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Problems and Progress in Integrated Control of Southern Blight of Vegetables

Southern blight, caused by the soil-inhabiting fungus *Sclerotium rolfsii* Sacc., is one of the most important diseases of vegetables and causes great economic losses in warm, humid regions. The host range of the fungus is very extensive—at least 500 species in about 100 plant families (1). Southern blight was first reported on tomato in 1892 and is economically serious on green bean, lima bean, garden beet, cantaloupe, carrot, eggplant, onion, pepper, potato, southern pea, sweet potato, tomato, and watermelon (1). Minor economic damage occurs on many other vegetables. *S. rolfsii* is distributed in tropical and subtropical regions where high temperatures prevail during the rainy season and is common in the southern United States, Central America, South America, Africa, Australia, India, the Caribbean region, and countries surrounding the Mediterranean (1).

Symptoms and Signs

S. rolfsii is a parasite of stem bases, shoots, leaves, fruit, and roots. Typically, yellowing and wilting of leaves are the first symptoms on pepper (Fig. 1), tomato, eggplant, potato, watermelon, bean, southern pea, and carrot. Early symptoms are readily confused with those of wilt diseases caused by certain fungi (*Fusarium* and *Verticillium* spp.) and bacteria (*Erwinia* and *Pseudomonas* spp.). Plants with single stems, e.g., eggplant and pepper (Fig. 1), usually die within a few days of infection, but only one or two runners may be killed on watermelon and other vining plants. *S. rolfsii* decays the base of the stem above and below the soil surface on tomato (Fig. 2), pepper, eggplant, and other plants with woody stems. The inner, woody cylinders of infected plant stems retain integrity, and plants may remain erect after death. White mycelial colonies appear superficially on the stem and surrounding soil. Numerous round, white, fuzzy sclerotia develop on the colony and gradually become smooth, hard, and light tan to dark brown. Mature sclerotia resemble mustard seed.

The storage roots of carrots are very susceptible to infection by *S. rolfsii.* Abundant mycelial growth and sclerotial development are readily evident, and

Fig. 1. Typical "hot spot" of southern blight in a bell pepper field. Infection also occurs randomly throughout the field, as evidenced by wilting leaves. (Courtesy R. S. Gurkin)

Fig. 2. Base of tomato plant infected with *Sclerotium rolfsii*, showing decayed cortex, white surface mycelium, and sclerotia resembling mustard seed.

Fig. 3. Cortical tissues of carrot with central "cone" of xylem and pith tissues removed. Remaining carrot tissue and adjacent soil are covered with white mycelium and sclerotia resembling mustard seed. (Courtesy R. S. Gurkin)

Fig. 4. Sweet potato root with several lesions of circular spot caused by *Sclerotium rolfsii*. The shallow, corky lesions are easily removed from underlying healthy tissue, which has a bitter taste.

Fig. 5. Tomato fruit infected with *Sclerotium rolfsii*, showing white mycelium and sclerotia resembling mustard seed.

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plants die quickly. When diseased carrots are pulled, the central "cone" of xylem and pith tissue slips out, leaving a hole surrounded by the outer cortical tissues, which are held in the soil by the extensive development of the fungus (Fig. 3). Decay can continue in harvested roots. Sweet potato roots in propagation beds are often badly decayed, although sprouts may or may not be killed. In sweet potato production fields, *S. rolfsii* causes circular spot (Fig. 4). Shallow, saucer-shaped lesions (about 1 cm in diameter) are randomly distributed on mature roots. Necrotic tissue is easily removed, exposing underlying healthy tissue that has a bitter taste. Circular spot can be confused with lesions caused by Streptomyces soil pox. Superficial mycelia and sclerotia are seldom associated with circular spot, and fungal isolations are difficult.

Fruits of tomato, pepper, eggplant, cantaloupe, and watermelon are readily infected by contact with infested soil. Tomato fruit have water-soaked lesions filled with mycelium and sclerotia (Fig. 5). Cantaloupe and watermelon are usually affected on the underside of mature or immature fruit, and masses of mycelium and sclerotia are produced as decay advances.

