Effect of Solar Heating and Soil Amendments of Cruciferous Residues on *Fusarium oxysporum* f. sp. *conglutinans* and Other Organisms

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ABSTRACT

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In the laboratory and in pots buried in the field, the severity of cabbage yellows and populations of *Fusarium oxysporum* f. sp. *conglutinans* in soils were markedly reduced by amendments of nine cruciferous species; moderately reduced by alfalfa hay; and increased by wheat straw, chicken manure, or steer manure. The effectiveness of a cabbage amendment was increased by drying the residue before incorporation and was directly related to the concentration and time of exposure. Solar heating (full sunlight, polyethylene cover) of pots of soil amended with cabbage residues practically eliminated propagules of *F. o.* f. sp. *conglutinans*, and cabbage yellows was undetected in cabbage growing in the soil. The effectiveness of the treatment was complete within the first 15 days. Especially significant is the fact that cruciferous amendments in conjunction with solar heating or shade treatments were far more effective than solar heating or shade treatments alone. In laboratory experiments populations of *F. o.* f. sp. *conglutinans* were reduced almost to zero (reduced by 99.4%), total fungi were decreased by about 20%, actinomycetes apparently were unaffected, and bacterial populations were increased 16-fold by gases arising from decomposing cabbage residues in soil in closed containers. The drastic reduction of propagules of *F. o.* f. sp. *conglutinans* only occurred in closed containers. In closed jars, the fungus, which had been growing on potato-dextrose agar in petri dishes suspended above soil containing cabbage residues or moistened cabbage alone, ceased growing. The effect was fungistatic, since growth resumed upon transfer of the fungus to fresh potato-dextrose agar. In contrast, when infested soil was suspended above the decomposing cabbage residues, the effect was fungicidal. A growth-promoting effect was observed on cabbage plants grown in soil amended with cabbage residues, but tomato plants wilted within 24 hr after being planted in the amended soil.

Additional key words: soil bacteria, soil fungi, soil solarization.

At times soil amendments may decrease (9,10,14,33,36,39) or increase (4,13,21,36) disease incidence. Solar heating (covering soil with a clear polyethylene tarp, exposed to full sunlight; also known as soil solarization) also has had variable effects on disease control. Katan (15) suggested that some of the vagaries of the treatments might be offset by combining effective organic amendments, pesticides, or biocontrol agents with solar heating. In this paper we report our studies on the effects of combining soil amendments of plant residues with solar heating on *Fusarium oxysporum* Schlecht. f. sp. *conglutinans* (Wr.) Snyd. & Hans. and other organisms. In another paper (26) we reported the use of these techniques to control cabbage yellows in the field.

The objectives of these experiments were to determine the effects of plant amendments and solar heating of soil on *F. o.* f. sp. *conglutinans* in the field and in the laboratory and to determine the effects of gases from amended soils on *F. o.* f. sp. *conglutinans* and associated microorganisms. An abstract of portions of the work was published earlier (25).

MATERIALS AND METHODS

Effect of solar treatments of amended soils on *F. o.* f. sp. *conglutinans* and incidence of cabbage yellows. Soil was infested with inoculum prepared by growing *F. o.* f. sp. *conglutinans* race 5 (24) for 3 wk in a wheat-sand mixture (22), screening it through a 1.7-mm-mesh sieve, and mixing it (1:9, w/w) with steamed U.C. soil mix (2) in a cement mixer. The soil-inoculum mixture was moistened to about 80% of its water-holding capacity (WHC) and left at 25 C for 5 wk to convert the fungus to chlamydospores. Two consecutive 6-wk crops of cabbage (*Brassica oleracea* var. *capitata* L.), cultivar Rio Verde, were grown in the soil in the glasshouse to increase the concentration of inoculum.

Amendments of cabbage, kale (*B. o.* var. *viridis* L.), mustard (*B. nigra* (L.) Koch), cauliflower (*B. o.* var. *botrytis* L.), broccoli (*B. o.* var. *botrytis* L.), collard (*B. o.* var. *acephala* DC.), Brussels sprouts (*B. o.* var. *gemmifera* DC.), turnip (*B. rapa* L.), radish (*Raphanus sativus* L.), alfalfa hay (*Medicago sativa* L.), wheat straw (*Triticum vulgare* L.), chicken manure, and steer manure were used. The cruciferous plants and steer manure were obtained from commercial sources, the wheat straw and alfalfa hay from the field, and the chicken manure from a poultry farm. Leaf and stem fractions of plant residues and manures, dried in the sun for 10 days, were ground in a Wiley mill until they passed through a 20-mesh screen (0.85 mm).

The effectiveness of treatments was determined by assaying populations of *F. o.* f. sp. *conglutinans* in the soil and by estimating disease severity on cabbage subsequently seeded in the soil. All population estimates were compared with assays of untreated infested soil assayed at the same time. The populations were estimated by the plate dilution method (up to 10^{-3} dilution) using Komada's medium (16). At the end of the treatment period soil samples were air-dried at 24 C for 24 hr, and 60-g samples in triplicate were vigorously shaken in 600 ml of sterile water on a mechanical shaker for 30 min. Serial dilutions of the mixture were made in sterile water and analyzed. For each dilution 1-ml samples were transferred to each of five petri plates. Colonies of *F. o.* f. sp. *conglutinans* were counted after incubation for 8 days at 25 ± 2 C under diffuse light in the laboratory. Initially some of the fusaria growing on the medium were transferred to potato-dextrose agar (PDA) and compared to known cultures of *F. o.* f. sp. *conglutinans* race 5, but eventually the colonies were recognizable without resorting to microscopic examination.

