Influence of Cultural Practices, Fungicides, and Inoculum Placement on Southern Blight and Rhizoctonia Crown Rot of Carrot

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ABSTRACT

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The influence of disking and deep plowing, layby and no-layby cultivation, and times and rates of fungicide application on the development of southern blight, caused by *Sclerotium rolfsii*, and Rhizoctonia crown rot, caused by *Rhizoctonia solani*, on processing carrots in North Carolina was investigated. Deep plowing combined with no-layby cultivation effectively reduced southern blight of carrot. Layby cultivations negated the beneficial effects of deep plowing. Fungicides used for control of southern blight were effective for layby carrots in deep-plowed soil and for both layby and no-layby carrots in disked soil. The development of Rhizoctonia crown rot of carrot was not changed significantly by land preparation and cultural practices. The 2× recommended rates and multiple applications of PCNB, furmecyclox, and carboxin provided greater crown rot control than did 1× recommended rates and single fungicide applications. Infection of carrots by *S. rolfsii* on colonized oat grains occurred from greater lateral distances and depths than infection by naturally produced sclerotial inoculum. The highest level of infection by naturally produced sclerotia occurred when sclerotia were in contact with the carrot storage root.

Additional key words: *Daucus carota* var. *sativa*, southern stem rot, southern wilt

Diseases caused by *Sclerotium rolfsii* Sacc. and *Rhizoctonia solani* Kühn seriously limit vegetable production in warm, humid areas of the world (1,2,14). *S. rolfsii* causes southern blight, a devastating disease of carrot (*Daucus carota* var. *sativa*). The organism causes a wet rot that completely destroys the root, and it can spread considerable distances among closely spaced carrots (22). Rhizoctonia crown rot and canker of carrot caused by *R. solani* is a serious disease of muck-grown carrots in the north central United States (9,16).

Control of southern blight and *Rhizoctonia* diseases has depended on soil management practices and fungicide applications (1,13,14). Deep plowing and nondirting cultivation (weed control by cultivation such that no soil is thrown onto the crop plant) have reduced incidence of southern blight of peanut (5,8). Deep plowing has also reduced Rhizoctonia fruit rot of cucumber (14) and Rhizoctonia root and hypocotyl rot of snap bean (13). Numerous chemicals have been tested for control of southern blight and Rhizoctonia rot (1,13,14,19), but many have given inconsistent performance (11).

This study determined the effect of disking and deep plowing, layby and no-layby cultivation, and times and rates of fungicide application on control of southern blight and Rhizoctonia crown rot of processing carrots in North Carolina. The effect of inoculum placement (lateral distance and depth) of *S. rolfsii* using colonized oat grains or natural sclerotia on the incidence of southern blight of carrot also was investigated.

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MATERIALS AND METHODS

Cultural and chemical control field experiments. Vegetable fields at Clinton, NC, infested with *S. rolfsii* were seeded with carrots (cultivar Danvers 126) on 1-m bedded rows with 36–48 seeds per linear meter. Standard fertilization and chemical weed control practices were used. Overhead sprinkler irrigation was applied as needed to maintain good crop growth.

PCNB 75WP at 11.2 and 22.4 kg a.i./ha, furmecyclox 40WP at 4.20 and 8.40 kg a.i./ha, and carboxin 75WP at 1.26 and 2.52 kg a.i./ha were applied using a carbon dioxide-pressurized backpack sprayer with a hand-held single-row boom equipped with two drop nozzles. The nozzles, with disk-core-type hollow-cone spray tips (D-4-25, Spraying Systems Co., Wheaton, IL) were spaced to spray a band 30.5–35.5 cm covering the soil bed surface and crown of the plants. The apparatus was operated at 5 km/hr, using a pressure of about 550 kPa at the boom to deliver 935.4 L/ha.

1982 Experiment. An Orangeburg loamy sand (75% sand, 17% silt, and 8%

clay in the A horizon, 1% organic matter, pH 5.0–5.5) and Wagram loamy sand (80% sand, 14% silt, and 6% clay in the A horizon, 1% organic matter, pH 5.0–5.5) were present in the field. The field had been cropped to carrots in 1979 and to both turnips and carrots in 1980 and 1981. The field was disked to a depth of 10–15 cm, bedded, and planted to carrots on 6 May 1982.

