Donald H. Smith
Texas A&M University Plant Disease Research Station, Yoakum

Robert H. Littrell
University of Georgia Coastal Plain Experiment Station, Tifton

Management of Peanut Foliar Dis

Fig. 1. Symptoms of early leaf spot on adaxial leaf surface.

Fig. 2. Brown and black spots on abaxial leaflet surface are symptoms of early and late leaf spot, respectively.

The peanut (*Arachis hypogaea* L.) originated in South America and is cultivated in tropical, subtropical, and warm temperate regions of the world. India, the People's Republic of China, the United States, Senegal, Sudan, and Nigeria produce nearly 75% of the world peanut crop. On a global basis, the peanut is cultivated on approximately 19 million hectares, with an average pod yield of nearly 1,000 kg/ha (892 lb/A). Crop management ranges from highly primitive, labor-intensive practices in some countries to virtually total mechanization in the United States. Correspondingly, disease management ranges from minimal to highly intensive practices, with a variety of chemical and nonchemical strategies.

This article pertains to the peanut-producing areas of the United States, ie, the Southeast (Alabama, Florida, and Georgia), the Southwest (New Mexico, Oklahoma, and Texas), and the East (North Carolina and Virginia). All cultivars of peanuts currently grown in the United States are susceptible to the major fungal pathogens of peanut foliage. Although several cultivars are grown, a preponderance of the acreage is planted to Florunner. Hence, the peanut crop is extremely vulnerable to the genetic modification of existing pathogens and to the introduction of unreported pathogens.

Internationally, Cercospora and Cercosporidium leaf spots, caused by *Cercospora arachidicola* Hori and *Cercosporidium personatum* (Berk. & Curt.) Deighton, respectively, are the most widely distributed and destructive foliar diseases. Peanut rust, caused by *Puccinia arachidis* Speg., and web blotch, caused by *Phoma arachidicola* Marasas, Pauer, & Boerema, are also widely distributed but of lesser economic importance; however, the distribution of peanut rust has increased at an alarming rate during recent years. Numerous minor fungal pathogens also attack peanut foliage. Virus diseases of peanut foliage reduce yields in some areas of the world but are not discussed in this article.

Annual crop losses attributable to fungal diseases of peanut foliage range from less than 1% to more than 50%, depending on disease management. The most intensive use of fungicides to suppress peanut foliar diseases is in the southeastern United States. In Georgia alone, the annual cost of managing foliar diseases with fungicides is nearly $20 million. The increasing importance that growers attach to management of foliar diseases is demonstrated by the fact that Georgia growers made 2.8 fungicide applications in 1963 and 6.6 applications in 1976.

Identification of foliar diseases is a prerequisite to selecting and applying appropriate fungicides. In addition, the grower must understand the disease cycle in order to use various chemical and nonchemical measures at the most appropriate times.

Leaf Spot Identification and Disease Cycle

Cercospora arachidicola, the causal agent of early leaf spot, survives from season to season in crop residue. Although a perfect state (*Mycosphaerella arachidis* Deighton) has been described, we believe it is rare and that ascospores are not an important source of primary inoculum; conidia produced on crop residue are probably the most important source. The first macroscopic symptoms usually appear on the adaxial surface of the lower leaves (Fig. 1) within a month after planting, depending on environmental conditions, planting time, previous cropping history, and tillage methods. Germination and penetration of aerial plant parts occur during periods of high relative humidity, and macroscopic symptoms develop within 10–14 days when the air temperature is 21 C or higher. Conidia are usually produced on stromatic tissue of the adaxial leaf surface and tufts of conidia are visible with the aid of a ×10 lens. Peak spore release periods occur at the cessation of leaf wetness in the morning and at onset of rainfall. Wind, splashing rain, irrigation water, and insects have been implicated as agents of spore dispersal, but the distance spores spread from the site of production has not been determined. Secondary infection of all aboveground plant parts continues through the growing season, and nearly complete defoliation is common if fungicides are not applied.