Ecology and Epidemiology

Temperature is the principal limiting factor in the geographic distribution of the fungus. The disease rarely occurs where average daily minimum winter temperatures are below freezing (0 C). Maximum disease occurs at 25–35 C, which is also the optimum range for mycelial growth and sclerotial germination of the fungus (1,14). High soil moisture favors disease development, and serious outbreaks are often associated with unusually wet seasons. In regions of the world where rainy seasons occur, the disease is most serious during wet periods. Many epidemics occur when rainy periods follow dry weather. Southern blight is not usually a problem on calcareous soils with a high pH. Mycelial growth of *S. rolfsii* occurs over a broad pH range but is greatest in the acid range. Sclerotial production and germination are also greater under acidic conditions. The fungus is strongly aerobic, which may account for its prevalence in light, well-aerated soils and for the reduced germination of deeply buried sclerotia (4,18).

S. rolfsii grows abundantly on decaying plant debris, and crop refuse from the preceding season is frequently overgrown by the fungus. Boyle, cited by Aycock (1), found that saprophytic media supplied to the infection court resulted in rapid mycelial growth of *S. rolfsii* and production of sufficient metabolites to kill cells of the host. The food base utilized by *S. rolfsii* is available only in crop refuse, dead weeds, or dead tissues of a living host. The common practice of applying soil to the base of plants is often detrimental because soil-covered lower leaves may form a "bridge" of dead tissue, furnishing an ideal medium for initiating pathogenesis (1). Senescent plant tissue is also a source of volatile compounds, e.g., alcohols and aldehydes, that stimulate sclerotial germination, thus initiating epidemics of southern blight. Burial of organic matter decreases disease incidence because the organic matter is located in an area ecologically unfavorable for development of the fungus.

Cultural Control

Early recommendations for controlling diseases caused by *S. rolfsii* emphasized the importance of sanitary and cultural practices (1). These included roguing, increasing plant spacing, eliminating weed hosts, preventing accumulation of dead leaves around plant bases, avoiding mechanical injury during cultivation, earlier harvesting of certain crops, and in the case of tomatoes, staking. These recommendations are still valid but certainly are not adequate by themselves. A number of new approaches to cultural control, many suggested for North Carolina vegetable growers, follow.

Site selection. Infections by *S. rolfsii* can be minimized by avoiding heavily infested fields. Problem fields may be identified by cropping history and by sampling soil for sclerotia of *S. rolfsii.* The inoculum density of *S. rolfsii* can be determined accurately by several sampling and assay techniques (2,14,16). Approaches to recovering *S. rolfsii* from soil include: a soil tray technique using aqueous methanol to detect viable sclerotia; a baiting technique using tissue segments to detect saprophytic growth; and wet-sieving, flotation-sieving, or elutriation to recover sclerotia directly. Viability of sclerotia can be determined with aqueous methanol or by plating sclerotia on an agar medium.

Correlations between inoculum density and disease development have been developed for carrot, tomato (Fig. 6), and pepper. Carrots should not be planted if the initial inoculum density is above one sclerotium per 300 cm^3 of soil, unless other stringent control measures are used (17). Soil samples should be taken as close as possible to planting time to ensure meaningful predictions of disease incidence (14). Predictive systems based on this information have been implemented for processing carrots in North Carolina.

Crop rotation. Crop rotation is a long-established practice to reduce disease. Because *S. rolfsii* has a wide host range, crop rotation obviously has less chance of success than if host range were more limited. *S. rolfsii* also persists in the soil saprophytically, maintaining itself at high levels on debris from plants that otherwise are not suitable hosts. Nevertheless, certain grass crops, e.g., bermudagrass, crabgrass, corn, wheat, and rye, are of definite value in reducing inoculum levels. Although it is difficult to single out rotation crops that will reduce disease, severe epidemics develop when susceptible crops are planted continuously.

