Solar heating combined with cabbage residues controlled cabbage yellow disease better than either method alone. Soil amendments plus cover under shade (right rear) were less effective.

Solar heating and amendments control cabbage yellows

José Ramirez Villapudua □ Donald E. Munnecke

In the overall scheme of things in agriculture, cabbage yellows is not a particularly damaging disease. The pathogen, however — *Fusarium oxysporum* f. sp. *conglutinans,* referred to as "Foc" — belongs to a group of troublesome, very damaging, and economically important fungi that cause the Fusarium wilt diseases. The main species, *F. oxysporum,* has varieties (called "forma species") that lead to heavy losses in crop plants worldwide, including cotton, tomato, banana, cucurbits, crucifers, and many ornamental crops.

The fungus survives in infested fields for long periods; in some cases, it has been known to prevent the replanting of a desirable crop. Farmers have controlled Fusarium wilt diseases mainly by using resistant varieties. With many crops, this approach has been successful, but new races of the pathogen sometimes develop or are introduced into an area, so that formerly resistant varieties become susceptible. A new race of *F. oxysporum* on cabbage was recently found and identified in California, and we decided to investigate ways to control the disease.

Solar heating of soil, or "solarization," involves covering moist field soils with a clear plastic tarp, which heats the upper 6 to 8 inches of the soil profile to temperatures that may kill soil-borne plant pathogens. The method has been used successfully in Israel and California to obtain field control of various diseases. It does not control some diseases, however, and it is not the panacea that we once hoped it would be.

Another method used to control, or at least to alleviate, the effects of soil-borne diseases has been the incorporation of crop residues into fields. Again, soil amendments have worked in some cases, but not in others.

We investigated the possibility that the two techniques, solar heating and crop soil amendments, could be combined to control cabbage yellows.

Solar heating of amended soil

Experiments using pots of soil buried in the field or kept in the laboratory were performed to: (1) select the organic amendment most suppressive to the cabbage yellows fungus, (2) find the best method of preparing the amendments and amounts of amendments to use, (3) investigate effects of time of exposure to the amendments, and (4) determine the effects of solar heating on the processes. We report here on some of our results.

The severity of cabbage yellows and populations of Foc in solar-heated soils were markedly reduced by amendments (added at 2 percent by weight) of nine cruciferous species, moderately reduced by alfalfa hay, and increased by wheat straw, chicken manure, and steer manure (fig. 1). A cabbage amendment was more effective if the residue was dried before incorporation. Effectiveness was directly related to the concentration of amendments and time of exposure. Solar heating (full sunlight, polyethylene cover) of soil amended with cabbage residues practically eliminated Foc propagules within the first 15 days, and cabbage yellows was undetected on plants grown in pots containing the soil.

Especially significant was the fact that solar heating or shade treatments plus cruciferous amendments were far more effective than solar heating or shade treatments alone.

Effect of gases from residues

The effectiveness of various organic amendments in controlling soil-borne plant pathogens has been attributed to the formation of toxic volatile compounds or to an increase in antagonistic soil microflora. Other researchers have shown that cruciferous amendments in closed containers decreased Foc propagules and cabbage yellows severity. Several researchers have demonstrated that sulfur-containing volatile compounds and ammonia from decomposing cabbage are fungitoxic.

We conducted experiments to determine the effects of (1) volatile compounds from cabbage on Foc propagules in soil, (2) gases emanating from soil amended with cabbage or from cabbage without soil on the growth of Foc, and (3) gases from cabbage on the soil microflora.

These studies showed that populations of Foc were reduced almost to zero (99.4 percent), total fungi were decreased about 20 percent, numbers of 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 Foc propagules occurred in closed containers (fig. 2). In closed jars, Foc ceased growing when placed on potato-dextrose agar in petri dishes suspended above the soil containing cabbage residues or moistened

