifoliate orange, when tried as a citrus rootstock in northern and central California orchards early in this century, was recognized for having cold tolerance during the freezes of 1910-20. Despite this useful characteristic, few plantings were made with the stock until additional irrigation water arrived on the east side of the Central Valley in the 1950s. After that, about 20,000 acres of Frost nucellar navel trees on trifoliate orange rootstocks were planted in Tulare and Fresno counties. Trees on certain selections of trifoliate orange are fairly tolerant of tristeza virus and also of some *Phytophthora* species and field populations of citrus nematodes in California.

In the mid 1970s, trees began to decline when they were 15 to 20 years of age, and the use of trifoliate orange was discontinued. Trees showed leaf discoloration, some defoliation, twig dieback, and subnormal growth. Some orchards have been removed; in others, individual trees have been replaced as they declined.

We found a disturbance at the budunion that appears to precipitate the decline. It could be an inherent incompatibility or it might be caused by a virus, mycoplasma, or some other submicroscopic infectious agent, as is the case with tristeza of sweet orange on sour orange rootstock, blackline of walnut, pear decline, and the like. Other researchers are conducting tests for infectivity.

In 1982, we began studies of pathological changes at the budunions of Frost nucellar navel orange trees to determine the nature of the decline. We examined 24 selections of trifoliate orange rootstocks at the University of California Lindcove Field Station, Tulare County. In 1984, we also sampled trees in two other Tulare County locations — Orange Cove and Terra Bella. The one-tree plots, replicated five times, were established in 1963 at the three locations by Dr. W. P. Bitters. He obtained most of the trifoliate orange selections from a collection established by Shannon, Frolich, and Cameron at U.C. Los Angeles (see *California Agriculture*, May 1961).

Our studies indicate that two disorders are associated with decline. This report is primarily concerned with one of the disorders, which involves the disorganization and proliferation of tissue at the budunion, climaxing with the formation of a tongue on the inner side of the bark and a groove in the wood. In the other disorder, shoulders form on overgrown rootstocks, followed by compression girdling.

Sampling

Radial sections were made from patches of bark ½ inch wide and 1 inch long from across the budunions. In an initial survey of trees begun in July 1982, such bark samples were taken from trees in two commercial orchards near Exeter and from three trees on Rubidoux trifoliate and one tree each on Kryder and Christiansen trifoliate in the rootstock plot at Lindcove. Later in the summer of 1982 and spring of 1983, all trees in replicates II, III, and IV were sampled.

In August 1983, trees on eight rootstocks at Lindcove were sampled in each of the five replicates, and in February 1984, the trees on the same eight rootstocks were sampled in replicate V. In October 1984, samples were taken from trees on Rich 16-6 and Yamaguchi rootstocks in all five replicates. At Orange

TABLE 1. Condition of budunions of Frost nucellar navel oranges on various trifoliate orange rootstocks in 1982 and spring of 1983.

Rootstock	Ratings in replicates on date sampled* II 7/28/82	III 3/29/83	IV 9/1/82
Large-flowered			
Webber-Fawcett	S Tr N - - 1	S - - - - 1	E - - - - 2
Kryder Med 51	E - - H U 2		E - - - U 2
Pomeroy	P T N H U 3	P D N H U 1	S D N H U 3
Benecke	P T N H - 1	S - - H U 1	E - - - U 2
Kryder 8-5	P D - - U 4	P T N H U 1	E - - - U 2
Rich 7-5	P T - H - 2	P T N H U 1	E - - - U 2
Argentina	P T - H U 6	P T N H U 3	P T N H - 1
Kryder 25-4	E - - - U 1		P T N H U 2
Kryder 60-2	P T N H U 4	P T N H U 2	P T N H - 5
Rich 12-2	E - - - - 1	E - - H U 1	P T N H U 1
Christiansen	P T N H U 1	S - - - - 1	P T - H U 1
Rich 5-2	S - - H U 2	S - - - U 2	P T N - U 1
Towne F	S - - H U 1		S - - H U 1
Kryder 28-3	S - - - U 1	E - - - U 2	E - - - U 2
Towne G	P T - H - 1		E - - - - 2
Yamaguchi	E - - - - 1	E - - H U 1	E - - - - 1
USDA	E - - - U 2	E - - H U 1	E - - - U 1
Small-flowered			
Jacobson	P T - H - 4		E - - - - 2
Rich 16-6	E - - - - 1	E - - - - 1	E - - - - 1
Rubidoux	S D - H U 3	E - - - - 1	E - - H U 1
Rich 21-3	E - - H U 1		E - - - U 2
Rich 22-2	S - - H U 1	S - - H U 1	E - - H U 3
Davis B	S - - - U 1	S - - - U 1	P T N H U 2
English Dwarf	P T N H U 2	E - - H U 1	P T - H U 3