Experimental units were single rows 7.6 m long arranged in a randomized complete block design with four blocks and five split plots. Whole plots were the three fungicides and subplots were five treatments: 1× fungicide applied 10 days before layby, 1× fungicide applied 1 day after layby, 2× fungicide applied 1 day after layby, 1× fungicide applied 10 days after layby, and an untreated control. Layby, in which soil was ridged over the crown of the carrot root to a depth of 2.5–5 cm, was done 97 days after planting. Disease incidence (calculated as percent infected plants in a 7.6-m row) of southern blight was rated eight times at about weekly intervals beginning on 20 July.

1983 Experiment. The soil in the field was Orangeburg loamy sand. The field had been cropped to rye and cowpeas in 1980, rye and corn in 1981, and tomatoes and rye in 1982. The 0.37-ha field was divided into two sections (61 × 30.5 m). One section was plowed 25–30 cm deep in September 1982 with a 45.7-cm moldboard plow equipped with moldboard extensions (trash covers). The other section was disked 10–15 cm deep. Rye was planted as a winter cover crop; both sections were disked 10–15 cm deep and rows were bedded before carrots were planted on 15 March 1983.

The experimental design consisted of two 5 × 5 latin squares with split plots with one square in each section. Whole plots in each section were the fungicides and subplots (single rows 5.5 m long) were 10 treatments: layby and no-layby cultivation controls done 94 days after planting; 1× and 2× fungicide applied 93 days after planting to layby plots and no-layby plots; 1× and 2× fungicide applied 79 and 93 days after planting to layby plots; and 1× and 2× fungicide applied 65, 79, and 93 days after planting to layby plots.

Disease incidence for both southern blight and Rhizoctonia crown rot was calculated as percent infected plants in a 5.5-m row. Disease foci per plot were counted and spread per focus was calculated by dividing the total distance occupied by infected plants in a plot by the number of foci. Disease incidence and number of foci were rated four times at about 9-day intervals beginning 105 days after planting.

Numbers of sclerotia of *S. rolfsii* were assessed before (September 1982) and after (May 1983) deep plowing and disking. Ten blocks (12.2 × 12.2-m) were demarcated in each half of the field. A soil sample was taken from the center of each block to a depth of 7.6 cm using a 10.5-cm-diameter golf cup cutter. The number of sclerotia in a 440-g subsample was determined using the aqueous methanol assay (20).

Several isolates of *R. solani* from infected carrots were tested for anastomosis group affiliation (18).

Inoculum placement studies. The effect of inoculum placement on infection of carrots by *S. rolfsii* was studied in the field and in greenhouse beds using two types of inoculum. Sclerotia or colonized oat grains were placed in soil at various combinations of distance and depth in relation to the carrot storage root. Infection was assessed 15 days after inoculation. Sclerotia were produced on loamy sand soil (3,20). Autoclavable bags containing 300 cm^3 of oats and 250 ml of tap water were autoclaved at 121 C and 1.05 kg/cm^2 of pressure for 1 hr on two consecutive days and inoculated with 1-cm-diameter mycelial plugs from potato-dextrose agar cultures. Bags were maintained at room temperature (about 25 C) for 2 wk with periodic shaking to ensure thorough colonization. The colonized oat grains were air-dried on a greenhouse bench and stored in polyethylene bags at 2 C until needed (7).

For the field experiments, a site from which no sclerotia had been recovered and in which no southern blight had been observed during the previous two seasons was chosen. The soil was Orangeburg loamy sand and Norfolk loamy sand (77% sand, 16% silt, and 7% clay in the A horizon, <1% organic matter, pH 5.0-5.5). Carrots were grown as described previously, except there were no layby cultivations and plots were hand-weeded. Plants were thinned to 10 per linear meter of row to reduce plant-to-plant spread. Tests were conducted on 73-day-old carrots in a completely random design with four replicates and 36 treatments. Inoculum placement at lateral distances from the root and depths ranging from 0 to 5 cm, at 1 cm increments, were tested in all combinations. In another experiment, carrots 93, 113, and 135 days old were inoculated in a randomized complete block design with five treatments and four blocks. The five inoculum placement treatments were 0/0, 0/1, 0/2, 1/0, and 2/0 (centimeters of lateral distance/centimeters of depth).

