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Target Spot of Tobacco

In the 1980s, a new leaf spot disease of tobacco (*Nicotiana tabacum* L.) became endemic in most tobacco-growing regions of the United States. The disease initially was diagnosed in 1984 in North Carolina, when an epidemic caused extensive losses in several locations and was present throughout the flue-cured tobacco-producing areas of the state (21). By 1990, the disease had been observed in most tobacco-producing areas of the United States. The disease was given the name Rhizoctonia leaf spot (21), and later target spot (22), because of the zonate appearance of mature leaf lesions (Fig. 1). The pathogen was identified as *Thanatephorus cucumeris* (A.B. Frank) Donk (anamorph *Rhizoctonia solani* Kühn anastomosis group (AG) 3).

The disease was reported from other tobacco-producing countries prior to the 1980s. The first report of the disease was from Brazil in 1948 (9). Costa (9) described the disease on oriental tobacco and called the disease halo-spot and leaf-scorch; the pathogen was identified as a strain of the fungus that caused damping-off of seedlings. Vargas (24) described the disease on tobacco in Costa Rica and determined that leaf infections were caused by basidiospores of *T. cucumeris*. The disease also has been reported from South Africa (17) and occurs in Zimbabwe (C. Fisher, *personal communication*). Although the disease now occurs worldwide, losses were either uncommon or unreported until the 1980s, when epidemics occurred in several countries. The disease has caused economic losses in flue-cured tobacco areas of North Carolina each year since 1984, with losses reaching a high of $25 million in 1989.

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Symptomatology

The pathogen infects plants of all ages. Initial symptoms of the disease are small, circular, water-soaked spots about 2–3 mm in diameter (Fig. 2). These primary lesions have a netlike appearance when held up to a light source, and the initial lesions usually remain distinct, even as the lesions start to enlarge (Fig. 3). This symptom is useful in separating target spot from other common leaf diseases such as brown spot, caused by *Alternaria alternata* (Fr. ex Fr.) Keissl., that also produce spots with concentric rings (20). Many primary lesions fail to develop beyond the initial stage (Fig. 4), even under optimum environmental conditions for the disease (22). Under conditions of moderate temperatures, high relative humidity, and prolonged periods of leaf wetness, lesions enlarge very rapidly (often reaching 5 cm or more in diameter), and damage to leaf tissue can be extensive (Fig. 5). Under less favorable conditions, lesions develop more slowly and halos are often present (Fig. 6). Tissue in the center of lesions is thin, and when dry may drop out, leaving a shot-hole type lesion and giving a ragged appearance to the leaf (Fig. 5). The life cycle of the fungus is completed when hymenia and basidiospores are produced on the surface of leaves or other plant tissues (Fig. 7).

Pathogen Identification and Characterization

During the 1984 epidemic in North Carolina, isolates of *T. cucumeris* were collected from diseased leaf tissue from the Coastal Plain and Piedmont regions of the state for identification and completion of Koch's postulates. The disease was difficult to reproduce in controlled inoculations with culture-produced inoculum. In fact, field symptoms of the disease could not be reproduced when mycelial inoculum, either on agar plugs or in infested soil, was placed on leaf tissue. However, when pathogen-infested rice grains were placed in soil, symptoms were readily reproduced and basidiospores were produced on hymenia (21). Subsequent tests concluded that basidiospores serve as primary and secondary inoculum in the disease (22).

All target spot isolates of *T. cucumeris* collected since 1984 in North Carolina have been similar in morphology (Fig. 8), growth rate, fungicide sensitivity, and other characteristics (21–23; H. D. Shew, *unpublished*). Colonies are typically light brown and zonate, and produce very few

Fig. 1. Target spot lesion on flue-cured tobacco showing concentric rings typical of rapidly expanding lesions on field-grown plants.

