

# Suppression of Corky Root of Tomatoes in Soils from Organic Farms Associated with Soil Microbial Activity and Nitrogen Status of Soil and Tomato Tissue

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## ABSTRACT

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In greenhouse experiments, corky root of tomatoes (*Lycopersicon esculentum* L.) was less severe in soil from organic farms than in soil from conventional farms when soil collected in the fall was infested with various concentrations of microsclerotia of *Pyrenochaeta lycopersici*. Maximum disease severity was obtained at inoculum levels of  $10^4$  and  $10^5$  microsclerotia per milliliter of soil. When soil samples were sterilized by gamma radiation, the increase in disease severity was greater for soils from organic farms than for soils from conventional farms, indicating that biological disease suppression might have been higher in organically managed than in conventionally managed soils. This was supported by

a positive correlation between increase in corky root severity after irradiation and soil microbial activity before irradiation. There was no correlation between corky root severity and soil nitrate concentration, but the disease increased at higher ammonium concentrations (in irradiated soil). Fertilization with ammonium nitrate increased corky root severity in organically managed soil but decreased the disease in conventionally managed soil. In a pasteurized conventional soil, however, corky root severity increased with increasing nitrate and ammonium concentrations in soil and with total nitrogen in tomato tissue when ammonium nitrate fertilizer was added. Corky root severity is determined partially by biological disease suppression and partially by nitrogen concentrations in soil and plant tissue.

*Additional keywords:* farming systems, fluorescein diacetate hydrolysis, nitrogen fertilization.

Health and environmental concerns associated with conventional agriculture have raised interests in alternative farming practices that may reduce the adverse effects of conventional production practices and at the same time sustain productivity. Alternative farming practices gained considerable attention in the last decade after the report by the U.S. Department of Agriculture on organic farming (36) and the publication of *Alternative Agriculture* by the National Research Council (23). Alternative agriculture encompasses various farming systems known as organic, regenerative, ecological, biological, and biodynamic. Even though they involve diverse practices, these farming systems pursue a common objective of elimination or reduction of reliance on synthetic fertilizers and pesticides. Instead, they emphasize greater use of biological resources such as animal manure, crop residues, composts, and other organic amendments to supply plant nutrients. They rely on biological and cultural methods for control of weeds, insect pests, and diseases (36). Currently, fewer than 5% (approximately 100,000) of the farmers in the United States identify themselves as organic farmers (2).

Organic soil amendments suppress various plant diseases either by increasing microbial activity, resulting in enhanced competition and/or antagonism, or by reducing the inoculum potential through stimulation of germination followed by lysis of germinating hyphae (4). However, disease suppression by organic amendments has been demonstrated mainly in experimental plots (4).

Recent on-farm studies of 27 organic and conventional tomato production systems in the Central Valley of California showed

that the severity of corky root caused by *Pyrenochaeta lycopersici* R. Schneider & Gerlach was less in organic farms than in conventional farms (39). Discriminant analysis of 11 soil and plant variables indicated that tissue nitrogen and soil nitrate were positively associated with corky root severity, whereas microbial activity was negatively associated with this disease. Because at least some corky root was found on most farms, we postulated that organically managed soil may be suppressive to *P. lycopersici*. This pathogen survives as microsclerotia in root debris (32). The survival propagules could be stimulated to germinate by organic amendments and then lysed and killed by soil microorganisms, as has been reported for other sclerotia-forming fungi such as *Verticillium* (12,14). Alternatively, high nitrogen concentrations in conventional farms may have rendered tomato plants more susceptible to corky root than those grown on organic farms. Increased susceptibility to root rots caused by high nitrogen concentrations in plant tissue also has been reported (13).

We report here the results of greenhouse experiments conducted to test three hypotheses: 1) corky root is suppressed in organically managed soil by one or more biological factors; 2) corky root severity is dependent on nitrogen concentrations in soil and in tomato tissue; and 3) fewer microsclerotia survive in organically managed soil than in conventionally managed soil.

## MATERIALS AND METHODS

**Sample collection.** Five organic and five conventional farms were selected from among those used previously for on-farm comparative studies in the Central Valley of California (39). The farms were selected on the basis of similarity of soil types and

the absence of other root diseases of tomatoes. Descriptions of soil texture, pH, and microbial activity of the soil samples are given in Table 1. Management of these farms has been described previously (39). Prior to sample collection, organic farms used chicken manure, compost, or green manure (vetch or an oat-vetch mix) for supply of nutrients. Conventional farms had applied 50 kg of nitrogen per hectare as preplant fertilizer. The year before the soil samples were taken, four of the organic farms grew mixed vegetables and one grew vetch for seed. Conventional farms grew wheat, beans, and squash. In each farm, an area of approximately 0.1 ha was selected, and 20 soil samples (about 2 L per sample site, 15–20 cm deep) were taken at random with a trowel. Sampling dates are given below under the description of each experiment. Twenty samples from each field were composited, passed through a 6-mm sieve, and stored at 5 C before use. Microbial activity of each composited soil sample was determined for two 5-g subsamples immediately after collection (39).

**Soil and plant tissue analyses.** Before each experiment, 500-g subsamples were air dried and submitted to the Department of Agriculture and Natural Resources Analytical Laboratory at the University of California, Davis. Soil nitrate and ammonium were determined according to Keeney and Nelson (15). Soil pH was measured in water (1:1, w/v) (21). At the end of some of the experiments, tomato shoots were dried in a forced-air oven at 80 C for 3–5 days for tissue analysis. Because the amount of tissue from individual plants was too small for analysis, tissue from all blocks was pooled and subdivided into two subsamples. Tissue nitrogen was determined with a nitrogen gas analyzer (LECO, St. Joseph, MI) (35). Phosphorus in tomato tissue was determined on a microwave digest by inductively coupled plasma atomic emission spectrometry (22,30).