*Key to abbreviations under II, III, and IV — **Column 1:** Condition of phloem; E - excellent, S - satisfactory, P - poor. (See explanations in table 2.) **Column 2:** T - tongue, Tr - tongue formed but then the cambium and phloem were reconstituted. D - disorganization at the budunion. **Column 3:** N - necrosis in disorganized or tongue tissue. **Column 4:** H - horizontal vascular tissue above the budunion. **Column 5:** U - undulations of trunk above the budunion. **Column 6:** Arabic numerals indicate amount of decline in a range of 1 to 10; 1 = normal, 2 = slight, 5 = moderate, 10 = dead. **In all columns,** "-" means that the feature was absent. Blank indicates tree was missing.

TABLE 2. Ratings of phloem at budunion of 1963-planted Frost navel orange trees with selections of trifoliate orange as rootstocks

Rootstock	Number of trees out of number tested (denominator) in each category*† Excellent I	Excellent II	Satisfactory I	Satisfactory II	Poor (tongue) I	Poor (tongue) II
Argentina	1/5	1/4	0	0	4/5	3/4
Kryder 60-2	0	0	0	0	5/5	3/3
Christiansen	0	1/4	0	0	5/5	3/4
Pomeroy	—	2/4	—	0	—	2/4
Yamaguchi	1/5	1/4	4/5	0	0	3/4
USDA‡	3/5	3/4	2/5	0	0	1/4
Rubidoux‡	3/5	1/4	1/5	2/4	1/5	1/4
Rich 16-6	5/5	2/2§	0	0	0	0

*Excellent: Normal band of functional phloem. Satisfactory: Adequate functional phloem, some aberrations not related to tongue formation. Poor: little or no functional phloem. Tongues or developing tongues present.
†Plot I, Lindcove, sampled August 18, 1983. Plot II, Orange Cove, sampled May 2, 1984.
‡Decline of Frost nucellar navel orange trees with Rubidoux and USDA rootstocks has been observed in commercial orchards at 15 to 24 years.
§Two of four trees on Rich 16-6 were excluded because isozyme tests by Dr. Micheal Roose indicated that they were on zygotic and not nucellar seedlings.

Cove, trees on the eight rootstocks were sampled in four replicates in May 1984 (table 2), and at Terra Bella, four trees on Rich 16-6 trifoliate were sampled in October 1984.

Results

Pathological changes at the budunion began with disorganization of bits of the phloem and cambial tissues. Proliferation of the disorganized tissue followed and necrotic pockets sometimes formed. The proliferated tissue enlarged into a tonguelike appendage that projected from the inner side of the bark.

At the same time, owing to disorganization and failure of the cambium to function properly, xylem tissue did not form at the budunion, and the proliferated tonguelike appendages occupied the resulting voids or grooves in the xylem. Affected tissue sometimes took on a brown discoloration. Tongue and groove formation tended to vary from spotty to continuous around the trunks. Where tongues or disorganization occurred, the cambium occasionally reconstituted itself and formed a new layer of normal phloem. The conducting tissue in the scion above the budunion was often turned from the vertical and oriented horizontally around the trunk.

Variability of selections

Trees on the various trifoliate selections were unequally affected by tongue and groove formation in the 1982-83 survey (table 1). Samples from some were normal, others showed pathosis (pathological aberrations) in only one of the samples, while others showed severe pathosis in two or three of the samples.