In crop sequence experiments conducted in North Carolina, some treatments reduced sclerotial numbers in the soil and subsequent disease incidence in susceptible carrots. Of 19 crop treatments, only sweet potato and buckwheat reduced preseason sclerotial counts and subsequent disease occurrence on carrot (Table 1). Sweet potato roots infected with *S. rolfsii* in the field produce very few sclerotia; this may

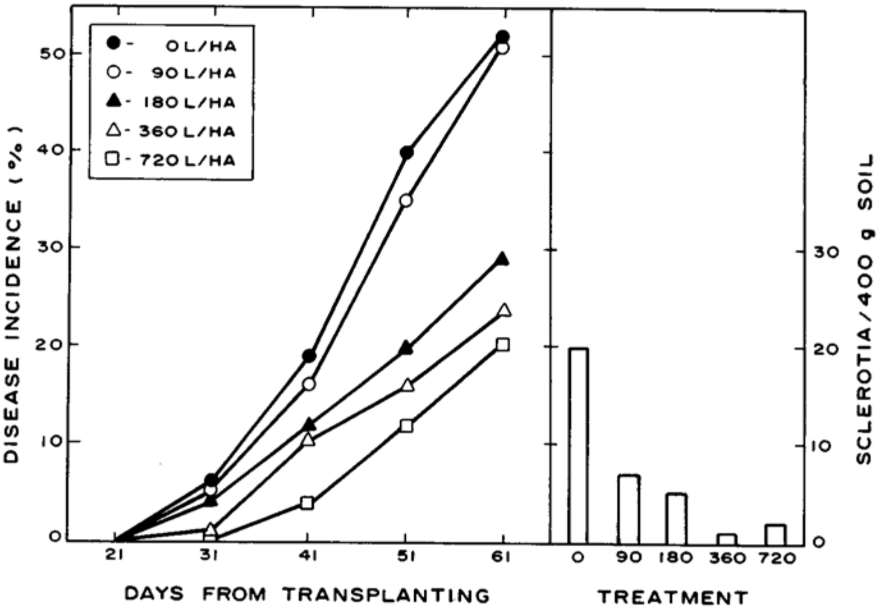

Fig. 6. Disease progress of southern blight of tomato and sclerotial counts of *Sclerotium rolfsii* with four rates of metam-sodium applied in irrigation water preplant.

account for reduced sclerotial numbers. Fresh-market tomato, hand-weeded fallow (weeds left on plots), naturally weedy, sweet corn, and processing tomato treatments increased sclerotial counts and disease incidence. Sweet corn seems to increase sclerotial counts more than field corn, but more research is needed to confirm this.

Planting date. For some vegetable crops, southern blight may be avoided or damage reduced by altering planting dates. In North Carolina, the incidence and intensity of southern blight of carrot decreased as the planting date was delayed at 2-week intervals, beginning 15 February (Fig. 7); no disease occurred in plots planted on or after 17 May. Carrots become diseased about 90–100 days after planting (9), when plant canopies shade the soil surface and create a microenvironment suitable for southern blight development. Also, the senescent leaves in the outermost whorl contact the soil, serving as an organic substrate for growth of *S. rolfsii*. Ambient and soil temperatures 90–100 days after a 17 May planting are too cool for southern blight development.

Land preparation. Plowing at least 20 cm deep with a moldboard plow equipped with heavy-duty disk coulters or moldboard extensions (trash covers) effectively removes inoculum (sclerotia and infested crop debris) and organic matter from the infection court (upper 8–12 cm) (9). Deep plowing is most effective with disk coulters or moldboard extensions that invert or "flip" the soil. Plowing should be done just before planting, and cultivation during the growing season should not bring buried litter back near the soil surface.

Postplant tillage. Conventional methods of cultivating vegetables favor the development of southern blight and may retard crop growth and maturation by injuring roots or other plant parts. Many cultivation procedures throw soil, infested soil debris, and sclerotia against the base of the plant and aerate the soil, favoring the development of *S. rolfsii*. In carrot, the beneficial effects of deep plowing can be negated by lay-by cultivation that brings soil, crop debris, and weed residue in contact with plants (9). Unfortunately, lay-by cultivation is a standard practice in carrot culture for preventing "greening" of the shoulder of the carrot root and for controlling weeds. In most other vegetable crops, herbicides diminish the need for lay-by cultivation.

