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SORGHUM DOWNY MILDEW...

A Disease of Maize and Sorghum

Texas A&M University • The Texas Agricultural Experiment Station • J. E. Miller, Director, College Station, Texas

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Authors

FREDERIKSEN, R. A., professor, The Texas Agricultural Experiment Station (Department of Plant Sciences)

BOCKHOLT, A. J., associate professor, The Texas Agricultural Experiment Station (Department of Soil and Crop Sciences)

CLARK, L. E., assistant professor, The Texas Agricultural Experiment Station (Department of Soil and Crop Sciences)

COSPER, J. W., county agent, Texas Agricultural Extension Service, Matagorda County, Bay City, Texas

CRAIG, J., research plant pathologist, Agricultural Research Service, U.S. Department of Agriculture, The Texas Agricultural Experiment Station (Department of Plant Sciences)

JOHNSON, J. W., assistant professor, The Texas Agricultural Experiment Station, Lubbock

Jones, B. L., assistant professor, The Texas Agricultural Experiment Station, Stephenville

MATOCHA, P., technician, The Texas Agricultural Experiment Station, Beeville

MILLER, F. R., research associate, The Texas Agricultural Experiment Station (Department of Soil and Crop Sciences)

REYES, L., research associate, The Texas Agricultural Experiment Station, Beeville

ROSENOW, D. T., associate professor, The Agricultural Experiment Station, Lubbock

TULEEN, DARLENE, technician, The Texas Agricultural Experiment Station (Department of Plant Sciences)

WALKER, H. J., agronomist, The Texas Agricultural Experiment Station (Department of Soil and Crop Sciences)

Preface

Sorghum downy mildew, a new major disease in North America, has been intensively studied by scientists of The Texas Agricultural Experiment Station. Information regarding sorghum downy mildew and its control has been herein consolidated and summarized from individual publications, progress reports and previously unpublished data. Virtually every sorghum and maize producer in South Texas knows about "downy." While many have their exclusive ideas as to its origin and sporadic occurrence, each knows the real and the potential menace of sorghum downy mildew.

Research nurseries on the Charles Diebel Farm, operated by Clarence Kramer, on the Otto Kertel Farm and on The Texas A&M Agricultural Experiment Station at Beeville have formed the nucleus for a Texas Agricultural Experiment Station downy mildew research program and, subsequently, a sorghum disease research program. These farmers and many others along the Gulf Coast have contributed generously to the understanding of sorghum downy mildew, and the authors are grateful for their cooperation.

Sorghum downy mildew, in particular, sparked the first Beeville Sorghum Disease Field Day (an event held annually since 1967 for the benefit of researchers from industry and neighboring states). In 1972, 70 visitors representing 11 States and eight countries attended the Field Day and toured the Berclair downy mildew nursery, and 136 persons representing 20 commercial firms, 19 States and several private foundations registered for the 1973 workshop on downy mildews of corn and sorghum.

Sorghum downy mildew is less threatening today because of the cooperative efforts of many people—State, U.S. Department of Agriculture and commercial researchers, extension specialists and farmers have all contributed to a better understanding of this disease.

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SORGHUM DOWNY MILDEW...

A Disease of Maize and Sorghum

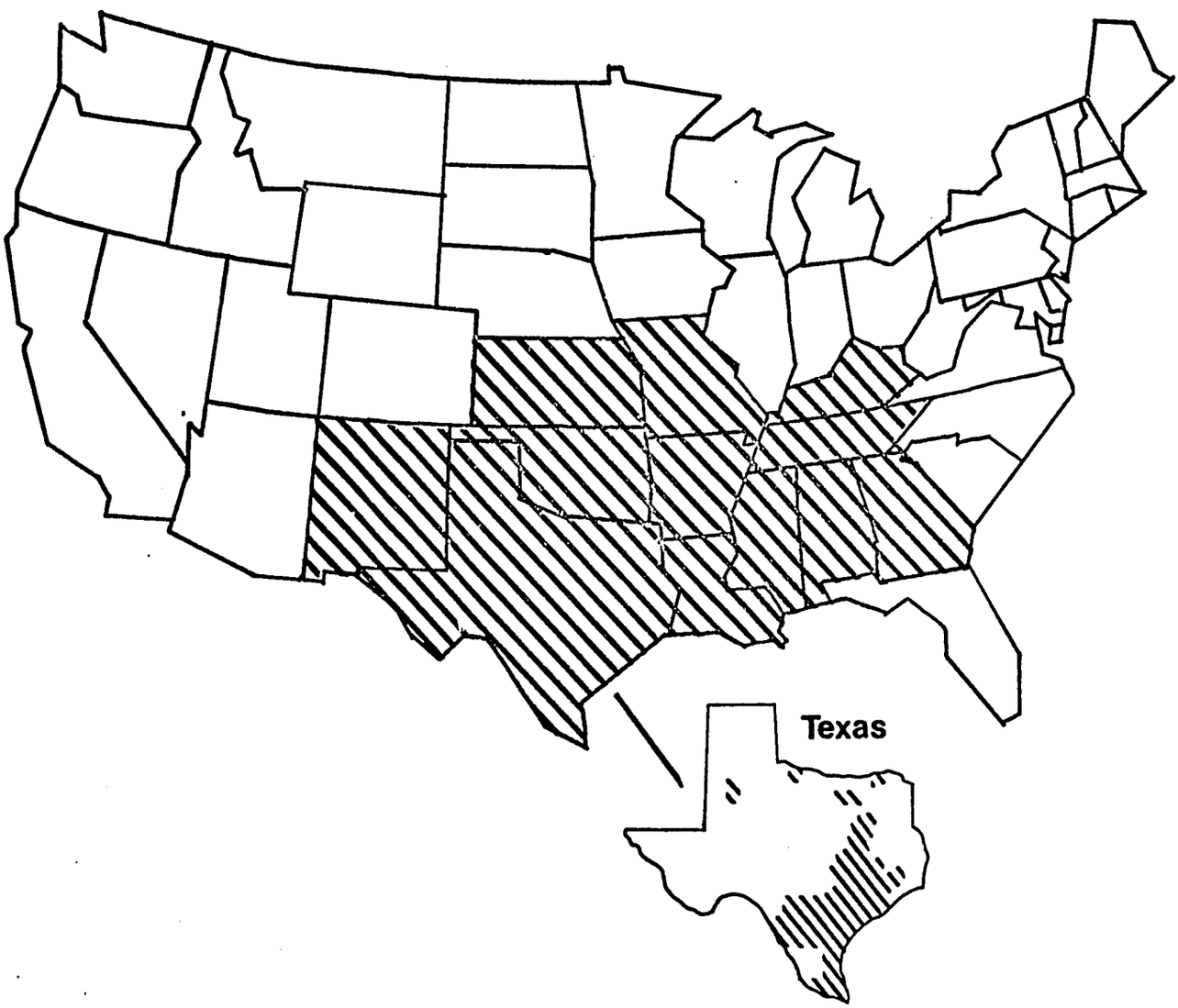


Figure 1. Geographic distribution of *Sclerospora sorghi* in the United States, 1973; reported occurrence in States covered by shaded area (Sorghum downy mildew was identified in at least two new areas in the Corn Belt during the summer of 1973: Southern Indiana and Northwestern Kentucky); occurrence in Texas counties noted by shading on map insert.

1. Introduction

For more than a decade the first tropical downy mildew on the North American continent has been recognized and treated. How sorghum downy mildew (SDM) came to the United States has not been satisfactorily explained. While Reyes, *et al.* (41) note that SDM was observed in the fall of 1961 at both College Station and Chillicothe, they also note that downy mildew was found in commercial fields in South Texas during 1962. Based on current understanding of the rate of spread of SDM, it is likely that the disease existed in South Texas prior to 1961 (26). The distinction of reporting the first occurrence of SDM in each of the 12 States currently listed (Figure 1) invariably goes to someone with the opportunity to make timely disease surveys where the appropriate host exists.

The earliest reports of SDM from northern Mexico parallel those from South Texas. The disease presently occurs on maize and sorghum in most warm humid areas of the world (Figure 2).

Maize, *Zea mays* L., and sorghum, *Sorghum bicolor* L. Moench, the principal hosts of *Sclerospora sorghi* (Kulk.) Weston and Uppal, represent commercial crops valued at nearly $6 billion in the United States in 1972. Estimates of the values on an international basis, especially in lesser developed areas, are measured in the lives of millions whose existence depends on these grains (43). Consequently, a disease with the destructive potential of SDM must be carefully studied, anticipated and controlled.

