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Citrus Canker in Florida

Fifty-seven years after citrus canker was last seen in Florida, a new form of this bacterial disease was found in the state, in September 1984 (8,18,20). The cause was determined to be *Xanthomonas campestris* pv. *citri* (Hasse) Dye. This finding immediately prompted a state and federal program to restrict further pathogen distribution and to eradicate the disease. This program continues, with 23 locations in nine counties confirmed as positive for the disease as of February 1987. The new form of this serious disease, with its unusual symptoms, has occurred mainly in citrus nurseries and is referred to as the nursery form of citrus canker.

The Asiatic form of citrus canker was found in October 1985 at one location in a north Florida county where citrus is uncommon. Asiatic citrus canker was also found from June through November 1986 in residences and in one commercial grove within two counties where citrus is common. The 1985 and 1986 infestations of Asiatic citrus canker are believed to be unrelated. An eradication and quarantine program for Asiatic citrus canker is in effect and is similiar to that for the nursery form. The occurrences of the Asiatic form and of the unusual nursery form of the disease apparently are not related.

Biological and Historical Background of Citrus Canker

Citrus canker is usually characterized by conspicuous, erumpent lesions that develop on leaves, twigs, and fruit. Severe infections result in defoliation, dieback, blemished fruit, and premature fruit drop (5,6,15,16,21; K. W. Loucks, *unpublished*). The disease has at least three distinct forms, based on geographic distribution and on differential susceptibility of citrus hosts to the pathogen (5,6,16). Canker A (Asiatic canker) is the most widely distributed form and is endemic in Asia, Africa, Oceania, and South America. Canker A affects many rutaceous hosts and has the broadest host range of the three forms. Canker B (cancrosis B) primarily affects lemon in Argentina, Uruguay, and probably Paraguay. Canker C (Mexican lime cancrosis) affects only *Citrus aurantifolia* (Christm.) Swingle 'Mexican' in Brazil. In 1981, a disease of Mexican lime caused by *X. c.* pv. *citri* occurred in Colima, Mexico. This disease, referred to as citrus bacteriosis, causes cankerlike lesions on leaves and twigs but not on fruit.

Citrus canker can be controlled by the use of cultivars with some resistance, carefully timed chemical sprays, windbreaks and other cultural practices, and phytosanitary measures (5,6,14–16). Controlling the disease does not preclude regulatory considerations, however. Because the pathogen is disseminated on citrus fruit, countries and states that do not have the disease prohibit or regulate the importation of potentially infected/infested fruit from areas where canker occurs (19).

The citrus canker bacterium was introduced into Texas in 1910 on infected trifoliate orange seedlings from Japan (21; K. W. Loucks, *unpublished*). During 1912–1913, the disease was observed in Florida citrus nurseries. By 1914 the disease was widespread, and a grower/shipper group in south Florida burned trees to eliminate the disease. This infestation of *X. c.* pv. *citri*, which most likely was caused by a strain of the A type, occurred in 26 Florida counties and in six other Gulf Coast states. In 1915, acting with newly acquired regulatory authority, Florida and the federal government initiated an eradication campaign in Florida. Similiar programs quickly began in other affected states. This campaign was based on regular nursery and grove inspection, on-site destruction of canker-infected trees and entire canker-infested nurseries, adherence to sanitation procedures by citrus workers, and strict enforcement of quarantines. The last canker-infected tree was found in Florida in 1927. Florida was declared free from the disease in 1933, after $6 million had been spent for eradication. In 1947, the United States was declared canker-free.

Citrus canker was eradicated from

Table 1. Initial diagnosis of nursery form of citrus canker in Florida in 1984

Analysis	Diagnosis
Isolation of the pathogen	Yellow pigmented bacterium
Presence of xanthomonadin pigment	*Xanthomonas*
Routine characterization (17)	*X. campestris*
Fatty acid analysis (19)	*X. campestris*
Positive pathogenicity tests on citrus at two separate laboratories	*X. c.* pv. *citri*
Serological tests (ELISA)	*X. c.* pv. *citri* but not of known groups of A, B, or C strains
Plasmid and chromosomal DNA analyses and bacteriophage sensitivity tests	Not of known groups of A, B, or C strains

Australia, New Zealand, South Africa, and certain areas in the state of São Paulo, Brazil (6,13,15,16). Eradication was attempted but not achieved in Argentina (12,14). Active eradication campaigns are now in progress in Florida (20), Brazil (16), Uruguay (6,16), Australia (13), and possibly North Yemen (7).

Vigilance for citrus canker did not end after the disease was eradicated from the United States. In Florida, some form of citrus survey for canker continued; port-of-entry inspections/interceptions of citrus contraband, including canker-infected citrus, were made by the USDA Animal and Plant Health Inspection Service (APHIS); and federal and state laws prohibited citrus importation in any form except seeds from canker-infested countries. During the 1970s and 1980s, however, an uneasiness developed among regulatory personnel that canker might appear again in Florida. New infestations were reported in the Western Hemisphere in Argentina, Brazil, and Mexico. Travel from these and other canker-infested countries increased, and as a consequence, 171 citrus canker interceptions were made at Florida's ports between 1 January 1971 and 23 June 1983 (2). In response to this uneasiness, the following measures were taken: the creation of a national working group on citrus canker, which set research priorities from 1976 to 1983; the establishment of a cooperative research program on citrus canker in Argentina by Florida and Argentina scientists from 1978 to 1982; and the development by scientists and plant protection regulatory officials of a Citrus Canker Disease Action Plan (1) for eradication of the disease should it be detected in the United States.