**Inoculum production.** A method modified from that of Clerjeau and Laterrot (3) was used to produce inoculum of *P. lycopersici*. One isolate, taken from farm 7 during the spring of 1991, was used. Fifteen grams of oat bran was mixed with 500 ml of flint-shot sand (Ottawa Industrial Sand Co., Ottawa, IL) and 40 ml of water in one-quart (0.94-L) mason jars. The jars were autoclaved for 30 min twice on consecutive days, and small blocks of 5- to 10-day-old cultures of *P. lycopersici* grown on either potato-dextrose agar or the medium of Grove and Campbell (11) were transferred into them. Jars were incubated for 5 wk at 22–25 C in darkness. The oat bran-sand medium was then passed through a 0.71-mm sieve to separate microsclerotia from the fine sand. Clumps of microsclerotia retained on the mesh were collected, dried at ambient temperature and humidity, and pulverized with a mortar and pestle. The microsclerotia were further separated in sterile distilled water in a Waring blender, and their viability was determined by dilution plating on the medium of Grove and Campbell (11). Unless otherwise stated, microsclerotia produced in this manner were used in all experiments.

**Plant growth and disease assessment.** Tomato seeds of the cultivar Blazer (Petoseed, Woodland, CA) were planted in pots

(13 mm in diameter) containing soil infested with various concentrations of microsclerotia and thinned to two plants per pot after emergence. The plants were kept in a temperature-controlled greenhouse with cool-white fluorescent light for 16 h per day. Mean temperatures were 21 C during the day and 18 C at night. The plants were watered every other day. They were uprooted for disease assessment 8 wk after planting, unless otherwise stated. The percentage of root length infected was determined with video image analysis (Decagon Devices, Inc., Pullman, WA). Since the contrast between healthy and diseased parts of the roots was not high enough to be distinguished by video image analysis, the healthy and diseased parts were cut apart and analyzed separately.

**Effect of inoculum density on disease severity.** To determine optimal inoculum densities for further studies, composite soil samples from two organic farms (1 and 4) and two conventional farms (6 and 7) were used (Table 1). Soil samples were collected during the spring (April) or fall (October) of 1991. During the spring sampling, there were no crops in any of the fields. Winter cover crops planted on the organic farms had been tilled into the soil 1–3 wk before sampling. During the fall sampling, all fields were fallow after incorporation of debris from various summer crops, except for one organic field that still had a mature tomato crop. The clay content of soils at the different farms varied from 20 to 30% and was similar for pairs of organic and conventional farms. One of four levels of inoculum (0,  $10^3$ ,  $10^4$ , or  $10^5$  viable microsclerotia per milliliter of soil) was mixed with each soil sample. The soil samples were adjusted to 18% soil moisture and dispensed into four pots each. Two tomato plants per pot were grown for 8 wk, and corky root severity was assessed as described above. The pots were arranged in a randomized complete block design, and the experiment was conducted twice.

**Effect of gamma radiation on disease severity.** Soil samples were collected during April 1992 from five organic and five conventional farms (Table 1) 1–3 wk after incorporation of manure or compost (7–10 tons per hectare) in organic farms and after application of starter fertilizers (50 kg of nitrogen per hectare) in conventional farms. During sampling, three of the organic and three of the conventional fields were planted to tomatoes. The rest of the fields (organic and conventional) were fallow. The clay content of the soil samples from the organic farms was 20–41%; that of samples from the conventional farms was 20–30%. Half of each soil sample was irradiated with 2.5 Mrad of gamma rays for 2 wk to eliminate microorganisms sensitive to this treatment. Irradiated and nonirradiated soil from each farm was infested with  $10^4$  microsclerotia per milliliter of soil or left noninfested and then added to five 13-cm-diameter pots per treatment. Pots with two tomato plants each were positioned on the greenhouse bench in a randomized complete block design. After 8 wk, corky root severity was assessed as described above.

**Effect of nitrogen fertilization on disease severity.** For one experiment, soil samples from two organic farms (1 and 4) and two conventional farms (6 and 7) were sampled during October 1991. Cropping conditions of the fields are described above. The soil samples were infested with  $10^4$  microsclerotia per milliliter of soil or remained noninfested. Half the infested and noninfested soil samples received 100 kg of nitrogen per hectare in the form of  $\text{NH}_4\text{NO}_3$  (0.40 g per 13-cm-diameter pot); the other half remained nonfertilized. The fertilizer was incorporated into soil in pots 1–2 cm below the level where tomato seeds were to be planted. Superphosphate was mixed into the soil at a rate of 100 kg of  $\text{P}_2\text{O}_5$  per hectare (0.8 g per pot). Two tomato plants were grown per pot as described above, and there were five replicates in a randomized complete block design. Corky root severity was assessed after 8 wk as described above.

In another experiment, the effects of six levels of nitrogen fertilization on corky root severity in pasteurized Yolo sandy loam were determined. This soil was collected from a weedy section in an experimental farm at the University of California, Davis, and was low in nitrogen. The soil was infested with  $10^4$  microsclerotia per milliliter or left noninfested. Superphosphate was added to infested and noninfested soil as described before.