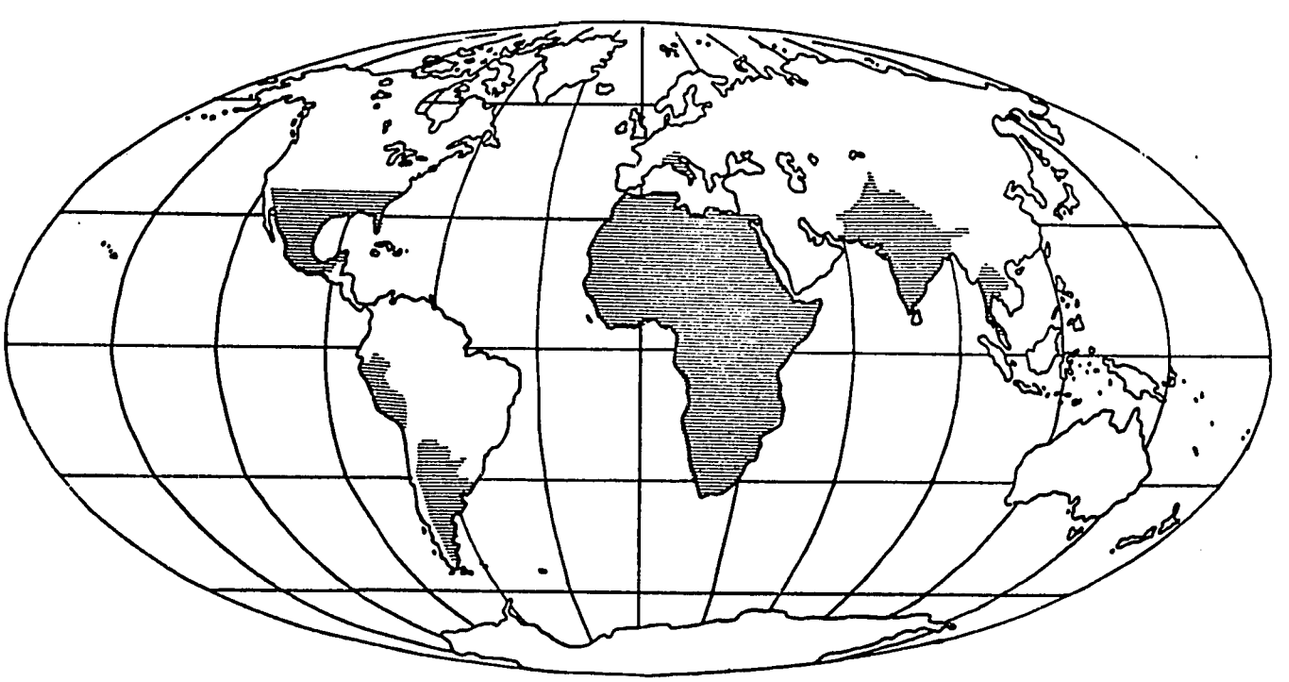


Figure 2. Geographic distribution of *Sclerospora sorghi*, 1973; reported occurrences in most African countries, India, Pakistan, China, Thailand, southern United States, Mexico, Peru, Argentina and Italy are designated by shaded areas. Distribution of other Sclerospora sp. is listed in Table 1.

2 Causal Organism and Host Symptoms

Sorghum downy mildew, caused by the fungus *Sclerospora sorghi* (Kulk.) Weston and Uppal, was first mentioned by Butler in India in 1907. Butler recognized the similarity of the oospores of *S. sorghi* to those of *S. graminicola* on millet and assigned it to the same species. In 1913, Kulkarni described the oospores and conidia. He used disease symptoms and characteristics of the asexual stage to differentiate *S. graminicola* var. *andropogonis-sorghi* (44).

Weston and Uppal, in 1932, renamed the fungus *S. sorghi* (50). Their paper reviewed the nomenclature of the fungus as a variety of *S. graminicola* and initiated a new species based on their observation that:

> The fungus on sorghum differs distinctively in its absolute lack of a dehiscence papilla in the apical wall of the conidia and their consequent germination by hyphae, and in the definite basal cell, extensive branch system and consequent arrangement of conidia in a hemispherical plane on the longer sterigmata of the conidiophores.

The two also were considered to be different species in that *S. graminicola* did not infect grain sorghum and *S. sorghi* did not infect millet.

In a study of gametogenesis and oospore formation in *S. sorghi, S. graminicola* and *Sclerophthora macrospora,* Safeeulla and Thirumalachar provided further evidence supporting the identity of these species (44). They found differences in the number of nuclei in the antheridia and oogonia between the two species. They also reported that the nuclei in the sexual bodies of *S. sorghi* are uniform in size but *S. graminicola* nucleus size is variable. Another distinguishing characteristic they described is the clear demarcation between ooplasm and periplasm in *S. sorghi* but not in *S. graminicola.* Finally, they observed that the oogonial wall of *S. sorghi* is not uniformly thick as in *S. graminicola* but has a wavy margin (Figure 4-B). The description of the fungus by Weston and Uppal is as follows:

> Conidiophores erect, spreading, comprising basal cell, main axis and more or less complex, usually dichotomously branched, expanded top [Figure 3-A]. The basal cell knobbed or bulbous at the bottom, then of fairly uniform diameter (7–9 μ), for length of approximately 100 to 150 μ until delimited usually by a complete septum, more rarely by a partial, ring-like thickening. The main axis expanding above to a diameter of 15 to 25 μ, and usually less than or equal to the basal cell length, i.e., extending about 80 to 150 μ, from the septum of the basal cell to the beginning of the branch system. The branch system comprising rapid successions of short, stout dichotomies usually involving primary, secondary and tertiary branches terminating in tapering sterigmata usually about 13 μ long, the branches so arranged that the conidia borne on their tips be approximately in a hemispherical plane [Figure 3-B].
>
> Conidia suborbicular, varying from 15 to 28.9 μ x 15 to 26.9 μ, most frequently 21 to 24.9 x 19 to 22.9, under natural conditions. Conidia hyaline, with a thin wall, continuous at the apex, unmodified, and quite without any papilla of dehiscence, hence germinating invariably by hyphae.
>
> Oogonial stage resembling that of *S. graminicola* in general structural characteristics, such as the thick, irregularly polygonally-angled oogonial wall closely enveloping the singly, hyaline, spherical oospore within, but differing slightly from *S. graminicola* on Pennisetum in effect on the host in that oospore, which develop chiefly within elongate reddish discolored areas in the mesophyll between the fibro-vascular bundles,

cause marked disintegration of the leaf tissue into tangled fibers. Oospores spherical, the majority between 31 and 36.9 μ in diameter, the mode being 35 to 36.9μ, extremes ranging from 25 to 42.9 μ, wall a light shade of Mars Yellow (of Ridgway's "Color Standards"), most frequently from 1.1 to 2.7 μ thick, extremes ranging from 0.3 to 4.3 μ; content finely granular with masses of oil globules, central or accentric in position; germination by means of unseptate, usually branched, hyaline germ tube, averaging 4.4 μ in width, extremes ranging from 2.5 to 8.3 μ.

S. sorghi is compared with other Sclerospora sp. in Table 1. Other downy mildews, presently restricted to the tropics, which pose possible threats to maize and sorghum in the Western Hemisphere are *S. philippinensis, S. maydis* and *S. sacchari.*

The SDM life cycle is summarized in Figure 3-C. The two spore stages of *S. sorghi* are capable of infecting susceptible host plants under widely differing environments. Oospores survive as resting spores in the soil on crop residue; infection studies with oospores (see Cultural Control Methods) suggest that these spores remain viable in the soil for several years. Conidia, on the other hand, appear to be very short lived. When Cosper (8) attempted to dislodge conidia by drying leaves, these spores failed to germinate. Many investigators have noted that conidia germinate *in situ* (8, 20, 49, 50), are produced daily (generally at night) and probably establish infection within a few hours (20, 31, 32). Some cultivars of maize and sorghum may be more vulnerable to conidial infection than others from both the standpoint of systemic infection and from local lesion infection (33). Virtually unique to the downy mildews are the many different phases of host-parasite interactions. *S. sorghi* colonizes its host through production of local lesions (foliar) and/or systemic invasion. Based on host and pathogen maturity, at least five compatible host-parasite interactions have been described:

local lesion HPI (pathogen reproduces asexually in seedlings or mature host tissue)

systemic—1 HPI (pathogen reproduces asexually in seedlings. Figure 6-A)

systemic—2 HPI (pathogen reproduces sexually in seedlings. Figure 6-A)

systemic—3 HPI (pathogen reproduces asexually in mature host tissue)

systemic—4 HPI (pathogen reproduces sexually in mature host tissue. Figure 6-C)

The relationships between these phases are not always evident. In certain cultivars local lesion infection in young seedlings progresses to systemic—1 and systemic—2 (33). This does not occur in other cultivars, particularly as infected host tissue matures.

