Corky Root of Tomato in California Caused by *Pyrenochaeta lycopersici* and Control by Soil Fumigation

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ABSTRACT

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Corky root occurs on processing and fresh market tomatoes (*Lycopersicon esculentum*) in scattered fields in northern and central California. The primary pathogen was confirmed to be *Pyrenochaeta lycopersici*, which was also recovered from nightshade (*Solanum nigrum*) but not from other plants in infested fields. *Colletotrichum coccodes* was isolated infrequently. Corky root severity declined as the transplanting date was delayed and the soil became warmer in a trial involving plants inoculated in the greenhouse and transplanted to the field and noninoculated plants transplanted into infested soil. Yield loss estimates of up to 70% were made by growers of processing tomatoes, and losses of the same magnitude occurred in fumigation experiments with fresh market tomatoes. In field trials, chloropicrin alone or in combination with methyl bromide (117-168 kg/ha injected and covered with a tarp) gave good disease control and large yield responses. Methyl bromide (262 kg/ha), chloropicrin (168 kg/ha without a tarp), and a metham sodium drench (935 L of 33% a.i./ha) gave intermediate disease control and yield responses.

Corky root (brown root rot) has been recognized as an important disease of tomatoes (*Lycopersicon esculentum* Mill.) in glasshouses in Europe for many years. The etiology of the disease was slow to be resolved because of the complex of fungi associated with diseased roots and because of the difficulty of nondestructive, sequential sampling of roots. Of two pathogenic fungi commonly isolated from infected roots, a gray sterile fungus (GSF), later identified as *Pyrenochaeta lycopersici* Schn. & Ger. (17), was considered as the primary pathogen; *Colletotrichum coccodes* (Wallr.) Hughes (= *C. atramentarium* (Berk. & Br.) Taub.) was the secondary pathogen (19). An improved method of inducing sporulation of *P. lycopersici* has been described (5). The relative roles of *P. lycopersici* and *C. coccodes* have been confirmed in England (11), Germany (9), Lebanon (7), and Massachusetts (12). A similar disease occurs on field-grown tomatoes in Florida, although the associated GSF has not been identified (20).

In California, corky root symptoms have been observed sporadically on field-grown, fresh market and processing tomatoes for many years, but the associated GSF has not sporulated or been identified. A GSF was isolated from strawberries (*Fragaria grandiflora* Ehrh.) and was pathogenic to strawberries and pines (*Pinus pinea* L.) in California (23). Other GSF isolates were obtained from tomato, potato (*Solanum tuberosum* L.), *S. sarachoides* Sendt., and other weeds found in strawberry fields (23). Although one isolate of GSF occasionally produced pycnidia of the *Pyrenochaeta* type in culture (22), it is not known whether this isolate corresponds to the later-described *P. lycopersici*.

Fumigants have been tested for control of *P. lycopersici* in glasshouses. Clerjeau et al (6) rated methyl bromide (MB) (800 kg/ha) above chloropicrin (CP) (650 kg/ha) or dazomet (700 kg/ha) for disease control and yield responses. Last et al (11) in England rated steam, CP with a water seal (628 kg/ha), and metham sodium (1,020 L of 33% a.i./ha) as equally effective. Metham sodium (200 L of 33% a.i./ha) delayed infection of tomatoes and increased yields (2). In Italy, moist heat or MB (700 kg/ha) controlled both *P. lycopersici* and *Verticillium dahliae* (14).

The objectives of this paper were to determine the causal agent of corky root of field-grown tomatoes in California and to test soil fumigants for disease control and effect on yield losses. Preliminary reports have been given (3,4).

MATERIALS AND METHODS

Isolation. Pieces of tomato root were surface-sterilized in 0.5% sodium hypochlorite for 2 min. Chips of cortical tissue from the margins of lesions were plated aseptically on acidified potato-dextrose agar. Transfers were made to provide one or two isolates of GSF from each collection of roots from an infested field. At first, the isolates were mass transfers maintained in tubes of potato-dextrose agar (PDA), but three improvements were made as trials progressed. First, each isolate was transferred to water agar (15 g of agar per liter of distilled water) and incubated a few days. Single hyphal tips were removed and grown on PDA to verify that they were GSF. Second, each hyphal tip isolate was transferred to soil tubes for storage as done by Goodenough and Maw (10). The soil tubes, containing moistened Yolo clay loam mixed with chopped tomato roots, were steam sterilized at 121 C for 30 min on two consecutive days. After inoculation, the soil tubes were kept moist by wrapping the cotton plug with Parafilm for about 2 wk and were shaken occasionally. The Parafilm cover was removed and the soil became air-dry, after which the tubes were transferred to a freezer. Third, the steps from isolation to inoculation of soil tubes were completed within 15–30 days.