Disease severity was assessed by sowing seeds of Rio Verde cabbage in soil from each treatment in 20-cm-diameter pots. After emergence, the seedlings were thinned to 20 seedlings per pot and grown for 5 wk at 24 C (night) to 28 C (day) in a growth chamber. Disease severity was rated according to Williams (37).

Two field experiments were made (10 October–11 December 1982 and 5 August–20 September 1983). The effects of solar heating, shade, and seven amendments (cabbage, mustard, kale, alfalfa, wheat, chicken manure, and steer manure) on populations of *F. o.* f. sp. *conglutinans* and the severity of cabbage yellows were evaluated. Residues were added singly to 4-kg portions of U.C. soil

mix infested with *F. o.* f. sp. *conglutinans* at the rate of 2% (w/w) and moistened to 60% WHC. Infested soil without amendments and uninfested soil without amendments served as controls. The experimental design was a randomized complete block with three replications of either shaded or solar-heated plots (Fig. 1). The amended soils were placed in 3.8-L cans sealed in plastic bags and buried in the field for 8 wk, with the tops of the cans flush with the soil surface, but the top surfaces of the cans were not covered by soil. The shaded and solar-heated plots, each containing 27 buried cans, were covered with a translucent polyethylene tarp for 8 wk. Shading was carried out by covering half of the plot with a tent of black polyethylene (2.4 × 3.5 m on the sides and 1 m high) to provide dense shade, assuring that no direct sunlight struck the plots. After 8 wk, the cans were moved to the greenhouse, and the soils assessed for populations of *F. o.* f. sp. *conglutinans* and disease severity.

In the 1983 field experiment the soil was amended only with dried cabbage (1%, w/w) and was analyzed after 15, 30, and 45 days. Soil and air temperatures were monitored with thermographic recording equipment.

Effect of nonsolar treatment of soils amended with plant residues or manures on *F. o.* f. sp. *conglutinans*. Tissues, including roots, of cauliflower, broccoli, cabbage, collard, Brussels sprouts, radish, and turnip were air-dried and ground as previously described. U.C. soil mix (500 g) infested with *F. o.* f. sp. *conglutinans* was amended in triplicate with the plant materials at a rate of 2% (w/w), enclosed in 0.945-L jars, and incubated in the laboratory at 23 C for 5 wk. After incubation the soils were placed in 20-cm-diameter pots, seeded with the cultivar Rio Verde, and placed in a growth chamber (24 C, night; 28 C, day). After emergence, the pots were thinned to 20 seedlings per pot, and ratings of cabbage yellows severity were made after 5 wk.

The effect of cabbage amendments on populations of *F. o.* f. sp. *conglutinans* in sealed and unsealed jars was measured in sandy loam soil infested with *F. o.* f. sp. *conglutinans*, amended with 1% dried cabbage, and adjusted with distilled water to 50% WHC. Before it was mixed in the soil, the dried cabbage residue was moistened with water (13 ml/g). Unamended soil was used as the control. Triplicate samples (500 g) of soils were placed in 0.945-L jars; half were sealed tightly with screw covers, and the other half left open. The moisture contents of the soils in open jars were maintained by the addition of sterile distilled water to keep a constant weight. Populations of *F. o.* f. sp. *conglutinans* were determined after 5, 10, and 15 days.

The effect of fresh versus dry cabbage residues as soil amendments on populations of *F. o.* f. sp. *conglutinans* was evaluated. Infested U.C. soil mix (500 g) was amended with 0.25, 0.5, 1.0, or 2% dry or fresh cabbage, on a dry-weight basis. The soils were sealed in 0.945-L jars, triplicated in a completely randomized design, and incubated at 23 C in the laboratory. Populations of *F. o.* f. sp. *conglutinans* were monitored 5, 10, 15, and 30 days after incubating by plating-out dilutions of the soils on Komada's medium. This experiment was repeated once.

Effect of gas from soils amended with cabbage residues on *F. o.* f. sp. *conglutinans* and other microflora. The media and dilutions used for the various organisms were, for *F. o.* f. sp. *conglutinans*, Komada's medium (16), 1×10^{-1} through 1×10^{-3} dilutions; for total fungi, Steiner-Watson's medium (30), 1×10^{-3} and 1×10^{-4} dilutions; for actinomycetes, Hsu-Lockwood's medium (12), 1×10^{-4} and 1×10^{-5} dilutions; and for total bacteria, Farley-Lockwood's medium (8), 1×10^{-4} through 1×10^{-6} dilutions. Soil samples (60 g) were prepared as described above. Populations of microorganisms were estimated by spreading 0.5 ml of each dilution on top of solidified medium (five plates per dilution) and incubating under diffuse light at 23 C. Colonies were counted 3, 7, 8, and 14 days after plating for bacteria, *F. o.* f. sp. *conglutinans*, total fungi, and actinomycetes, respectively.