Nursery Form of the Disease

Initial detection/diagnosis. A nurseryman alerted the Division of Plant Industry, the state regulatory agency, to a disease at his 55-acre (23-ha) citrus nursery in southern Polk County. Because a serious disease was suspected on many citrus hosts, the nursery was quarantined soon after the site was visited on 27 August 1984. The concerted efforts of several scientists from state and federal agencies resulted in identification of the pathogen on 8 September as *X. c.* pv. *citri* (Table 1).

Symptoms. Leaf lesions at this nursery and subsequent infested sites were atypical of citrus canker. Instead of the usual extensive erumpent tissue, leaf lesions were mostly flat and sometimes sunken, with extensive water-soaking, chlorosis, and necrosis (Fig. 1). Lesion size and appearance varied with age of the leaf at the time of infection and with variety. Because of the atypical leaf symptoms, referring to the disease as Xanthomonas leaf spot of citrus has been suggested (10).

The appearance of twig lesions or cankers differs from that of leaf lesions and is more typical of citrus canker. Distinctly raised, watery, blisterlike lesions as well as brown, corky, erumpent lesions with dark, greasy-appearing margins commonly develop on twigs of affected trees (Fig. 2).

No infected fruit were found at the original site, but fruit infection was soon demonstrated experimentally. Lesions were observed on the fruit as well as the stems and leaves of *Poncirus trifoliata* (L.) Raf. 'Flying Dragon' in a field nursery in August 1985. Fruit lesions were sunken, necrotic in the center, and surrounded by water-soaking and chlorosis (Fig. 3). Fruit lesions penetrated only into the rind—a characteristic of fruit lesions caused by other strains of citrus canker bacteria (6).

Distribution. The nursery form of citrus canker has been confirmed in 20 nurseries and on immature trees at three grove sites. Figure 4 shows the distribution of the disease in Florida. The disease has been found in nine counties, and most of the infestations have occurred in the "ridge" citrus region of Polk and Highlands counties.

All infestations of nursery canker after the original one have been much less extensive within the site. Infected or infested citrus were found in 50% of the blocks of site 1, whereas about 10% of the citrus in site 11 showed symptoms. In some nursery sites, fewer than 10 plants were infected. Among the three grove infestations, only 11 immature citrus trees showed symptoms of the disease. Sites 13 and 22 had four resets with symptoms, and these resets originated in canker-infested nurseries. Site 15 involved resets from an infested nursery, but seven adjacent immature trees had symptoms.

The nine sites of 1984 were linked to site 1 or site 6 by citrus nursery stock sales. Origin of the infestation could not be explained for site 1 only. In 1985 and 1986, however, nine of the 13 positive sites were not linked by nursery sales, and the nine infestations were not readily explainable by other known means of transmission, such as workers, equipment, and windblown rain.

Citrus hosts. Not only was disease distribution greatest at site 1, but diversity of infected hosts was also greatest there. Table 2 lists the host range of nursery canker. Sixteen selections of citrus and citrus relatives within four species and four hybrid crosses have been natural hosts. The most common host has been the rootstock citrumelo, a hybrid between trifoliate orange and grapefruit (*P. trifoliata* × *C. paradisi* Macf.). Citrumelo (cv. Swingle and clone 80-3) was involved in 15 of the 23 positive sites and has been the sole host "infected" in 10 sites; in seven of these 10, the origin of infestation was unexplained. Most of this citrumelo involvement occurred in 1985 and by year's end had a significant impact on the use of this rootstock by nurserymen. Grapefruit, the second most frequently infected host and one of the parents of citrumelo, was affected in seven sites. Mandarin orange (*C. reticulata* Blanco), considered to be

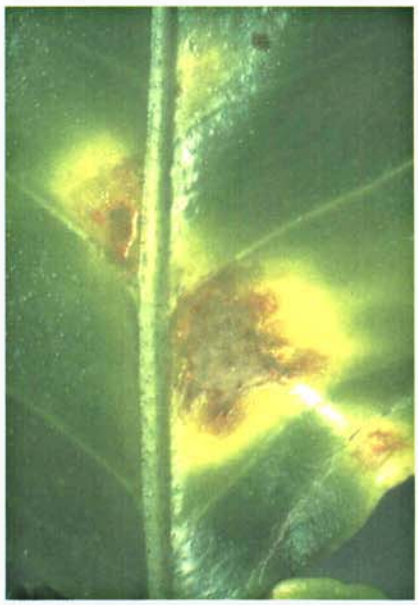

Fig. 1. Leaf lesions of the nursery form of citrus canker on grapefruit (*Citrus paradisi*) are sunken, water-soaked, and surrounded by chlorosis.

Fig. 2. Stem lesion of the nursery form of citrus canker on citrumelo (*Poncirus trifoliata* × *Citrus paradisi* cv. Swingle) is raised, brown, and corky with a greasy-appearing margin.

Fig. 3. Fruit lesions of the nursery form of citrus canker on *Poncirus trifoliata* cv. Flying Dragon are sunken, necrotic, and surrounded by water-soaking and chlorosis.