TABLE 1. A COMPARISON OF SCLEROSPORA SPECIES CLOSELY RELATED TO *S. SORGHI*[1]

Species	*S. sorghi*	*S. graminicola*	*S. philippinensis*	*S. maydis*	*S. sacchari*	*S. miscanthi*
Hosts	*Sorghum* sp. *Zea mays* *Euchlaena* sp.	*Sorghum* sp. *Zea mays* *Setaria* sp. *Euchlaena* sp. *Saccharum* sp. *Pennisetum* sp.	*Sorghum* sp. *Zea mays* *Saccharum* sp. *Euchlaena* sp.	*Zea mays* Teosite x Maize Hybrids	*Zea mays* *Saccharum* sp. *Euchlaena* sp.	*Sorghum plumosum* *Miscanthus* sp. *Saccharum* sp.
Geographic distribution[2]	Africa India Pakistan China Thailand USA Mexico Peru Argentina Italy (questionable report)	most continents growing maize, sorghum and the millets	Philippines Indonesia India Nepal	Indonesia	Australia Fiji Islands Philippines Taiwan New Guinea India Nepal Japan	Philippines Taiwan
Oospore size (μ)	31 - 69	30-60			40 - 50	40 - 50
Oospore germination	Germ tube	Germ tube			Germ tube	
Conidial size (μ)	15-29 x 15-27	14-23 x 11-17	14-57 x 11-27	28-45 x 16-22	24-41 x 15-23	
Conidial germination	Germ tube Zoospores	Zoospores	Germ tube	Germ tube	Germ tube	
Conidiophore size (μ)	180 - 300	268	150 - 400	150 - 300	190-280	
Basal cell	Present	Absent	Present	Present	Present	

[1]Amended from Dickson (10).
[2]Distribution data according to B. L. Renfro (mimeographed report).

Figure 3-A. Scanning electron micrograph of conidiophores of *Sclerospora sorghi* as they appear on sorghum leaves, 250 X. (Photo courtesy of A. Pedrosa, December 1973.)

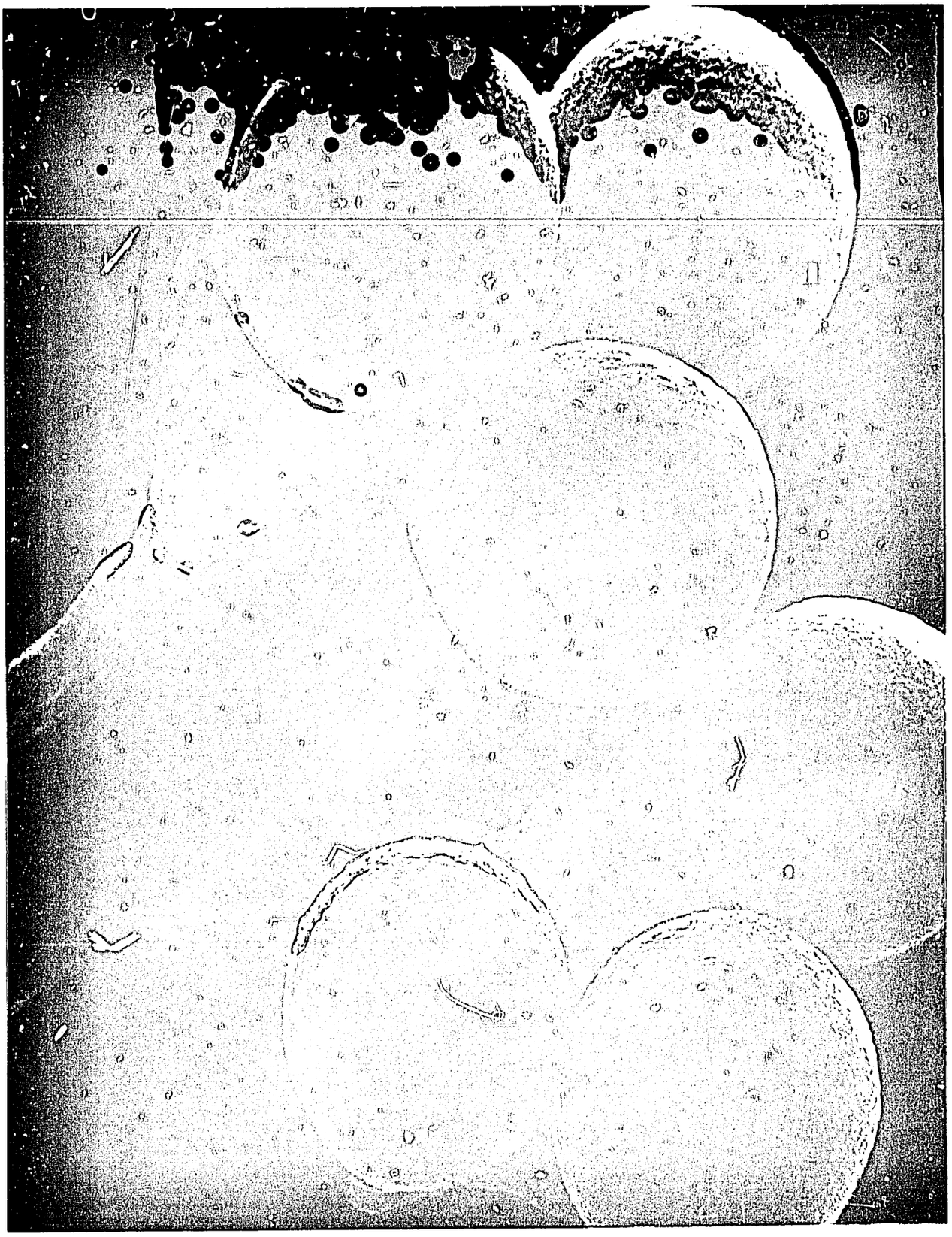


Figure 3-B. Scanning electron micrograph of conidia and sterigmata of *Sclerospora sorghi*, 3,000 X. (Photo courtesy of A. Pedrosa, December 1973.)