The color of the lesion on the abaxial leaf surface is useful for distinguishing between *C. arachidicola* and *Cercosporidium personatum*, the causal agent of late leaf spot. Lesions of *C. arachidicola* are brown and those of *C. personatum* are black (Fig. 2). Field diagnosis of early leaf spot appears simple, but some phytotoxicity symptoms,

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eg, those induced by fentin hydroxide and some organophosphorus compounds, are very similar to early leaf spot symptoms. Incubation of leaves in a moist chamber for 48 hr at room temperature will induce sporulation if the causal agent is *C. arachidicola*.

The disease cycle of late leaf spot is similar to that of early leaf spot, but onset is usually 3 or 4 wk later in the growing season, provided both pathogens are present. Conidia of *C. personatum* are produced on the abaxial leaf surface, and tufts of conidia are easily observed with a ×10 lens (Fig. 3). Sporulation occurs on virtually all late leaf spot lesions, whereas some lesions of early leaf spot are nonsporulating. *C. personatum* produces haustoria and *C. arachidicola* does not.

Peanut Rust Identification and Disease Cycle

Puccinia arachidis, the causal agent of peanut rust, does not survive from season to season in the United States; airborne uredospores are introduced annually from other peanut-producing countries. Uredial pustules were observed in the United States in southern Texas during the first week of July 1971, a year in which rust reached epidemic proportions in Texas and was widely distributed in Georgia. A telial state of *P. arachidis* has been reported but has never been observed in the United States.

Diagnosis of *P. arachidis* is based on the observation of pustules on the abaxial leaf surface (Fig. 4). Flecks are visible 2 or 3 days before uredospores appear. McVey (8) inoculated 30-day-old peanut plants, placed them in a moist chamber for 16–24 hr, then returned them to a greenhouse where night temperatures were 22–25 C and day temperatures were