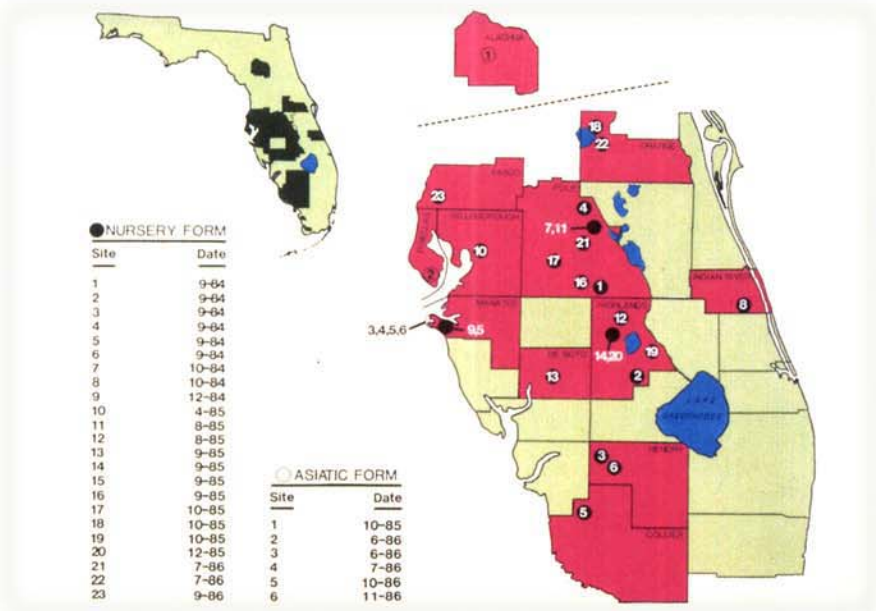

Fig. 4. Sites in Florida infested with the nursery and Asiatic forms of citrus canker from September 1984 to November 1986 (Alachua County has been moved southward in the partial map).

Fig. 5. (Right) Trees treated with diquat at 300 ppm and (left) untreated trees in a Florida citrus grove near a nursery infested with *Xanthomonas campestris* pv. *citri*.

relatively resistant to other types of canker (6), was reported twice where other hosts were also infected. Sour orange (*C. aurantium* L.) has been found in infested nurseries but has not been naturally infected, even though it is experimentally susceptible. Mexican lime and Persian lime (*C. aurantifolia* hybrid) have not been in the inventory of infested nurseries but are experimentally susceptible. As with other citrus cankers, Mexican lime is more susceptible than Persian lime to the nursery type of citrus canker.

The occurrence of citrus canker in Florida may be related to the fact that the citrumelo cultivar Swingle has become very popular as a rootstock in Florida since its release to the industry in 1974. The use of Swingle citrumelo as a rootstock for registered budwood in nurseries increased steadily from 4.7% in 1975 to 30.1% in 1985. Statistics for 1986 are not yet available, but it is expected that there were fewer budded citrumelo than in 1985 and, furthermore, that the number of unbudded citrumelo plants in nurseries was much lower than in previous years. Trifoliate orange, one of citrumelo's parents, comprised 1.2% of rootstocks used during 1984–1985; grapefruit comprised 3.8% of registered scion used in nurseries (C. O. Youtsey, Chief of Budwood Registration, *personal communication*).

Eradication and regulatory program. Upon the initial confirmation of citrus canker, the Citrus Canker Disease Action Plan (1) was adopted as a working guide for the program. The plan specifies procedures for survey, eradication, and regulatory actions. Florida's commissioner of agriculture and the deputy administrator of APHIS immediately assembled a Joint State/Federal Citrus Canker Technical Advisory Committee and charged them to recommend policy. The 17 members of this committee represent citrus industry groups, research and regulatory scientists, and state and federal regulatory personnel. The committee met two or three times a week initially, then weekly, and, by late 1984, monthly or bimonthly. In late 1985, a seven-member biologically oriented Special Task Force on Citrus Canker was named to explore citrus canker biological issues and present recommendations to the technical advisory committee. Recommendations by the technical advisory committee that are adopted by the commissioner and the deputy administrator become policy as part of the action plan and are filed and included as part of the citrus canker rule under Florida Statute 581, which specifically grants pest eradication and control authority. The action plan, which is in its fourth edition (3), is administered by the state and federal regulatory agencies through the Citrus Canker Project director's office. During the summers of 1985 and 1986, the Citrus Canker Project employed approximately 800 and 500 people, respectively.

A thorough survey of all citrus is essential to locate and delimit centers of infection. This is a monumental task, since Florida has over 600,000 acres (250,000 ha) of citrus, approximately 1,000 citrus nurseries, over 1,300 retail citrus outlets, and an estimated 1.4 million residences that have citrus. The number of inspectors assigned to survey has varied from 30 to 600, and higher numbers are employed in the summer and fall when conditions for disease development are optimal. The frequency of inspection varies from once or twice a month for nurseries to at least once a year for groves and residences. The number of inspections for groves varies according to risk. For example, groves where resets purchased from an infested nursery have been removed or that border an infested nursery are considered high risk and are inspected two to four times a year. Destination of the fruit also affects the number of inspections. Two preharvest inspections are required when fruit is intended for fresh fruit markets, but no special preharvest surveys are necessary for citrus that is to be processed. Repeated surveys are necessary because the pathogen may infest the foliage but cause no symptoms, infection and symptom development are seasonal, low levels of canker are difficult to detect when symptoms are sparse and other diseases are present, and citrus stock is constantly being moved unless quarantined.