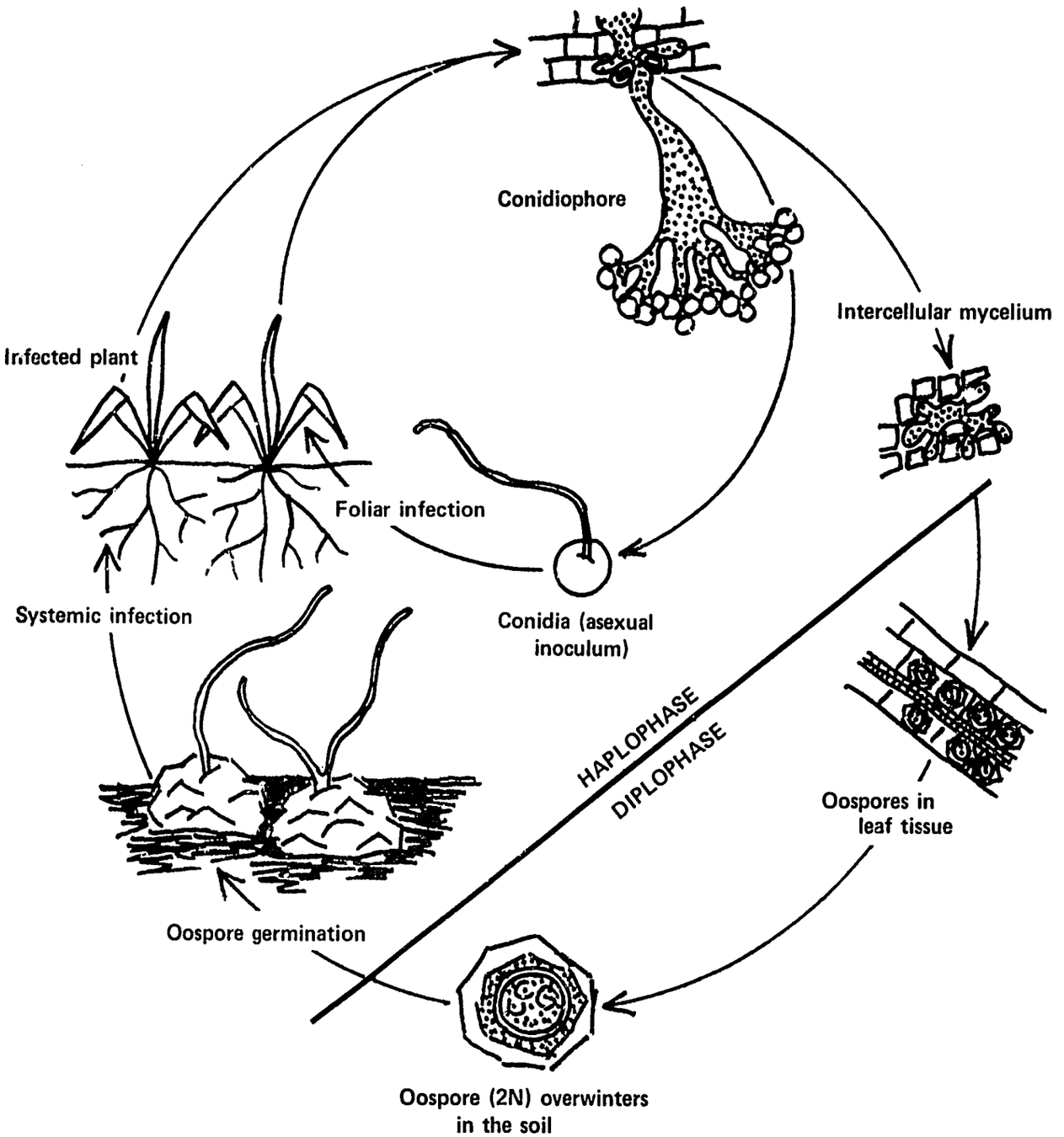


Figure 3-C. Life cycle of *Sclerospora sorghi.*

Although no maize or sorghum cultivars appear resistant to local lesions (14, 15, 16), many differ greatly in size and number of lesions per leaf. Differences in systemic phases may be related to stage of host tissue differentiation and maturity in relation to the site of pathogen invasion. These phases are more distinct in sorghum than in maize.

Disease Symptoms in Sorghum

SDM may occur in either a systemic or a localized form in sorghum. The systemic form of the disease is caused by infection of seedlings by oospores of *S. sorghi* in the soil or infection by conidia soon after seedling emergence from the soil. Systemically diseased seedlings exhibit chlorotic or pale yellow

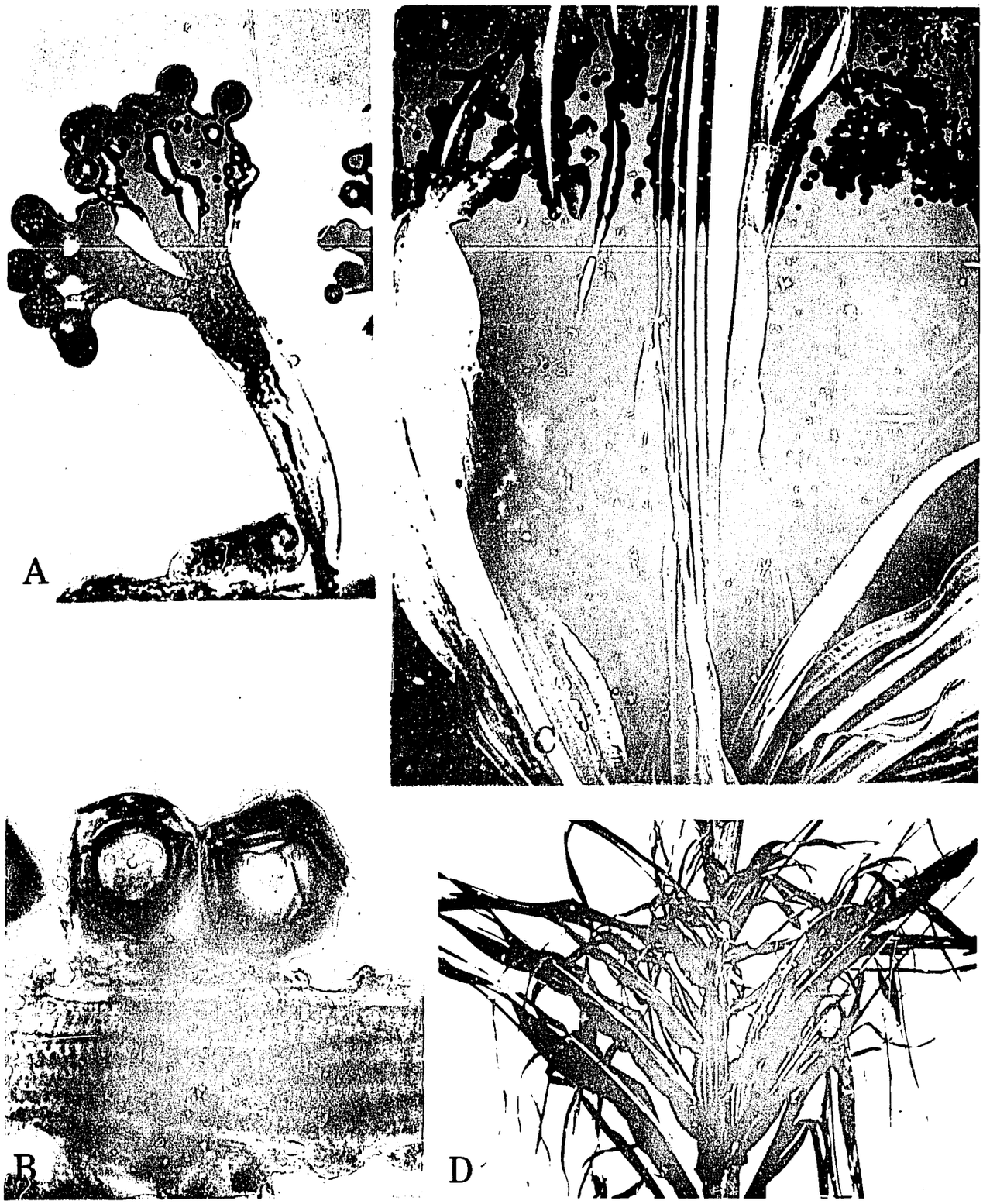


Figure 4-A. Conidia and conidiophores of *Sclerospora sorghi*.

Figure 4-B. Mature oospores adjacent to the sorghum vascular tissue.

Figure 4-C. Systemically diseased sorghum plant with typical sorghum downy mildew striping.

Figure 4-D. Shredding of leaves on systemically diseased sorghum plant.

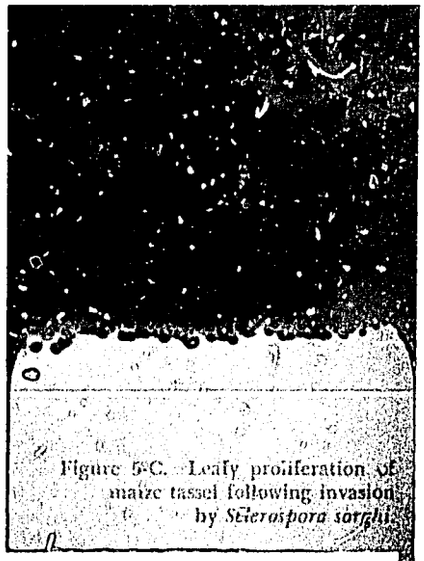


Figure 5-C. Leafy proliferation of maize tassel following invasion by *Sclerospora sorghi*.

Figure 5-B. "Half leaf" invasion of maize leaf by *Sclerospora sorghi*.

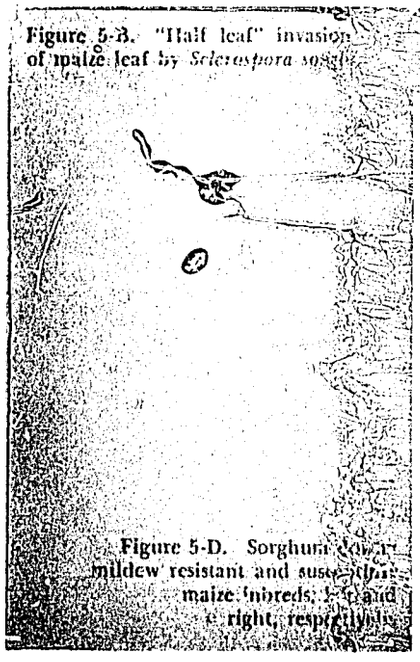
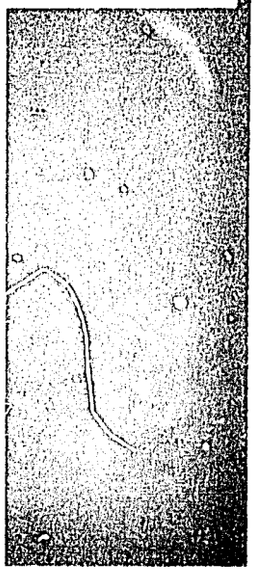


Figure 5-D. Sorghum downy mildew resistant and susceptible maize inbreds, 1- and 2- right, respectively.