Twelve greenhouse beds (2.4 × 1.2 × 0.3 m) containing nonsterile loamy sand soil with <1% organic matter and a pH of 6.0–6.5 were prepared. The previous crop was tomatoes. Beds were fertilized according to soil test recommendations and watered daily with misting nozzles to prevent standing water on the soil surface. Methomyl was used for whitefly control.

Three- to 4-wk-old Danvers 126 seedlings were transplanted 5 cm apart within the row in three equally spaced rows per soil bed. Seedlings were later thinned to 10.2 cm apart within the row to give about 72 carrots per bed.

Carrots 71, 95, and 135 days old were inoculated with sclerotia, but only 71- and 95-day-old carrots were inoculated with infested oat grains. Half of the plants in each bed were inoculated with sclerotia. The other half were inoculated with infested oat grains. Twenty-two inoculum placement treatments were applied randomly to individual carrots in each half of each bed: 0/0, 0/1, 0/2, 0/3, 0/4, 0/5, 1/0, 1/1, 1/2, 1/3, 1/4, 1/5, 2/0, 2/1, 2/2, 2/3, 2/4, 2/5, 3/0, 3/1, 3/2, and 3/3 (centimeters of lateral distance/centimeters of depth).

Data analysis. Data were subjected to analysis of variance, single-degree-of-freedom contrasts, or chi-square analysis (21).

RESULTS

Cultural and chemical control experiments—*S. rolfsii*. In 1982, PCNB, furmecyclox, and carboxin did not differ significantly in their effects on disease incidence at any of the eight rating dates; however, treatment effects did exist. At 111 days after planting, disease incidence for the untreated control was greater ($P = 0.05$) than for 1× fungicide applied 10 days before layby and 1× and 2× fungicide applied 1 day after layby. At 127 days after planting, disease incidence for the control and for 1× fungicide applied 10 days after layby was greater ($P = 0.05$) than for 1× fungicide applied 10 days before layby and 1× and 2× fungicide applied 1 day after layby.

In 1983, disease incidence and number of disease foci in deep-plowed soil were about 50% of that in disked soil. Also, recovery of sclerotia of *S. rolfsii* was less ($P = 0.01$) in deep-plowed soil (Table 1). Number of disease foci and final disease incidence were greater ($P = 0.01$) after layby cultivation than in the no-layby

Table 1. Recovery of sclerotia of *Sclerotium rolfsii* before and after disking and deep-plowing land preparation treatments

	No. of sclerotia recovered[a]	
Sampling time	Deep plowing[b]	Disking[c]
Sept. 1982 (before disking or plowing)	8.7	8.7
May 1983 (after disking or plowing but before disease onset)	0.7[d]	3.8[d]

[a]Numbers represent mean number of viable sclerotia in ten 440-g soil samples taken in each land preparation environment and assayed by the aqueous methanol method

[b]Deep plowed 25–30 cm deep in September 1982.

[c]Disked 10–15 cm deep in September 1982.

[d]The LSD ($P = 0.01$) for number of sclerotia recovered in May 1983 is 2.3.

cultivation but only in deep-plowed soil (Fig. 1). In disked soil, final disease incidences for the layby and no-layby cultivations were not different.

In 1983 at the final rating 132 days after planting, disease incidence and number of disease foci for the furmecyclox treatments were less ($P = 0.01$) than for PCNB or for carboxin in disked soil (Fig. 2). In deep-plowed soil, final disease incidence, number of disease foci, and spread per focus with furmecyclox were less ($P = 0.05$) than with PCNB but not different from those with carboxin (Fig. 2). Final disease incidence for both the layby and no-layby cultivations was greater ($P = 0.01$) than for the fungicide treatments in disked soil only. In deep-plowed soil, final disease incidence for the layby cultivation, but not for the no-layby cultivation, was greater ($P = 0.01$) than for the fungicide treatments.

Efficacy of fungicides did not vary significantly with different rates and timing of application. Treatments in which fungicides were applied were equally effective in either deep-plowed or disked soil.