Cultures stored in soil tubes were recovered for sporulation and pathogenicity trials by sprinkling soil from these tubes onto plates of PDA that were incubated at 24 C for 2–3 wk. These plates were sometimes stored in a refrigerator for another month before being used as inoculum, but no subtransfers were made from these plates to increase inoculum for additional experiments.

Identification of GSF. Initially, we used water agar, V-8 agar (15), and Matsushima's agar (13) in the sporulation tests. The media were tested without amendment or with pea (*Pisum sativum* L.) straw or tomato roots (sterilized in propylene oxide) and under fluorescent lamps at room temperature or in the dark at 18 or 24 C. Later tests were done with tomato or melon (*Cucumis melo* L. var. *inodorus* 'Honeydew') seedlings by the Clerjeau method (5). Seeds of these hosts were surface-sterilized in 0.5% sodium hypochlorite for 10 min and germinated aseptically on moist filter paper in petri plates. Seedlings in each plate were inoculated with 5-mm-diameter plugs from the margins of colonies growing on PDA. The plates were incubated in clear plastic boxes in a growth chamber at 18 C with a 16-hr photoperiod and were examined occasionally for 1 mo. More pycnidia were produced on melon

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seedlings than on tomato seedlings, which were omitted in later tests.

The GSF isolates were not identified as *P. lycopersici* until they were verified to have setose pycnidia and hyaline, single-celled conidia (approximately 4.5 × 2 μm) borne on ramose conidiophores as illustrated in the literature (5,17).

Pathogenicity tests. Tomato cultivar VF145-B7879 was used as the host in two types of tests. In the pot test, cultures from two plates of PDA were comminuted in a blender in 100 ml of sterile distilled water and used to infest soil for two replicate pots (10 cm diameter). The soil was a 1:4 (v/v) mixture of pasteurized Yolo clay loam and pasteurized river sand. About 25 seeds were sown in each pot, and the pots were maintained in a greenhouse for 4–6 wk. In the flask test, patterned after Manning and Vardaro (12), we used 250-ml Erlenmeyer flasks with 50 ml of sterile, half-strength Hoagland's solution with 15 g of agar per liter. Tomato seeds were surface-sterilized as above, and four to 10 seeds were germinated on the agar for 5 days before adding four plugs (5 mm diameter) from the margins of colonies growing on PDA. The flasks were incubated in a growth chamber at 27 C with a 16-hr photoperiod for 5–6 wk.

Seedlings in both tests were examined for brown lesions on the upper portion of the taproot. Pathogenic isolates caused distinct brown lesions that were 1–2 cm long. In the flask test, these lesions extended into the lower hypocotyl. Weakly pathogenic isolates caused mild brown discoloration or minute necrotic flecks on the taproot. There were no symptoms on the adventitious roots that formed abundantly on plants in the pot test. In the flask test, necrotic lesions often developed on secondary roots in the medium. Reisolations were made from representative seedlings in each test. A GSF resembling the inoculated fungus was recovered.

Fumigation. The 1979 plot was located in a field of Porterville adobe clay soil in the fresh-market tomato production area of Tulare County. Fumigants were injected into moist, tilled soil with a tractor-mounted unit that had two shanks 30 cm apart. The fumigants were injected 15 cm to each side of the future plant row. The soil of fumigated and check plots was covered to a width of 60 cm with a 1-mil polyethylene tarp whose edges were buried in the soil by hand. Each replicate consisted of one bed 15 m long, and there were four replicates in a randomized complete block design. The fumigants and rates of application, which were within the registered rates, were MB, 269 kg/ha; CP, 168 kg/ha; ethylene dibromide (EDB), 107 kg/ha, plus CP, 94 kg/ha; MB, 262 kg/ha, plus CP, 117 kg/ha; and a nontreated check.