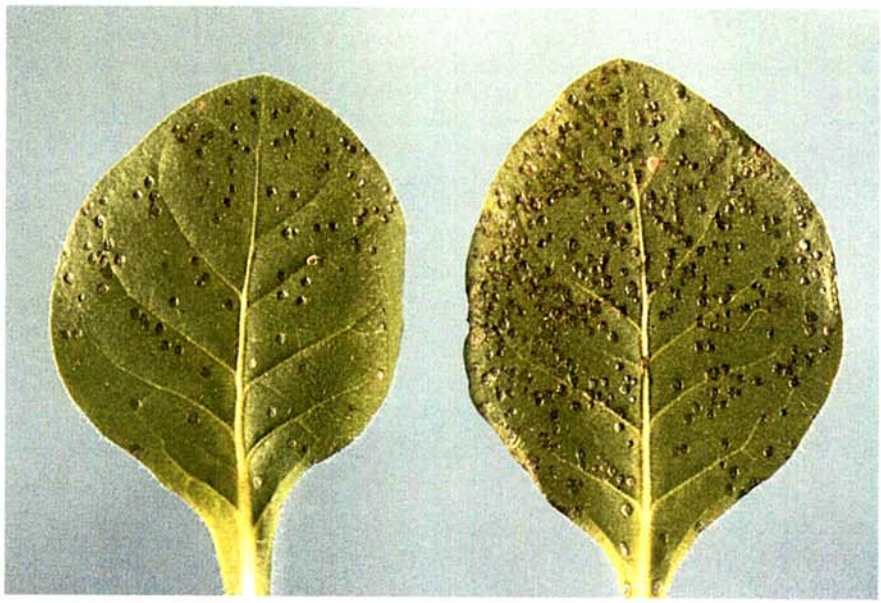

Fig. 2. Abundant primary lesions on leaves of greenhouse-produced tobacco seedlings.

Fig. 6. Small target spot lesions with prominent haloes on tobacco.

Fig. 3. Large target spot lesions on tobacco leaf with primary lesions still visible.

Fig. 4. Tobacco leaves with numerous primary lesions but only two lesions that continued to develop.

Fig. 5. Large target spot lesions on leaf of flue-cured tobacco under field conditions. Note large coalescing lesions and ragged appearance of leaf tissue.

Fig. 7. Typical hymenium of *Thanatephorus cucumeris* on lower leaf of tobacco under high moisture conditions. Abundant basidiospores are produced on hymenia.

sclerotia on agar media, except for a sclerotial crust in the center of the colony after 7–14 days of growth on a medium such as potato-dextrose agar (Fig. 8). The uniformity of the target spot pathogen collected from diverse geographic areas over multiple years was unexpected based on the known heterogeneity in morphology of *R. solani* (19). In contrast, isolates of *R. solani* obtained from stem lesions (sore shin) on tobacco plants in North Carolina are more typically heterogeneous in morphology and differ from target spot isolates.

Initial anastomosis tests identified target spot isolates as *R. solani* AG2-2 (21), but a later study (23) concluded they are members of AG-3, as previously determined for isolates from tobacco leaves in South Africa (17). AG-3 isolates of *R. solani* have been primarily associated with diseases of potato (1,7,16), but there are reports of AG-3 from other solanaceous plants, such as tomato (11) and eggplant (15).

Host Range

Because of the severity of the epidemic of target spot in 1984, and the possibility that a new pathogen had been introduced, the host range of target spot isolates of *T. cucumeris* was investigated. Tests were conducted under controlled environmental conditions in the Southeastern Plant Environment Laboratory (phytotron) (12), where optimum conditions for the production of hymenia and basidiospores could be established (22). Seventeen crop and ornamental plants, and eight species of weeds frequently found in tobacco fields (Table 1), were grown in phytotron soil mix infested with *T. cucumeris*. Plants and soil were observed daily for the presence of hymenia, and plants were observed for leaf spots and web blight caused by *T. cucumeris* over a 4-week period. Hymenia formed abundantly on 16 of the 23 plant species tested (Table 1, Figs. 9 and 10), but the presence of hymenia was not correlated with the development of disease. On most species, plant tissue appeared to serve only as a means of support for hymenia; hymenia were easily removed (peeled) from plant surfaces without any apparent injury to the plants.