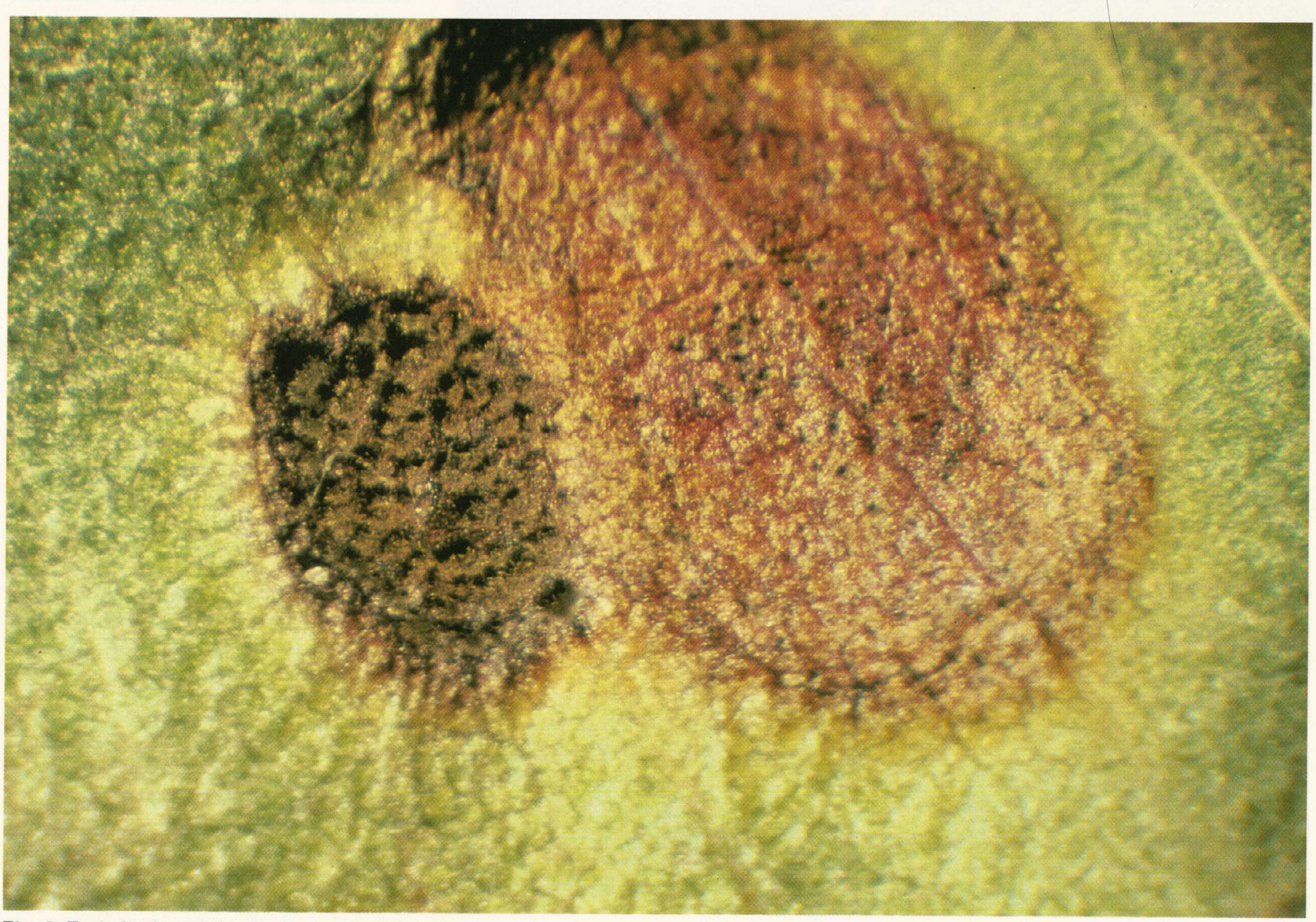

Fig. 3. Early leaf spot (brown lesion) and late leaf spot (black lesion covered with tufts of conidia) on abaxial leaflet surface.

30–43 C; pustules were produced in 10–12 days. Van Arsdel (12) indicated that the incubation period under field conditions was 10–15 days.

Web Blotch Identification and Disease Cycle

The web blotch fungus was first observed in the United States during the 1972 growing season and has subsequently been reported in several states, but significant crop losses attributable to web blotch have occurred only in Texas and Oklahoma. Moreover, its importance as a foliar pathogen of peanuts appears to be diminishing in the United States. We believe this is partially because the acreage of highly susceptible Spanish-type cultivars is decreasing while that of Florunner, a cultivar with moderate resistance to web blotch, is increasing.

Although the disease cycle of web blotch has not been thoroughly studied, we know the fungus survives from season to season on crop residue. The source of primary inoculum is unknown, but the fungus produces conidia, ascospores, and chlamydospores. Philley (10) demonstrated direct penetration of adaxial leaf surfaces and a subcuticular mode of colonization. He also found that the optimum temperature for growth of the fungus in vitro was 20 C. In greenhouse inoculations with mycelial/conidial suspensions, we observed symptoms within a week. Although we do not have supporting data, we believe conidia may constitute an important source of secondary inoculum during the growing season. Blamey et al (2) compared the seasonal progress of early leaf spot and web blotch and concluded that web blotch required longer leaf wetness periods and that optimum temperature requirements for infection by *P. arachidicola* were lower than those for *C. arachidicola*. Both web and blotch symptoms (Fig. 5) appear under field conditions, but web symptoms predominate in greenhouse studies. Web blotch symptoms do not usually appear on the abaxial surface until the leaf is moribund.