Metham sodium was tested as a drench in a separate trial in the same field with three replicates in a randomized block design. A furrow measuring 0.45 × 15 m was opened, and about 300 L of water containing 710 ml of metham sodium (33% a.i.) were placed in the furrow. This rate was equivalent to 935 L of 33% metham sodium per hectare. As the solution percolated into the soil, the furrow was closed. Two treatments, with or without a 1-mil polyethylene tarp over the treated soil, were compared with the nontreated check.

The chemicals were applied in August 1978 when the soil temperature was above 20 C at the 15-cm depth. Tomatoes (cultivar Jackpot) from a commercial nursery were transplanted into both trials on 13 March 1979 at a spacing of 0.6 m along the row. They were maintained by the grower with the usual irrigation, fertilization, and pest control until harvest on 20 June 1979.

Chemicals selected for the 1980 plot were applied at the same rates in October 1979 when the temperature was 15 C at the 15-cm depth. The plot was in the same district but on Greenfield sandy loam soil. There were five treatments with five replicates, each 3.6 × 30.5 m, in a randomized block design. The CP and MB + CP fumigants and tarp, if specified, were applied by a commercial fumigation rig that treated and covered a 3.4-m-wide strip. The metham sodium was mixed with irrigation water as it flowed through a ditch onto each plot, where it was ponded by earthen dikes and allowed to percolate into the soil. Tomatoes (cultivar 6718) were transplanted at 0.6-m intervals in three rows in each replicate on 12 February 1980. Plants from the center row of each replicate were harvested on 18 June 1980.

Corky root severity and plant yield. Yield and disease severity were measured when the first fruits were ripe. Ten consecutive plants that were at least five plants from the end of the row were harvested. Each plant was weighed with fruits; then the fruits were removed, sorted by size, and counted. The fruits were sized as being larger or smaller than 7.3 cm in diameter; the larger fruits correspond to U.S. standard sizes "extra large" and "maximum large." The major roots were dug with a shovel and rated for corky root severity: 0 = no lesions; 1 = 1 or 2 corky lesions; 2 = intermediate between 1 and 3; 3 = about 50% of the roots with corky lesions; 4 = intermediate between 3 and 5; 5 = all root surfaces with confluent corky lesions.

RESULTS

Isolation and identification of *P. lycopersici*. The symptoms were corky lesions on the taproot and major secondary roots as illustrated by others (8,9,12). When there were many corky lesions, the fine feeder roots were absent or badly decayed.

Many fungi developed in isolations from the margins of the corky lesions. The pathogenicity of GSF, *Fusarium* sp., *Stemphylium* sp., and an unidentified hyphomycete that developed from the first isolation was tested; only GSF was pathogenic and caused root necrosis. Thereafter, attention was directed to determining the association of GSF with corky root, identifying GSF, and fulfilling Koch's postulates.

In each year from 1976 through 1978, GSF grew from about 40% of the 400–800 tomato root pieces plated out. Fifteen GSF isolates were collected in 1976 and maintained on PDA. Most isolates were pathogenic in early trials but lost pathogenicity to tomatoes in later trials. Therefore, GSF isolates collected in 1977 were stored in soil tubes. Fourteen of 16 isolates were pathogenic on tomato and remained so even in repeated trials.

Sporulation was tested with the isolates collected in 1976 and 1977. Some of the 1976 isolates were tested on media for sporulation, and all the isolates were tested by the Clerjeau method (5). Only one isolate that had been transferred into a soil tube 2 wk after isolation in 1977 sporulated and was identified as *P. lycopersici*. All other isolates had been kept only on agar media or had been transferred to soil tubes after 5–12 wk on agar media. Three single-conidial isolates were obtained from pycnidia of the sporulating culture; all produced GSF colonies and were pathogenic, but only one sporulated and was identified as *P. lycopersici*.

Consequently, all 32 GSF isolates collected in 1978 were transferred to soil tubes soon after isolation. Twenty-three isolates were pathogenic on tomato and were identified as *P. lycopersici*, including two isolates from *Solanum nigrum* L. Five isolates were pathogenic on tomato but did not sporulate. In all, *P. lycopersici* was isolated and identified from processing tomatoes, fresh market tomatoes, and *S. nigrum* from 12 fields in six counties: San Benito, San Joaquin, Santa Clara, Solano, Stanislaus, and Tulare.