With the exception of sugar beet, only Solanaceous plant species were attacked by tobacco isolates of AG-3 in our studies. Primary lesions caused by basidiospore infections developed on tobacco (both flue-cured and burley cultivars), tomato (cotyledons only), eggplant, and sugar beet. Lesions enlarged rapidly on both flue-cured and burley tobacco but failed to enlarge on tomato, and only a few primary lesions expanded

beyond the initial lesion size on eggplant and sugar beet. Web blight was observed on seedlings of nightshade, horsenettle, and petunia; but no leaf spots initiated by basidiospores were observed. It was noteworthy that potato was the only Solanaceous plant in these tests that showed no disease development on leaves or stems, even though hymenia were present on stems (Fig. 10). This observation was later confirmed in a study in which tobacco and potato were grown in the presence of tobacco and potato isolates of *T. cucumeris* AG-3 (23). In this study, only tobacco isolates caused leaf spot and stem rot (damping-off) diseases on tobacco (Fig. 11), and only potato isolates caused disease on potato (23).

Also of interest in these studies was the infection of sugar beet by tobacco isolates of AG-3 (22). Occurrence of AG-3 on sugar beet was reported from Japan (18) and recently was found under field conditions in Minnesota (25). No basidiospore infections were observed on leaves in the field, but superficial hymenia of *T. cucumeris* frequently were present on petioles, and yields were suppressed in the presence of the pathogen. Infested fields had a history of potato production, so isolates most likely were potato isolates of AG-3. Thus, it appears that sugar beet may be attacked by both tobacco and potato isolates of AG-3, even though the isolates are limited to their respective hosts under artificial inoculations.

The results of these tests indicated that other major crop and ornamental plants grown in North Carolina were not at risk from the target spot pathogen, nor were they likely to serve as significant sources of inoculum for subsequent infection of tobacco.

Fig. 8. Ten field isolates of *Thanatephorus cucumeris* collected during the 1984 epidemic of target spot. Isolates were collected from diverse geographic regions of the state.

Table 1. Development of symptoms and hymenia by target spot isolates of *Thanatephorus cucumeris* on selected crop and weed species

Species	Hymenium[y]	Symptoms[z]
Ambrosia artemisiifolia L. — ragweed	−	−
Arachis hypogaea L. — peanut	+	−
Beta vulgaris L. — sugar beet	+	+
Brassica oleracea L. var. *capitata* L. — cabbage	+	−
Capsicum frutescens L. — bell pepper	+	wb
Chenopodium album L. — lamb's-quarters	+	−
Cucumis sativus L. — cucumber	+	−
Cynodon dactylon (L.) Pers. — common bermudagrass	−	−
Eleusine indica (L.) Gaertn. — goosegrass	+	−
Festuca arundinacea Schreb. — tall fescue	+	−
Glycine max (L.) Merr. — soybean	−	−
Gossypium hirsutum L. — cotton	−	−
Ipomoea purpurea (L.) Roth — morning-glory	+	−
Lycopersicon esculentum Mill. — tomato	+	+
Nicotiana tabacum L. — tobacco	+	+
Petunia × *hybrida* Hort. Vilm.-Andr. — petunia	−	wb
Phaseolus vulgaris L. — green bean	−	−
Solanum carolinense L. — horsenettle	+	wb
Solanum melongena L. — eggplant	+	+
Solanum nigrum L. — nightshade	+	wb
Solanum tuberosum L. — potato	+	−
Xanthium strumarium L. — cocklebur	+	−
Zea mays L. subsp. *mays* — corn	−	−

[y] Hymenium of *T. cucumeris* present/absent on plant tissues. Hymenia were superficial in all cases.

[z] + = Presence of primary lesions caused by basidiospore infection, and wb = presence of web blight.

Fig. 9. Hymenia of *Thanatephorus cucumeris* on leaflets of peanut. No symptoms developed on peanut leaves or stems, and the hymenia could be removed with no apparent damage to the underlying leaf tissue.