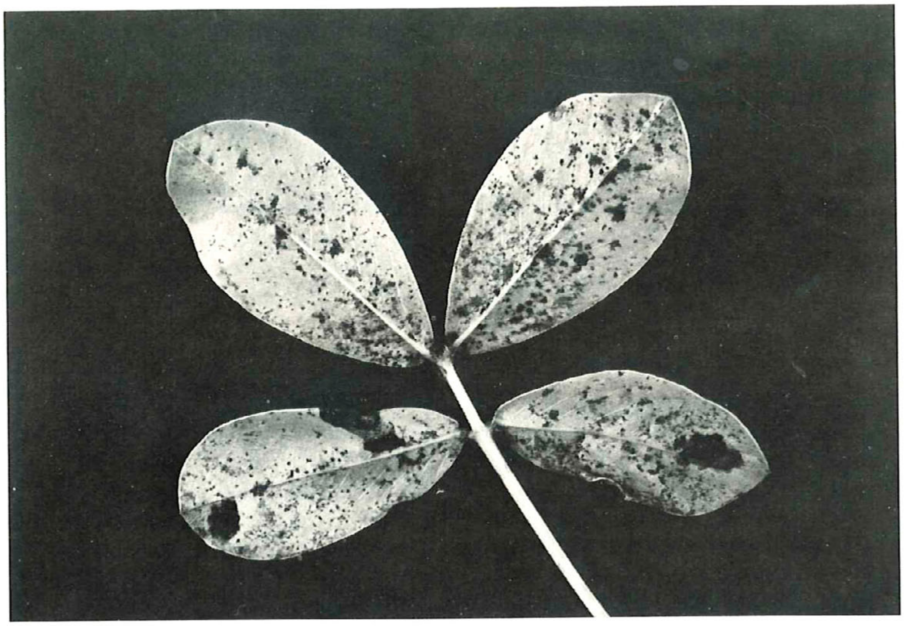

Fig. 4. Rust pustules on abaxial leaf surface.

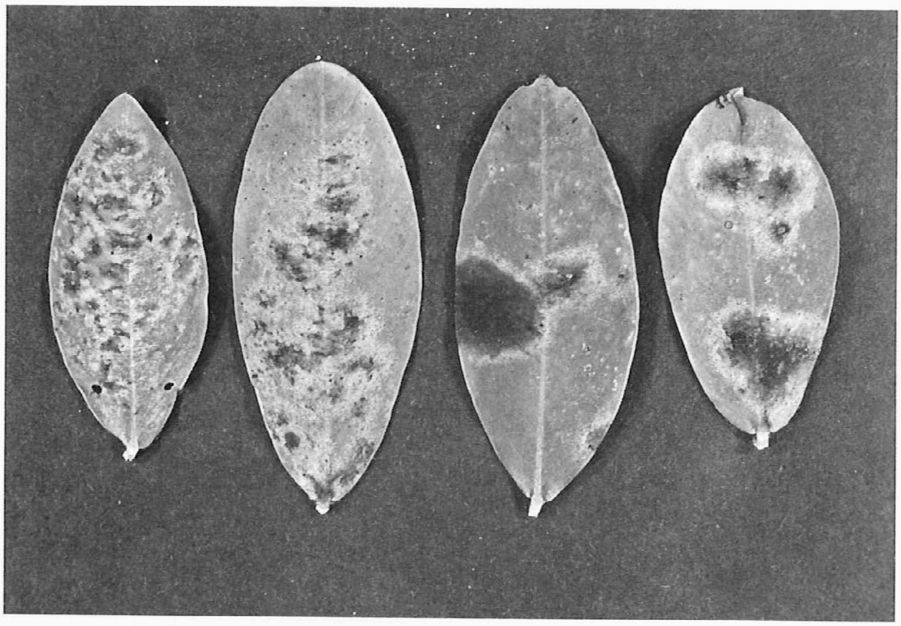

Fig. 5. Web blotch symptoms on adaxial surface of leaflets.

Disease Assessment Methods

Evaluation of fungicides for efficacy against foliar diseases of peanuts usually requires disease assessment, yield, and market-quality data. The "main stem" disease assessment method is useful but time-consuming. At least five main stems are cut in each replicate; then the number of leaflets, the number of infected leaflets (ie, with one or more lesions), and the number of abscinded leaflets are counted. Data are expressed as percentage of infected leaflets, percentage of abscinded leaflets, or a combination of infected and abscinded leaflets. Insect infestations, drought stress, nutritional status of the plants, and pesticide phytotoxicity can contribute to defoliation and interfere with this method.