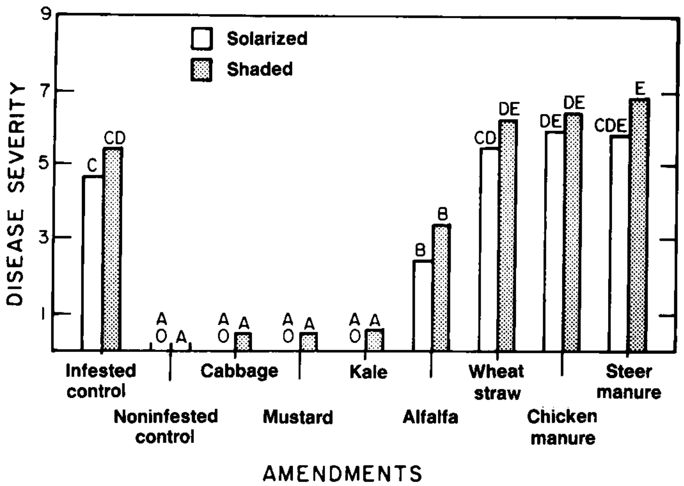

Fig. 1. The combination of solar heating and 2 percent by weight of various soil amendments reduced *Fusarium oxysporum* infection (cabbage yellows) to undetectable levels. (The same letter above bars indicates no significant difference.)

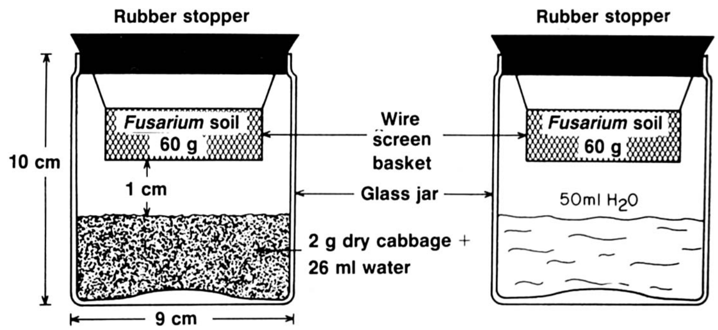

Fig. 2. The fungicidal effects of gasses from dried cabbage residues are illustrated in an experiment in which infested field soil is suspended in air above the preparation in a tightly stoppered glass jar. The treatment eliminated *Fusarium* propagules. In control jar at right, containing plain water, there was no effect on the organism.

cabbage alone. The effect was fungistatic, since growth resumed upon transfer of the fungus to the fresh agar. In contrast, when infested soil was suspended above the decomposing cabbage residues, the effect was fungicidal.

Field tests

Since incorporation of dried cruciferous amendments into solar-heated soil in pots buried in the field markedly decreased Foc, and toxic gases from decomposing cabbage directly or indirectly eliminated Foc propagules from soil, we tested these means of control in the field.

We conducted two experiments at the University of California, Riverside, in the same field, one from September 5 to October 20, 1983, and the other from July 9 to August 9, 1984. We had previously infested the field artificially with Foc. Three replicate plots were arranged in a randomized block design for each experiment. The plot sizes were 8 by 20 feet for experiment 1 and 8 by 12 feet for experiment 2.

Experiment 1 included the following treatments, all of which were exposed to full sunlight: (1) cabbage mixed in soil, covered with clear polyethylene tarp (solar heating plus cabbage); (2) cabbage mixed in soil, not covered with tarp; (3) no cabbage amendment, covered with tarp (solar heating alone); and (4) no cabbage amendment, not covered with tarp. Experiment 2 tested the same sunlight treatments, and each also was shaded, making a total of eight treatments. Shaded plots were covered with black polyethylene tents that allowed air to circulate freely underneath.

We used cabbage plants ('Headstart') grown at UC Riverside. In 1983, approximately 3,000 heads of cabbage were chopped with a machine and dried in the field for 10 days. The residue was raked, collected, and bagged. In 1984, approximately 4,000 heads of cabbage were chopped by machine into pieces approximately 1½ inches in diameter and scattered on a plastic sheet to dry. The chopped cabbage was stirred daily with a side-delivery rake on a tractor for 10 days until it was used.

The sun-dried cabbage, applied at the rate of 1 percent by weight (estimated) in both experiments, was mixed to a depth of approximately 6 inches in the soil with a Rototiller (approximately 8 tons per acre). The soil was irrigated by sprinklers to a depth of 30 inches three days before application of the translucent plastic covers. The polyethylene covers, 1 mil (0.025 mm) thick, were especially formulated to withstand solar irradiation. Uncovered plots were sprinkled at three-day intervals. Cross-contamination of plots was minimized by fencing, by ditching between plots to prevent water-borne contamination, and by workers using clean plastic bags over their shoes for each plot. The plots remained weed-free until the end of the treatment period without the use of herbicides.

Thermographs from sensors buried at several depths continuously recorded soil temperatures in covered and uncovered plots (table 1).