Samples of sandy loam soil from a field infested with the fungus were placed in a wire screen basket suspended from a rubber stopper and hermetically sealed (Fig. 2). Dry cabbage residues (2 g), moistened with 26 ml of water, were placed at the bottom of each jar. There was an air space of approximately 1 cm between the bottom of the basket and the cabbage residues. Controls consisted of jars containing soil in baskets suspended over 50 ml of distilled water. The soil infested with *F. o.* f. sp. *conglutinans* was adjusted with distilled water to 50% of field capacity and thoroughly mixed before using. Treatments were triplicated, and after 30 days at room temperature, the soil was removed, dried, and assayed for populations of *F. o.* f. sp. *conglutinans*, total fungi, bacteria, and actinomycetes.

Effects on the growth of *F. o.* f. sp. *conglutinans* on PDA were determined by procedures similar to those used by Richardson and Munnecke (27) for fungicide assay. In one experiment, triplicated lots (100 g) of U.C. soil mix, in 485-ml widemouthed jars, were amended with 1, 5, or 10 g of dry cabbage and adjusted with distilled water to 50% WHC. Before it was mixed in the soil, the dry cabbage was moistened with water (13 ml/g). Unamended soil was used as a control. In another experiment, the jars contained 1, 5, or 10 g of dry cabbage residues moistened with 100 ml of water. The control consisted of jars containing 120 ml of distilled water only.

Agar disks, 6 mm in diameter, were cut from a 6-day-old culture of *F. o.* f. sp. *conglutinans* growing on PDA at 23 C. The disks were taken before the colony reached the edge of the petri dish. The disks were centered on the agar surface of plastic petri dishes containing 15 ml of PDA; a dish was inverted over the mouth of each jar, and the jars were sealed with cellophane tape. The jars were incubated at 23 C until the mycelium of the fungus in the untreated series approached the edges of the plates, after approximately 6 days. The effect on linear mycelial growth was determined by measuring the colony diameters at 24-hr intervals. Each treatment was replicated three times.

To distinguish fungistatic from fungicidal effects, the plates were left in place for an additional 9 days, and then inoculum disks were cut from the mycelium, transferred to fresh PDA in petri dishes, and incubated at 23 C for 6 days. Growth of the mycelium was measured daily.

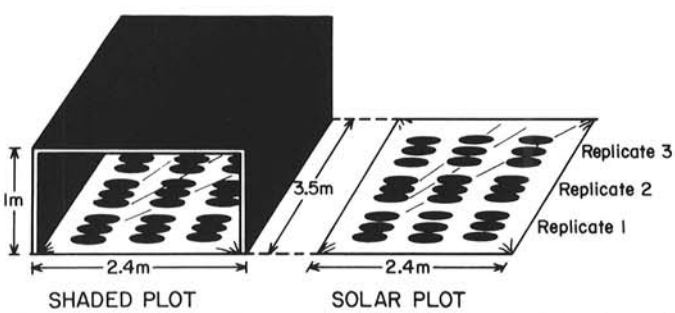

Fig. 1. Diagram of the field plot used to study the effect of solar heating and soil amendments on the survival of *Fusarium oxysporum* f. sp. *conglutinans* at Riverside, California. Soils and amendments were mixed and placed in 3.8-L cans sealed in plastic bags and buried in the field. The surface of the soil of the shaded and sunlit plots was covered with translucent polyethylene tarps.

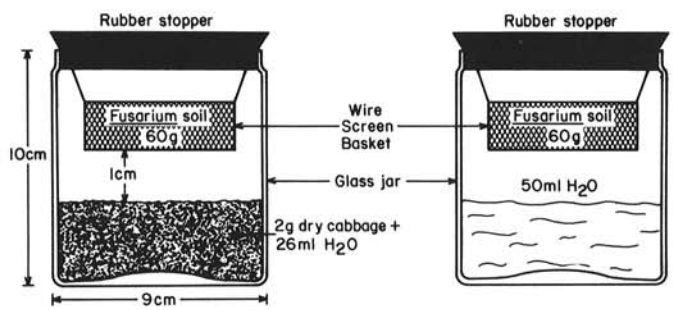

Fig. 2. Method used to determine the effects of gases from dried cabbage residues in water and in soil on microflora in a field soil infested with *Fusarium oxysporum* f. sp. *conglutinans*. The infested soil was suspended in wire screen baskets in air above the residue preparation.

RESULTS

Effects of various organic residues and solar heating on populations of *F. o.* f. sp. *conglutinans* and severity of cabbage yellows. Maximum temperatures in the solar treatments at the 5-cm depth during the experiment in 1982 were low, never exceeding 40 C, and they even were below 20 C at times. Initially, temperatures at the 5-cm depth in the solar-heated plots were 10–15 C higher than under shade, but during cloudy periods the difference was only 4–5 C. In spite of this, significant results were obtained (Table 1). Disease severity and populations of *F. o.* f. sp. *conglutinans* in the soil were markedly reduced by amendments of cabbage (9 propagules per gram of air-dried soil [ppg]), kale (15 ppg), and mustard (9 ppg); moderately reduced by amendments of alfalfa hay (229 ppg); and increased by amendments of wheat (1,625 ppg), chicken manure (1,800 ppg), and steer manure (2,017 ppg), in comparison with unamended infested soil.