Visual rating on a one-to-ten or one-to-five scale to estimate leaf area covered by symptoms and/or defoliation is less time-consuming than the main stem method. An estimate of leaf area covered by pustules is useful for assessing peanut rust. Early and late leaf spot may be assessed by the number of spots per leaf. Various other methods are also used.

Relationship Between Defoliation and Yield

Yield losses are usually greater when defoliation begins early in the growing season and progresses rapidly. Therefore, initiation of a fungicidal spray program early in the season, either before onset or at first appearance of symptoms, is crucial to preventing substantial crop losses. Effective season-long disease management provides insurance against losses that result when foliar diseases reach epidemic levels, especially when harvesting is delayed because of inclement weather, or when other unforseen circumstances arise.

Backman et al (1), after a multiyear analysis of data from a large number of small plots, concluded that losses from leaf spot amounted to 15.7 kg/ha (14 lb/A) for each percent increase in leaf spot infection and that losses were even greater when infection exceeded 40%. Yield losses result from both reduced number and size of pods, but reduced

Fig. 6. (Left) Sprayed and (right) unsprayed peanut fields.

number probably accounts for a majority of the loss.

Fungicides Used

Before 1971, dust formulations of copper, sulfur, and copper plus sulfur were routinely used to suppress peanut foliar diseases in the United States, and certain other fungicides were applied as sprays. After the introduction of benomyl, chlorothalonil, and fentin hydroxide, however, there was a rapid change from dusting to spraying. The differences between a field sprayed with multiple applications of a fungicide and an unsprayed field are striking (Fig. 6).

Chlorothalonil, one of the most extensively used fungicides, is effective against early and late leaf spot, rust, and web blotch. Before tolerant strains developed in the southeastern United States, benomyl was highly effective against early and late leaf spot, though ineffective against web blotch or rust. Tank mixes of benomyl and mancozeb are used in Oklahoma and Texas because of effectiveness against rust, web blotch, and both leaf spot diseases. Fentin hydroxide is effective against early and late leaf spot, but its phytotoxicity, either when used alone or when mixed with certain other compounds such as toxaphene, has reduced its level of acceptance by peanut growers. A flowable formulation of captafol is effective against both early and late leaf spot. Various formulations, especially flowable products containing copper, sulfur, or copper plus sulfur, are marketed under a number of trade names in the peanut-producing areas of the United States.

Increased pod yields attributable to effective management of foliar diseases has been demonstrated by various workers in several states. For example, Backman et al (1) evaluated benomyl, chlorothalonil, copper hydroxide plus sulfur, and fentin hydroxide during four growing seasons. They found that mean pod weights from sprayed plots ranged from 782.4 to 1,458.3 kg/ha (698 to 1,301 lb/A)higher than those from unsprayed plots. In addition, the mean percentage of defoliation shortly before harvest over 4 yr ranged from 17.5 to 30.3% in sprayed plots, compared with a 4-yr mean of 59.3% in unsprayed plots.

Tank mixes of certain organic fungicides and flowable sulfur are used by growers in some areas of the United States, the rationale being that sulfur may improve disease control, act as a nutrient, and suppress mites. Laboratory tests have shown that a mixture of sulfur and another fungicide reduces sporulation of *C. arachidicola* and *C. personatum*. A tank mix of fentin hydroxide and a flowable sulfur is recommended by the extension service in Georgia. Although statistically significant increases in yield, disease suppression, and market quality are not always evident, multiyear trends indicate that addition of sulfur is justifiable on a cost/benefit basis.

Specific recommendations about rates, scheduling of applications, livestock feeding restrictions, mite suppression, sequential application of different kinds of fungicides, disease management approaches in irrigated and dryland areas, and subtle differences in performance arising from local conditions are published by cooperative extension service plant pathologists in each peanut-producing state. A partial list of currently registered fungicides is presented in Table 1.