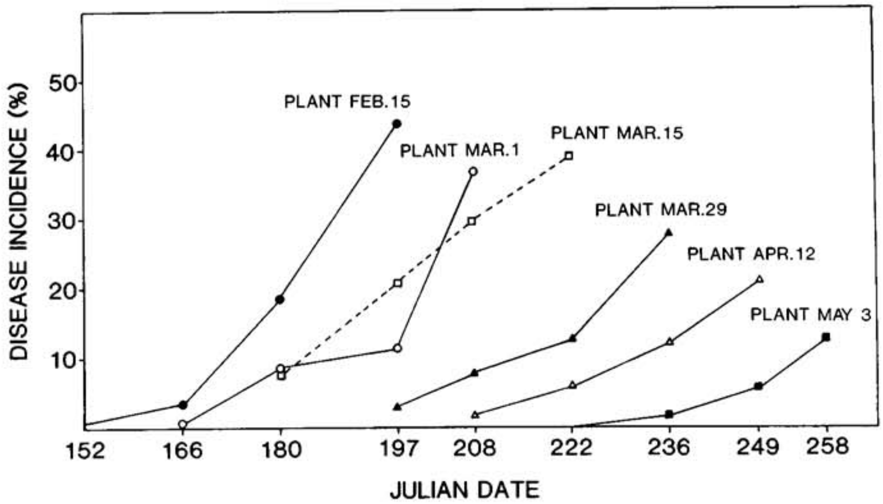

Fig. 7. Disease progress of southern blight of carrot for six planting dates.

Table 1. Effect of 20 different treatments applied in the summer on *Sclerotium rolfsii* sclerotial counts and southern blight incidence on carrot

Treatment	Sclerotial count[a]	Blight incidence (%)
Solar heating, polyethylene mulch	2	1
Buckwheat	5	1
Sweet potato	6	4
Cantaloupe	7	15
Pepper	10	15
Rye straw + Roundup herbicide	10	14
Bare fallow + Roundup herbicide	10	15
Cucumber	10	15
Squash	10	16
Eggplant	11	18
Southern pea cv. Colossus	12	25
Soybean	13	27
Peanut	14	27
Milo	14	25
Southern pea cv. Iron	15	27
Tomato, fresh-market	17	31
Bare fallow, hand-weeded	17	29
Weeds	20	37
Corn, sweet	22	36
Tomato, processing	31	53

[a] Number of sclerotia in 400-cm^3 soil samples taken just before carrots planted.

Weed control. Certain weeds growing either in fallow fields or in rotation crops can cause an increase in inoculum of *S. rolfsii* (Table 1). Both host and nonhost weeds favor disease development by increasing inoculum, shading soil, and serving as organic substrates or food bases for infection of the vegetable host. For example, goosegrass, a very common weed, increased sclerotial counts of *S. rolfsii* in experimental field plots in North Carolina (8). Because excess cultivation can increase development of southern blight, weeds should be controlled with the herbicides registered for the particular vegetable crop.

Chemical Control

Numerous chemicals inhibit sclerotial germination or mycelial growth of *S. rolfsii* and effectively control southern blight on various crops in the field.