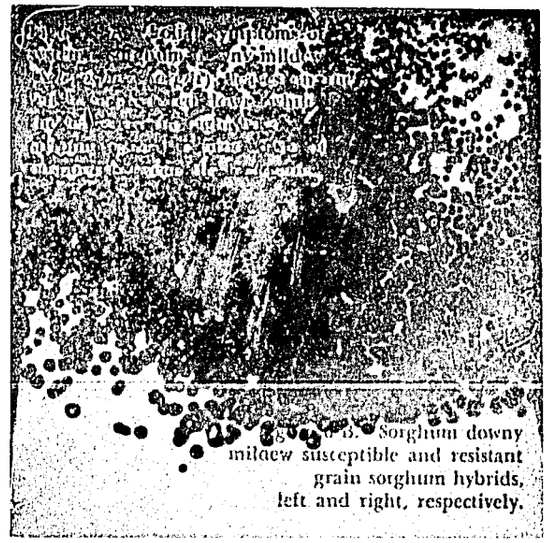


Figure 6-B. Sorghum downy mildew susceptible and resistant grain sorghum hybrids, left and right, respectively.

Figure 6-C. Proliferated plant growth in grain sorghum caused by *Sclerophthora sorghi*.

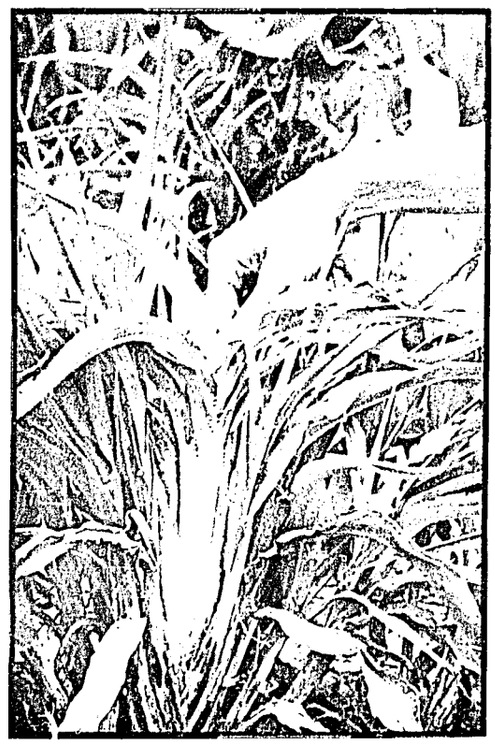


Figure 6-D. Proliferated plant growth in grain sorghum caused by *Sclerophthora macrospora*.

areas on the leaves. Often the first leaf to exhibit symptoms will show chlorosis only on the basal half. Under conditions of cool temperature and high humidity, the lower surfaces of the chlorotic areas on the leaves will be covered with a white downy growth composed of conidia and conidiophores of the pathogen (Figures 4-A, 6-A). Later leaves exhibit parallel stripes of green and white tissue (Figures 4-C, 6-A). The chlorotic stripes develop reddish brown streaks denoting the presence of oospores. The chlorotic interveinal tissue becomes necrotic, and the leaves shred. Leaf shredding is a common symptom of sorghum affected by downy mildew (Figure 4-D). Plants which become systemically infected as seedlings are usually stunted and often die prematurely; those that survive usually fail to flower. If systemic infection occurs after the plants have passed the seedling stage of growth, the plants may flower, but grain production will be absent or severely reduced, and diseased plants at times will continue to grow and proliferate much like crazy top (Figures 6-C and 6-D).

The localized form of the disease is caused from foliar infection by conidia. This type of infection produces stippled necrotic areas on the leaves. Such infection may remain localized or become systemic and produce the characteristic symptoms of striped leaves, shredding and sterility.

Sorghum plants which are systemically infected with SDM in the seedling stage readily succumb to root rot caused by *Fusarium moniliforme* (3) and are frequently invaded by *Cercospora sorghi*, the pathogen causing grey leaf spot. In paired plant comparisons, seedlings with SDM were found to have nearly 30 times more grey leaf spot lesions than healthy plants (25). These symptoms are further enhanced by more apparent symptoms of a darkly bordered lesion on a chlorotic leaf as opposed to the darker healthy leaf. Under some conditions the presence of grey leaf spot aids in estimating the incidence of downy mildew.

Disease Symptoms in Maize

Although maize appears to be susceptible to systemic infection throughout its growing season, it has been artificially inoculated only in the seedling stage (14, 45). Infected maize plants are chlorotic, stunted and occasionally have striped leaves. The first diseased leaf usually has a sharp margin between diseased and nondiseased tissue, forming a "half-diseased leaf" (Figure 5-B). This symptom, typical of downy mildew, differentiates it from the similar symptoms of maize dwarf mosaic virus infection. It has been observed that plants grown from infected seeds will develop symptoms on the coleoptile. Leaves of infected plants are narrower and more erect than those of healthy plants (Figure 5-A) (34).

Under favorable environmental conditions asexual sporulation may be abundant, although less dense than that found on sorghum. Down may form on the upper or lower surfaces of the first two or three infected leaves and is identical with that found on lower leaf surfaces of diseased sorghum plants (15). Oospores are found embedded in leaf and tassel tissue between veins. These spores are about 45 μ in diameter, but range in size from 30 to 70 μ.

Plants with SDM frequently have phylloided tassels similar to those which characterize crazy top, caused by *Sclerophthora macrospora* (Sacc.) Thirum., Shaw and Naras. (14, 15), but differing in that the tissue infected by *S. sorghi* is not so twisted or deformed (Figure 5-C). Seed production on diseased plants is negligible or nonexistent in all but a few cases of late infection.

The long delay from emergence to symptom development under some conditions may be related to time of infection, site of infection, type of inoculum and the influence of the environment on the host-parasite interaction. Plants developing SDM during ear and seed differentiation frequently have few seeds, most of which are infected by the pathogen.

Plants with SDM are brittle and subject to stalk breakage and lodging. These plants are extremely susceptible to corn smut, caused by *Ustilago maydis* (DC.) Cda. In a field of Tx28A, more than 90 percent of the plants with SDM were smutted, whereas, only a trace of smut was detected on plants free from symptoms of downy mildew. This field, near Roundtop, Texas, in 1968 had an incidence of nearly 30 percent SDM.

Leaf shredding rarely occurs in maize; however, it can be observed in plants infected by both bacterial stripe and SDM. Local lesions on maize are elongate, chlorotic and occur principally on the lower leaves. Frequently, on very susceptible cultivars, local lesions may mimic systemic infection.

Although no plants have been observed to recover from SDM, a remission of foliar symptoms has been noted in some maize cultivars. The effect of SDM on maize may range from a lethal effect on seedlings (for example, Oh51A) to production of an apparently "healthy" but sterile mature plant (for example, NYF) (17).

3 Infection Process and Seed Transmission

S. sorghi is easily identified by staining leaf material heated in a 1:1 solution of a Sudan III stain preparation and lactophenol (15). Oospores of the fungus can be differentiated from those of other *Sclerospora* species by their characteristic position embedded in mesophyll cells parallel to and between veins in maize and sorghum leaves. *S. macrospora* mycelium, for instance, appears intervascularly, distorting vascular tissue when stained.

The controversy over whether oospore germination takes place via germ tubes has been reported by several researchers (8, 48, 50). Germination 'au naturel' needs further investigation. Oospores have been observed in wax-embedded specimens adhering to the radicle of germinating sorghum seeds at the point of its rupture through the pericarp. Infection following oospore inoculation has been shown to occur in sorghum plants with excised primary roots, indicating oospores are capable of invading prop roots as well as primary roots (J. F. Rivers, unpublished data). Intercellular invasion of fungus mycelium or plasmodium also has been observed in histological studies, but the story of the infection process as initiated by oospores is incomplete.