Disease incidence in non-fungicide-treated soil was greater in 1982 (47.2%) than in 1983 (23%). In 1982, southern blight began to increase 1 wk after layby (104 days after planting) (Fig. 3). In 1983, southern blight began to increase about 12 days after layby (105 days after planting) (Fig. 4).

Cultural and chemical control experiments—*R. solani*. Only slightly less disease developed in deep-plowed than in disked soil. The cultural practices of layby or no-layby cultivation did not differentially affect final disease incidence rating and number of disease foci ($P = 0.05$) of crown rot.

In both deep-plowed and disked soil, final disease incidence and number of disease foci for the two checks (layby and no-layby) were greater ($P = 0.01$) than for the fungicide treatments. Fewer ($P = 0.05$) foci occurred with the furmecyclox treatments than with PCNB and carboxin in deep-plowed soil but not in disked soil. Also, final spread per focus was less ($P = 0.05$) with furmecyclox (1.5 cm) than with carboxin (4.6 cm) in deep-plowed soil only, but spread per focus of *R. solani* with PCNB (3.6 cm) was not different from that with furmecyclox or carboxin.

Less disease developed for treatments involving multiple fungicide applications and the 2× fungicide rate. In deep-plowed soil, triple applications (65, 79, and 93 days after planting) of both the 1× and 2× fungicide rates applied to layby-cultivation carrots resulted in less ($P = 0.05$) disease incidence and fewer ($P = 0.01$) disease foci than did a single application (1 day before layby) of both the 1× and 2× rates applied to layby-cultivation carrots. In disked soil, triple

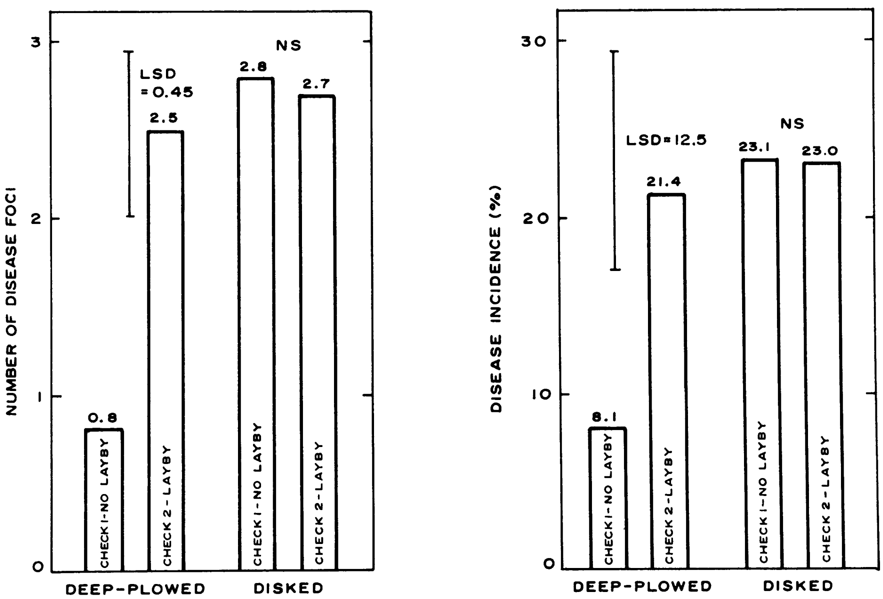

Fig. 1. Number of disease foci and disease incidence of southern blight of carrot caused by *Sclerotium rolfsii* for layby and no-layby treatments in deep-plowed and disked soils in 1983. LSDs are for $P = 0.05$.