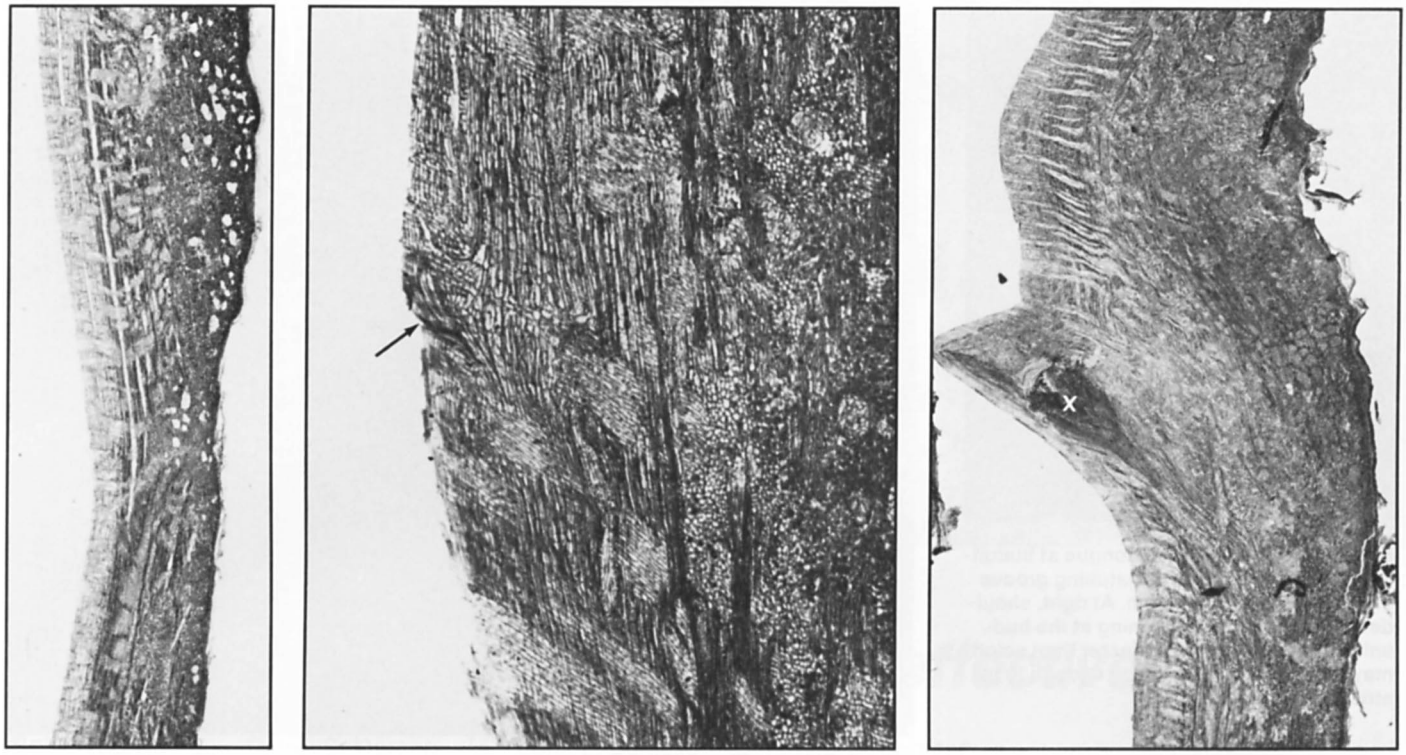
The selections were also graded for undulations, horizontal orientation of vascular tissue, and other abnormalities. Translocation was probably sufficiently blocked in trees on the more severely affected rootstocks to cause the mild to severe decline that has been observed in a few trees thus far. In declining trees in commercial orchards, blockage has been indicated by a negative starch test with a solution of iodine in potassium iodide below the budunion in the wood.

Trees on eight rootstocks in the five replicates sampled in 1983 and 1984 also varied in condition (table 2). Following are details of more intensive studies of trees on certain rootstocks.

