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Gray Leaf Spot of Corn: A Disease

Gray leaf spot of corn has increased in prevalence and severity throughout the southeastern and mid-Atlantic corn-growing areas in recent years. The causal fungus, *Cercospora zeae-maydis* Tehon & Daniels, has been considered a minor pathogen throughout its history, nearly 60 years since it was first described from Alexander County, Illinois (23). Although occasionally damaging (12,13), until recent years the disease has appeared so late in the season that yield loss is negligible. The increase in severity has accompanied an increase in the practice of minimum tillage of corn, especially where corn follows corn as the primary crop. Current reports indicate a growing concern by farmers, plant pathologists, and breeders over the potential of gray leaf spot disease of corn.

The Disease

Symptoms. Mature leaf lesions are linear-rectangular and delimited in breadth by major veins (Fig. 1), a characteristic of *Cercospora* infection in graminaceous hosts. The lesions are tan until dense sporulation under humid conditions produces a grayish cast; hence the common name. Lesions develop slowly in comparison with those caused by most other foliar pathogens, requiring 2–3 weeks for full expansion. Mature lesions are 1–6 cm long and 2–4 mm wide, width being determined by interveinal breadth. If adjacent interveinal areas are infected, two single lesions may appear as one broad one.

Early infections are not distinctive from those caused by some other pathogens, except for a yellow halo visible when pinpoint lesions are observed by transmitted light. Within 2 weeks, such lesions gradually elongate, appearing as streaks before developing their dark grayish brown rectangular shape. Gray leaf spot can be readily distinguished from lesions of southern corn leaf blight by viewing through transmitted sunlight. Gray leaf spot lesions are completely opaque, well-defined dark rectangles, whereas southern leaf blight lesions transmit light and are light reddish brown without distinctive borders.

Stalk lesions are common in severely infected fields, resulting from spread of the fungus through leaf sheaths, especially just below the sheath-blade juncture. Stalk deterioration is a serious aspect of the disease that results when leaf lesions cover most of the photosynthetic surface and extreme water loss occurs. Stalks become so weakened that lodging precludes mechanical harvest. Such severe effects result when leaf lesions appear in early July, as often occurs when infested debris from the previous crop remains in the field.

History. According to Chupp in his 1953 *Cercospora* monograph (7), *C. zeae-maydis* has been reported from Peru, Colombia, Brazil, Trinidad, South Carolina, Tennessee, Kentucky, and Illinois. It also has been reported from Costa Rica (6), Virginia (19,21), and North Carolina (16). We have obtained specimens from Missouri, Iowa, Mexico, Central America, and Venezuela. Not until 1972 and subsequent seasons, however, have major crop losses been observed consistently in the United States.

Hyre's report (12) of damage in Kentucky and eastern Tennessee in 1943 was the only indication of the potential severity of gray leaf spot until Roane observed the disease near Blacksburg in southwestern Virginia in 1949, primarily in river bottom fields (19). In 1950 it became severe by September 1, causing complete destruction of leaves, and was observed at elevations as high as 1,000 m. The unusual damage that year by this relatively minor disease was attributed to its early appearance (July 1) and to the absence of northern leaf blight (*Exserohilum turcicum* = *Helminthosporium turcicum*), which when present early in the season destroyed leaves before the onset of gray leaf spot.

Severe damage in 1962 to a 12-ha field in South Carolina (80–90% leaf area affected) apparently was an isolated instance of the specific microclimate being ideal for gray leaf spot development (13). Other fields of the same variety along the Whitewater River valley showed insignificant numbers of lesions. Leonard (16) reported gray leaf spot to be the most destructive disease of corn in the mountainous areas of North Carolina in 1973, with a striking increase in the number of fields affected.

The movement of gray leaf spot in Virginia from the river bottomlands west of the Blue Ridge Mountains across the ridge to Virginia Beach (16 km from the Atlantic Ocean) was noted by Roane et al in 1973 (21), where the disease occurred in an intensive corn-production area. At that time, they anticipated that gray leaf spot probably would become more widespread and destructive as no-till cultural practices increased. In the areas of our observations in Virginia, 250 km north of Blacksburg, gray leaf spot occurred early enough in 1972 to cause severe damage to fields west of the Blue Ridge Mountains. Similar damage to fields in that area occurred in 1973, in all cases associated with no-till cultural practices. In some fields in 1973 and 1974, losses approached 80–100% because stalk deterioration following desiccation of leaves resulted in such severe lodging that corn could not be harvested mechanically. In 1979 Hilty et al (11) reported increasing prevalence and severity of gray leaf spot in Tennessee from 1973 through 1978, in all cases limited to fields in which minimum tillage had been practiced.