Preplant chemicals and application techniques. Fumigants such as metam-sodium (Vapam), Vorlex (a mixture of methyl isothiocyanate, 1,3-dichloropropene, and other chlorinated C_3 hydrocarbons), methyl bromide, and chloropicrin, when applied to soil, reduce southern blight incidence. These fumigants are registered on all vegetable crops. Deep moldboard plowing followed by use of Vorlex (75 or 150 L/ha applied with a single chisel 15 cm deep in the row) reduced sclerotial counts of *S. rolfsii* at transplanting time and southern blight incidence on tomato 66 days later (10). Disking soil and applying the same rate of Vorlex also reduced sclerotial counts and disease incidence, but to a lesser extent (10). Metam-sodium applied in irrigation water to infested soil at 90, 180, 360, and 720 L/ha resulted in lower sclerotial counts at tomato transplanting time (Fig. 6) (10). Subsequent southern blight incidence on tomato was reduced with 180, 360, or 720 L/ha of metam-sodium but not by 90 L/ha. Metam-sodium applied at 180 and 460 L/ha also suppressed southern blight of carrot planted on six dates. Chloropicrin is consistently effective (1) but is expensive and difficult to apply. Methyl bromide controls *S. rolfsii* satisfactorily and is widely used to treat soil in infested seedbeds and fields of high-value crops (1). Methyl bromide injected under polyethylene at 490 kg/ha was not as effective as metam-sodium applied at 748 L/ha in controlling southern blight of field-grown tomato transplants (12).

The rate and method of application affect performance of general-purpose fumigants. McCarter et al (12) found that drench application of metam-sodium at 748 L/ha was more effective and gave better control of southern blight of tomato than soil injection or incorporation. Conversely, Vorlex applied at 280 L/ha as a drench was not as effective as the same amount injected into the soil. Krikun et al (11) reported successful application of metam-sodium in irrigation water, and many workers have verified that dilute concentrations of metam-sodium in irrigation water effectively control soilborne pathogens, including *S. rolfsii*. Irrigation rates may be varied to apply the chemical to the required depth in soil; 230–460 L/ha of metam-sodium in irrigation water is as effective as 700–930 L/ha applied by other methods.

Postplant chemicals and application techniques. Chemical control of *S. rolfsii* on a commercial basis was not possible until pentachloronitrobenzene (PCNB) became available after 1945 (1). PCNB is registered on several vegetable crops for control of southern blight, usually at transplanting or seeding. Although PCNB may be effective, its use may not be practical because of cost, unpredictable occurrence of the fungus, and uncertain seasonal conditions (1). PCNB is relatively insoluble, and uniform distribution in the top 1–6 cm of soil is necessary for successful blight control. Mixing treated soil with untreated soil or burying plant material or other organic material near the plant curtails the effectiveness of PCNB. In tomato plots that had been deep-plowed and treated with Vorlex before planting, the incidence of southern blight was not lowered further by lay-by application of PCNB at 0.9 or 1.8 kg a.i./ha (11). In several tests on carrots, however, lay-by application of PCNB at 11.2 or 22.4 kg a.i./ha reduced the incidence of southern blight (10).

Carboxin (Vitavax), a fungicide registered for control of southern stem rot on peanuts, controls southern blight of many vegetables (Table 2). Applications at lay-by and 14 days later are more effective than application at lay-by only. With processing carrots, where lay-by cultivation is a necessity, carboxin reduced southern blight to a level equal to that of the no-cultivation control. Carrot growers can minimize both southern blight losses and operating expenses by combining lay-by cultivation and fungicide application into a single operation.

Triphenyltin hydroxide (Du-Ter), registered for control of Alternaria and Cercospora leaf spots of carrot and early and late blights of potato, controlled *S. rolfsii* in a number of experiments. The recommended rates for carrot and potato leaf diseases are 0.28–0.7 kg/ha, but the rates necessary for control of southern blight range from 2.2 to 4.4 kg/ha. Phytotoxicity was observed on carrot when 4.4 kg/ha was applied 2 weeks before lay-by. Further research on efficacy and chemical residue is necessary with triphenyltin hydroxide.

Sterol-inhibiting fungicides are not registered on vegetable crops but are effective for controlling southern blight. Furmecyclox was the most effective fungicide for control of southern blight of carrot in North Carolina.

Certain pesticide application techniques may be useful in controlling southern blight. Split applications of the sterol-inhibiting fungicide etaconazole to carrots just before and immediately after lay-by cultivation was more effective in reducing southern blight than one application either immediately before or just after lay-by. Etaconazole applied in 0.2–0.3 cm of water for 15 minutes through overhead sprinkler irrigation at lay-by, followed by a band spray 2 weeks later, was the most effective treatment in many field tests. Although etaconazole is no longer available, these application techniques may be useful with other pesticides.