Plant tissues often secrete substances which affect the propagules of pathogens. Zoospore chemotaxis in Phycomycetes induced by root exudates is a well-documented phenomenon (28). Apparently maize and sorghum seedlings, whether susceptible or resistant to SDM, may similarly stimulate germination of soil-borne oospores (25). The inoculum potential of soil samples containing SDM oospores was significantly reduced when the soils were reused in a soil-temperature tank experiment (Table 4, technique 2). A second planting of maize (Tx173D and Tx508) and sorghum (Tx412) was sown in soil in which SDM-susceptible and SDM-resistant varieties had grown at 19°, 22°, 25° and 28° C for 30 days before being removed. Control soil was held at the same temperatures and watered as were the samples in which maize and sorghum grew. Infections in maize were reduced from 26–56 percent in unused soil to 0–18 percent for sorghum. Maize infection increased at 28° C, but temperature appeared to have little or no effect on Tx412 under these parameters.

When soil serves as the source of the inoculum (Table 4, technique 2), dilutions do not appear to diminish its disease-producing capacity (25). Dilutions of soil-borne inoculum with sterile soil (1:1, 1:2, 1:10 and 1:100) produced plants with insignificant differences in SDM infections. A probable explanation is that these soils contained high numbers of oospores, and it takes just one viable spore to produce an infected plant.

The limits of environmental factors which favor oospore germination and plant infection are still being explored. Data in this area are based on heterogeneous soil-borne oospores assayed by plant infections.

Cross-genera inoculations are readily accomplished with both conidia and oospores from sorghum infecting maize and conversely. Conidia of *S. sorghi* have been observed germinating frequently *in situ* and on the surface of leaves by means of germ tubes. Cosper (8) reported that the germinating conidia produced appressoria near the junctions of cells where the fungus directly penetrated sorghum leaves. Jones (32) reported stomatal penetration followed by development of intercellular mycelium with haustorial invasion occurring within an hour of germination. As mycelium growth continues, cushions of mycelial strands develop within the substomatal cavity from which sporangiophores arise and emerge through the stomata to complete the cycle of asexual reproduction (Figure 7).

The infection process initiated by conidia only recently has been investigated; its study followed the development of inoculation techniques (Table 4). By use of these techniques, the effects of environmental conditions on conidial infection can be defined. Some factors are under investigation:

TABLE 2. COMPARISON OF SORGHUM DOWNY MILDEW RATINGS FOR SORGHUMS GROWN IN 1972 FIELD TESTS AT BERCLAIR, TEXAS, WITH INFECTION RESULTING FROM CONIDIAL INOCULATIONS MADE UNDER CONTROLLED CONDITIONS

Designation	Field rating[1]	Percent infection[2]
IS1022C	4	97
IS2403C	1	19
IS2579C	2	90
IS2816C	1	66
IS3614C	4	76
IS7435C	4	70
IS12608C	1	21
IS12609C	1	27
IS12610C	1	32
IS12662C	1	34

[1]Based on a scale of increasing disease severity: 1 = resistant; 2 = moderately resistant; 4 = moderately susceptible when grown in the Berclair downy mildew nursery.

[2]Inoculation by technique 4 (Table 4) at College Station.

Moisture: *S. sorghi,* like other downy mildew species, requires high humidity to germinate and infect maize and sorghum. Heavy dews provide the saturated atmosphere necessary for downy mildews to complete their asexually reproductive cycle under field conditions.

Temperature: The optimum temperature at which conidia shed, germinate and infect in the laboratory is 21° C. This may or may not be the optimum for disease development under field conditions. Conidial production curves have not been plotted, but infections have occurred in plants incubated at temperatures ranging from 15° to 30° C.

TABLE 3. EFFECT OF MOISTURE CONTENT AND LENGTH OF STORAGE ON OCCURRENCE OF SEED-TRANSMITTED SDM IN MAIZE[1]

Moisture content	Percent transmission in days after harvest[2]		
	7 days	26 days	40 days
30	30	4	0
18	21	2	0
9	0	0	0

[1]Seedlings grown in greenhouse at 28° C, seed held at 3° C to prevent spoilage (from Jones *et al.,* 1972, 34).

[2]Based on five replications.

Light: Conidial inoculations in the absence or presence of light gave some surprising results which bear further investigation. A greater incidence of infection occurred in sorghum when inoculations were made in the light rather than when light was excluded.

Host Resistance: SDM "field resistance" did not hold up under laboratory conidial inoculations, although in tests with 10 converted sorghum lines, those that were resistant in the field showed a comparatively lower degree of infection with artificial inoculations (Table 2). There was a positive correlation between infection in the field and infection from laboratory conidial inoculations for the same sorghum lines even though the percentage of plants infected following artificial inoculation was higher for each line tested. There is evidence to suggest that some sorghums acquire resistance as they mature (33). Environmental factors governing resistance to SDM need closer scrutiny before adequate theories on the physiology of host resistance are advanced.

TABLE 4. COMPARATIVE SORGHUM DOWNY MILDEW INOCULATION TECHNIQUES

Inoculation technique	Inoculum used	Expected infection with susceptible sorghum	Expected infection with susceptible maize	Suggested use—studies of:
1. Ground and sieved leaves	oospores	10–50%[1]	10–50%[3]	Infection process Host resistance Oospore ecology Oospore germination and survival
2. Infested soil	oospores	80–100%[1]	80%[4]	Varietal screening for resistance Methods of control
3. Soil dust	oospores	no data	no data	Oospore germination
4. Conidial shed at germination	conidia	80–100%[1]	60%[4]	Infection process (systemic phase) Host resistance Conidia ecology Conidia germination and survival
5. Conidial shed on seedlings	conidia	0–70%[2]	no data	Infection process (local lesion phase) Varietal screening for resistance Methods of control

[1]Tx412 (unpublished data by R. A. Frederiksen and D. Tuleen).

[2]SA372 (B. L. Jones, 7th Biennial Grain Sorghum Prod. Confr., 1971).

[3]1968 evaluation of 92 maize genotypes (unpublished data by R. A. Frederiksen and J. W. Cosper).

[4]Tx325 (unpublished data—limited testing by R. A. Frederiksen and D. Tuleen).

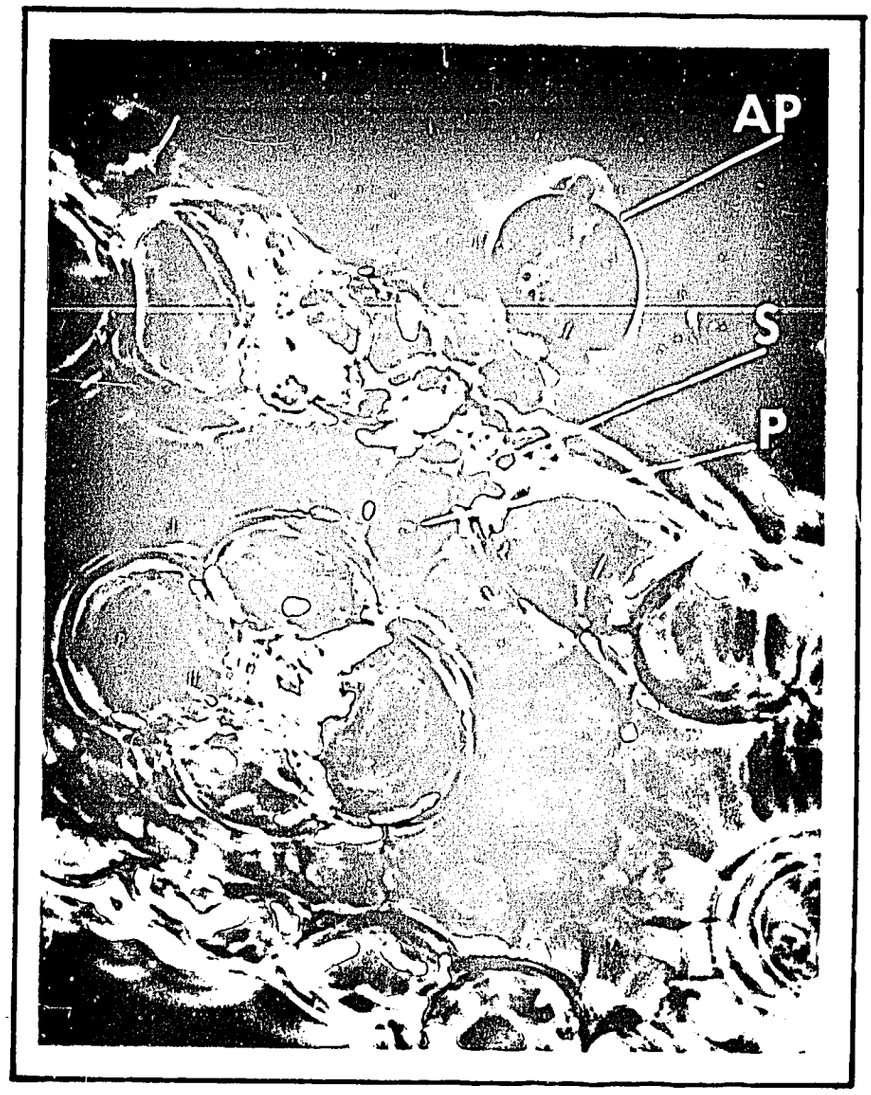


Figure 7. Photomicrograph of the penetration of a sorghum leaf by *Sclerospora sorghi*. Note the appressoria (AP) above the stomata (S) with a peg (P) penetrating the leaf.