Other hosts in these same fields were examined in the same or later years. Lesions resembling corky root were observed on pepper (*Capsicum annuum* L.) once, but only *Colletotrichum coccodes* was isolated. Other hosts had no symptoms and no GSF was isolated when 12–30 root pieces were plated out. These were *Lactuca serriola* L., *Sonchus oleraceus* L., *Erigeron canadensis* L., *Senecio vulgaris* L., *Amaranthus retroflexus* L., *Daucus carota* L., *Medicago hispida* Gaertn., *Melilotus officinalis* (L.) Lam., *Portulaca oleracea* L., *Malva* sp., and *Chenopodium* sp.

Pathogenicity tests. Although most isolates of GSF collected from corky root lesions are probably *P. lycopersici*, especially if they are pathogenic on tomato, it should not be assumed that all are. Five such GSF isolates that

sporulated and were identified as *Podospora anserina* (Cesati) Niessl, *Sphaeronema* sp., or other fungi that produced pycnidia were not pathogenic on tomato.

Colletotrichum coccodes, in contrast, grew from about 5% of the tissue chips cultured from 1976 to 1978. These isolates came from tomato plants from a few of the fields where samples were taken. Five of these isolates of *C. coccodes* were tested for pathogenicity on tomato. In a pot test, all five decayed the fine feeder roots but did not kill the plants. In a flask test, all five killed and colonized the entire tomato seedling. In both tests, black sclerotia formed abundantly in decayed tissue, but there were no brown lesions typical of infection by *P. lycopersici*.

Attempts were made to reproduce corky root lesions by inoculating tomato plants in experimental plots at Davis. Trials in 1977 and 1978 were unsuccessful, possibly because the methods of infesting field soil were unsatisfactory or the isolates had lost pathogenicity or the trials were done too late in the season. In 1979, seedlings were inoculated in the greenhouse by sowing them in infested soil in Todd planter flats (Speedling Inc., Sun City, FL 33586). Three weeks later, they were transplanted to the field with intact root balls into noninfested field soil. The infested soil used in the flats was prepared as in a pot test for pathogenicity, except that the inoculum consisted of the pooled cultures of four isolates of *P. lycopersici* that were pathogenic on tomato. Fresh inoculum in the flats was prepared for each of four sets of plants that were transplanted at 3-wk intervals to the field. At each date, seven plants were transplanted 22 cm apart in one row in each of four replicate blocks in a randomized block design. Two check plots were planted about 10 m away with noninoculated plants. The negative check was in noninfested soil and the positive check was in infested soil 15–20 cm deep hauled from a nearby field. Soil temperatures at the 10-cm depth were recorded with a model H thermograph (Ryan Instruments, Kirkland, WA 98033).

Typical corky root lesions developed on the roots of inoculated plants (Table 1), and GSF was recovered from these lesions. The severity rating was low because lesions only developed on roots in or near the infested soil ball. Noninoculated plants in noninfested soil had no lesions, whereas those in naturally infested soil had coalescing lesions on most of the roots. Corky root was most severe in the two earlier plantings made in colder soil (Table 1).

Soil fumigation. In the 1979 plot, CP and MB + CP effectively reduced disease severity, increased plant size, and increased the yield of large fruits (Table 2). Neither MB nor EDB + CP reduced disease severity or increased yields significantly compared with the nontreated check. The adobe clay soil was difficult to fumigate and the inoculum distribution was not uniform, as shown by the large standard deviation of the disease index of the nontreated check (Table 2).

In the metham sodium plot, the plants in treated soil were significantly larger (5.8 and 5.9 kg/plant without or with a tarp, respectively) than those in nontreated soil (3.9 kg/plant). The disease severity rating was reduced significantly to 0.4 ± 0.2 by metham sodium with a tarp. Metham sodium without a tarp had a disease severity rating of 2.9 ± 1.4, which was not significantly different ($P = 0.05$) from the nontreated check with a disease severity rating of 4.4 ± 0.6. There were no significant differences in yield of fruit, but a data recording error is suspected.

In the 1980 plot, the soil was uniformly infested and corky root was severe in all nontreated checks (Table 3). Both MB + CP and CP, if applied with a tarp, gave effective control of infection by *P. lycopersici* and increased plant size and yield. Metham sodium and CP applied without a tarp gave smaller growth and yield responses. Metham sodium, however, produced plants with a much lower disease severity than did CP without a tarp, which was equal to the nontreated check (Table 3).