In experiment 1, we determined the effects of the treatments on Foc by estimating the disease severity on cabbage seedlings grown in the treated soil. We took soil samples from the 6-inch depth at the end of the 45-day treatment period, planted 'Rio Verde' cabbage seeds in the soil, and evaluated disease severity on individual plants after 30 days in a growth chamber at 75° to 82°F. The results were expressed as the means of three replicates per treatment involving a total of 40 seedlings per sample.

In experiment 2, after plots were cleared at the end of the 30 days, we took soil samples from each plot from depths of 0 to 4, 4 to 8, 8 to 12, and 12 to 16 inches and air-dried them. Samples from each depth diluted in sterile water were uniformly spread on plastic petri dishes containing a medium that stimulated Foc to

TABLE 1. Highest (H) and maximum average (M) soil temperatures attained in soil in experiments 1 and 2 in field plot at UC Riverside

	Soil depth (inches) and temperatures (°F) attained*							
	4 inches		8 inches		12 inches		16 inches	
Treatment	H	M	H	M	H	M	H	M
				°F				
Experiment 1 (Sept. 5 - Oct. 20, 1983)								
Full sun								
Tarped	127	109	102	90	95	79	95	80
Not tarped	99	92	N.A.†	N.A.	N.A.	N.A.	N.A.	N.A.
Experiment 2 (Jul. 9 - Aug. 9, 1984)								
Full sun								
Tarped	126	120	101	97	101	98	99	98
Not tarped	104	96	96	92	95	92	95	92
Shaded								
Tarped	91	89	N.A.	N.A.	92	89	92	84
Not tarped	90	90	N.A.	N.A.	92	89	91	84

* Temperatures recorded at 2 p.m. with a soil thermograph.
† N.A. = not available.

grow but suppressed other fungi. Foc colonies were sufficiently different in color and shape from other Fusaria to be easily counted after incubation for eight days at 78°F under diffuse light.

We also planted seeds of 'Rio Verde' cabbage in field soil taken from the same depths. After emergence, the seedlings were grown for five weeks at 75° (night) to 82°F (day) in a growth chamber. We rated disease severity by averaging the data from three replicates per treatment of 60 seedlings per sample.

In addition, the field plots were hand-seeded densely with the 'Rio Verde' cultivar in five rows per plot, approximately 6 inches apart. After emergence, seedlings were thinned to 2-inch intervals. Plants were observed frequently for yellows symptoms and, after 70 days, disease severity ratings were made from the three central rows. Disease incidence was indicated by 50 plants selected at random from each plot and rated for internal stem discoloration. Roots were excised, surface-sterilized, and plated on an agar medium to detect Foc.

Foc was practically eliminated and cabbage yellows was not detected in the field in the treatments combining solar heating of soils with cabbage amendments (1 percent by weight). Both solar heating alone and cabbage amendments plus cover under shade were effective, but not as effective as the combination of solar heating and cabbage amendments. In contrast, cabbage amendments without cover were ineffective, whether under shade or in direct sunlight.

Conclusions

In laboratory and field tests, solar heating of soil amended with cruciferous crop residues controlled cabbage yellows and practically eliminated the pathogen (Foc) from infested soil. The use of a tarp is necessary, not only to increase the temperature of the soil to critical levels under solar heating, but also to trap fungitoxic gases emanating from the amendments.

Polyethylene tarps are readily available and can be laid by hand over small areas or by machines over large acreages. Crop residues from a previous crop possibly may be used — certainly residues from cruciferous plants should be tried.

The concentration of cabbage used in our trials was high. Results from laboratory experiments suggest that lower concentrations are feasible and should be tried in future field trials. The technique, which is effective, safe, and easy to apply, may prove useful against other soil-borne diseases as well as cabbage yellows.

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Host range and life cycle of *L. africanus*

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Widespread in the Imperial Valley, this needle nematode can cause severe seedling disease at relatively low populations

In 1969, a needle nematode was first reported to be causing a disease of head lettuce in the Imperial Valley of southern California. Root tips of lettuce seedlings attacked by this external parasite, *Longidorus africanus,* are swollen and usually have necrotic spots at the feeding sites. Seedlings are severely stunted when compared with nematode-free plants.

Because of the importance of this nematode in fall-planted lettuce, chemical control with preplant fumigants has proved to be profitable. Information has been lacking, however, on distribution of

Swelling and dead spots on root tips of a lettuce seedling and a six-week-old lettuce plant are symptoms of soil infestation by the needle nematode, *Longidorus africanus.* The nematode is widespread in a broad range of Imperial Valley crops.