Solar heating alone significantly ($P = 0.05$) decreased the number of propagules of *F. o.* f. sp. *conglutinans* per gram of soil (375 ppg), but not as much as the combination of solar heating plus cruciferous amendments (0 ppg). Disease severity in the same plots also was practically zero, indicating that *F. o.* f. sp. *conglutinans* probably was effectively eliminated by the treatments. In the infested control soil under shade there were 1,250 ppg. In soils amended with manures and subjected to solar heating, the populations of *F. o.* f. sp. *conglutinans* remained higher than in the infested control.

Disease severity, in all treatments, was consistently but not significantly ($P = 0.05$) less in solar-heated treatments than under shade. This was probably because the maximum ambient temperatures were very low. Cruciferous residues were excellent amendments under either shade or solar heating, and there were no significant differences in populations of *F. o.* f. sp. *conglutinans*, disease severity, and the percentage of dead plants when these treatments were compared. This indicates that the amendments were very effective, even at the low temperatures attained in the experiment.

During the second field experiment high maximum temperatures were recorded at a depth of 20 cm in the solar-heated soil, but low temperatures were recorded in the shaded soil (Fig. 3). Solar heating plus cabbage amendment was the most effective treatment; propagules of *F. o.* f. sp. *conglutinans* were practically eliminated, and cabbage yellows was undetected (Fig. 4). However, there were no significant differences ($P = 0.05$) in comparison with soils treated with cabbage under shade. Solar heating alone was partially effective but significantly different in comparison with the infested control (no amendment and shaded). In contrast, in the untreated infested soil there were 1,200 propagules of *F. o.* f. sp. *conglutinans* per gram of air-dried soil, and disease severity was 8.73.

The effects of the various treatments were expressed within the first 15 days, since the results of the 30- and 45-day treatments were not significantly different from those of the 15-day treatments.

Cabbage plants grown in soil amended with cabbage residue were taller and greener than those in unamended soils. However, tomato seedlings transplanted to cabbage-amended soil wilted and died in 1 day. This indicates that cruciferous amendments may be very phytotoxic to other crop plants.

All types of the dried cruciferous amendments added to soil infested with *F. o.* f. sp. *conglutinans* markedly reduced cabbage yellows. No significant differences due to amendments from different cruciferous species were observed. The disease severity index was approximately 0.5 on plants in soils amended with cabbage, cauliflower, broccoli, collard, Brussels sprouts, turnip, or radish, as contrasted to an index of over 7 in the unamended control.

Effects of cabbage amendments on populations of *F. o.* f. sp. *conglutinans* in soil in open and closed jars. Populations of *F. o.* f. sp. *conglutinans* were not affected in soil incubated in open or closed jars in the absence of cabbage residues (Fig. 5). In the sealed jars containing cabbage, populations of *F. o.* f. sp. *conglutinans* were reduced practically to zero by day 15. The reduction was linear for the period from 5 to 15 days after amendment, with a correlation coefficient of −0.99. In contrast, in the unsealed cabbage-amended soils, populations of *F. o.* f. sp. *conglutinans* initially increased sharply and then dropped linearly to values near those of the control after 15 days. Thus, the effect was observed

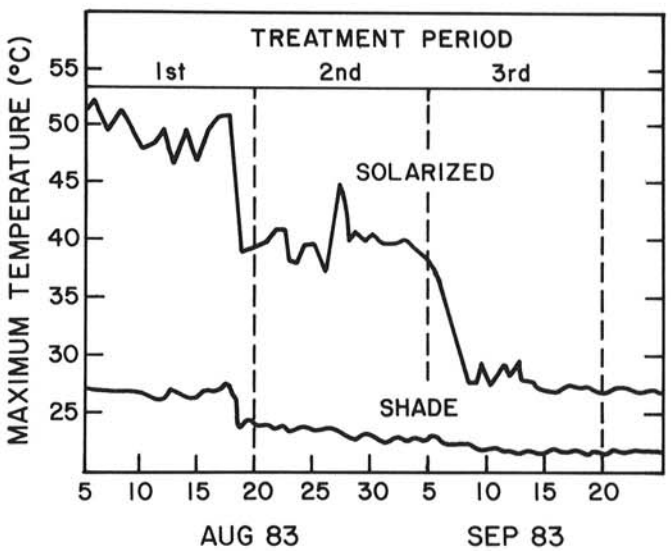

Fig. 3. Maximum temperatures attained at a depth of 20 cm in soil in cans buried in shaded and in full-sun plots.