Corky root severity and plant yield. The yield loss due to corky root can be estimated from the fumigation plots. In the 1979 plot, the nontreated check with a disease severity rating of 2.6 produced 23% fewer large fruits than the best fumigation treatment. Because of the variable disease severity ratings among nontreated check replicates, a correlation analysis between disease severity and yield for each of the 20 replicates in this plot was done. The correlation coefficient obtained was −0.574, which was highly significant ($P = 0.01$). This predicts a yield loss of 50% of large fruits when we compare plants with no disease and those with a disease severity rating of 5. In the 1980 plot, the nontreated check with a disease severity of 4.8 yielded 73% fewer large fruits and 40% fewer small fruits than the CP treatment with a tarp. These figures are within the range of estimates provided by four producers of processing tomatoes in Solano, Santa Clara, San Joaquin, and Merced counties. These growers estimated that

Table 1. Development of corky root symptoms on tomatoes transplanted into the field at Davis, CA, in 1979

		Disease severity rating[b]		
		Inoculated plants[c]	Noninoculated plants	
Transplant date	Soil temperature[a] (C)	Noninfested soil	Noninfested soil	Infested soil[d]
14 March	13.4	0.3	0.0	4.0
6 April	16.1	0.3	0.0	3.4
29 April	20.6	0.1	0.0	1.6
17 May	24.3	0.0	0.0	0.5

[a] Mean soil temperature for 1 wk after transplanting date.
[b] 0 = no lesions, 1 = one or two lesions per plant, 2 = intermediate between 1 and 3, 3 = about 50% of root system with lesions, 4 = intermediate between 3 and 5, 5 = entire root system with lesions. The severity ratings are averages from a total of 25–28 plants in four replicates randomly arranged in each plot.
[c] Before transplanting, the plants were grown in the greenhouse for 3 wk in pasteurized soil infested with pooled inoculum of four isolates of *Pyrenochaeta lycopersici*.
[d] Soil 15–20 cm deep brought in from a nearby field.

Table 2. Comparison of four soil fumigants applied for control of *Pyrenochaeta lycopersici* in Porterville adobe clay soil, Tulare County, CA, in 1979

			No. of fruits per plant[b,d]	
Treatment[a]	Disease severity[b,c]	Avg. weight of plant with fruit[b] (kg)	Large	Small
MB + CP	0.3 ± 0.2 y	8.0 ± 0.4 x	22.6 ± 2.1 y	20.4 ± 5.4 z
CP	0.7 ± 0.2 y	7.4 ± 0.9 xy	22.2 ± 5.8 y	20.1 ± 5.6 z
EDB + CP	1.6 ± 0.9 yz	6.3 ± 1.1 yz	19.0 ± 3.7 yz	16.0 ± 3.6 z
MB	1.1 ± 0.8 yz	6.1 ± 1.2 yz	16.8 ± 3.8 z	19.5 ± 3.7 z
Check	2.6 ± 2.0 z	5.7 ± 1.5 z	17.3 ± 4.2 z	17.7 ± 4.4 z

[a] MB + CP = methyl bromide plus chloropicrin (262 + 117 kg/ha); CP = chloropicrin (168 kg/ha); EDB + CP = ethylene dibromide + chloropicrin (107 + 94 kg/ha); MB = methyl bromide (269 kg/ha).
[b] Means and standard deviations for 10 plants from each of four replicates in a randomized block trial. Means in columns followed by the same letter do not differ significantly ($P = 0.05$) by Duncan's multiple range test.
[c] Severity rated on a five-point scale; see footnote b in Table 1.
[d] Fruits were sized as being larger or smaller than 7.3 cm in diameter.