With survey, there is considerable movement of vehicles and people from one location to another. Disinfestation of vehicles and tools, as well as of hands, shoes, and clothing, is required before and after each inspection. Disinfestants that are approved for use are 70% isopropyl or ethyl alcohol or 2,000 ppm quaternary ammonia (i.e., double and quadruple chain formulations only).

Surveyors are trained to recognize citrus canker by symptoms. Field diagnosis is not always reliable because citrus canker symptoms resemble those of other diseases. Specimens are submitted for diagnosis to the state's plant disease quarantine laboratory at the Florida Department of Agriculture and Consumer Services in Gainesville. Whereas the initial diagnosis in 1984 was elaborate, subsequent diagnoses have been based on pathogenicity on citrus and are often supplemented with an immunofluorescent analysis, ELISA, and a DNA probe. Pathogenicity tests are performed with bacteria isolated from two separate collections so as to minimize the possibilities of mix-ups and laboratory contamination. Also, corroborative pathogenicity tests are conducted at a USDA Agricultural Research Service

(ARS) laboratory in Beltsville, Maryland. When citrus canker is reported, scientists and regulatory personnel visit the site for an assessment.

Site personnel are interviewed about relevant activities, and nursery (or grove) records are reviewed to obtain information about citrus received and sold. If nursery sales link one site to another, the date of stock delivery from the infested site is the date of infestation. In the absence of a stock delivery date, the oldest symptoms are analyzed to approximate the time of infestation. Lesion age can be estimated from infected tissue age because citrus tissue is susceptible to natural infection only during its early stages of development. By this analysis, the most probable date of infection can be established and the date of infestation estimated.

Citrus trees leaving the nursery between the dates of infestation and canker detection are considered to be "exposed." Exposed citrus may have gone to other nurseries, groves, retail outlets, and homeowners' yards. The exposed citrus as well as the entire infested nursery site are probable sources of new infestations. Accordingly, infested and exposed citrus are subject to destruction and/or quarantine.

Nearly 20 million young citrus trees have been destroyed because of the nursery form of citrus canker (Table 3). In the first 17 canker-infested nurseries (i.e., September 1984 through October 1985), the entire citrus inventory was destroyed regardless of the number or distribution of infected plants. It was reasoned that windblown rain, workers, and equipment had moved the pathogen well beyond the infected plants and infested the nursery. Exposed citrus that had left the nursery from the date of infestation to that of canker detection was also destroyed in its new site even if symptoms of citrus canker were absent. If the new site was another nursery or retail outlet, the destruction extended 125 ft (38 m) beyond the exposed citrus into the surrounding citrus. If that site were a grove or homeowners' yard, only the exposed trees were destroyed. In late 1985, another large field nursery was found to have citrus canker on a few citrumelo plants (site 20, Fig. 4). By this time, the consensus among scientists, regulators, and those in the citrus industry was that less severe host destruction measures were in order because the disease had not manifested itself in mature groves and did not always appear to be serious in nurseries. A major policy change, termed risk assessment, began with the 18th canker-infested nursery.

Risk assessment involves weighing situational factors about the infestation and attempting to achieve eradication by minimal host destruction and implementation of quarantines and/or surveillance. Situational factors include amount and location of the infection within the site, pathogenic aggressiveness of isolated strains compared with other similiar strains from Florida, worker activity within and from the infested area, disinfestation procedures used at the site, and field vs. greenhouse where there would be differences in climatic factors such as wind, rain, etc. Accordingly, in the 18th canker-positive nursery, over 720,000 citrus trees were destroyed in the infested block and in an adjacent barrier radius of 125 ft (38 m). The remaining 1–7 million trees were quarantined and have been regularly inspected since without canker being detected. Sale of trees from this nursery resumed in January 1987. In July 1986, a large indoor nursery containing 300,000 citrus plants had nearly 200 canker-infected plants (site 21, Fig. 4). Under this particular risk assessment, only infected trees were destroyed; adjacent exposed plants were voluntarily destroyed. If inspections continue to be negative for canker, the nursery will likely be permitted to sell citrus in the spring of 1987. At risk-assessed sites 20 and 21, copper-containing bactericides are being used on a regular basis. At canker site 23 (Fig. 4), a small field nursery, the owner elected to destroy all plants. Risk assessment policies have also modified the destruction of grove resets. Policy evolved in 1986 from destroying exposed resets that had moved from an infested area and buffer zone of the nursery to allowing all exposed resets to remain under surveillance. Over 290,000 grove resets in 17 counties that would have been destroyed under the earlier policy have been retained by risk assessment. Only four of these resets have been found to have the disease (site 22, Fig. 4). As of February 1987, no trees had to be destroyed because of canker eradication policies.