Application schedules. The first fungicide application is usually made either before or at the first appearance of symptoms, ie, 30–40 days after planting, with subsequent applications at intervals of 10–14 days until 2 or 3 wk before the anticipated harvest. Thus, foliage is usually sprayed five to seven times during the growing season. The initial and final applications of the season and the total number of applications differ widely among production areas and among growing seasons in a particular locale because of variable environmental conditions.

A disease-forecasting system based on duration of leaf wetness and minimum daily temperatures was developed, evaluated, and computerized in Georgia. Because of the availability of fungicides that provide satisfactory disease suppression when applied on a 10–14-day schedule, however, the forecasting system has not been accepted by peanut producers.

Application methods. Fungicides are applied with various kinds of tractor-propelled sprayers, fixed-wing aircraft, helicopters, and sprinkler irrigation systems. With fixed-wing aircraft and tractor-propelled sprayers, water delivery rates range from 3 to 25 gal per acre. In some peanut-producing areas, a combination of these application methods is used during a growing season. Generally, early-season applications are made with a tractor-propelled sprayer. Later, aircraft are advantageous because of the possibility of plant injury by tractor wheels. In addition, avoiding late-season tractor use reduces soil compaction and lessens the probability of predisposing plants to infection by soilborne pathogens.

Not only can satisfactory management of foliar diseases with fungicides be obtained with fixed-wing aircraft, but aerial application is the only satisfactory method during rainy weather. Water delivery rate, swath width, wind speed, relative humidity, and nozzle type and arrangement are factors to be considered.

With ground application equipment, water delivery rates ranging from 46.8 to 233.8 L/A (5 to 25 gal/A) are satisfactory. Hollow cone nozzles (three per row) are set at a height that facilitates uniform coverage of peanut foliage. A pump pressure of 60–75 psi provides sufficient coverage.

The use of sprinkler irrigation systems for applying fungicides is a recent development in management of peanut foliar diseases. The fungicide is introduced into the water during the first 15–30 min of the irrigation period. Although this is convenient for the grower, the comparative efficacy of injecting a fungicide at the beginning or near the end of the irrigation period has not been thoroughly studied. With center pivot irrigation systems,

Table 1. Partial list of fungicides that have been or are being used for management of foliar diseases of peanuts[a]

Common name	Chemical name
Benomyl	methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate
Captafol	*cis*-N-[(1,1,2,2-tetrachloroethyl)thio]-4-cyclohexene-1,2-dicarboximide
Chlorothalonil	tetrachloroisophthalonitrile
Copper ammonium carbonate	copper ammonium carbonate
Copper hydroxide	copper hydroxide
Fentin hydroxide	triphenyltin hydroxide
Mancozeb	zinc ion and manganese ethylenebisdithiocarbamate 80%, a coordination product of manganese 16%, zinc 2%, and ethylenebisdithiocarbamate 62%
Maneb	manganese ethylenebisdithiocarbamate
Sulfur	elemental sulfur

[a]This should not be construed as a list of recommended fungicides. Disease management recommendations are published annually by extension plant pathologists in each peanut-producing state.

continuous injection of the fungicide into the irrigation water is necessary. The effectiveness of irrigation water as a medium for applying fungicides depends on uniformity of water distribution, which may be altered by nozzle height and type, water pressure, and wind speed and direction.

Regardless of the method of application, it is essential that the fungicide is applied uniformly to the peanut foliage.