Fertilizers. Although southern blight has seldom been controlled by altering fertilizer regimes, disease development is influenced by nutrition of the host and by the effects of nutrients on *S. rolfsii* and associated soil microflora (3,15). Disease incidence is lower when ammonium fertilizers in the form of urea, ammonium nitrate, and ammonium bicarbonate are applied, provided increased nitrogen levels are not detrimental to crop growth or yield. Ammonia released by ammonium fertilizers may directly inhibit sclerotial germination and retard mycelial growth of *S. rolfsii*. Ammonium fertilizers may indirectly limit disease by altering host susceptibility or increasing populations of antagonistic soil microorganisms. Calcium fertilizers such as calcium nitrate and calcium sulfate suppress southern blight by increasing calcium levels in host tissue. Higher calcium levels in cell walls may partially offset the action of oxalic acid and cell-wall-degrading enzymes produced by the fungus. Normal liming of soil with hydrated lime generally does not reduce disease because the soil pH is not raised enough to inhibit *S. rolfsii*. Also, calcium levels in the host are not sufficiently changed by normal liming. However, 13–18 t/ha of hydrated lime mixed in the top 15 cm of bedding soil effectively reduced *S. rolfsii* in sweet potato beds and increased yields of sweet potato sprouts (1).

Chemical control of foliar diseases. Foliar diseases of vegetables should be controlled for several reasons: Plants with healthy foliage are subjected to less stress, diseased leaves that dehisce or touch the soil surface serve as a food base for *S. rolfsii*, and chemicals registered for foliar disease control may also be useful for controlling *S. rolfsii*. Du-Ter is registered for control of leaf spots of carrot and is also effective for controlling southern blight. Chlorothalonil (Bravo) and benomyl (Benlate) are also registered for control of foliar diseases of vegetables and have reduced southern blight of carrot in some tests in North Carolina.

Control by Solar Heating

The approach to controlling soilborne diseases by solar heating of the soil was developed in Israel (7). Moistened soils are mulched 2–4 weeks during the hot season with transparent polyethylene sheets, thereby increasing soil temperatures. Solar heating reduces sclerotial numbers and limits disease caused by *S. rolfsii* (7). The pathogen can be effectively eliminated from soil to depths of 6–20 cm, depending on geographic location, soil type, and time of year. Solar heating combined with application of the fungus *Trichoderma harzianum* Rifai resulted in less disease than either treatment alone and was approximately equal to methyl bromide for control of *S. rolfsii* on potatoes in field plots (7). In North Carolina, we found that solar heating was more effective than any rotation crop in reducing inoculum density and disease in carrots (Table 1). Solar heating was equal to deep plowing with a moldboard plow with moldboard extensions.

Table 2. Control of southern blight of tomato, pepper, and carrot with carboxin

Treatment	Number of applications	Southern blight incidence (%)[a] Tomato	Pepper	Carrot
Control	0	40	43	33
Carboxin 75W, 1.6 kg/ha	1	20	24	17
	2	5	13	24
3.2 kg/ha	1	17	16	11
	2	4	11	14
6.4 kg/ha	1	16	16	...
	2	4	7	...

[a] LSD ($P = 0.05$) was 4, 8, and 7% for tomato, pepper, and carrot, respectively.

Biological Control

Several microorganisms, including bacteria, actinomycetes, a mycorrhizal fungus, and *Trichoderma* spp., inhibit growth and sclerotial production by *S. rolfsii* (14). Some microorganisms have suppressed disease in controlled experiments (7), but instances of effective field control have been few. *T. harzianum,* a destructive mycoparasite that competes aggressively with other soil fungi, suppresses southern blight when applied to field soils. Solar heating, which favors the growth and development of *T. harzianum*, enhances biological control of *S. rolfsii*. The application of antagonistic microorganisms to large fields is not generally economical at this time but combined with other practices, such as solar heating, may be useful for southern blight control in the future (7).