TABLE 1. Effects of soil amendments, solar heating, and shading on cabbage yellows and populations of *Fusarium oxysporum* f. sp. *conglutinans* in soil in pots buried in the field for 8 wk

	Shaded			Solar-heated		
Treatment	Propagules per gram[x]	Disease severity[y]	Dead plants (%)	Propagules per gram	Disease severity	Dead plants (%)
Uninfested soil	0[z] a	0.0 a	0 a	0 a	0.0 a	0 a
Cabbage	9 a	0.5 a	3 a	0 a	0.0 a	0 a
Mustard	9 a	0.5 a	3 a	0 a	0.0 a	0 a
Kale	15 a	0.6 a	7 ab	0 a	0.0 a	0 a
Alfalfa hay	229 b	3.4 b	20 b	44 a	2.6 b	15 ab
Infested soil	1,250 e	5.5 cd	45 c	375 c	4.7 c	43 c
Wheat straw	1,625 g	6.2 de	50 cd	875 d	5.5 cd	42 c
Chicken manure	1,800 h	6.4 de	55 cd	1,255 e	6.0 de	42 c
Steer manure	2,017 i	6.9 e	63 d	1,374 f	5.8 cde	43 c

[x] Propagule population per gram of soil after 8 wk was estimated by the plate dilution method on Komada's medium (16).
[y] Disease severity was rated on 60 seedlings of cabbage, cultivar Rio Verde, on a scale of 0 (no disease symptoms) to 9 (death of seedlings).
[z] Means (three replicates) in the same column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

only in a closed system.

Effectiveness of fresh and dry cabbage residues as soil amendments on *F. o.* f. sp. *conglutinans*. Dried cabbage was more effective than fresh cabbage amendments (based on dry weight) in reducing the populations of *F. o.* f. sp. *conglutinans* (Fig. 6). These populations were substantially reduced in soils amended with dried cabbage as soon as 5 days after amendment, and the response was directly related to the concentration of the amendments. By days 13, 15, 23, and 30, propagules of *F. o.* f. sp. *conglutinans* were not detected after the soil had been amended with 2, 1, 0.5, and 0.25% dried cabbage, respectively. The curves plotting propagule counts versus time of exposure were linear and parallel, indicating that the effect of dried cabbage amendment on the survival of *F. o.* f. sp. *conglutinans* was directly related to the concentration of the amendment and the time of exposure. Correlation coefficients of −0.98 and −0.91 were found between propagule populations and rates of dried cabbage amendments at 5 and 10 days after treatment, respectively. A still higher coefficient (−0.99), was found between populations of *F. o.* f. sp. *conglutinans* and the time of exposure.

The reduction of populations of *F. o.* f. sp. *conglutinans* by fresh cabbage amendments also was related to the concentration of the amendments and the time of exposure, but the response was more variable than with dried cabbage amendments. Except for the lowest concentration (0.25%), the curves plotting propagule counts versus time of exposure were linear.

The relationship between the response of *F. o.* f. sp. *conglutinans* to fresh cabbage amendments and its response to dried cabbage amendments is shown graphically in Figure 7, wherein the time of exposure required to attain an LD_{90} dose (resulting in 10% survival of propagules, compared to survival in the unamended infested soil assayed at the same time of incubation, as shown in Fig. 6) is plotted against the log of the percent cabbage amendment. The responses to fresh and dried cabbage only differed in the time of exposure; fresh cabbage required about 10 days longer to have the same effect as dried cabbage on *F. o.* f. sp. *conglutinans*.

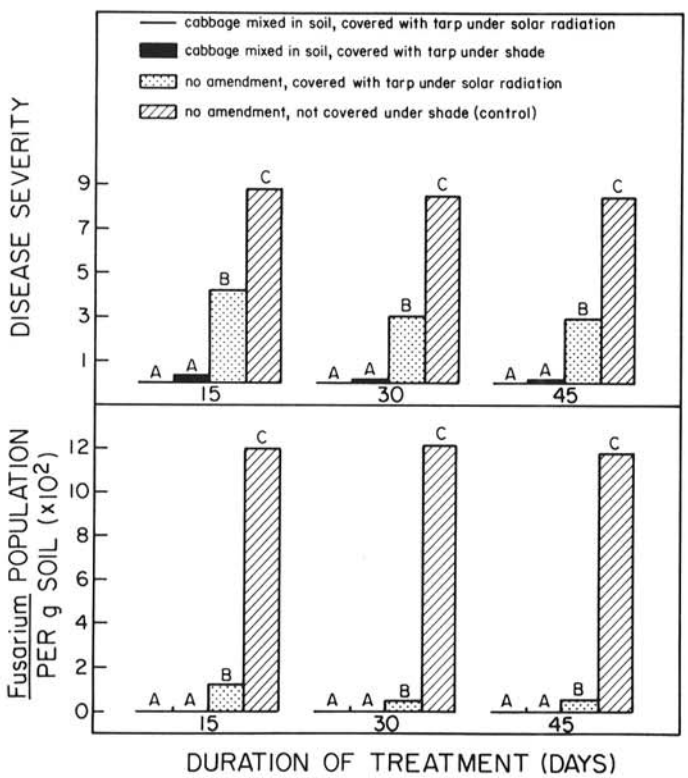

Fig. 4. Effect of the duration of soil solar heating and 1% dry cabbage amendments on the severity of cabbage yellows and populations of *Fusarium oxysporum* f. sp. *conglutinans*. The same letter above the bars indicates that the means (three replicates) of the data are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