Fig. 10. Hymenia of *Thanatephorus cucumeris* on potato stems.

Fig. 11. Host specificity observed in tobacco and potato isolates of *Thanatephorus cucumeris* (*Rhizoctonia solani* AG-3) on tobacco seedlings.

Disease Cycle and Epidemiology

The most important environmental factor in the development of target spot is moisture (22). Temperature affects many developmental stages in the disease, but usually is not limiting when conditions of high moisture and leaf wetness are present (22). The first epidemic of target spot occurred in June and July 1984, during a period characterized by frequent rain showers and moderate temperatures. These months also correspond to a period of rapid growth of the tobacco plant, which results in a closed canopy and shading of lower leaves. These conditions extend periods of leaf wetness on lower leaves and are favorable for leaf infection, lesion development, and secondary inoculum production (22). Similar conditions occurred again in 1989, but the epidemic was even more widespread and caused much greater damage to the tobacco crop. The increased severity of the epidemic probably was due to more widespread rain showers and a greater abundance of initial inoculum in tobacco soils in 1989.

Since the first epidemic in 1984, when the disease was observed only on field plants, target spot also has become important as a seedling disease. Until recently, tobacco seedlings were grown in fumigated seed beds in the field prior to transplanting, but now a majority of growers produce their seedlings in greenhouses. Environmental conditions in greenhouses can be highly conducive to the development of target spot, and an epidemic of target spot within a greenhouse can be very destructive. Disease usually is observed after leaves of seedlings touch, forming a canopy that keeps leaves wet for extended periods. Basidiospores landing on wet leaves infect and produce a lesion that initially is quite similar to anthracnose, caused by *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. in Penz. (20). The source of basidiospores is thought to be outside the greenhouse, but the overwintering or primary source of inoculum has not been identified for greenhouse or field infections. It is common to see numerous lesions on a single leaf (Fig. 2); and if the disease is not stopped at this stage, plant death can result as the pathogen grows from the leaf tissue into the stem. Plants with stem lesions should not be transplanted to the field. Plants with leaf lesions also should be avoided if possible. Although the lesions rarely progress on infected plants after transplanting, infected leaves may provide a source of inoculum for infection of plants later in the growing season.

A second target spot epidemic can occur on field plants. Inoculum is produced once leaves are large enough to shade the soil, which provides high relative humidities and mild temperatures at the soil surface. Basidiospores are produced on hymenia on the soil surface and are dispersed onto lower leaves where they infect leaf tissues. Once lesions are formed, secondary inoculum is produced on the lower and sometimes upper leaf surfaces, and the disease progresses up the plant and to other plants.

All cultivars of flue-cured and burley tobacco are susceptible to target spot (H. D. Shew and C. E. Main, *unpublished*). Differences in disease severity have been observed among genotypes in field and phytotron tests, but the level of resistance was not high enough to provide adequate control of the disease under favorable environmental conditions.

Origin of Target Spot Isolates of *T. cucumeris*

What factors were responsible for the outbreak of this new leaf disease? Was the pathogen a sore shin strain of *T. cucumeris* that became important because of changes in tobacco production practices, or was it a recently introduced organism?

Target spot isolates of *T. cucumeris* can cause sore shin (stem rot) of tobacco seedlings (Fig. 12), but isolations from field plants with symptoms of sore shin rarely yield AG-3 isolates. The majority of sore shin isolates are members of AG-4 (20). Distribution of AG-3 isolates in North Carolina tobacco soils has not been investigated, but it is possible that the target spot pathogen existed prior to 1984 as a member of the group of fungi that cause sore shin. Unfortunately, sore shin isolates of *T. cucumeris* were not characterized prior to the epidemic of target spot in 1984, so conclusions on the prevalence of AG-3 isolates prior to this time are not possible.