TABLE 1. Texture, pH, and microbial activity of soil sampled from organic and conventional farms during the spring of 1992

Type	Sand (%)	Silt (%)	Clay (%)	pH	Microbial activity <sup>a</sup>
Farm number					
Organic					
1	27	47	26	7.1	1.00
2	42	38	20	7.1	1.22
3	11	48	41	6.9	0.48
4	27	50	23	7.1	1.02
5	30	45	25	7.0	1.00
Conventional					
6	19	51	30	7.5	0.19
7	42	38	20	7.0	0.17
8	34	40	26	7.2	0.22
9	23	55	22	7.0	0.48
10	25	54	21	6.9	0.33

<sup>a</sup> Micrograms of hydrolyzed fluorescein diacetate per gram of dry soil per minute.

$\text{NH}_4\text{NO}_3$  (0, 0.21, 0.42, 0.63, 0.84, or 1.05 g per pot; equivalent to 0, 50, 100, 150, 200, or 250 kg of nitrogen per hectare, respectively) was added to each pot as described above. The plants were uprooted and assessed for disease severity 6 wk after planting. There were three replicates in a randomized complete block design, and the experiment was conducted twice.

**Survival of microsclerotia in soil.** Microsclerotia used to determine their longevity in soils were produced according to Shishkoff and Campbell (32). Initially,  $10^4$  microsclerotia per gram of dry soil were mixed with soil samples from five organic and five conventional farms (Table 1) collected during November 1992. All fields were fallow at the time of sampling. Soil infested with microsclerotia was added to 10-cm-diameter pots in three replicates. The pots were placed in a growth chamber with 12 h of light (photon flux density =  $250\text{--}300 \mu\text{E m}^{-2}\text{s}^{-1}$ ) in a randomized complete block design. The mean temperatures in the growth chamber were 20 C during the day and 9 C at night. The soil was remoistened every other day by adding water to saucers underneath the pots and by periodically misting the soil surface with water. To determine the density of microsclerotia, one soil sample was taken with a spatula from each pot every 2 wk for 10 wk. A 5-g subsample from each sample was suspended in 45 ml of sterile distilled water and stirred for 5 min. Four dilution

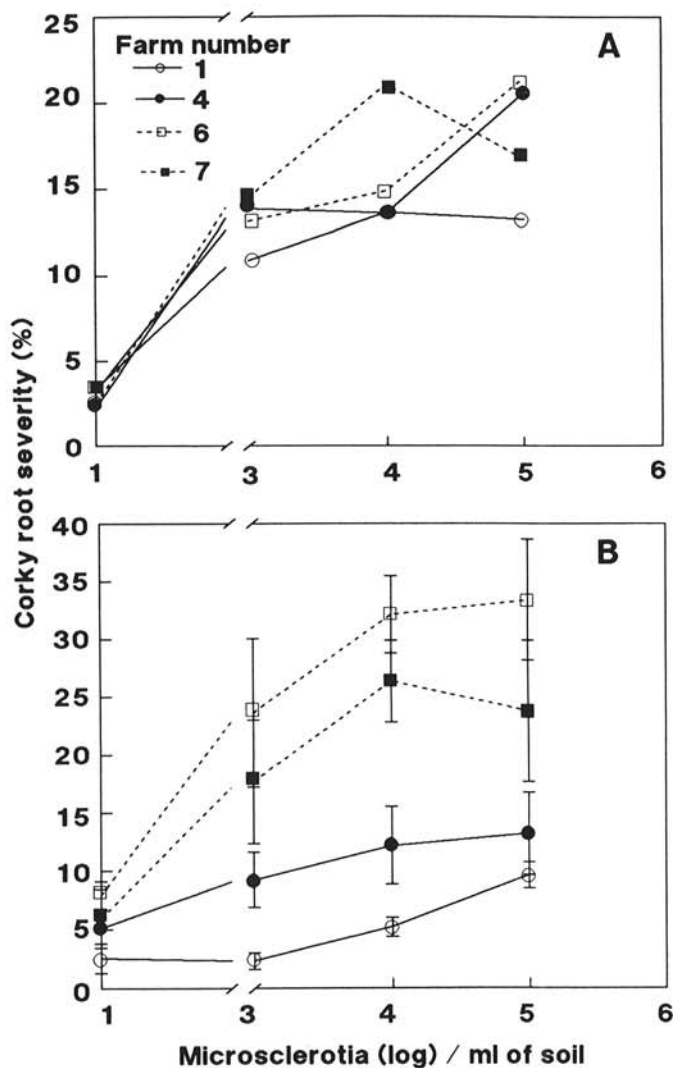
series were made by transferring 1 ml of suspension to tubes containing 9 ml of sterile distilled water. One hundred microliters of each dilution was then plated on the semiselective medium of Grove and Campbell (11) in duplicate. Characteristic colonies of *P. lycopersici* were counted 10–15 days later.

**Statistical analyses.** Analyses of variance with interaction terms were used for the corky root severity data from all factorial experiments (inoculum density, fertilization, and radiation experiments). Numbers of colony-forming units per gram of soil in the survival experiment were analyzed by analysis of variance at each sampling period. Ammonium and nitrate contents of soil and nitrogen and phosphorous concentrations in tomato tissue were compared for organic and conventional farms, irradiated and nonirradiated soil, and fertilized and nonfertilized soil by paired or independent *t* tests. Pearson's correlation coefficients were determined for corky root severity, soil nitrogen, tissue nitrogen, and phosphorous. All data were analyzed with the Statistical Analysis Systems software (SAS Institute, Inc., Cary, NC).