Table 3. Comparison of four soil fumigants applied for control of *Pyrenochaeta lycopersici* in Greenfield sandy loam soil, Tulare County, CA, in 1980

Treatment[a]	Tarp[b]	Disease severity[c,d]	Avg. weight of plant with fruit[c] (kg)	No. of fruits per plant[c,e]	
				Large	Small
MB + CP	Yes	0.2 ± 0.3 x	9.8 ± 0.8 x	25.1 ± 4.9 wx	34.6 ± 8.1 x
CP	Yes	0.5 ± 0.1 x	9.9 ± 0.9 x	27.4 ± 2.8 w	31.9 ± 3.6 xy
CP	No	4.4 ± 0.4 z	6.6 ± 1.4 y	18.6 ± 4.6 y	27.8 ± 5.8 xy
Metham sodium	No	1.9 ± 0.6 y	7.0 ± 1.1 y	21.0 ± 5.0 xy	24.4 ± 6.0 yz
Check	No	4.8 ± 0.1 z	3.3 ± 1.0 z	7.3 ± 4.3 z	19.5 ± 4.5 z

[a] MB + CP = methyl bromide plus chloropicrin (262 + 117 kg/ha); CP = chloropicrin (168 kg/ha); metham sodium = 935 L of 33% a.i. product per hectare.
[b] Replicate was or was not covered by a 1-mil polyethylene tarp as the fumigant was injected.
[c] Means and standard deviations from 10 plants in each of five replicates in a randomized block design. Means in columns followed by the same letter do not differ significantly ($P = 0.05$) by Duncan's multiple range test.
[d] Severity rated on a five-point scale; see footnote b in Table 1.
[e] Fruits were sized as being larger or smaller than 7.3 cm in diameter.

severely affected crops yielded 22, 49, 66, and 70% less fruit than expected in the absence of corky root.

DISCUSSION

These studies show that the etiology of corky root of field-grown tomatoes in California was the same as reported for glasshouse tomatoes elsewhere (9,11, 12,19). *P. lycopersici* was the primary pathogen and was distributed throughout the northern and central California tomato-growing districts. *Colletotrichum coccodes* was of secondary importance as a pathogen of tomato and was isolated much less frequently from corky root lesions. It is not clear whether the less frequent isolation reflected a less extensive distribution of *C. coccodes* or the fact that most samples were collected from plants during their vegetative growth stage before *C. coccodes* had colonized the tissue (11). Distinctive lesions of *C. coccodes* were observed on fresh market tomatoes in 1979 and 1980 after the harvest season was completed. These lesions were gray with black sclerotia (black dot), but there was no severe rot like that reported on hydroponically grown tomatoes (18).

P. lycopersici in California occurred on both processing and fresh market tomatoes. The fungus also infected and caused brown lesions on the roots of *Solanum nigrum* (nightshade). Presumably, weeds such as nightshades aid in the perpetuation of the fungus in the absence of tomatoes. Corky root symptoms were not common on peppers grown in infested fields, and we did not isolate the fungus from the few lesions that were tested. *P. lycopersici* has been a problem on peppers in Germany (16), and peppers were susceptible in our in vitro pathogenicity tests. The importance of *P. lycopersici* to peppers needs additional study, as does the possibility of *P. lycopersici* being the sterile gray fungus involved in strawberry black root rot (23).

The high rate of success in inducing sporulation of *P. lycopersici* in 1978 is attributed to the short period the isolates had been grown on nutrient agar. Loss of ability to sporulate, as well as loss of pathogenicity to tomato and melon, is common for *P. lycopersici* (5,10).

Our results confirmed that soil fumigation effectively reduced soilborne inoculum and the incidence of corky root, but at lower dosages than used in Europe (6,11,14). Better results were obtained with CP or MB + CP than with MB alone, indicating that CP is more effective than MB. This is the reverse of the ranking obtained by Clerjeau et al (6). The reasons for this difference are unknown. Metham sodium was also effective, particularly if the soil was tarped, which may not be economically feasible. Metham sodium and CP without a tarp gave about the same yield response in our 1980 plot. This agrees with similar comparisons tested by Last et al (11); however, our lower dosage of CP did not reduce disease severity as much as their CP treatment did.

Although corky root can be severe in individual fields, its importance in the processing tomato industry is small because of its sporadic distribution, the large areas available for rotation, and a long planting season. Even if there is a high inoculum potential in a given field, there is a possibility that late plantings in warm soil may escape severe disease. Corky root is a cool temperature disease (19), which was confirmed in this study. Corky root may be a more serious problem in certain fresh market districts where there is little leeway in planting time and less opportunity for rotation.

Two types of yield loss estimates were obtained in these studies. The data from fumigation plots are biased by nonspecific responses to fumigation, especially with CP (1,21), and the growers' estimates are subjective. Nevertheless, yield losses up to 70% are not much greater than those in England (8,11) and equivalent to the losses summarized by Termohlen (19).

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