Although the first epidemic of target spot was observed in 1984, a leaf spot caused by *T. cucumeris* had been diagnosed in the Plant Disease and Insect Clinic at North Carolina State University prior to 1984 (R. K. Jones, *personal communication*). The disease was thought to be the result of soil that was infested with the sore shin pathogen splashing onto the lower leaves of plants, because only leaves close to the soil were infected. Isolates of *T. cucumeris* obtained from these leaf spots were not maintained, so once again, comparison with target spot isolates was not possible. Leaf symptoms observed in 1984 differed from those observed in previous seasons, in that lesions were not limited to the lower leaves and severity of the disease was much greater. A few isolates of AG-4 (typical sore shin group) were obtained from leaf spots during the 1984 and 1989 epidemics (H. D. Shew, *unpublished*), so isolates of AG-4 may have been responsible for the occasional *T. cucumeris* leaf spots diagnosed prior to 1984 on tobacco.

Genetic polymorphisms would be expected within populations of *T. cucumeris* if the pathogen had been present in North Carolina soils for many years prior to 1984. To investigate the genetic variability within target spot isolates, field isolates and single basidiospore isolates were studied using somatic interactions and randomly amplified polymorphic DNA (RAPD) analysis. In addition to determining anastomosis group, somatic interactions can be used to investigate genetic relatedness and mating behavior within an anastomosis group (2,10). Isolates collected between 1984 and 1989 were paired in all combinations on potato-dextrose agar plus activated charcoal (6) to determine somatic interaction types (4,10). A wide range of macroscopic interactions were observed on the nutrient medium (Fig. 13), indicating that isolates obtained from various parts of the state, although very similar in morphology, were not clonal. Not surprisingly, these isolates produced very few polymorphisms using RAPD markers; coefficients of similarity ranged from 0.84 to 1.0. Based on these investigations, it is likely that target spot isolates of *T. cucumeris* were present in North Carolina before 1984, but additional genetic markers and studies with isolates from a wider geographical area are required before the origin of the pathogen can be determined.

If the pathogen was present prior to 1984, why were no epidemics observed on flue-cured tobacco? Rain showers were frequent in several areas of the state in 1984, but similar shower frequency had been observed in previous years without target spot developing. Several significant changes in tobacco production occurred in the years just before the 1984 epidemic. A major addition to tobacco culture was the introduction and widespread use of the fungicide metalaxyl (Ridomil) for the control of the black shank pathogen, *Phytophthora parasitica* Dastur var. *nicotianae* (Breda de Hann) Tucker, and the blue mold pathogen, *Peronospora tabacina* D.B.

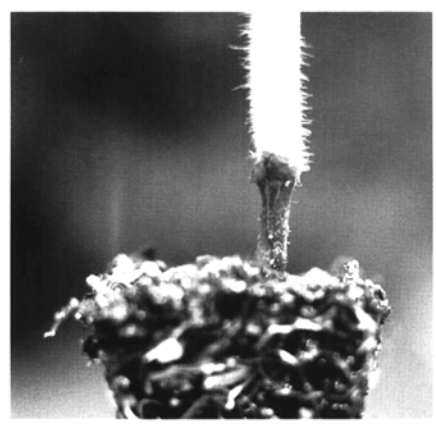

Fig. 12. Stem rot of greenhouse tobacco seedling caused by target-spot isolate of *Thanatephorus cucumeris*.

Adam. The fungicide is applied as a preplant soil treatment, and up to 90% of the total tobacco acreage in North Carolina was treated with the fungicide for several years prior to 1984 because of the threat of the blue mold disease. This fungicide also is effective in suppressing many species of *Pythium*. An antagonistic relationship between species of *Pythium* and *Rhizoctonia* has been observed in vitro (5) and in vivo (8,13,14), and suppression of *Pythium* spp. may play a role in the increased incidence of diseases caused by *T. cucumeris* (8).

There also was a major change in cultivars during this time, with K-326 becoming the predominant cultivar. However, based on information from field and phytotron tests, this cultivar is not more susceptible than previously grown cultivars, so it is unlikely that it played a significant role in the establishment of this disease.