Benomyl-Tolerant Strains of Leaf Spot Pathogens

Because of its effectiveness against early and late leaf spot, benomyl was quickly accepted and extensively used by peanut growers in the southeastern United States for 3 yr. During the third year (1973), the effectiveness of benomyl was obviously diminishing. Plant pathologists began to monitor fields with histories of extensive benomyl use and to check seasonal progress of benomyl-tolerant strains in fungicide evaluation tests. Benomyl-tolerant strains of *C. arachidicola* and *C. personatum* were demonstrated by field observations and by the use of a benomyl-amended agar bioassay. Benomyl-tolerant strains of *C. arachidicola* were as virulent and survived as readily as benomyl-sensitive strains. Benomyl was withdrawn from the recommended list of fungicides, and the use of alternative protectant fungicides was suggested. Adoption of these recommendations in the 1974 growing season probably averted substantial crop losses. This experience illustrates the risks involved with extensive local use of one systemic fungicide and the value of monitoring to detect the onset of fungicide-tolerant strains. Continued monitoring can also be used to study the feasibility of reintroducing benomyl if the population of benomyl-tolerant strains subsides.

Because of ineffectiveness against rust and web blotch, benomyl alone was not used extensively in Oklahoma and Texas. Rather, benomyl-mancozeb tank mixtures and other fungicides were used. Consequently, no benomyl tolerance problems of practical importance have arisen in the peanut-producing areas of Texas and Oklahoma. The high incidence of benomyl-tolerant strains at one research station in Texas was attributed to selection pressure resulting from application of benomyl alone in small-plot field tests for more than a decade.

Nontarget Effects of Fungicides

Fungicides against specific pathogens also have effects on nontarget pests. For example, Backman et al (1) observed a consistently higher level of southern blight (*Sclerotium rolfsii* Sacc.) on Florunner foliage sprayed with benomyl than on unsprayed plants. Porter (11) found that Sclerotinia blight (*Sclerotinia sclerotiorum*) was more severe on Virginia 61R peanuts sprayed with chlorothalonil than on unsprayed plants. Campbell (3) reported that the use of either fentin hydroxide or copper ammonium carbonate to control foliar diseases suppressed populations of the two-spotted spider mite.

SADH and Disease Management

SADH (succinic acid 2,2-dimethylhydroxide) is the only growth regulator approved for use on peanuts and consistently results in compact plants because of shortened internodes. Also, rows are readily discernible at harvest. Initially, SADH was suggested as an aid to foliar disease management because more thorough coverage with fungicides could be achieved on compact plants. However, application of SADH alone or mixed with foliar fungicides has not improved the performance of fungicides.

Resurgence of Late Leaf Spot

Since 1976, there has been a gradual shift from a predominantly early leaf spot population to a substantial incidence of late leaf spot in the southeastern United States. The reason is not clear, but some plausible explanations are worth considering. First, later harvest of the peanut crop in recent years may have contributed to an increased inoculum potential of the late leaf spot fungus. Second, the use of highly effective fungicides for early leaf spot may have altered the leaf surface microflora, thereby providing a competitive advantage for the late leaf spot fungus. Third, the extensive cultivation of one susceptible cultivar (Florunner) in Alabama, Florida, and Georgia may have favored development of late leaf spot. Other possible contributing factors include nutrient status of the crop, drought stress, previous crop sequence, irrigation practices, and fungicide application schedules and methods. Obviously, incomplete knowledge about the ecology and epidemiology of early and late leaf spot precludes a satisfactory explanation of the long-term population dynamics of these two pathogens.

Resurgence of late leaf spot is not a new phenomenon. During a 5-yr period in the late 1920s and early 1930s in Georgia, Woodruff (13) reported that early leaf spot occurred annually and that late leaf spot contributed to severe defoliation in 2 yr. A few years later, again in Georgia, Jenkins (7) reported that early leaf spot reached epidemic proportions in August and early September, whereas late leaf spot was most destructive from September through harvest. Based on our experience, late leaf spot was of minor importance in Georgia from 1967 to 1976. In 1947, Miller (9) collected peanut leaves from 10 southern states and reported that 82% of the lesions were caused by the early leaf spot fungus. He also noted that in Virginia, late leaf spot epidemics occurred about once every 4 yr and early leaf spot epidemics occurred annually. Hemingway (6) reported that late leaf spot increased at a faster rate than did early leaf spot. During the 1979 growing season, the relative proportion of early and late leaf spot was monitored in a small-plot field test in Georgia. Late leaf spot was not observed until the second week in July, but by the end of the season more than 99% of the lesions were caused by the late leaf spot fungus.