Table 2. Infected hosts at sites of nursery form of citrus canker in Florida during 1984–1986

Hosts	Sites[a]
Scions	
Citrus paradisi, grapefruit cvs. Ruby Red, Marsh, Duncan	1, 6, 7[b], 8, 9, 15, 21
C. sinensis, sweet orange cvs. Valencia, Pineapple, Hamlin, Navel	1, 3[b], 5, 13
C. reticulata × *C. paradisi* and hybrids and backcrosses tangelo cvs. Minneola, Nova tangerine cv. Sunburst	8, 21, 22[b], 23[b]
C. reticulata × *C. sinensis*, tangor cv. Murcott	1, 9
Rootstocks	
Poncirus trifoliata, trifoliate orange cv. Flying Dragon	11
P. trifoliata × *C. sinensis*, citrange cv. Carrizo	1
P. trifoliata × *C. paradisi*, citrumelo cv. Swingle, clone 80-3	1, 2[b], 4[b], 5, 10[b], 11, 12[b], 14[b], 15, 16[b], 17[b], 18[b], 19[b], 20[b]
C. reticulata, mandarin cv. Cleopatra	1,21

[a] Shown in Figure 4; 1984 = sites 1–9, 1985 = sites 10–20, 1986 = sites 21–23.
[b] Sole host at site.

Table 3. Number of citrus plants destroyed to eradicate nursery form of citrus canker in Florida, 19 August 1984 to 7 November 1986

Locations (no.)	No. of plants destroyed
Infested nurseries (20)	11,781,398
Exposed nurseries (90)	5,605,242
Exposed retail outlets (627)	70,875
Groves (resets) (347)	1,454,607
Homeowners' yards (16,055)	30,359
Plus voluntary destructions in any of above (328)	1,033,884
Total	19,976,365

Destruction of trees of an infested or exposed site commences as soon as legally and logistically possible. Various means have been used to destroy citrus. A specially built propane-fired burner on sleds used for the first infestation left charred remains and living roots that had to be removed mechanically or by hand. The destruction of trees in this 55-acre (23-ha) nursery took 24 days. Various methods have since been developed to expedite plant destruction in field nurseries, greenhouses, grove sites, retail outlets, and homeowners' yards. Bulldozing and hand-pulling are used to collect plants, which are then doused with fuel and burned or buried in approved landfills. Plants in retail outlets or homeowners' yards are generally cut up, placed in bags, and removed from the property.

The first nursery where canker was detected was heavily infested and

surrounded by groves. A herbicide was applied to grove trees within 125 ft (38 m) of the nursery. When a sublethal dose of diquat (300 ppm) is properly applied to citrus, leaves die within 4 days (Fig. 5), twigs die back to brown wood in 3 wk, and the tree resprouts within 30 days. Thus, any infestation on leaves and recent infections on green wood are likely to be destroyed. No citrus canker has been found in the groves around the first nursery or in treated groves surrounding other infested nurseries.

Quarantines on nurseries have been long and severe because nursery stock movement carries a high risk of pathogen dissemination and because the disease has been primarily a nursery problem. Table 4 lists the chronology of quarantine-related activities in citrus nurseries. Citrus nurseries that had no apparent connection to infested sites began selling citrus almost 3 months after the quarantine was imposed. Nurseries with stock transfers from infested nurseries were quarantined for 7 mo, and only after the canker-susceptible spring flush was repeatedly surveyed. In the 26 months of the eradication program, nurseries that sell citrus to retail outlets and homeowners were under quarantine for 22 months and did not resume sales until late October 1986. This drastic action was needed because two infested nurseries sold extensively to retailers, and poor and incomplete sales records made locating the plants that moved from retailer to homeowner very difficult. Regulatory officials fear that if citrus canker becomes established in dooryards, eradication will be difficult, if not impossible.

In September 1985, a quarantine was placed on all nursery movement. This quarantine was recommended for 13 months and was imposed because of too many unexpected occurrences in nurseries during the preceding months, too much movement of exposed citrus to groves, the inability to explain how the bacterium was introduced into many of these nurseries, and the unexplained and many occurrences on citrumelo. The reaction of the citrus industry to the announcement of an extended quarantine was intense. Grove owners wanted trees to replant frozen-out groves and to replace trees removed because of canker regulations and various diseases. Nursery owners claimed they could not endure another prolonged quarantine. Three public hearings were held, and a special task force was appointed to make recommendations on the proposed 13-month quarantine. Special multicomponent protocols adopted on two subsequent dates gradually lifted the proposed 13-month quarantine. In November 1985, the following recommendations were among those first adopted:

1. Planting citrumelo and selling citrumelo seedlings were temporarily banned until a statewide survey was made of citrumelo foliage (i.e., suckers or sprouts from roots) emerging from grove trees where this highly canker-susceptible rootstock was used.

2. Sale of nursery stock free from citrus canker was allowed 60 days after all citrumelo rootstock had been removed by voluntary destruction or by budding. (Many nurseries had destroyed their citrumelo before this policy was implemented.)

3. A training and certification program for budders was instituted. (In some of the "unexplained" infestations, budding activities and budders could have been inadvertent disseminators of canker and a possible explanation for the infestation.)

Over 35,000 citrumelo sprouts in groves throughout the state were surveyed without citrus canker being detected, suggesting that the disease was not endemic in Florida and/or always associated with citrumelo. Also, over 900 budders and nurserymen were trained and certified for propagation activities. Accordingly, the quarantine was again relaxed in February 1986. Citrumelo could be used as a rootstock in nurseries physically separated by various distances from other citrus nursery stock but had to be grown as a single crop and could not be mixed with plants of different ages. Thus, the changes made in November and February averted the 13-month quarantine on nurseries and minimized the risks of distributing the pathogen.