Disease Management

Management of target spot must take into consideration epidemics on greenhouse seedlings and on field plants. Target spot is managed in greenhouse systems with a combination of cultural and chemical practices. In North Carolina, Section 18 exemptions for the use of iprodione (Rovral 4F and 50W) have given producers an effective method to halt epidemics within a greenhouse. Nonetheless, growers are rapidly adopting better management practices, including improved ventilation and sanitation, that have reduced, but not eliminated, the need for fungicide applications to control target spot. In addition, producers are encouraged to maintain adequate plant nitrogen levels because leaf tissue low in nitrogen is very susceptible to lesion expansion and severe target spot damage (Table 2).

Ventilation of greenhouses is critical. Growers are encouraged to keep all vents open continuously unless temperatures drop below 16 C. Target spot is enhanced when growers attempt to encourage rapid plant growth by closing vents to elevate temperatures. Closed vents not only elevate temperatures but also greatly increase humidity and leaf wetness, which provide optimum conditions for target spot initiation and development (22).

Sanitation is very important in the management of other seedling diseases but may have limited impact on target spot. Previously used polystyrene trays have many cracks and crevices in their walls, and many microorganisms, including *T. cucumeris*, can survive surface disinfection procedures and periods of storage between uses in these protected areas. Most growers wash and then dip trays in a 10% chlorine bleach solution to remove pathogen inoculum, but these methods may not be totally effective for the isolates of *T. cucumeris* that cause stem rot or target spot. Fumigation of trays with methyl bromide is more effective in eliminating *T. cucumeris* from infested trays and is rapidly being adopted by growers. However, with the likely demise of methyl bromide in the near future, other methods will be needed to effectively sanitize trays. Primary inoculum for target spot epidemics probably is produced outside the greenhouse in many cases, so sanitation will not be highly effective in preventing epidemics of target spot in the greenhouse.

Target spot does not develop in the field until plants are about a meter high and the upper leaves are large enough to shade the lower leaves. This means that epidemics develop in mid- to late-season in flue-cured tobacco. Iprodione sprays have been used on field plants in some states, but concerns about residues from fungicide applications close to harvest will probably limit fungicide use in the field for target spot control.

Since target spot development is very sensitive to environmental conditions, especially high humidity and leaf wetness, practices that open the plant canopy and increase air circulation and reduce leaf wetness should reduce the rate of disease development. In fact, early harvesting of lower leaves from infected plants of flue-cured tobacco greatly reduces subsequent disease development. Harvesting before maturity reduces the quality and value of the lower leaves, but it may save a large percentage of the remainder of the crop. At present, early harvest and maintaining adequate nitrogen levels are the only management practices available to growers. The low level of resistance present in currently used cultivars means other sources of resistance must be identified, if possible, and introduced into agronomically acceptable cultivars.

As world supplies of high-quality tobacco have grown, research efforts have increased on ways to reduce production costs to U.S. growers. One method being considered is the use of increased plant densities. However, in tests conducted to date, more target spot was observed in high-density plantings (G. F. Peedin, *personal communication*), so future testing must consider management practices that also minimize losses to leaf spots.

The Future

Many questions remain about the disease and pathogen. Further genetic characterization of target spot isolates of *T. cucumeris* is being done to increase our understanding of the origin of these isolates and their relationship to other members of AG-3 and to target spot isolates from other states and countries. North Carolina isolates have been characterized by using RAPDs, and characterization