Host Resistance

Although *S. rolfsii* is pathogenic on many plant species, susceptibility within species is often associated with age and succulence of host tissue. Generally, plants with woody stems are much less susceptible after the seedling stage, whereas plants with fleshy roots or stems are highly susceptible as they approach maturity. Cultivated tomato (*Lycopersicon esculentum* Mill.) carries little resistance to *S. rolfsii*, but certain strains of *L. pimpinellifolium* (Jusl.) Mill. show resistance. Resistance in *L. pimpinellifolium* is due to a complete ring of heavily suberized phellem cells formed at the ground level in stems when the plants are 6–9 weeks old. Southern blight is not a serious problem on these plants unless the phellem ring is broken by some other organism or mechanical injury. Resistance is increased when plants are grown on soil high in calcium or calcium is added as a sidedress to the crop. Six tomato breeding lines with resistance to southern blight from *L. pimpinellifolium* have been released jointly from Texas and Georgia agricultural experiment stations (13).

Pepper (*Capsicum* spp.) germ plasm shows a wide range of disease reaction to southern blight (5). Germ plasms with the highest level of resistance include *C. chinense* L. PI 224428, *C. frutescens* L. 'Greenleaf Tabasco' and 'McIlheny Tabasco,' and *C. annuum* L. 'Golden California Wonder,' 'Santanka,' and PI 163192. Southern pea and sweet potato (both seedbed and field) also have significant genetic variability, with several accessions of southern pea showing promising levels of resistance (6).

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Integrated Control Practices

The control of southern blight is difficult, but losses can be reduced by following a "total program" over a period of several years:

1. Avoid problem fields, identified by cropping history and preplant inoculum densities;
2. Use crop rotation sequences that reduce inoculum levels and disease incidence;
3. If possible, plant at times that avoid maximum disease;
4. Apply 230 L/ha of metam-sodium in irrigation water to a depth of 12.7 cm;
5. Bury crop litter 8–13 cm deep with a moldboard plow equipped with disk coulters or trash covers;
6. Minimize tillage to avoid bringing buried litter back to the soil surface during the current crop season;
7. Apply a calcium fertilizer such as calcium sulfate (gypsum) or calcium nitrate at 100 kg of calcium per hectare within 50 days after planting;
8. Apply a nitrogen-containing fertilizer such as urea or ammonium nitrate at 100 kg of nitrogen per hectare between 50 and 80 days after planting;
9. Control weeds with a registered herbicide and, if absolutely necessary, shallow cultivation;
10. Apply a postplant fungicide registered for controlling southern blight on the target host; and
11. Control foliar diseases.

Prospects for Control of Southern Blight

The most exciting prospects for future control strategies are solar heating, biological control, host resistance, and new postplant fungicides. The efficacy of solar heating with transparent polyethylene mulching has been demonstrated but currently is economical only for high-value crops. Solar heating is most effective when temperatures are high, but many susceptible vegetable crops are planted in the spring when temperatures are cool. Further research is necessary to study the economic benefits and costs of solar heating and the timing of solar heating in relation to crop production. *T. harzianum* effectively controls *S. rolfsii* on a small scale, but, again, further research is needed to determine what factors favor natural increase of *T. harzianum* in field soils. The most desired control measure would be the use of vegetable cultivars that have useful horticultural characteristics and high resistance to *S. rolfsii*. Breeding programs to incorporate southern blight resistance in carrot, pepper, southern pea, sweet potato, and tomato are being conducted in North Carolina, South Carolina, Georgia, and Texas. Hopefully, useful cultivars will be released from these programs in the near future. New postplant fungicides are urgently needed. Carboxin, which is registered on some field crops for control of southern blight, is the most likely candidate. Other experimental fungicides, e.g., furmecyclox and propiconazole, have given excellent control of southern blight, but extensive testing is needed for efficacy and residue analysis.

No single method will consistently control southern blight of vegetables. Complete control will be difficult. Integrated control programs employing any and all combinations of available methods must be continually investigated and implemented.

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