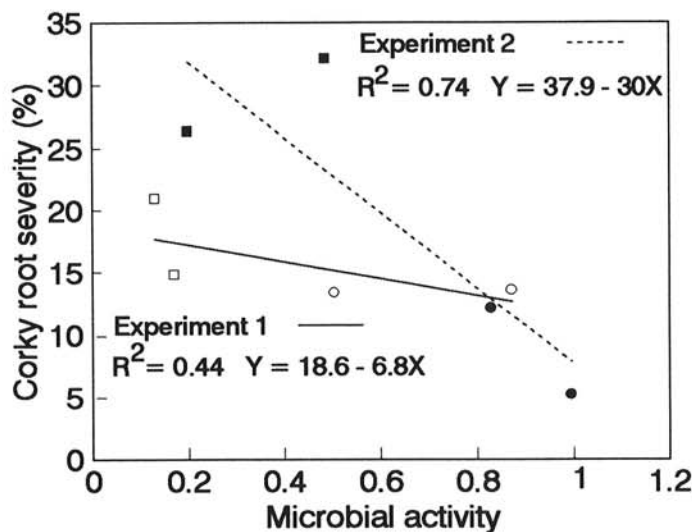
## RESULTS

**Effect of inoculum density on disease severity.** In both experiments, corky root severity was generally greater at higher levels of inoculum than at lower levels (Fig. 1A and B). For samples collected during the spring of 1991 (Fig. 1A), there was no significant difference in corky root severity between organically and conventionally managed soils at any inoculum level. However, there was a slight but significant ( $P = 0.05$ ) negative correlation between microbial activity and corky root severity at  $10^4$  microsclerotia per milliliter of soil (Fig. 2). For soil samples collected during the fall of 1991, disease severity was greater in soils from conventional farms than in those from organic farms at all inoculum concentrations. The difference in disease severity between soils from organic farms and those from conventional farms was significant at  $10^4$  microsclerotia per milliliter. Microbial activity was again negatively correlated with disease severity at  $10^4$  microsclerotia per milliliter of soil (Fig. 2). Disease severity in noninoculated soil was 0–7% in the first experiment and 0–9.1% in the second experiment.

**Effect of irradiation on disease severity.** Corky root severity was 0–10% in noninoculated, nonirradiated soil and 0% in noninoculated, irradiated soil. Disease severity in noninoculated, nonirradiated soil was subtracted from severity in inoculated, nonirradiated soil before data analysis. Corky root severity (adjusted for disease in noninoculated soil) was slightly, but not



**Fig. 1.** Severity of corky root on tomato (percentage of root length infected) at different inoculum densities of *Pyrenochaeta lycopersici* in soils from organic farms (1 and 4) and conventional farms (6 and 7) sampled A, during the spring and B, during the fall. Differences in corky root severity between organic and conventional soils sampled during the spring were insignificant. Bars represent standard errors. There was no significant difference in corky root severity between management types in spring samples.



**Fig. 2.** Relationship between severity of corky root on tomato at  $10^4$  microsclerotia of *Pyrenochaeta lycopersici* per milliliter of soil and microbial activity (micrograms of hydrolyzed fluorescein diacetate per gram of dry soil per minute). Soils were sampled from organic (○ and ●) and conventional (□ and ■) farms during April (○ and □, experiment 1) and October (● and ■, experiment 2).

significantly, less in organically managed soil than in conventionally managed, nonirradiated soil (Fig. 3). There was, however, a significant interaction between irradiation and origin of the soil samples with respect to disease severity ( $P = 0.0001$ ). Disease severity increased in all irradiated soils compared with their nonirradiated counterparts. The increase in disease severity after irradiation was significantly ( $P = 0.017$ ) greater in organically managed soils than in conventionally managed soils (Fig. 3 and Table 2). The relative increase in disease severity after irradiation was positively correlated ( $r = 0.88$  and  $P = 0.0001$ ) with microbial activity in nonirradiated soils (Fig. 4).

The concentrations of nitrate and ammonium in nonirradiated soils did not differ significantly between organic and conventional farms (Table 3). Nitrate concentrations in irradiated soil from all farms were less than those in nonirradiated soils ( $P = 0.02$ ), whereas soil ammonium concentrations were greater after irradiation than before ( $P = 0.0001$ ) (Table 3). Total nitrogen concentrations in tissue of inoculated tomato plants were similar for plants grown in organically and conventionally managed soils and for those grown in irradiated and nonirradiated soils (data not shown). There was no correlation between corky root severity and available nitrogen in soil (soil nitrate plus ammonium) or total nitrogen in tomato tissue.

**Effect of fertilization on disease severity.** The effect of fertilization with ammonium nitrate on corky root severity depended on the origin of the soil (Fig. 5A and B; interaction between fertilization and farm type was significant at  $P = 0.0001$ ). In soil from organic farms, corky root severity was greater in fertilized than in nonfertilized soils at all inoculum levels. However, disease

severity in soil from conventional farms was generally less in fertilized than in nonfertilized soil, except at 0 and  $10^4$  microsclerotia per milliliter for one of the farms. Soil nitrate concentrations increased from 8–17 to 25–76  $\mu\text{g}/\text{ml}$  after fertilization with ammonium nitrate (Table 4). There was only a weak positive correlation between corky root severity and soil nitrate concentration for all soils ( $r = 0.41$  and  $P = 0.02$ ), but a strong positive correlation between soil nitrate and disease severity occurred at the highest inoculum density in fertilized soils ( $r = 0.97$  and  $P = 0.02$ ).