Not until 1976 did gray leaf spot move

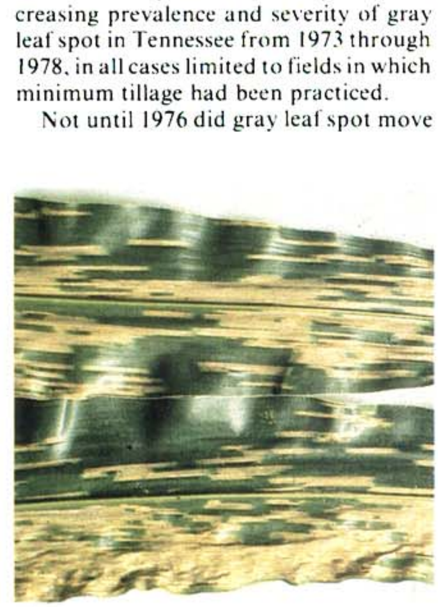

Fig. 1. Typical leaf lesions of *Cercospora zeae-maydis*.

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on the Move

significantly northward, apparently "jumping" the 100 miles of cattle and horse country (with little corn) between north central Virginia and the tri-state juncture of Virginia, West Virginia, and Maryland. During the intervening years, we had searched unsuccessfully for lesions of gray leaf spot in Maryland. Since its arrival in Maryland and Jefferson County, West Virginia, in 1976, the disease has been moving steadily northward, causing appreciable damage as far north as Franklin County, Pennsylvania, by 1980 (1) and 100–130 km farther north by 1981 (2). Gray leaf spot was collected east of Chesapeake Bay for the first time in 1981 (Kennedyville, Maryland, by T. Ishler).

Epidemiology. The potential for damage by gray leaf spot disease first came to our attention in September 1973, when we received leaf specimens from Edinburg, Virginia, for identification. The leaves, 90% of their surface covered with the rectangular lesions characteristic of *C. zeae-maydis*, were typical of the severely infected corn plants in minimum-tillage fields throughout the area (14). We visited these fields during the following January to determine whether no-till cultural practices were contributing to the recent increase in severity of this disease. We gathered abundant pieces of leaf and ear shuck debris, the leaf debris bearing rectangular silhouettes of gray leaf spot lesions (Fig. 2). When these lesions were incubated in moist chambers, conidiophores bearing conidia of *C. zeae-maydis* arose from about 20% of the substomatal stromata of the fungus. Ear shuck debris also showed lesions bearing conidiophore fascicles. In studies of overwintering of *C. zeae-maydis* in North Carolina, Payne and Waldron (18) collected conidia in the air above corn debris as early as June 19.

Collections of debris in April yielded similar results, thus providing circumstantial evidence that inoculum is available for early infection of corn planted by no-till methods. In the same fields on July 19, we observed fully expanded lesions of gray leaf spot on lower leaves. In mid-September, all leaves were severely blighted and desiccated (Fig. 3). Neighboring fields planted by conventional tillage, and from which corn plants of the previous crop had been removed for silage, showed far fewer lesions in July, and buildup of the disease was estimated to be delayed by 3 weeks. This delay in onset of the epidemic prevented serious stalk deterioration, and yields were good despite abundant leaf lesions.

The pattern of meteorological conditions associated with severe damage by gray leaf spot disease has not been fully elucidated. High rainfall in the spring is not necessarily conducive to early onset of the disease. If infection does appear early on lower leaves, it may become "dormant" during a dry summer, then burst out in severe proportions with muggy overcast and rainy days in the later summer and fall. For example, 1974 and 1976 were characterized by early rains, summer drought, fall rains, and severe gray leaf spot damage. In 1975, rain was plentiful in both spring and summer, but there was little gray leaf spot disease at harvest. We cannot explain the low amount of gray leaf spot following the wet summer in 1975, and we have no basis to postulate that a period of dry weather in midsummer enhances the disease. We can only infer that a dry summer does not ensure low damage by gray leaf spot. It is probably as explained by Higgins (10) for *C. bolleana* (Thüm.) Speg., that "stromata are formed and can 'sit' indefinitely during a dry period."