Even though only three grove sites have been found infested with the nursery form of citrus canker, numerous regulations have been placed on fresh fruit movement. These regulations have undergone minor changes since initially promulgated, and most are still operative. In September 1984, all fruit movement stopped, at the very beginning of the harvesting season. Movement to states not producing citrus began 11 days after canker was announced, and intrastate movement began 2 months later. At these times, acceptable protocols were established to relax the quarantines on interstate and intrastate movement. A certification protocol to move Florida fruit to citrus-producing states was developed but as of November 1986 had not been sanctioned by those states or approved by APHIS.

Fruit movement from and within Florida carries very little risk when coupled with special regulatory actions. Special regulatory actions are expedited by compliance agreements between the regulatory agencies and the citrus shippers. These agreements specify in writing certain criteria that must be met before a consignment can be moved. With intrastate movement, for example, packinghouses are under an agreement: 1) to accept fresh fruit only from groves certified to be canker-free (determined by special survey before harvest) and with no exposed resets from canker-positive nurseries, 2) to receive fruit from groves in a tarped conveyance, 3) to treat fruit with 2% chlorine for 2 minutes at pH 7 or with sodium *o*-phenylphenate (SOPP) for 1 min, 4) to disinfest trucks, boxes, and tarps, 5) to dispose of any plant refuse in an approved manner, and 6) to issue limited permits. The limited permit indicates that fruit can move and states that the packinghouse has met the conditions of the compliance agreement. Limited permits may be temporarily withheld from packinghouses that do not fully comply. Thus, fruit moves with an extremely low risk of spreading the pathogen. Compliance agreements are used for a wide variety of operations. During the 1984–1985 fruit season, compliance agreements were made with 229 packinghouses, 251 processing

Table 4. Chronology of quarantine-related activities in citrus nurseries because of nursery form of citrus canker in Florida, 10 September 1984 to 27 October 1986

Date	Activities
10 September 1984	Quarantine on all nurseries and groves
4 December 1984	Exposed nurseries remain quarantined, but intrastate movement permitted from noninfested/nonexposed nurseries to other nurseries and groves
7 January 1985	Exposed nurseries remain quarantined, but intrastate movement permitted from noninfested/nonexposed nurseries to retail outlets and homeowners
1 April 1985	Intrastate movement permitted from exposed nurseries to other nurseries and groves
15 May 1985	Quarantine on nursery stock movement to retail outlets and homeowners
5 September 1985	Quarantine on nursery stock movement to nurseries and groves
22 November 1985	Intrastate movement permitted, with regulatory limitations, from nurseries to other nurseries and groves but not to retail outlets and homeowners
24 February 1986	Regulatory limitations reduced on intrastate movement from nurseries to other nurseries and groves but no movement permitted to retail outlets and homeowners
27 October 1986	Intrastate movement permitted from nurseries to retail outlets and homeowners

plants, 139 gift-fruit shippers, 60 scale operators (independent buyers), 88 seed extractors, 1,342 retail outlets, and 54 flea markets. A total of 43,090,471 boxes of fresh fruit were shipped under compliance agreements, and 111,121 limited permits were issued. Statistics were similar for the 1985–1986 fruit season.

Other Floridians have also been affected by the citrus canker regulations. Over 16,000 homeowners have had exposed citrus destroyed in their yards (Table 3)—and without any governmental financial assistance. They were not able to purchase Florida citrus fruit for 2 months in 1984 and could not move fruit from their property or buy citrus trees at nurseries and retail outlets (except for a few months in 1985) until October 1986 (Table 4).

Asiatic Form of the Disease

In October 1985, two immature *C. hystrix* DC. plants near an oriental restaurant in Alachua County (Fig. 4) had raised, erumpent leaf and stem lesions characteristic of citrus canker. On the basis of serological analysis, phage typing, genomic DNA analysis, and pathogenicity of the isolated pathogen, the disease was diagnosed as the Asiatic form of citrus canker. Because this small infestation was 100 miles (161 km) north of commercial citrus plantings and no citrus was moved from the infested property, it was perceived as a minimal threat to commercial citrus. Further, results of a nationwide survey of restaurant properties, nurseries, and retail suppliers likely to contain or stock *C. hystrix* were negative for citrus canker. Origin of the pathogen in this occurrence of citrus canker remains unexplained, although there is some conjecture that it could have been introduced as a condiment from the Far East.

During the summer and fall of 1986, Asiatic citrus canker was diagnosed on mature and immature citrus at numerous residences and in one grove in central west Florida near the Gulf Coast (Fig. 4). The host range was wide and typical of Asiatic canker; grapefruit, Mexican lime, and the orange cultivar Pineapple were most severely affected. Infestation statistics from five sites were: St. Petersburg in Pinellas County, 22 trees in eight residences; Holmes Beach (Ana Marie Island) and Bradenton in Manatee County, 501 trees in 259 residences and 51 trees in 28 residences, respectively; and Palmetto in Manatee County, 1,067 trees in a 362-acre (146.5-ha) grove and four trees in two residences. The five infested sites were separated by 1–14 miles (1.6–22.5 km) and estimated to have had citrus canker for less than 1 to over 2 years. Windblown rain was the most likely means of localized pathogen spread within most sites, and lawn care workers and movement of citrus by homeowners have been suggested as means of more distant spread. Investigatory efforts have not indicated an origin for the infestation by Asiatic canker along the Gulf Coast of central Florida.