In the experiments with pasteurized Yolo sandy loam, severity of corky root was positively correlated with the levels of  $\text{NH}_4\text{NO}_3$  added (Fig. 6). Disease severity also increased with increasing tissue nitrogen (Fig. 7). However, both pH and phosphorous contents in the soil decreased (from 7.8 to 7.2 and 0.46 to 0.16%, respectively) at increasing levels of ammonium nitrate applied. Thus, corky root severity was negatively correlated with soil pH ( $r = -0.81$  and  $P = 0.001$ ) and phosphate ( $r = -0.78$  and  $P = 0.003$ ). These factors were confounded with nitrogen in their effects on corky root.

**Survival of microsclerotia in soil.** The number of colony-forming units of *P. lycopersici* declined over time in all soils

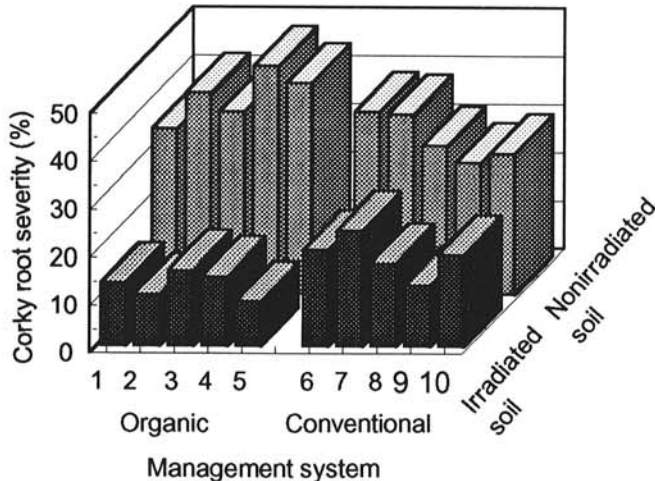


Fig. 3. Severity of corky root on tomato (percentage of root length infected) in nonirradiated and irradiated soils from organic farms (1–5) and conventional farms (6–10). Differences in disease severity between nonirradiated soils from organic and conventional farms were insignificant. Percentage of increase in disease severity after irradiation was significantly higher in organic soils than in conventional soils.

TABLE 2. Increase in disease severity (percentage of root length infected) in irradiated soils compared with nonirradiated soils from organically and conventionally managed farms

Organic farms		Conventional farms	
Farm number	Increase <sup>a</sup> (%)	Farm number	Increase (%)
1	156	6	86
2	277	7	53
3	138	8	76
4	221	9	111
5	358	10	52
Mean $\pm$ SD	230 $\pm$ 91	Mean $\pm$ SD	76 $\pm$ 25

<sup>a</sup> Increase (%) = [(severity in irradiated – severity in nonirradiated soil) / severity in nonirradiated soil]  $\times$  100.

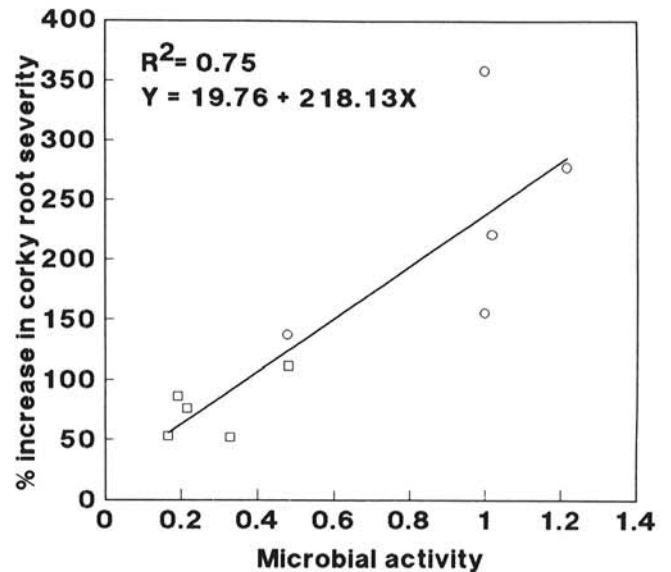


Fig. 4. Relationship between percentage of increase in severity of corky root on tomato in irradiated soil compared with nonirradiated soil and microbial activity (micrograms of hydrolyzed fluorescein diacetate per gram of dry soil per minute).  $\circ$  = Soils from organic farms, and  $\square$  = soils from conventional farms.

TABLE 3. Ammonium and nitrate concentrations in nonirradiated and irradiated soils sampled from organic and conventional farms during the spring of 1992

Type	Farm number	Nonirradiated soil		Irradiated soil	
		$\text{NH}_4^+\text{-N}$ ( $\mu\text{g}/\text{g}$ ) <sup>a</sup>	$\text{NO}_3^-\text{-N}$ ( $\mu\text{g}/\text{g}$ )	$\text{NH}_4^+\text{-N}$ ( $\mu\text{g}/\text{g}$ )	$\text{NO}_3^-\text{-N}$ ( $\mu\text{g}/\text{g}$ )
Organic	1	6.2	16.7	36.8	10.2
	2	2.7	51.6	15.6	7.8
	3	4.5	32.2	23.9	16.2
	4	3.0	21.8	33.8	23.9
	5	3.1	57.6	23.5	17.9
Conventional	6	3.9	82.5	26.8	33.8
	7	3.2	...	16.4	...
	8	5.8	43.5	20.9	20.8
	9	3.2	24.9	36.3	15.0
	10	3.0	22.4	16.4	10.4

<sup>a</sup> Per gram of dry soil.