Seed Transmission

Several authors have noted or suggested seed transmission of SDM (4, 17, 33). Jones *et al.* (34) demonstrated that *S. sorghi* can be seedborne under very specific conditions. As soon as the seed dried or had been stored for a few days, however, the mycelium associated with the seed lost its ability to infect maize seedlings (Table 3).

Occasionally sorghum heads on systemically infected plants have a few normal appearing seed. During the summer of 1971, 400 such seed with glumes attached and 400 with glumes removed were planted immediately after collection and 1 month after collection. Previous observations had shown that most of the glumes had mycelium and oospores, while few seed did. From those seed planted with glumes attached 1 day after harvest, 1.5 percent of the developing seedlings had SDM; those with glumes removed had none. One month later nearly identical observations were noted: 1 percent of the seedlings with glumes attached became infected, whereas no SDM was found among those without glumes.

Fortunately most sorghum hybrids are derived from comparatively resistant Kafir steriles; consequently, few seed-parent plants become diseased. When one does, it usually is barren; yet occasionally a systemically diseased plant will bear a few seed. If by some remote chance the glumes remain on the seed, there is about one chance in a hundred that it will develop SDM if planted within a short period after harvest. As remote as this possibility is, it appears to be one of the major means for long distance dissemination of SDM. The likelihood of a similar seed transmission of the pathogen in maize is much less.

Another probable method of dissemination is by airborne oospores. In making sorghum-sudangrass hybrids, sudangrass pollinator rows may be shredded prior to the harvesting of the seed-parent rows. The sudangrass pollinator rows in an SDM area generally have a fairly high incidence of disease. Exposed sorghum seed could be coated with airborne oospores. Such seed contamination is less likely in maize with the husk protection.

4 Inoculation Techniques

Natural infection by parasitic fungi cannot satisfy the inoculum needs for the many areas of research on plant diseases. Uniform distribution of virulent and viable inoculum is essential where natural infection cannot be depended upon—studies of host-parasite interactions require more sophisticated control over experimental conditions than field tests allow. The obligate parasitic nature of the downy mildew pathogen of maize and sorghum poses problems in artificial inoculations that are not encountered in studies of many plant parasitic fungi.

Since *S. sorghi* is capable of systemically infecting maize and sorghum from either sexually produced oospores or the asexual conidia, the life cycle of the fungus and environmental conditions conducive to its development have been studied and inoculation techniques devised which mimic nature (Table 4).

Inoculations With Oospores

Oospores which develop in parenchyma cells between vascular bundles in mature maize and sorghum leaves have been collected from ground and sieved tissue, as well as from soil, and used in inoculations as follows:

1. Shredded leaves are ground in a Wiley Laboratory Pulverizing Mill, sieved through a No. 200 mesh sieve (74-micron openings) and sowed with seed in sterilized soil. Cosper (8) reported best infection when seed were coated with the oospore-leaf material; less infection appeared with inoculum banded either above or below the seed prior to sowing. Infection was shown by J. F. Rivers (unpublished data) to occur when oospore inoculum was placed in sterile soil as far as 3 inches from sorghum seed. Stored oospore-leaf inoculum declined in potency when stored at room temperature. Infection was usually reduced to less than 10 percent after storage for 18 months, with negligible infection after 3 years. After 3 years of storage at approximately 1° C and −10° C, however, 40-percent infection has been noted (25).
2. Soil collected from fields with a history of SDM serves as a good source of inoculum. Up to 100-percent infection has been observed in susceptible sorghum hybrids planted in trays of a soil-temperature tank and maintained at 27° C.
3. Oospores also have been removed from the soil by pulverizing dry soil in a Waring blender and removing the resulting dust. A surprisingly large number of oospores which have undergone weathering can be extracted by this method. The heterogeneous oospore population in the soil is preferable for testing probable sources of resistance in the host, but a more homogeneous population is needed for oospore survival and studies investigating environmental factors conducive to germination.

Inoculations With Conidia

The characteristic white bloom or down appearing on the underside of systemically infected maize and sorghum leaves is the asexual inoculum of the fungus. Conidiophores arise through stomata to produce a crop of conidia on sterigmata at the apices of their branches under favorable climatic conditions.

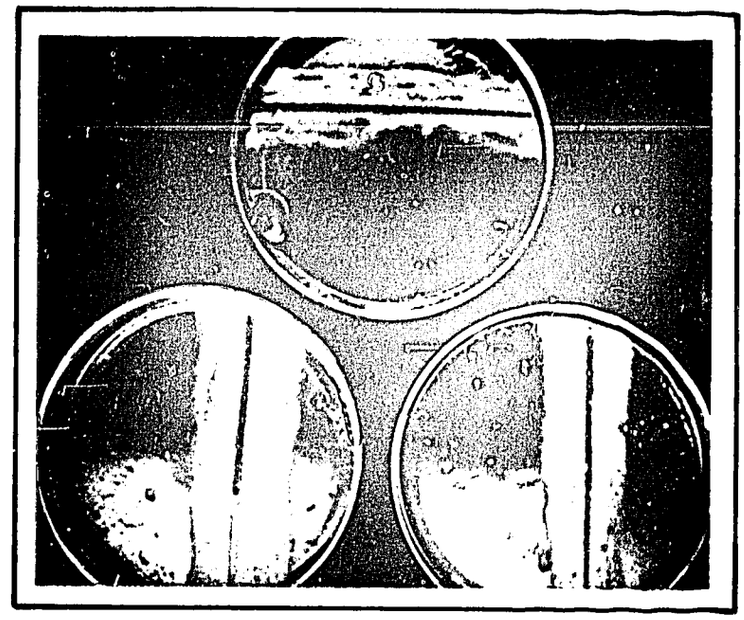


Figure 8. Conidia released from systemically infected sorghum leaves incubated overnight.

These short-lived conidia which germinate by means of germ tubes to systemically infect sorghum and maize seedlings are utilized in inoculations as follows:

1. Leaves producing abundant conidia are harvested and washed clean of down before being used to produce asexual inoculum in laboratory tests (Figure 8). Test seed are hydrated and left to germinate in moist paper towels until the embryonic shoot can be seen emerging through the pericarp (approximately 24 hours). It is at this point that the greatest susceptibility occurs; as they mature, maize and sorghum become succeedingly resistant to infection (33). Germinating seeds are placed, embryo side up, on moist paper in petri plates; the freshly harvested and washed leaves are stretched across the rim of the plate and secured with its top. It is important to prevent the leaf from curling and provide the greatest possible area of conidial exposure to the embryos below. Conidia are released about 8 hours after the leaves are removed from plants, regardless of the time of day they were harvested or whether in low light or darkness. The optimum temperature for conidial formation and infection, using this method, was found to be 21° C in a saturated atmosphere. Following exposure to conidial shed for 24 hours, the seedlings are either planted in soil and maintained at 27° C or fixed for histological examination.

2. To observe the infection process for sequential time periods following soil emergence, conidial inoculation of seedlings was used by Jones (31). In this procedure seedlings were grown in greenhouse flats in rows. Infected sorghum leaves are harvested late in the afternoon and placed on top of the seedlings with the lower leaf surface downward. The seedlings are covered overnight with sheets of polyethylene to maintain a high relative humidity at 20° to 28° C. Conidia, which form on the leaves during the night, are discharged onto the seedlings, and infection occurs. An abundance of conidia is usually released and forms visible spore prints on seedlings. This technique can be used to incite early systemic infection as well as local lesions.