Effects of volatiles from cabbage residues on propagules of *F. o.* f. sp. *conglutinans* and associated soil microflora. After 30 days populations of *F. o.* f. sp. *conglutinans* decreased by 99.4% (from 19.1×10^2 to 12.0 ppg) in treatments involving cabbage. Total fungal populations decreased by about 20% (from 25.8×10^3 to 20.6×10^3 ppg), but populations of certain fungi, such as *Penicillium* spp. and *Aspergillus* spp., increased or remained the same. The total population of actinomycetes was not changed (6.1

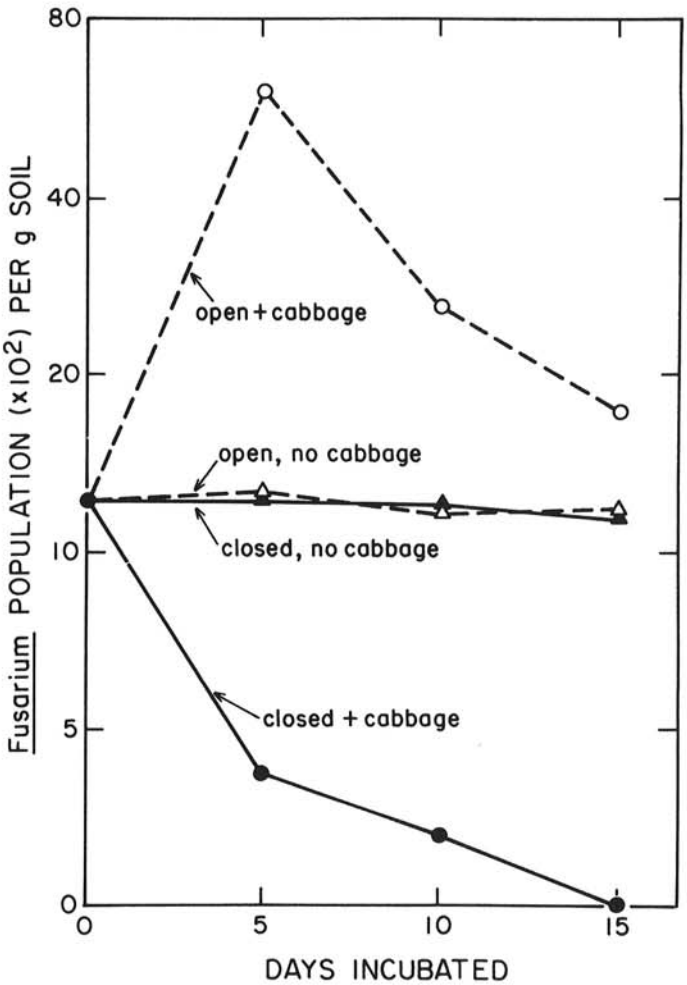

Fig. 5. Effect of amending field soil with dried cabbage (1%, w/w) in open and closed containers at 26 C for 5, 10, and 15 days on the number of propagules of *Fusarium oxysporum* f. sp. *conglutinans*.

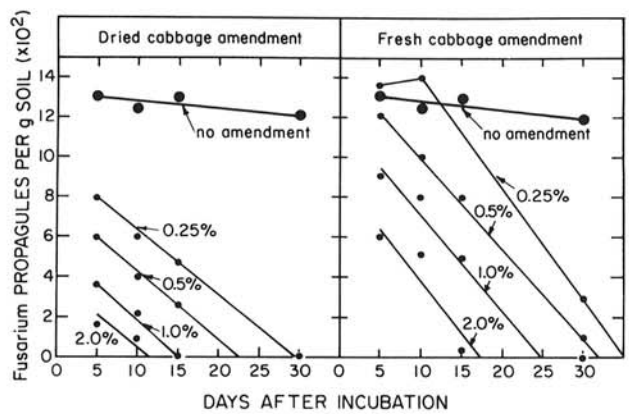

Fig. 6. Effect of fresh and dried cabbage amendments added to soil on the population of *Fusarium oxysporum* f. sp. *conglutinans*. Soil samples (500 g) held in closed containers were amended with fresh or dried cabbage (on a dry-weight basis) at rates of 0.25, 0.5, 1.0, and 2.0%.

$\times 10^5$ ppg), but some qualitative differences were noted. Some fast-growing types, usually present after incubation for 3 days, were not found in soils exposed to cabbage vapors. Since the total counts in treated and untreated soils were equal, other groups had taken the place of those eliminated by the gases. The presumed stimulation by the emanations was not investigated further. There was a 16-fold increase in total bacteria (from 7.1×10^6 to 113.8×10^6 ppg) in the treated soils. Qualitative differences between treatments were not apparent.

Effects of volatiles from cabbage on mycelial growth and sporulation of *F. o.* f. sp. *conglutinans*. Volatiles from soil amended with 1, 5, or 10% cabbage adversely affected mycelial growth and sporulation of *F. o.* f. sp. *conglutinans* (Fig. 8). Complete inhibition of radial growth occurred 24 hr after the application of cabbage amendments at a concentration of 10%. *F. o.* f. sp. *conglutinans* resumed growth at its original rate when the plates were transformed to fresh air or when portions of the fungus were transferred to fresh PDA and incubated in fresh air. Thus, the effect of the volatile substances was fungistatic. The gases were not absorbed by the PDA; presumably, the fungistatic effects were due to the direct action of the gases on the mycelium of *F. o.* f. sp. *conglutinans* and not to an accumulation of toxicants in the PDA.