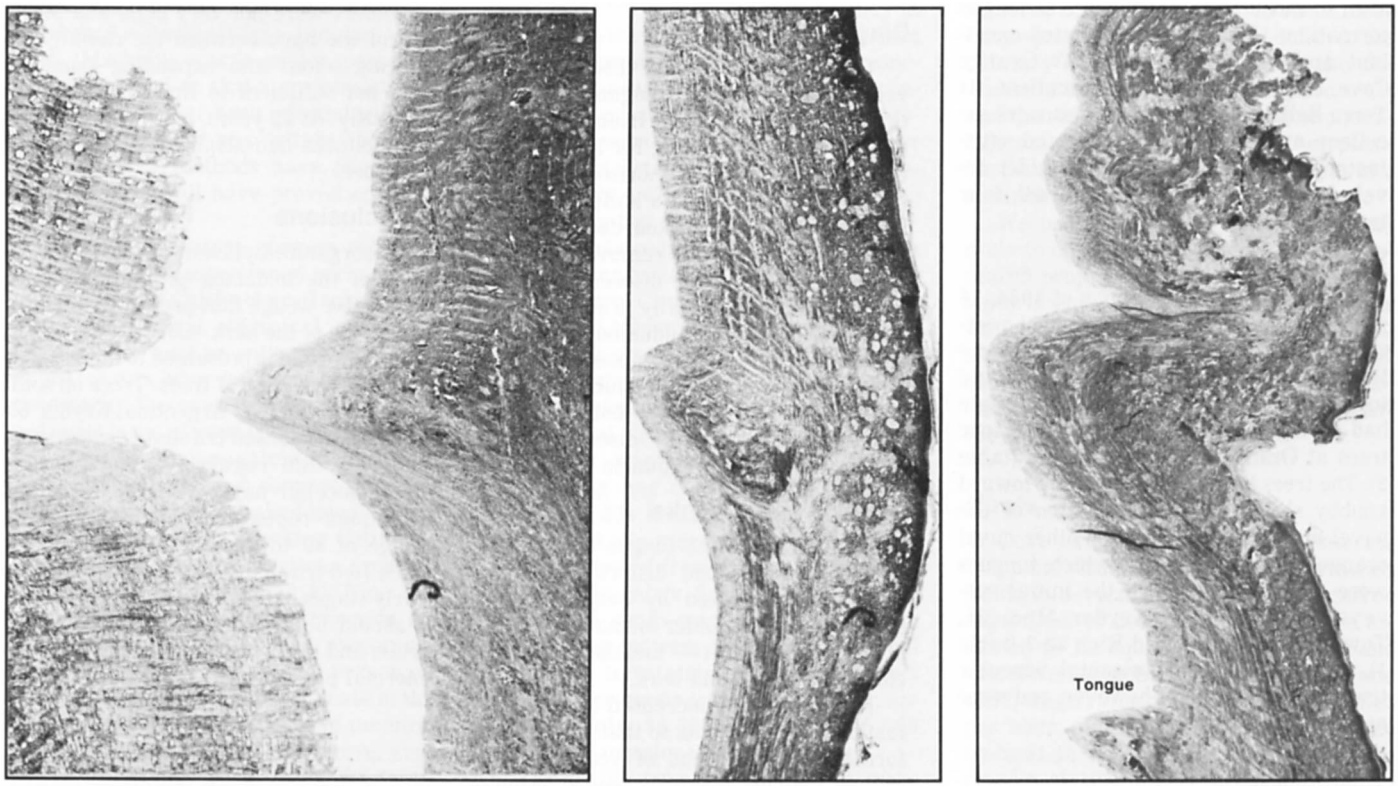
Rubidoux

Rubidoux is the oldest and best known of the trifoliate rootstocks in California. In an experiment with 1929-planted rootstocks at Riverside, five Washington navel oranges on Rubidoux were sampled in November 1951 (at 22 years) and July 1952. Of the ten samples, three showed early disorganization, one showed moderately advanced pathosis, one had advanced tongue formation, and five were normal. In one of the commercial orchards at Exeter, many 1956-planted Frost nucellar navel trees on Rubidoux had declined by July 1982 (26 years). Bark showed advanced tongue and groove formation in two trees that were sampled. At Lindcove Field Station on the same date, one of three trees sampled showed early disorganization. In a later sampling of three replicates, the phloem of two trees was rated excellent and one was satisfactory. In August 1983, five samples were collected from trees at Lindcove and four at Orange Cove; two showed well-developed tongues (table 2), and the other seven were normal.

Apparently it takes 25 years for the tongue and groove disorder to become very extensive and a limiting factor for trees on the Rubidoux rootstock, and some may not be affected even by then. Trees with initial disorganization might revert to normal phloem formation, as was indicated by samples with disorganized phloem in previous annual rings but with normal current phloem.