<sup>b</sup> Data missing.

(Fig. 8). There were no significant differences in colony-forming units per gram of dry soil between soils from organic and conventional farms at all sampling dates. However, numbers of colony-forming units 2 wk after incorporation were negatively correlated with microbial activity at the start of the experiment (Fig 9;  $r = -0.56$  and  $P = 0.09$ ).

## DISCUSSION

Addition of high levels of inoculum of *P. lycopersici* relative to background levels in natural field soil resulted in less disease in organically managed soils than in conventionally managed soils,

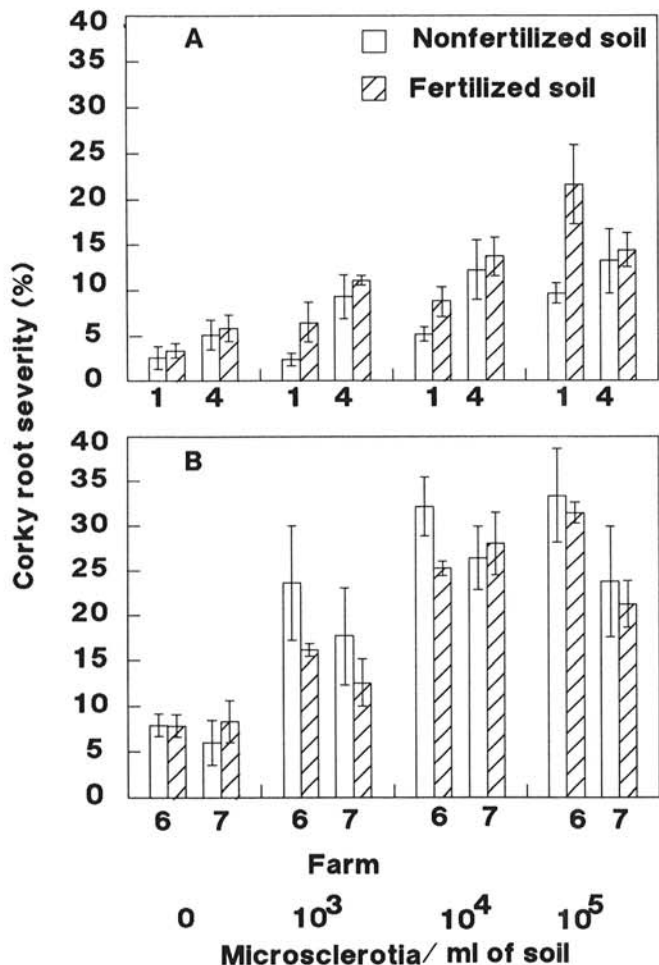


Fig. 5. Severity of corky root on tomato in nonfertilized soil and soil fertilized with 100 kg of nitrogen per hectare from A, organic farms and B, conventional farms at different inoculum densities of *Pyrenochaeta lycopersici*.

TABLE 4. Ammonium and nitrate concentrations in fertilized and non-fertilized soils sampled from organic and conventional farms during the fall of 1991

Type Farm number	Nonfertilized soil		Fertilized soil	
	NH <sub>4</sub> <sup>+</sup> -N (μg/g) <sup>a</sup>	NO <sub>3</sub> <sup>-</sup> -N (μg/g)	NH <sub>4</sub> <sup>+</sup> -N (μg/g)	NO <sub>3</sub> <sup>-</sup> -N (μg/g)
Organic				
1 <sup>b</sup>	4.2	14.8	7.2	41.2
4 <sup>c</sup>	4.9	8.2	2.6	24.6
Conventional				
6 <sup>c</sup>	6.3	17.0	6.8	76.2
7 <sup>c</sup>	5.3	10.2	2.9	34.7

<sup>a</sup> Per gram of dry soil.

<sup>b</sup> Tomatoes in field at time of sampling; manure applied during the spring of 1991.

<sup>c</sup> Fields fallow; various summer crops incorporated into soil.

particularly those sampled during the fall. This indicates that natural disease suppression may have contributed to the lower incidence and severity of corky root in organically managed soils previously observed in a field survey in central California (39) in addition to lower levels of incidence and severity resulting from potential differences in field inoculum levels (39). The occurrence of disease suppressiveness in soils from organic farms is supported by the finding that the relative increase in disease severity in irradiated compared with nonirradiated soil was significantly higher for organic farms than for conventional farms, although disease severity in the untreated soil samples (collected during the spring) was similar for both farm types. A separate experiment conducted on the same samples from three organic and three conventional farms showed that disease suppression in organic soils was significantly correlated with cellulolytic actinomycetes and total actinomycete populations (38).