DISCUSSION

The best control of cabbage yellows was obtained with cruciferous amendments. Dried cabbage amendments were more effective than fresh cabbage amendments in reducing the populations of *F. o.* f. sp. *conglutinans* (Fig. 7); therefore dried cabbage was used as the soil amendment. This may be fortunate, because if these methods are to be used commercially, dried cabbage could be produced at any time and stored in plastic bags. Fresh cabbage amendments also were fungicidal, but they were slower-acting. It is possible that cabbage residues remaining after harvest may be used to control the disease.

The outstanding control of cabbage yellows attained by the use of solar heating plus cabbage amendments was due to an elimination of propagules of *F. o.* f. sp. *conglutinans*. These results, along with those obtained with 0.25% cabbage amendments (Fig. 6), suggest that cabbage residues left after harvest possibly may be used to control cabbage yellows if the field is covered with a solar tarp during the early summer. In this research, solar heating was effective in controlling cabbage yellows from August to September but not from October to November. Solar heating during summer is feasible, since cabbage is not grown in southern California in the summer, and summer temperatures are high enough to kill the pathogen. Since cabbage is a cool-temperature crop, this control should have wide application.

Differences between dried and fresh cabbage in reducing the propagule density of *F. o.* f. sp. *conglutinans* in amended soils enclosed in jars may be related to their rates of decomposition. It is known that easily decomposable plant materials control soil pathogens in short periods of time (6). Dried cabbage in moistened soil decomposed sooner than fresh cabbage, and this may account for the 10-day delay in action with fresh cabbage (Fig. 7).

Some researchers found that alfalfa hay (10), wheat straw (14), chicken manure (9,33,36), and steer manure (9) were effective against diseases such as Verticillium wilt of potato, take-all of wheat, and Phytophthora root rot of avocado, but these amendments were ineffective in our studies against cabbage yellows. It is possible that these amendments provided a nutrient base for saprophytic growth of *F. o.* f. sp. *conglutinans* and thereby increased the disease severity in plants subsequently grown in the soil. This phenomenon was reported to occur with various species of *Fusarium* (4,13,21,25,29,38), including *F. o.* f. sp. *conglutinans* (4).

A growth-promoting effect was observed on cabbage plants grown in soils amended with cabbage residues, but tomato plants wilted within 24 hr of planting in the amended soil. This indicates that caution must be taken in the use of residues as soil amendments.

Solar heating alone was not very effective in controlling cabbage yellows in these trials, probably because the maximum temperatures attained during the treatment periods presumably were too low. This is substantiated by the fact that the solar heating carried out from August to September was more effective than that carried out from October to November. Despite the low temperatures during the period of treatment, 70% of the propagules of *F. o.* f. sp. *conglutinans* were eliminated; however, the population was still high enough to kill 43% of the plants. The

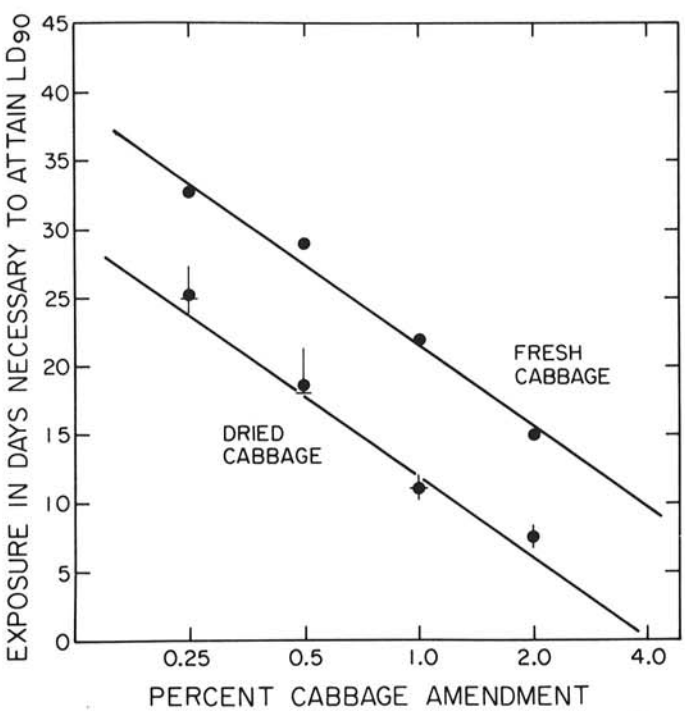

Fig. 7. Relationship between the response of *Fusarium oxysporum* f. sp. *conglutinans* to fresh cabbage amendments and its response to dried cabbage amendments. The days of exposure required to attain an LD_{90} dose (Fig. 6) are plotted against the log of the percent cabbage amendment.