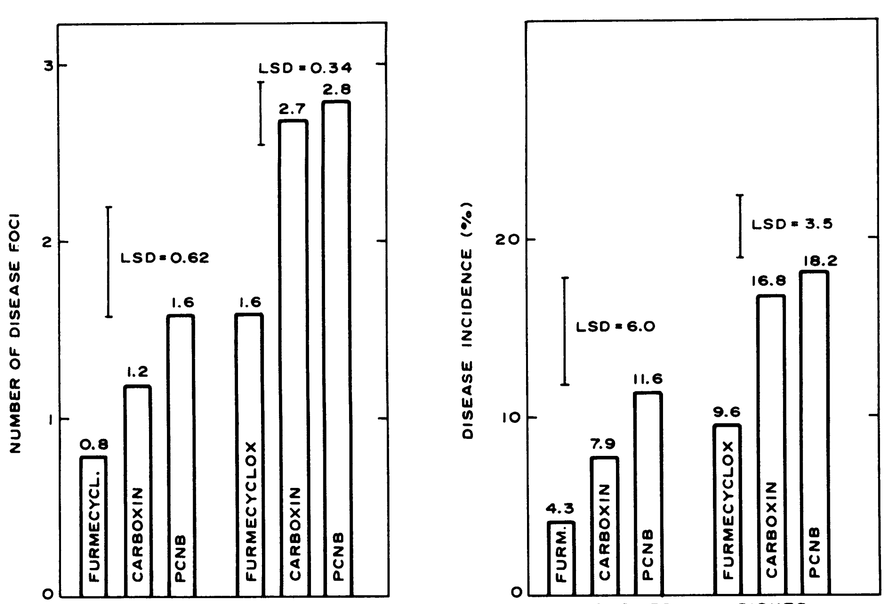

Fig. 2. Number of disease foci and disease incidence of southern blight of carrot caused by *Sclerotium rolfsii* for fungicide treatments in deep-plowed and disked soils in 1983. LSDs are for $P = 0.05$.

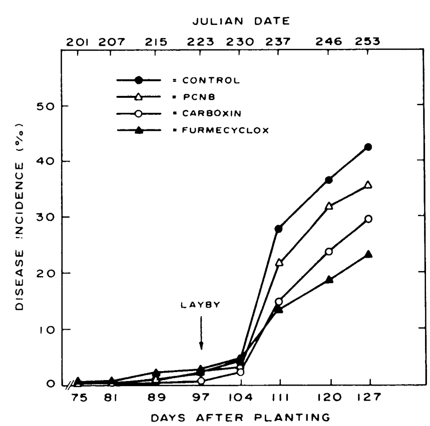

Fig. 3. Disease progress of southern blight of carrot caused by *Sclerotium rolfsii* in 1982.

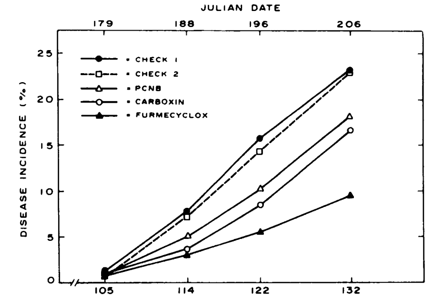

Fig. 4. Disease progress of southern blight of carrot caused by *Sclerotium rolfsii* in disked soil in 1983.

applications resulted in less (P = 0.12) final disease incidence and fewer (P = 0.01) disease foci than the single application. In both deep-plowed and disked soil, double applications (79 and 93 days after planting) of both 1× and 2× fungicide rates applied to layby-cultivation carrots resulted in fewer (P = 0.05) disease foci than did a single application (1 day before layby) of both 1× and 2× rates applied to layby-cultivation carrots. Also, in deep-plowed soil, fewer (P = 0.05) disease foci developed with triple applications than with double applications. Disease incidence and number of disease foci were significantly less (P = 0.05) with the 2× fungicide rates applied to layby-cultivation carrots than with the 1× fungicide rates applied to layby-cultivation carrots in disked soil but not in deep-plowed soil. Spread per focus was less with multiple applications and 2× fungicide rates in deep-plowed soil at the third rating (122 days after planting), but

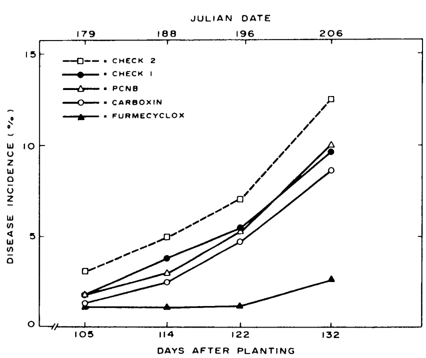

Fig. 5. Disease progress of Rhizoctonia crown rot of carrot caused by *Rhizoctonia solani* in disked soil in 1983.

at the final rating (132 days after planting), these differences were no longer apparent.