Bark of a healthy tree (left) shows normally growing cambium and phloem. Decline begins with disorganization of bits of the phloem and cambial tissues at the budunion (center photo, arrow). Disorganized tissue expands (right), enlarging into a tongue that projects into the wood from the inner side of the bark. Pockets of dead tissue (x) sometimes form.



As tongue forms, disorganized tissue and failure of cambium cause a void in xylem at the budunion (left). Above union, vessels in xylem have become horizontal. Cambium may form a new layer of normal phloem where disorganization occurred (center). Upward push of faster growing rootstock may cause undulations and creases in bark above budunion of afflicted tree (right).

Back of bark patch shows tongue at budunion of tree in decline and matching groove on the face of the cambium. At right, shoulders resulting from thickening at the budunion as rootstock grows faster than scion may pinch conducting tissue enough to restrict translocation.

Rich 16-6

At Lindcove, five Rich 16-6 trees were sampled 17 times between July 1982 and October 1984. Not one sample showed even so much as an early stage of tongue formation; 15 samples were rated excellent and two satisfactory. At Orange Cove, two trees were rated excellent. At Terra Bella, two of four samples were excellent, and two others were rated satisfactory. A limited amount of shoulder development was beginning on all four trees.

Yamaguchi

From 1982 to the summer of 1984, 16 samples from trees on Yamaguchi rootstock at the Lindcove Field Station were free of phloem disorganizations and tongues, but in October 1984, one sample had a tongue. In May 1984, three of four trees at Orange Cove had tongues (table 2). The trees had a slight tendency toward knobby shoulders and undulation of the navel orange bark. The only other navel orange combinations for which tongues were not encountered in the initial surveys were trees on Kryder Med. 51, Towne F, Rich 21-3, and Rich 22-2 (table 1). They all showed horizontal vascular tissue and undulations, however, and were not sampled further.

Argentina, Kryder 60-2, and Christiansen

Trees on these three rootstocks at Lindcove and Orange Cove regularly yielded samples with the tongue and groove syndrome, Eight of nine Argentina samples had tongues, ten of ten Kryder, and eight of ten Christiansen.

Diagnosis

The tongue and groove disorder in advanced stages may be diagnosed by cutting a rectangle of bark from across the budunion and examining for a tongue on the cambial face and a horizontal groove in the wood. The tip of a knife, such as a linoleum knife, is worked deep into the groove in the wood for removal of bark.

Early stages of the disorder can only be detected anatomically. The cambium and bark above the budunion may show undulations or wrinkles caused by an upward compression. The resulting creases in the bark should not be confused with the tongues formed by disorganization and proliferation of budunion tissues.

Distortions of trunks

In addition to the tongue and groove formation, we found distortions of the trunks characterized by overgrowth of the rootstocks, shoulder formation, and — above the budunion — undulations of the cambium, wood, and bark.

Rootstocks had increased in diameter faster than scions had, so that shelves had formed over a period of years. As the shelves formed, shoulders tended to build up on them because secondary thickening was not only radial but also vertical. The upward enlargement of the rootstock caused the bark of the navel orange scion to be pushed vertically, resulting in undulations and creases.

In the 20-year-old trees under study, shoulders were not very high, and pinching of the bark between the radially enlarging scions and expanding shoulders was not sufficient to limit translocation seriously. At 22 years, trees with Rich 16-6 rootstocks had sloping shelves without shoulders.

Conclusions

Disorganized phloem and cambial tissues at the budunion proliferate into a tonguelike wedge that protrudes from the inner side of the bark. Affected tissue acts as a girdle and is presumed to be responsible for the decline of trees. Trees on some rootstocks, such as Argentina, Kryder 60-2, and Christiansen trifoliates, were more severely and regularly affected than Frost nucellar navel trees on USDA and Rubidoux rootstocks when in the age range of 19 to 20 years. One rootstock, Rich 16-6 trifoliate, was not showing even early stages of tongue formation. Rich 16-6 should be included in future rootstock trials and it may be the best bet for commercial planting.

Henry Schneider is Plant Pathologist, Department of Plant Pathology, University of California, Riverside, and John E. Pehrson, Jr., is Cooperative Extension Subtropical Horticulturist, UC Lindcove Field Station, Exeter. *The authors are indebted to the Citrus Research Board for financial support.*