C. zeae-maydis seems to "bloom" suddenly after late summer rains and overcast days of high relative humidity, compared with the slowness of full lesion expression after initial infection in the spring. Apparently, the substomatal stromata are already established and need only brief exposure to moisture to produce condiophores and conidia rapidly. The propensity of *C. zeae-maydis* to flourish at higher elevations, as reported by Leonard in North Carolina (16) and as we have observed in Central American highlands, could be attributed to the frequent "hanging" of mists before and after dew formation because of wide diurnal fluctuations of temperature. These mists effectively extend dew periods and are ideal for gray leaf spot development.

Over most of the eastern seaboard in 1980, more than 50% of the days were overcast during the growing season, with consequent high relative humidity and severe gray leaf spot. Relative humidity is probably more critical than any other single factor except dew in promoting severity of disease development. Beckman et al (5) measured gray leaf spot severity in relation to temperature, relative humidity, and rainfall and concluded that high temperature and low rainfall are not range-limiting factors. They suggested that the occurrence of severe gray leaf spot after full canopy development may indicate the importance of relative humidity. Rupe et al in Kentucky (22)

Fig. 2. Winter silhouettes of *C. zeae-maydis* lesions on leaf debris.

Fig. 3. Gray leaf spot disease in mid-September at Edinburg, Virginia.

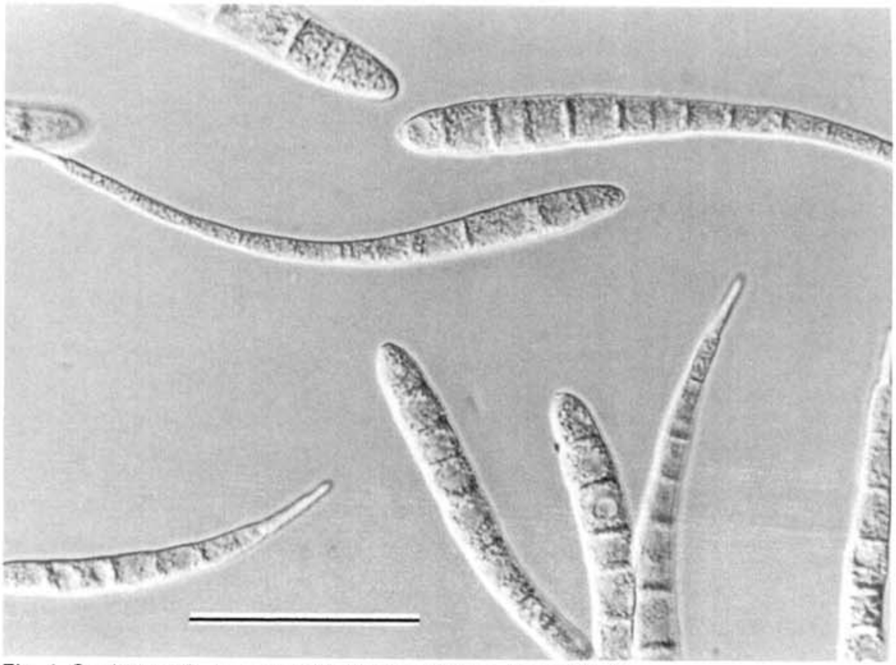

Fig. 4. Conidia of *C. zeae-maydis* from leaf lesion. Bar = 50 µm.

found disease progress and diurnal aerial spore content to be influenced by physiologic age of the plant and by the environment. The disease was restricted to areas with at least 12–13 hours of relative humidity over 90% and 11–23 hours of leaf wetness daily. However, their observations that initial symptoms appeared at anthesis and were delayed by 2–3 weeks for every 3-week delay in planting are somewhat divergent from our findings, viz., that initial symptoms may appear considerably before anthesis and that earlier maturing and/or planted cultivars are more likely to escape severe damage.

Until recently, severe gray leaf spot in Maryland had been limited to areas with poor air drainage, eg, low spots in fields or fields bordered by trees or streams and especially no-till fields in which the disease had been present the preceding season. In 1981, however, gray leaf spot in some parts of Maryland apparently was not limited by any of these factors. For the first time, it was severe in Washington County in well-aerated fields and even in some conventionally plowed fields. This suggests that inoculum has become so abundant in these areas that it spreads readily from its origins in no-till and/or poorly aerated fields.