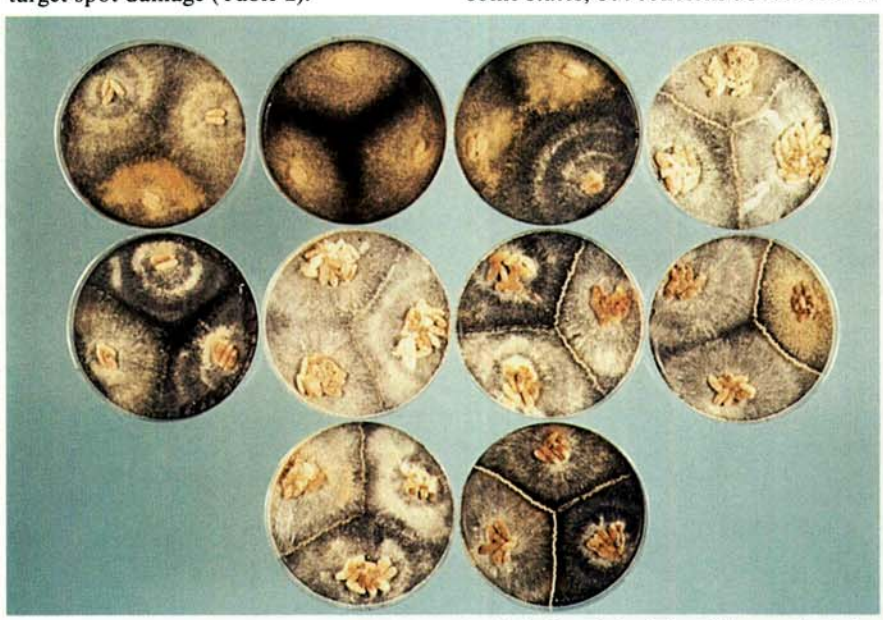

Fig. 13. Range of somatic interactions observed with field and single basidiospore isolates of *Thanatephorus cucumeris* on potato-dextrose agar amended with activated charcoal.

Table 2. Effect of nitrogen rate and fungicides on severity of target spot on flue-cured tobacco

	Nitrogen level (kg/ha)/ leaf area damage (%)	
Treatment	**58.8**	**85.7**
Control[x]	30 a[y]	23 a
Fungicides[z]	16 b	14 b

[x] Mean of two control plots per rep.
[y] Mean leaf area damage at the end of July. Values were geometric midpoint of Horsfall-Barratt ratings. Different letters within columns indicate significant differences at $P = 0.05$.
[z] Mean of eight fungicide treatments. No differences were observed among fungicide treatments, so results were combined for comparison to control plots.

of isolates from other hosts and locations will increase our understanding of relationships within this group of fungi, including host specificity.

Research on sources of resistance also is in progress. High levels of resistance to *T. cucumeris* have not been found in species of *Nicotiana,* but even moderate levels of partial resistance may greatly reduce losses during epidemics of the disease. Although *T. cucumeris* and tobacco often are used as a model system in studies of transgenic resistance, it is unlikely that transgenic tobacco will be used in the near future, if ever, in commercial tobacco production. Therefore, other management practices will be needed to minimize losses to this disease. These practices may include the use of biocontrol organisms to reduce inoculum production and leaf infections (3), and the use of soil amendments that reduce initial inoculum levels of *T. cucumeris* in soil.

The development of target spot as a new and important disease in tobacco provides another example of the dynamic nature of the interactions of soil microorganisms and the potential for a new or previously minor pathogen to become a major factor in crop production.

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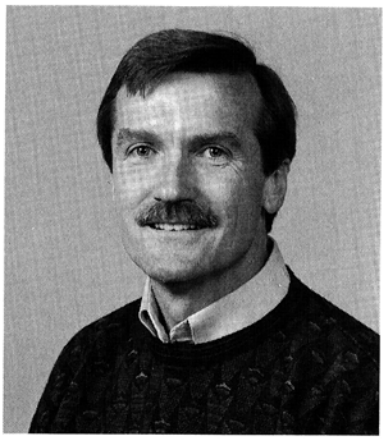

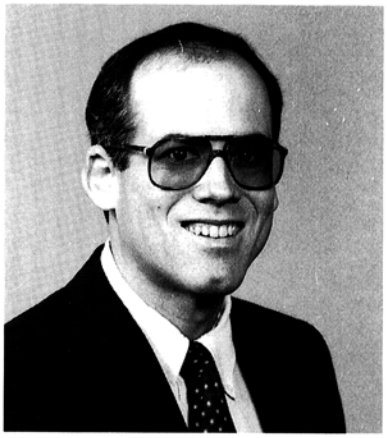

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