Rhizoctonia crown rot was initiated about 75 days after planting compared with 105 days after planting for southern blight, but left unchecked, crown rot caused less disease incidence than did southern blight (Fig. 5).

Three isolates of *R. solani* from carrot (one isolated from leaf petiole tissue, one isolated from crown tissue, and one isolated from cankers below the soil line on the storage root) belonged in anastomosis group 2.

Inoculum placement studies. In both field and greenhouse experiments, carrot infection caused by oat grains colonized by *S. rolfsii* was greater (P = 0.01) than that caused by sclerotia for the overall combinations of distance and depth of inoculum placement (Fig. 6). Infection was greater (P = 0.01) when the sclerotia were in contact with the carrot storage root than when they were 1 cm or more from the root. Sclerotia generally infected at depths no greater than 1 cm except when in contact with the root, in which case infection occurred as deep as 5 cm. Infection from colonized oat grains was greatest at distances of 0–2 cm, gradually diminishing at greater distances but occasionally occurring at distances greater than 4 cm. Oat grains colonized by *S. rolfsii* caused infection readily at depths as great as 5 cm. The mycelium from oat grains tended to grow to the soil surface and produce sclerotia directly over the point of oat grain placement. Host age had no influence on infection from either sclerotia or colonized oat grains.

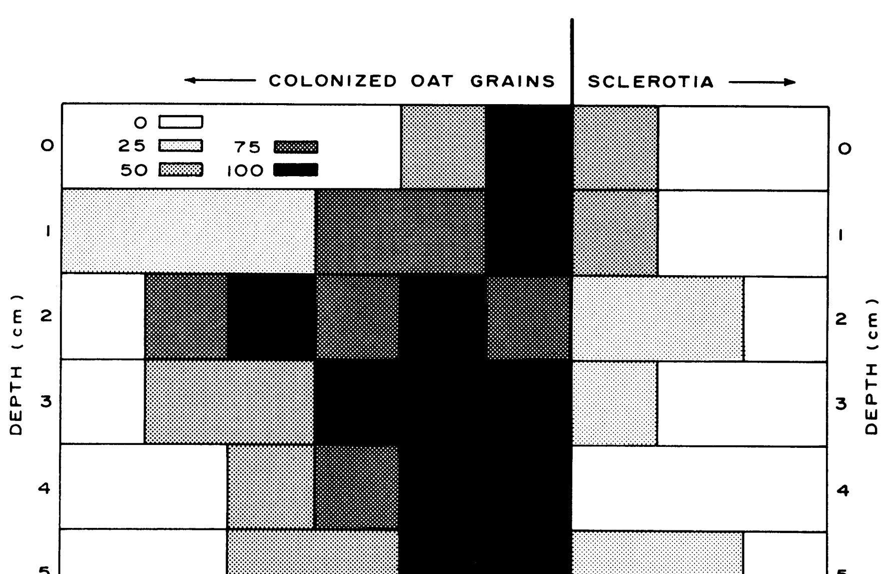

Fig. 6. Effects of inoculum source (colonized oat grains and natural sclerotia) and placement (lateral distance and depth in centimeters) of *Sclerotium rolfsii* on infection of the carrot storage root. On the scale in the upper left hand corner, 0, 25, 50, 75, and 100 are percent disease.

DISCUSSION

Land preparation was a major soil management practice that greatly infuenced southern blight of carrot. Effects of disking or deep plowing for control of southern blight of carrot are similar to those obtained with southern stem rot of peanut (5,8). Deep plowing was recommended for control of stem rot of peanut in Georgia as early as 1952 (5). Effectiveness of deep plowing was reported later in Virginia (8). The rationale for deep plowing is to promote decay of organic matter, remove organic matter from the infection court, and to bury sclerotia below the infection court (6,8). Burying crop debris at least 10 cm deep should be accomplished using equipment that inverts the soil (8). Merriman et al (15) used wheat grains to simulate the effects of cultivation on distribution of sclerotia of *Sclerotinia sclerotiorum* in soil and concluded that disk harrowing left most grains at 0–5 cm, whereas moldboard plowing buried grains to a depth of 15–20 cm. Plowing a second time may return viable sclerotia to the soil surface (15).