Eradication policies formulated for the nursery form of citrus canker were applied to the Asiatic form. The 1,645 infected trees in the grove and the residences were destroyed, 1,111 exposed citrus trees within 50 ft (15.2 m) of infected trees were severely pruned, and 3,067 exposed grove trees were voluntarily destroyed. All infected or exposed trees have been destroyed.

To determine the eradication efficacy of chemical defoliation, 23 infected grapefruit trees and 360 symptomless trees in an isolated 6-acre (2.5-ha) block of the grove were treated with diquat (300 ppm) in July 1986. The trees resprouted, and as of November 1986 no canker had been detected on the new foliage.

Some regulatory policies on the Asiatic form are the same as those for the nursery form, but others are unique or more stringent. Fruit from over 22,000 trees remaining in the once infested grove can move only to nearby processing facilities until canker is no longer a problem in the grove. Fresh fruit movement within 1–1.5 miles (1.6–2.4 km) of an infested property is regulated as to packinghouse location and fruit-marketing destination; with the nursery form, such movement is regulated up to 0.5 miles (0.8 km). Because much of the infestation has occurred in residences and because many residents in the area use lawn care services, 225 services are under compliance to disinfest hands, clothing, and equipment between lawns (properties) and to dispose of citrus clippings properly.

Costs

The eradication and regulatory program cost $25 million from September 1984 to 1 July 1986. This disbursement included a financial assistance plan that distributed over $12.3 million of state and federal funds to nurserymen, grove owners, and citrus retailers affected by tree destruction. This is the first time compensation has been given for a plant disease and was made possible at the federal level by the secretary of agriculture declaring an extraordinary emergency. Compensation approached capital replacement costs and greatly enhanced the cooperation and support given the eradication program by the citrus industry. State and federal governments shared funding of the program equally until 31 March 1986, when the federal government withdrew financial support. Funding after this date has been based on a per-box tax for citrus

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fruit, an excise tax on citrus nursery plants, a special grant from the USDA, and general revenues appropriated by the Florida legislature. Budgeted appropriations for the current fiscal year are nearly $8 million.

Despite the funds provided by the state and federal governments, the citrus industry has borne considerable expense for the program. Compensation did not approach actual values. Quarantines in nurseries stopped sales, required the tending of plants being held, and limited future plantings. The meeting of compliance agreements by grove owners, packinghouses, and citrus haulers added to the expense. Finally, fresh fruit markets in California, Arizona, Texas, and parts of Louisiana lost because of the quarantine have not yet been regained. The nursery quarantines are estimated to have cost about one year's production, or about $60 million (J. B. Race, *personal communication*). During the 1984–1985 and 1985–1986 fruit harvesting seasons, nearly $30 million were spent to meet compliance agreements involving citrus fruit, and $8 million were lost because fruit could not be shipped to citrus-producing states and territories (W. B. Lester, *personal communication*).

Research

The United States Congress has appropriated $1 million a year for 3 years for citrus canker research, with the University of Florida Institute of Food and Agricultural Sciences (IFAS) receiving 75% of the $3 million and the USDA-ARS receiving 25%. This money has been appropriated to aid the eradication program and has provided new data that have resulted in some policy and procedural changes. Areas of research emphasis include: 1) improved detection and identification methods as reliable alternatives to visual surveys and host bioassays; 2) genetics of *X. campestris* other than *citri*; 3) epidemiologic research in infested nurseries in Florida and in field plots in Frederick, Maryland, where isolates of the nursery group from Florida and an isolate of the A group from Argentina were introduced onto citrus in the warmer months of 1985 and 1986; 4) field research in 1985 and 1986 with canker group A in Argentina where *X. campestris* pv. *citri* is endemic; 5) field research in Hastings, Florida, 100 miles (161 km) north of commercial citrus, with the nursery group of strains beginning in the spring of 1987; and 6) methods for eradicating the pathogen that would minimize or avoid plant destruction.

Perspective and Prospects

Since September 1984, Florida's citrus industry has been threatened with two forms of citrus canker. The novel nursery form, with its flattened leaf and stem lesions and raised stem cankers, was the first to be detected and has affected only immature trees in 20 nurseries and three groves. The Asiatic form, with its erumpent lesions on leaves, stems, and fruit, was first detected in 1985 at a residence in an area where citrus is not produced but later surfaced in an apparently unrelated and significant infestation in the summer of 1986 along the Gulf Coast in central Florida. Here, the disease has occurred mainly on mature trees in residences and one grove.