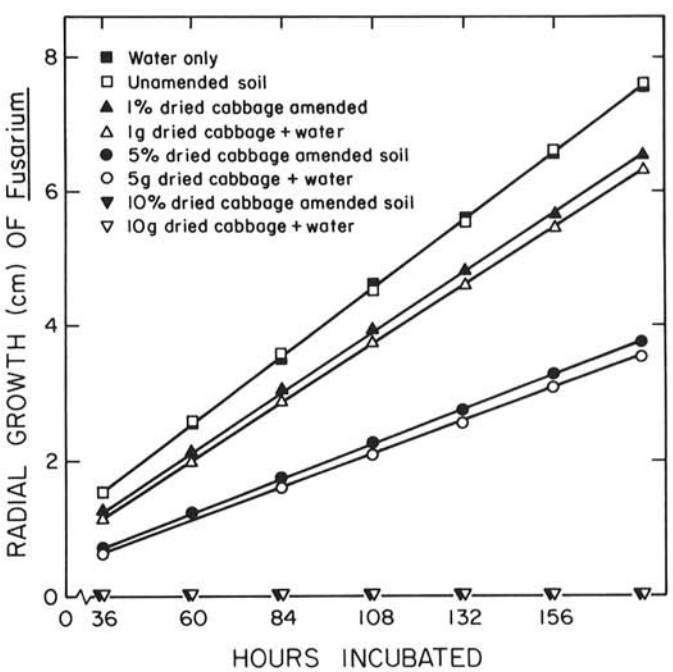

Fig. 8. Radial growth of *Fusarium oxysporum* f. sp. *conglutinans* on potato-dextrose agar cultures continuously exposed to volatile substances from cabbage-amended soil and from cabbage alone plus water, at 23 C.

disease severity index was 4.7, compared to 5.5 for plants grown in shaded soil. Most of the effects of treatments were complete within the first 15 days. The effect of solar heating alone corresponded with the soil temperatures attained (Fig. 3). Higher temperatures were recorded in the first 15 days of the treatment period, and this was associated with higher suppression of cabbage yellows. Especially significant is the fact that solar heating plus cruciferous amendments or shade treatments plus cruciferous amendments were far more effective than solar heating alone or shade treatments alone. This indicated that in these experiments the cruciferous amendments were the more effective factor, rather than solar heating.

Gases from decomposing cabbage may play a major role in the decline of propagules of *F. o.* f. sp. *conglutinans* in the soil. Similar findings were demonstrated earlier by Lewis and Papavizas with *Rhizoctonia solani* (19) and *Aphanomyces euteiches* (18).

Volatile compounds from cabbage were inhibitory to *F. o.* f. sp. *conglutinans* in closed jars but stimulatory in open jars. Presumably inhibition of the pathogen could be attributed to toxic gases evolved from cabbage. Also, the populations of *F. o.* f. sp. *conglutinans* declined gradually. This is in agreement with the correlation coefficient of the relationship between propagule population and cabbage concentration (−0.91) and that of the relationship between propagule population and the time of exposure (−0.99). In contrast, the high populations of *F. o.* f. sp. *conglutinans* in open jars probably were due to the escape of most of the toxic gases, thus allowing germination and reproduction of the pathogen. This agrees with results obtained by Toussoun et al (32), who found that decomposing residues of broccoli strongly stimulated chlamydospore germination of *F. solani* f. sp. *phaseoli* in soil, especially during the early stage of decomposition.

Gases from cabbage adversely affected in vitro mycelial growth and sporulation of *F. o.* f. sp. *conglutinans*, but these effects could be reversed by transferring the fungus to fresh PDA. Thus, their effect was fungistatic rather than fungicidal. Some toxic cabbage volatile compounds are soluble in water (18), and the compounds presumably were absorbed by soil in higher concentrations than by the agar.

It is not possible, with the evidence available, to indicate the role, if any, of the associated soil microflora in the decline of *F. o.* f. sp. *conglutinans* propagules in cabbage-amended soil. However, it is possible that gases from cabbage at first stimulate the propagules to germinate. At this stage they would be in their most susceptible state, and upon continued exposure to volatile materials, they would be highly susceptible to attack by antagonistic soil microflora, which are stimulated by or resistant to the gases.

Fusaria normally lie dormant in the soil as chlamydospores, because of fungistatic factors, but when certain nutrients are placed in the soil, fungistasis is overcome (3,7,22,31,32,35). Nutrients from decomposing residues of broccoli (32) and certain compounds, such as ethylene, ammonia, acetone, ethanol, methanol, formaldehyde, acetaldehyde, and propionaldehyde, were reported to stimulate germination of propagules of *F. o.* f. sp. *conglutinans* race 1 and other *Fusarium* spp. (11,23,28). Many of these substances are formed by cabbage (17,20) during the early stage of decomposition, and they may stimulate the germination of propagules of *F. o.* f. sp. *conglutinans*. Subsequent substances such as sulfides or thiocyanates (1,5,17,20,34) are formed, which are fungistatic and fungicidal, respectively. Isothiocyanates, however, have not been detected in the atmosphere above decomposing dried cabbage in soil (19) or in the soil. It is certain that cabbage volatile compounds are involved in and play a very important role, either directly or indirectly, in the elimination of *F. o.* f. sp. *conglutinans*.

Whatever the mechanism of action, the use of solar heating of amended soils deserves extensive study, using this as well as other systems, because it is effective in the field (26), and because it also poses so many fascinating aspects of scientific interest.

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