Soils suppressive to various pathogens have been described over the years. The suppression was attributed to physical, chemical,

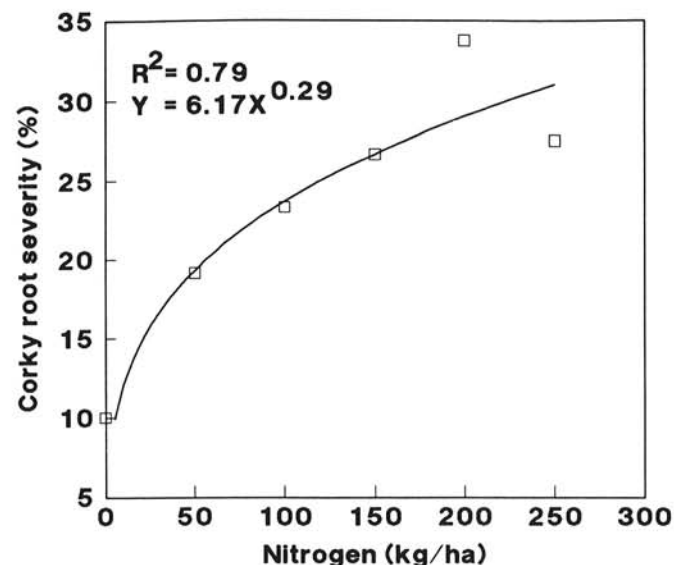


Fig. 6. Relationship between corky root severity on tomato (percentage of root length infected) and different levels of nitrogen applied to pasteurized soil in the form of ammonium nitrate. The experiment was repeated twice. Since both experiments produced similar results, only one of the results is shown.

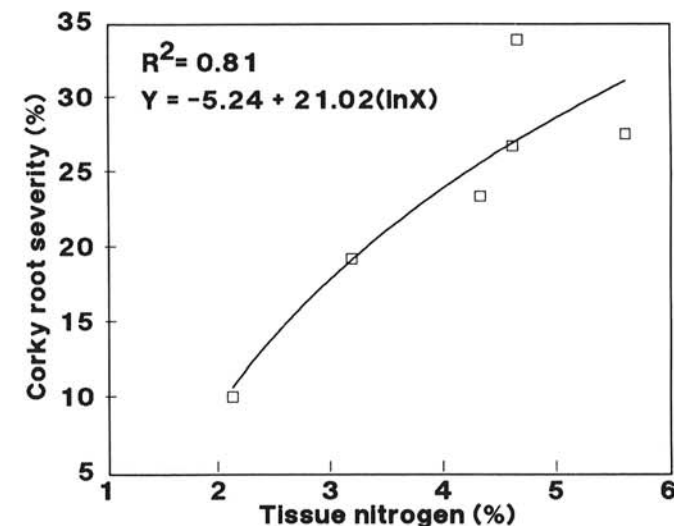


Fig. 7. Relationship between corky root severity (percentage of root length infected) and nitrogen concentration (percentage of dry weight) in shoots of tomatoes grown in pasteurized Yolo sandy loam soil. The experiment was repeated twice. Since both experiments produced similar results, only one of the results is shown.

or biological factors or combinations of these factors (31). Suppression of Fusarium wilt of melons was linked to microbial activity associated with montmorillonite clays (1). *Pythium ultimum* was suppressed by elevated chloride ions and competition from *P. oligandrum* (19). *Sclerotinia minor* (17) and *Phytophthora cinnamomi* (18) were suppressed by microbial activity, which was enhanced by the addition of organic amendments.

In our experiments, soil from organic farms that had received various forms of organic amendments had higher microbial activity than did soil from conventional farms. Moreover, corky root severity of tomato plants grown in these soils was negatively correlated with microbial activity. A negative correlation between corky root severity and soil microbial activity was also observed in a field survey (39). On the basis of the field survey data, we hypothesized that one or more biological factors might be involved in disease suppression on organic tomato farms. This hypothesis was supported by a higher relative increase in corky root severity after gamma irradiation of organically managed soils than of conventionally managed soils.

One possible mechanism of biological disease suppression is stimulation of germination and subsequent lysis of germ tubes in soil high in organic matter content (24,27). In that case, a faster decline in viability of microsclerotia would be expected in organically managed soil than in conventionally managed soil exposed to drying and wetting cycles. In our experiment with microsclerotia of *P. lycopersici*, numbers of colony-forming units retrieved from organically managed and conventionally managed soil were similar. However, 2 wk after incorporation of the microsclerotia, the numbers of colony-forming units were negatively correlated to initial microbial activity in soil, indicating that the initial decline in viability of the microsclerotia was related directly to microbial activity. Nevertheless, other mechanisms of biological disease suppression also may be involved in suppression of corky root on tomato. *P. lycopersici* has a low competitive saprophytic ability (6) and a low competitive ability on tomato roots (7). The low competitive ability of the pathogen coupled with high microbial activity in soils from organic farms suggests competition to be a more likely mechanism of suppression.

When soil samples were collected during the spring, corky root severity was slightly, but not significantly, less in organically managed soils than in conventionally managed soils. In samples collected during the fall, however, the severity of the disease was significantly less in soils from organic farms than in soils from conventional farms. The reason for this difference is not clear. One explanation for the similarity in corky root severity in organically and conventionally managed soils sampled during the spring might be the similarity in concentrations of ammonium in soil and of nitrate and nitrogen in tomato tissue. Conventional farms were sampled before side-dressing with nitrogen fertilizers, whereas organic amendments had already been applied in the