Agronomic Practices

Several crop management practices reduce the amount of primary inoculum. Burial of crop residue with a moldboard plow to a depth of at least 15.2 cm (6 in.) reduces the amount of inoculum and is especially important when crop rotation is not part of the management program. Crop rotation is a very effective way to reduce the inoculum potential of both soilborne fungal and nematode pathogens of peanuts. When peanuts are planted on land that has not been planted to peanuts for one or more years, the onset and progress rate of early and late leaf spot are delayed, as contrasted with continuous peanut culture. We believe the inoculum essential for the onset of early and late leaf spot epidemics is either in the field where peanuts are planted or in nearby peanut fields, ie, within a mile. Dissemination of *C. arachidicola* conidia to a height of 2.7 m (9 ft) has been demonstrated by using container-grown peanut plants as spore traps.

In the peanut-producing area of southern Texas, early planting avoids rust epidemics. For example, peanuts are planted intermittently from early March until mid-July. Because peanut rust pustules have never been observed before the first week in July, a crop planted in early March is usually exposed to rust for less than a month before harvest. This brief exposure precludes crop losses attributable to peanut rust. In addition, fewer applications of fungicides are required to manage early and late leaf spot when peanuts are planted during early March. Because inoculum concentration increases as the season progresses, foliar disease is managed to some degree by planting successively later crops in fields not adjacent to previously planted peanut fields and not located in the direction of prevailing winds. The direction of the prevailing wind is extremely relevant to development of peanut rust epidemics, because uredospores are adapted to long-distance dispersal, ie, hundreds of kilometers (miles).

Such environmental modifications as irrigation, skip row patterns, in-row spacing, row orientation, and cultivars with a canopy architecture that shortens the leaf wetness period may be useful in delaying epidemic progress of foliar diseases. Chevaugeon (4) found an inverse relationship between in-row spacing of plants and intensity of late leaf spot, and Farrell et al (5) reported the same relationship with both early and late leaf spot. In both cases, disease severity increased as in-row spacing decreased.

Future Trends in Management of Foliar Diseases

Breeding for resistance of foliar diseases of peanuts is under way at several locations in the United States and in other countries, but release of agronomically acceptable foliar disease-resistant cultivars within the next decade is unlikely. In the meantime, the prospects for refining existing chemical and nonchemical strategies are good. In irrigated production areas, applications of fungicides with sprinkler irrigation systems are expected to increase and the use of aerial and ground application equipment to decrease. More attention will be given to developing spray schedules with minimal effects on nontarget organisms and use patterns that delay appearance of fungicide-tolerant strains of foliar pathogens. As a result of the growing energy problem and the increasing cost of production, it is quite probable that strategies for suppressing foliar diseases will be vastly different by the beginning of the 21st century.

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Donald H. Smith

Dr. Smith is associate professor at the Texas A&M University Plant Disease Research Station, Yoakum, where he conducts research on epidemiology and control of foliar diseases of peanuts. He received his Ph.D. in plant pathology at Pennsylvania State University in 1966, served as a Kettering Foundation postdoctoral teaching fellow at Albion College, Albion, Michigan, from 1966 to 1967, and was assistant professor at the University of Georgia Agricultural Experiment Station at Experiment from 1967 to 1973.

Robert H. Littrell

Dr. Littrell is associate professor and head of the Plant Pathology Department at the University of Georgia Coastal Plain Experiment Station, Tifton. After receiving a Ph.D. from Clemson University in 1964, he worked with the Florida Agricultural Experiment Station at Bradenton on diseases of ornamental plants. Since joining the faculty at the University of Georgia, he has been involved in research on diseases of small grain and, more recently, has been responsible for research on control of foliar diseases of peanuts and pecans.