The Pathogen

Morphology. *C. zeae-maydis* represents the section of the genus having relatively broad and large conidia. Mature conidia are 70–180 µm long and 5–6 µm wide at the base, tapering to 2–3 µm at the apex (Fig. 4). As with most fungi, however, these dimensions, as well as those of conidiophores, vary considerably with the conditions under which these structures are formed, especially with respect to natural or artificial substrate, moisture, light, and age of the stroma.

Conidia are hyaline, have 6–10 septa, and germinate readily (within 3 hours) from any cell, three or four germ tubes typically emerging during the infection process on corn leaves. As many as 10 conidia are borne sympodially on dark, geniculate conidiophores that emerge in clusters of up to 20 from stromatic tissue formed in substomatal chambers. Conidiophores bearing conidia can be found emerging from all stomate-forming corn tissues: leaf blades (Fig. 5), sheaths, and husks. Spermogonia bearing spermatia develop in mature lesions from the stromatic cells in each stomatal cavity, within 3 days of incubation in a moist chamber or in the field during late summer or early fall as conditions of high humidity and/or rainfall promote their development. We have observed a perfect state, a species of *Mycosphaerella*, in overwintered field specimens (15). The rarity of its occurrence and maturation, however, indicates it is not a source of inoculum in the spring.

Inoculation studies. Having observed the devastating potential of gray leaf spot disease manifested in cornfields of north central Virginia in 1973, we began immediate testing of some 100 lines from state experiment stations and commercial hybrids from private companies, using artificial inoculation to determine whether there were discernible differences in susceptibility among available germ plasm. We were understandably frustrated when no lesions developed following procedures that would have yielded excellent infection by other common fungal foliar pathogens. Similar failures to obtain infection with this pathogen were soon reported by other workers (9,16).

The classic works of Higgins, notably his studies on *C. bolleana* (10), gave us the clue that patience is required in obtaining artificial infection with *Cercospora* species. We experimented with various methods of providing the essential moisture, including up to 96 hours of incubation in a "dew" chamber (17), subsequent incubation under a plastic tent with manually controlled periodic misting through an atomizer, and exposure on greenhouse benches with an automatic misting system, using various combinations of time for each phase. All led to infection after the required amount of time: 18 days for lesions of the size shown in Figure 6.

In addition to the patience needed by the observer, *Cercospora* does require somewhat longer leaf wetness periods and perhaps higher relative humidity for optimal symptom expression than do many other fungal pathogens. Our facilities, however, have not been amenable to working out the precise minimal requirements for infection and disease development. Recent studies by Beckman and Payne (3,4) provide histological evidence that sustained periods of high relative humidity are more important for the development of *C. zeae-maydis* than plant or leaf age. They observed stomatal tropism of conidial germ tubes under high relative humidity but not in the presence of free water, though growth was extensive.

Minimal requirements for relative humidity and free moisture are not precisely known, but an excellent system for artificial inoculation in a greenhouse reveals varietal differences in response of plants at all stages of development beyond the four-leaf stage. Twelve rows of corn are grown in each of two greenhouse beds, three hills per row, three plants per hill, space permitting either two or three replicates of twelve or eight lines, respectively. Plants are inoculated at any stage beyond the fourth leaf by spraying with a conidial suspension prepared by dislodging conidia from 5-day flood cultures on V-8 juice agar in 300-ml Erlenmeyer flasks by agitation with sterile distilled water and glass beads. Distilled water is added to make 2 L of suspension with conidial concentration of 2×10^4/ml. The air-conditioned greenhouse is equipped with two steam nozzles at the height of 3 m; these are turned on at the time of inoculation and left steaming overnight, resulting in an incubation period of 12–15 hours at 28–29 C and 100% relative humidity. The wafting steam deposits a layer of moisture effectively simulating "dew." Symptom development is identical with that in nature; the lesions in Figure 1 are from greenhouse inoculations. Differences in varietal reaction are quite evident and correspond to field reactions.

Cultural behavior. *C. zeae-maydis* grows on agar media with the compact, slow-growing colony type characteristic of the genus. Growth habit ranges from black, densely sporulating cushionlike colonies to white, cottony mycelial growth, one type often "mutating" from the other (Fig. 7). Intermediate types include gray, moderately sporulating colonies often with pink, red, or purple pigment, depending on the substrate, due to formation of cercosporin crystals (Fig. 8). Cercosporin is a photoactivated phytotoxin produced by many species of *Cercospora* (8).