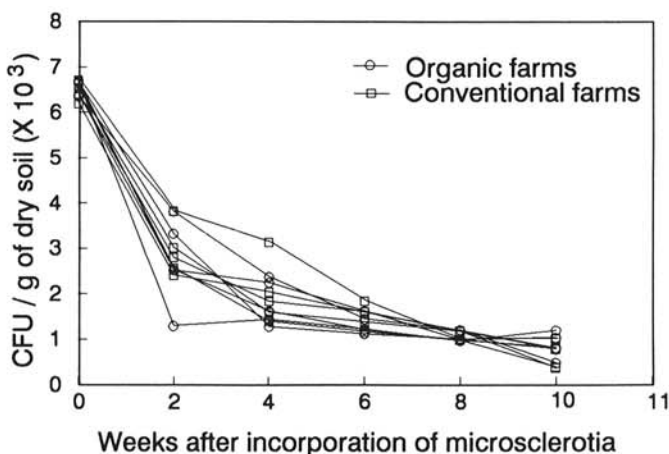


Fig. 8. Inoculum density (cfu/g of dry soil) after incubation of microsclerotia of *Pyrenochaeta lycopersici* in potted soils from organic and conventional farms.

organic farms, resulting in similar nitrogen concentrations in both soil types. In one of the experiments, fertilization with ammonium nitrate of soils from organic farms increased the disease at all inoculum levels. Nitrogen in the form of ammonium nitrate reduced microbial antagonists in the bean rhizosphere (26) and reduced suppressiveness of organic amendments to Fusarium root rot of bean (20). Thus, the relatively high nitrogen concentrations in organically managed soils may have affected tomato rhizosphere microbial populations antagonistic to *P. lycopersici* and may have negated the effect of microbial activity (which was higher in organic farms) on disease suppression. High levels of nitrogen may also have rendered the plants more susceptible to infection by *P. lycopersici* (25,33). However, soils from both organic and conventional farms sampled during the fall had lower levels of nitrate than those sampled during the spring. Thus, disease suppression by high microbial activity in organically managed soils was probably not counteracted by soil nitrate levels in the fall.

In separate experiments on the effect of nitrogen on corky root severity in pasteurized soil, corky root severity was related to levels of ammonium nitrate applied and the associated concentrations of ammonium and nitrate in soil and total nitrogen in tomato tissue. In the field study mentioned above (39), high levels of soil nitrate and tissue nitrogen were also consistently associated with relatively high corky root severity. Association of nitrogen with plant disease severity is well documented (13). The effect of nitrogen on root diseases is dependent on the form in which the nitrogen is applied (13). Fusarium root rot of beans (16), common root rot of wheat (37), and rice blast (25) were associated with high soil nitrate concentration. Ammonium also has been known to enhance several root rots and cortical diseases of plants (13). Ammonium increases incidence and severity of foot rot of wheat caused by *Cercospora herpotrichoides* (10) and stem and stolon rot of potato caused by *Rhizoctonia solani* (12).

The individual effects of ammonium and nitrate in soil and of nitrogen concentration in tomato tissue were not unraveled in these experiments because all these factors were confounded. When ammonium nitrate fertilizer was added to pasteurized soil, both nitrate and ammonium concentrations were positively correlated with corky root severity. However, there was no clear relationship between disease severity and soil nitrate in most experiments with natural field soil, whereas there was a significant relationship between disease severity and ammonium in the gamma radiation experiment. However, the relationship between ammonium and disease severity might have been coincidental because higher concentrations of ammonium were found in irradiated soil than in nonirradiated soil. Thus, the effects of ammonium and nitrate on corky root severity are unclear.

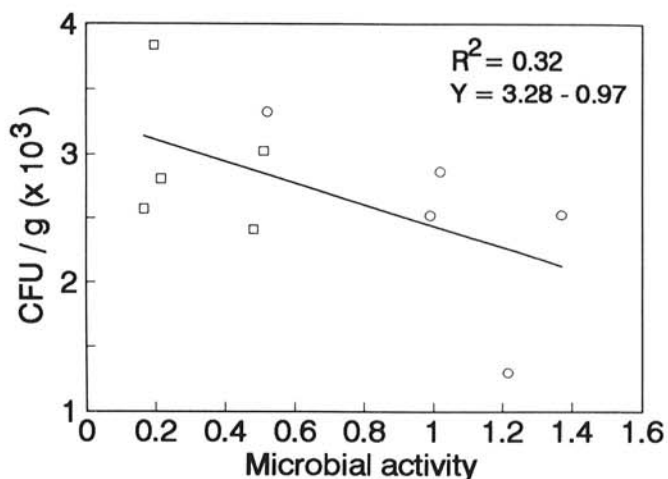


Fig. 9. Relationship between density of *Pyrenochaeta lycopersici* (cfu/g of dry soil) and microbial activity (micrograms of hydrolyzed fluorescein diacetate per gram of dry soil per minute) in organic and conventional soils 2 wk after incorporation of microsclerotia (10<sup>4</sup>/ml of soil). ○ = Soils from organic farms, and □ = soils from conventional farms.

Effects of nitrogen and those of pH and phosphorous on corky root severity were confounded. In the experiment with pasteurized soil, increasing applications of ammonium nitrate resulted in decreasing soil pH and phosphorous concentrations in tomato tissue, despite the application of superphosphate to all soils. This was expected (34), but it precluded definite conclusions about the effect of nitrate and ammonium on corky root severity.

These experiments showed that suppression of corky root in soils from organic farms is associated with both soil nitrogen status and microbial activity. Soils from organic farms are higher in microbial activity and biomass than are soils from conventional farms (29,39). Organically managed soils may also contain lower concentrations of nitrate than do conventionally managed soils (8). In addition, root diseases are often less severe on organic or low-input farms than on conventional farms (5,9,28). This is, however, the first report of experiments in which these factors were investigated simultaneously under controlled environmental conditions with known amounts of inoculum.

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