Citrus canker has been met by a state and federal eradication program. To this end, all infested and exposed trees have been destroyed, severely pruned, or chemically defoliated. Pruned or defoliated trees are being inspected for the disease under quarantine or other regulations. Over 17,500 properties have been affected by these eradication procedures, and nearly 20 million immature and 5,000 mature trees have been destroyed. The eradication program also involves regulations that limit the further dissemination of the pathogen and thereby reduce the number of future eradication sites. To this end, regulations have affected millions of Floridians and people elsewhere. Nurseries are enduring lengthy quarantines; packinghouses are under compliance agreements to meet certain requirements, including disinfesting the fruit; citrus plants are generally not permitted to leave the state; fruit is not allowed to go to citrus-producing states; homeowners are not permitted to move fruit from their own properties; and citrus trees in the state are being continually surveyed for the disease. Regulations are also designed to keep the citrus industry viable. During most of 1986, citrus nurseries sold citrus to groves and other nurseries; during 1985–1986, over 57 million boxes of fresh fruit were moved to markets and another 137 million boxes were processed; and homeowners are now able to buy citrus trees for their yards. In 1986, surveyors found less of the nursery form of citrus canker than they did in 1984 or 1985 but did find a new infestation of the Asiatic form. Hopefully, no new areas of infestation will be found, tree destruction and regulations will end, and only periodic surveys for the disease will be necessary after eradication is accomplished.

The eradication program is based on biological principles. Accordingly, the program has been frequently changed as more is learned about the infestation and the biology of the pathogen. Policies in 1986 were considerably more relaxed than in 1984, with quarantines and surveillance replacing plant destruction. Policies regulating movement of citrus have eased since the distribution of the disease became known. Such policies are innately conservative, however, because one cannot be certain where an infestation might occur among the over 100 million citrus plants in the state, because the disease may develop several months after exposure to the pathogen, and because movement of citrus that could harbor the pathogen is considerable and constant.

Although there is probably never a "good" time to opt to eradicate a disease, citrus canker was detected during the same decade that severe freezes were eliminating citrus acreage. Citrus acreage dropped from 845,263 in 1980 to 624,492 in 1986 (4). Tree replacement in frozen-out groves and the planting of new groves in south Florida have been affected by citrus canker destruction and quarantine policies.

Opposition to the eradication program was slight during the fall of 1984 but has increased considerably with time. Whiteside (22,23) questions whether the costs of eradication policies outweigh the economic impact of the disease and believes that citrus canker has been vastly overrated as a destructive disease in Florida. He postulates that even the Asiatic form would not likely become problematic in Florida groves because of prevailing climatic conditions and that the 1912–1927 infestation of the Asiatic form in Florida was largely self-eliminating in groves once the disease was eradicated in nurseries. The self-elimination of the disease in groves, as suggested by Whiteside (23), is a possibility that is difficult to evaluate in retrospect when over 15,000 infected grove trees were burned between 1914 and 1927 (K. W. Loucks, *unpublished*). Although it is generally recognized that a citrus industry can "live" with citrus canker and remain viable, the disease can exact a price. Not only are new chemical and cultural practices often required but fresh fruit markets are likely to be lost. These realities, especially the loss of fresh fruit markets, have prompted Florida's citrus industry to continue to support and sanction eradication.

Investigatory efforts have not disclosed an origin or a means of introduction of the pathogen causing either form of the disease. An explanation would be reassuring if only to prevent repeated introductions and eradication programs. The Asiatic form occurs elsewhere and is regularly intercepted at Florida's ports, but the nursery form seems shrouded in mystery. It is not known to occur elsewhere. Isolates of the nursery form are heterogeneous relative to pathogenicity, serology, and DNA analyses (11), whereas isolates of the Asiatic form from various areas of the world are homogeneous. Also, how the pathogen arrived at the site cannot be explained in nearly half of the nursery form occurrences, many of which are on the rootstock citrumelo. These disturbing attributes of the nursery form have led some to postulate that the pathogen may be endemic. No one, however, has demonstrated the presence of the patho-

gen at locations other than the 23 infested sites. Gabriel et al (9) have evidence suggesting that strains of *X. campestris* pv. *citri* causing both Asiatic and nursery canker may be genetically closely related to *X. campestris* pv. *phaseoli* (Smith) Dye and pv. *alfalfae* (Riker, Jones & Davis) Dye. They also indicate that the nursery form strains are pathologically closely related to the two leguminous pathovars. More research is needed on pathogen ecology as well as on basic genetics that includes pathogenicity to resolve the origin dilemma.

Additional problems surround the nursery form and its eradication. The disease has been only relatively serious in two large field nurseries, one of which was the first to be found infested and which led to initiation of the eradication program. An argument has developed over the apparent inability of the nursery form to cause problems on mature citrus trees in groves even though many were exposed. Field research to attempt tc resolve this issue is commencing in 1987. The widespread occurrence of the Asiatic form in 1986 has invited comparisons with the nursery form, and many believe the nursery form to be less serious. The restrictions placed on the rootstock citrumelo have been criticized as counterproductive to eradication because they have reduced the preferred host of the nursery form and may have made it more difficult to detect and eradicate; there is evidence, however, that grapefruit is at least as susceptible as citrumelo to canker. Eighteen litigations involving destruction of exposed citrus and/or compensation have resulted; the state has prevailed in 17 verdicts, and the 18th verdict is under appeal by the state and involves full instead of partial compensation for the destruction of exposed citrus.

Only time will tell if citrus canker will once again be eradicated from Florida. Continuation of the eradication program depends on the support of the citrus industry and the general public, on funding for the program, on the courts, and on reasonable cause to presume the disease is being mitigated and eventually will be eradicated.

Acknowledgments

We thank J. M. Mattes for typing the manuscript, V. J. Windsor for Figure 1, S. M. Garnsey for Figure 2, J. W. Lotz for Figures 3 and 5, and C. R. Walton for Figure 4.

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