Spermogonia, bodies containing spermatia, the presumed male gametes of the sexual state of the pathogen (15), are often formed in culture. One of our strains even produced these structures almost exclusive of conidia or aerial mycelium.

C. zeae-maydis sporulates most abundantly on V-8 juice agar at 25–28 C under alternating light and dark regimes; the number of hours of each or the quality/intensity of light appears not to be critical. Conidiophores are formed in both light and dark, but a dark period is essential for conidial initiation. To produce conidia for use in greenhouse inoculations, we maintain a highly sporulating strain by constant vigilance against intrusion by mycelial components. Through frequent selection and flood transfer via sterile distilled water and glass beads, we have maintained the same highly sporulating strain for 8 years (Fig. 8); the strain was originally isolated from Missouri specimens received from O. Calvert.

Discussion

What are the prospects for reducing or eliminating the threat of gray leaf spot as an increasingly serious disease of corn in certain areas of the United States? Each of the most traditional concepts for cultural and genetic control of crop diseases—rotation, sanitation, and resistant cultivars—can play a major role in controlling gray leaf spot.

Rotation. Rotation of crops is a promising alternative for two reasons: 1) In our experience, *C. zeae-maydis* does not survive in diseased corn debris in the field beyond 1 year and 2) in contrast to such pathogens as species of *Gibberella*, for example, *C. zeae-maydis* is pathogenic only to corn among crop species. There are many areas along the eastern seaboard where corn has been in continuous production for some 200 years, probably for good reason. However, in view of current disease and pest threats specific to corn—new races of northern leaf blight, anthracnose, Diplodia stalk and ear rots, Kabatiella eyespot, gray leaf spot, and European corn borer—more frequent rotation of crops to include immune hosts, such as soybeans, wheat, rye, barley, oats, or hay crops, should be considered for these areas.

Sanitation. The importance of sanitary measures in reducing pathogen propagules from one season to the next has been emphasized repeatedly throughout our training in plant pathology. How can we now so readily ignore this important aspect in our recommendations for disease control when the consequences are so obvious? The relationship during recent years between increased prevalence and severity of gray leaf spot and the progressively greater acreages of corn grown under minimum tillage has been noted consistently in reports released or published about this disease since 1974 (1,2,9,11,14,20,21).

We recognize the unquestioned positive benefits of minimum tillage under appropriate circumstances, especially with respect to energy and soil conservation. But our observations and those of our colleagues cited above, and of farmers already affected adversely by gray leaf spot disease, strongly suggest that the practice of minimum tillage must be evaluated carefully with regard to the balance between the assets of conservation of energy and soil and the liabilities of potential disease and insect problems. In areas where gray leaf spot was severe the previous season, for example, fields should be plowed, turning under as much of the plant debris as possible, before the new crop of corn is planted. Removing the previous crop for silage and planting a winter cover crop considerably reduces the threat of early gray leaf spot infection.

Resistant cultivars. How near are we to having cultivars resistant or tolerant to

Fig. 5. Conidiophores emerging from stomata in leaf lesion.

Fig. 6. Lesions of *C. zeae-maydis* 18 days after artificial inoculation.

Fig. 7. Sporulating sector in mycelial colony on V-8 juice agar.

Fig. 8. Sporulating strain maintained 8 years. Red pigment is cercosporin, a phytotoxin produced in the presence of light.

Fig. 9. Fleck-type reaction of a resistant inbred (left) and reaction of a susceptible line (right).

gray leaf spot? There are a number of sources of resistant germ plasm, ranging from immunity (no lesions) through high resistance (fleck-type lesions) down to tolerance (slowly developing or relatively few lesions), among the experimental lines and commercial hybrids we have tested in the greenhouse or observed in field plots. The striking contrast between the fleck-type reaction of a highly resistant inbred and the reaction of a typical susceptible line in a field test is shown in Figure 9. The most nearly immune reaction we have observed in greenhouse tests was that of a tropical variety from France, received from F. Kaan. We have observed as much as 1 week difference in time of full symptom expression among commercial hybrids, slow development being a desirable quality that might be compared with "slow rusting" in small grain response to rust diseases. The longer it takes for lesions to mature, of course, the longer will be the time required for production of secondary inocula for disease spread.