Cultural practices that avoided the dirting of soil around the bases of peanut plants have been recommended (5,6,8). Dirting cultivation brings crop debris and weed residue, all of which could serve as a food base for infection by *S. rolfsii*, in contact with the crop plant. These organic residues also may produce volatile chemicals that stimulate mycelial growth from sclerotia to the residues or to the host (3). Smothering and shading of carrot leaf petioles resulting from dirting cultivation creates weakened tissue and an environment conducive to infection. No-layby cultivation was not effective in controlling southern blight of carrot in the disked soil (Fig. 1) because sclerotia and crop debris were not sufficiently displaced from the carrot root zone for the no-layby cultivation to be effective.

Deep plowing displaces sclerotia as well as organic substrate from the carrot root zone, resulting in a decreased inoculum density in the root zone. Layby cultivations move both sclerotia and organic substrate closer to the carrot crown. From our results, it is apparent that in the absence of organic substrate, only sclerotia in direct contact with the carrot root are likely to cause infection. If a suitable substrate is present (colonized oat grains), both competence distance and competence depth of the inoculum may be increased (10).

Chemical control of southern blight was less effective than cultural control. Results from 1982 indicated that fungicides should be applied before or at about the same time as layby cultivation. In 1983, fungicide efficacy did not vary with different rates and timing of application, and in the deep-plowed soils, fungicides did not give added benefit unless layby cultivation was used. Layby cultivation has long been, however, a standard practice in carrot culture to prevent "greening" of the shoulders of the carrot root (4). Since fungicide application does reduce disease incidence in dirted carrots, growers can minimize both disease loss and operation expense by combining the layby cultivation and fungicide application into a single operation.

Disease incidence of southern blight began to increase in both years about 105 days after planting. At this age, plants have developed sufficient canopy to shade the underlying soil surface, creating a microenvironment suitable for southern blight development. Also at this age, some of the older leaves in the outermost whorl become naturally senescent and decumbent petioles allow the leaf tissue to contact the soil. Further defoliation may occur in maturing carrots infected by *Alternaria dauci* (Kühn) Groves & Skolko, and these dead leaves can serve as an organic substrate for growth of *S. rolfsii* (5). Fungicide applications during or just before activity of *S. rolfsii* should prove more effective than earlier applications made when much of the inoculum consists of the ungerminated sclerotia. The fact that incidence of southern blight was greater in a disked environment in 1982 than in 1983 may have occurred for several reasons. The field used in 1982 had been cropped to carrots for three continuous years and probably had a higher inoculum density than did the field used in 1983. Alternaria leaf spot was severe in 1982 but not in 1983. The occurrence of Rhizoctonia crown rot in 1983 also reduced the number of plants available for infection by *S. rolfsii*.

Soil management practices did not greatly influence the development of Rhizoctonia crown rot of carrot. Deep plowing was not as effective for control of Rhizoctonia crown rot of carrot as for control of cucumber fruit rots (14) and root and hypocotyl rot of snap bean (13). In our studies, the deep plowing took place 6 mo before planting, and *R. solani* may have had adequate time after the deep-plowing treatment to recolonize the upper soil levels in these studies.

Cultivation of soil against the petioles of flat-planted sugar beets increased incidence of the crown rot phase of dry rot canker caused by *R. solani* (12). Our results showed no differences between layby and no-layby cultivations on the development of Rhizoctonia crown rot of carrot. Perhaps sufficient *R. solani* inoculum was present near the soil surface so that additional contact between the carrot crown and the soil did not appreciably increase the inoculum density of the fungus around the root.

Rhizoctonia crown rot was controlled more effectively with chemical applications than with cultural practices. Higher fungicide application rates and multiple applications were more effective than lower rates and single applications. Deep plowing just before planting may help control Rhizoctonia crown rot of carrot and should be investigated. Crown rot of carrot increased rapidly about 1 wk before harvest, indicating that additional late-season fungicide application may be advantageous where harvest is delayed. Early-season seedling disease of spring-planted carrots is not a problem, apparently because of low soil temperature (17).

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