The immune or high "fleck" resistance has not yet been incorporated into a commercial hybrid. The inbred or tropical lines so far showing such strong resistance lack agronomic characters desirable for use in breeding. Such "high"-type resistance may also depend on a single gene that, as has happened in other host-parasite relations, could be overcome by a single-gene mutation in the pathogen. For this reason, the modern concept of breeding for disease resistance looks more favorably toward a broader, polygenic basis—which, although usually not as high a degree of resistance, may be more stable.

Roane et al (20,21) reported results of cultivar trials in Virginia in which they rated lines for reaction to natural infection by *C. zeae-maydis*, as have Hilty et al in Tennessee (11) and Ayers (and cooperators) in Pennsylvania (1). We have inoculated similar trials artificially in Maryland for evaluation of commercial inbreds and hybrids. Roane and coworkers found poor resistance among 49 hybrids grown in an area heavily littered with maize residue where gray leaf spot had been severe the previous season (1972) (21). The slight degree of resistance they did find was characterized by "chlorotic," as opposed to "necrotic," lesions on upper leaves. In 1974 they rated 193 commercial hybrids and some 590 inbred and experimental lines. Many inbred lines, but only 8 hybrids, showed resistance (20). Of 35 Tennessee maize cultivars observed by Hilty et al (11), only inbred T222 had high resistance. Results of Ayers's tests of late-medium and long-season hybrids for reaction to gray leaf spot in an epidemic area of Pennsylvania in 1980 are available from him upon request (1).

In our field and greenhouse tests, several hybrids have shown "tolerance"—relatively few lesions and slow development of symptoms. A number of commercial inbreds, a few tropical lines, and a teosinte-maize hybrid (received from W. Galinat) have shown several types of highly resistant reactions, the lesions of which sporulate sparsely. As far as we know, none of these types of resistance has yet been incorporated into a commercial hybrid.

Outlook. The first gray leaf spot lesions of the 1982 season in Maryland were found in Washington County on July 1, the earliest date yet reported for this state. Early July has been considered a critical date in southern Virginia for initial symptom expression in relation to ultimate crop losses (21). Early onset of the disease is generally a key to high potential damage in a given season, provided climatic conditions are favorable for disease development. This combination did not occur in Maryland in 1982. The disease appeared early, but summer drought prevailed into September, the usual late summer rains with morning fogs and long dew periods coming only after September 10. Considerable leaf damage and stalk deterioration occurred in some fields, especially in minimum-tilled fields where gray leaf spot had been severe in 1981, but disease buildup was late enough to allow most crops to escape severe injury. In the Shenandoah Valley of Virginia, however, early onset of the disease combined with high relative humidity, muggy days, August rains, and overcast skies to cause severe losses.

Similar situations prevailed in river bottomlands of central and western

Illinois (B. Jacobsen, *personal communication*) and southeastern and eastern Iowa (R. Nyvall, *personal communication*) during the past season. Severe infection was evident by the third week of August and was attributed to the combination of a wet season, 25% less-than-normal solar radiation (many cloudy or hazy days), high relative humidity, and a high percentage of no-till fields. Gray leaf spot was observed by Nyvall to be considerably more severe in fields where copious amounts of debris remained from the previous corn crop. Severity and incidence of gray leaf spot in Kentucky during 1982 was the second highest in 11 years of observation, according to J. Hartman (*personal communication*). He observed that for the first time the disease had "moved" from the eastern Appalachian areas into central and western Kentucky. Although there was less total rainfall than in the previous season, there were more overcast days, more foggy mornings, and heavier dews than normal in these areas. Hartman reported that many growers in the eastern areas had shifted to white corn cultivars because of their tolerance to gray leaf spot.

Our observations and those of our colleagues support a consensus that the combination of several important factors is essential to provide optimal conditions for gray leaf spot development: 1) more than 50% overcast days during the growing season, 2) high relative humidity, 3) morning fogs and extended dew periods associated with rains in August and early September, 4) minimum tillage in fields where disease was present during the preceding season, and 5) susceptible cultivar of corn. Infested debris (with minimum tillage) is believed to become especially important where environmental conditions are marginal.

On the optimistic side, several newly released commercial hybrids showed promise for gray leaf spot tolerance in cultivar tests conducted in high-stress locations in Maryland during the past season.

It is evident that gray leaf spot has achieved the status of a potentially major disease for some areas and, depending primarily on climatic conditions and availability of inoculum, could become a critical factor affecting corn production in the United States.

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