5 Economic Impact

SDM has become an accepted hazard in sorghum and maize cultivation in Texas across the Coastal Prairies, Rio Grande Valley and parts of the Central Blacklands. It spread and reached epidemic proportions in 6 to 8 years after the first reported occurrence in 1961 (11) and is presently one of the major factors lowering yields of broomcorn, some forage and grain sorghums and sweet and field maize (2, 12) (Figure 5-D). Broomcorn suffered serious yield losses in 1967 and 1968 due to heavy SDM infection; consequently, broomcorn acreage has dropped from 25,000–30,000 acres in 1960 to less than 5,000 acres in 1971 (13). Sweet maize, which once was a profitable crop in the area, has been moved to other locations not yet heavily infested. Several commercial maize fields have been wiped out and others heavily damaged. Farmers have had to discontinue the use of sorghum-sudangrass hybrids as green manure, pasture, silage and hay crops because of their susceptibility and consequent heavy residual inoculum to any succeeding susceptible crop. Many fields which are now heavily infested should not be planted to the susceptible higher yielding grain sorghum hybrids.

Within the coastal area, several distinct disease patterns are evident. Fields of sorghum following sorghum-sudangrass hybrids, or fields with long histories of grain sorghum production, have a higher percentage of diseased plants than fields of sorghum or maize following a nonsusceptible host.

The incidence of systemically infected plants in 1967 ranged from about 1 percent when grain sorghum followed a nonsusceptible crop to as high as 30 percent in another location in the same field when it followed a crop of diseased sorghum (20, 23). These differences in disease incidence were frequently defined, clearly revealing where the susceptible crops had been grown previously as well as demonstrating the limited movement of oospore inoculum under the conditions that prevailed during 1966 and 1967.

Since 1968, the disease has become more or less stabilized due to the rapid decrease in cultivation of very susceptible sorghum-sudangrass hybrids. In 1971, at least one commercial company released two hybrids with high levels of resistance, and in 1973 at least three other firms had downy mildew-resistant materials available. In Texas counties with long histories of SDM, resistant hybrids or less susceptible hybrids have been enthusiastically accepted. Nevertheless, the majority of acreage is still planted with susceptible hybrids.

In 1972, 177 out of 191 commercially available grain sorghum hybrids tested were classified as susceptible (29) (Figure 6-B). Similar evaluations made in 1968, which included forage hybrids as well as grain types, again revealed a high degree of SDM susceptibility in the majority of cultivars tested (24).

Evaluations of 92 commercially grown field maize and 16 sweet maize hybrids obtained from 12 cooperating hybrid seed companies were made at Berclair in 1972. Only 11 of these hybrids had less than 10 percent SDM, whereas 37 had over 50-percent infection (Tables 5 and 6); Texas maize hybrids, Texas 30A, Texas 19W, Texas 17WA and Texas 17W had 37.1, 33.9, 26.5 and 26.1 percent SDM, respectively. Under conditions more favorable for infection, these hybrids will approach 100-percent infection. Other hybrids, many extremely important to the Corn Belt, are generally more susceptible than the susceptible Texas hybrids.

Grain Yield Losses

Sorghum and maize incurred an estimated $2.5-million loss to SDM in 1969 (13); however, a better basis for estimates of disease losses is needed. Estimates of SDM in grain sorghum fields range from no effect on yields to as much as 70-percent loss in grain yield. The actual effect is obviously difficult to estimate because it is dependent on such factors as plant populations, environmental conditions, hybrid susceptibility, crop maturity at time of estimate and incidence of SDM.

Effects of a disease on yield are relatively easy to measure in diseases for which satisfactory field scale inoculation techniques are available. Lacking suit-

TABLE 5. INCIDENCE OF SORGHUM DOWNY MILDEW IN SELECTED SWEET MAIZE HYBRIDS AT BERCLAIR, TEXAS, 1972

Line	Replication I Stand	Replication I No. with SDM	Replication II Stand	Replication II No. with SDM	Percent SDM
1 Deep Gold	40	10	28	21	46
2 Midway	24	24	30	27	94
3 Idabelle-N	20	20	30	30	100
4 Idabelle (SxR)-T	20	20	20	20	100
5 Golden Cross Bantam	20	20	20	20	100
6 H18	15	15	20	20	100
7 Gold Winner-T	25	25	2	1	96
8 Gold Winner-N	20	20	20	17	93
9 NK51036-N	20	20	20	18	95
10 NK51036-T	10	10	20	20	100
11 Valley Market	10	10	10	7	85
12 Stylepak	25	22	15	12	85
13 Foremost	20	20	20	20	100
14 Bonanza	25	24	20	18	93
15 Jubilee	30	30	30	30	100
16 Silver Queen	30	30	25	25	100

able techniques for field inoculations, researchers designed an experiment to obtain information on the effect of SDM on yield in grain sorghum (unpublished data by R. A. Frederiksen and H. Walker). The three hybrids tested were C48a (susceptible to SDM in the seedling stage), R1029 (susceptible throughout the growing season) and RS671 (resistant). Plant densities of 3, 6 and 9 inches between plants were used; treatments were plants with SDM rogued as they developed, healthy plants rogued to stimulate SDM plant losses and no roguing. The tests were planted at College Station in 1970 and at Berclair in 1971 in a section of a previously established downy mildew nursery.

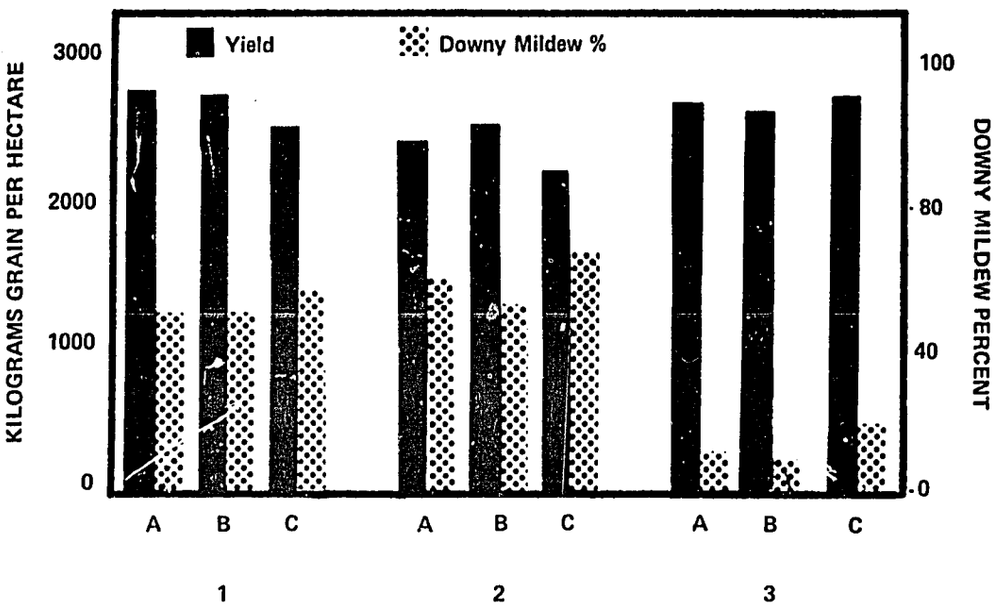
Yields and percent SDM for the three treatments of the hybrids tested are shown in Figure 9. The susceptible hybrids (1 and 2), with between 49 and 66 percent infection, had decreased yields for plots not rogued (B) and plots in which healthy plants were rogued (C). Treatment had little effect on yield in the resistant hybrid. Hybrid 1 had high yields when diseased plants were rogued (A) and in plots not rogued (B), perhaps because, with low seasonal moisture, plant competition was reduced in plots which were rogued or lost seedlings to SDM.

The regression of yield plotted against percent SDM is presented in Figure 10 and shows a curvilinear effect. The rising portion of the curve, beginning at about 10 percent SDM, describes the favorable effect of plant removal under conditions of moisture stress. Also noteworthy is the gradual yield loss beginning at approximately 30 percent SDM; losses are sharp and essentially linear when over 50-percent infection occurs. The information discussed herein and field observations do not imply that a little SDM is not damaging; the organism's capacity for devastation has been repeatedly demonstrated, and an active program to restrain this disease is essential.

Forage losses can be high; Cosper (8) noted that infected plants had a reduction in yield of from 56 to 80 percent in dry weight. Plants systemically infected in the seedling stage usually died; those seedlings which survived and those which became infected at a later stage of maturity yielded 56 to 82 percent less than did the adjacent healthy plants. The vast majority of systemically infected sorghum plants produced no seed. Regrowth from clipped forage plots

TABLE 6. RANGE IN SUSCEPTIBILITY TO SORGHUM DOWNY MILDEW OF SELECTED MAIZE HYBRIDS FROM 10 MAJOR HYBRID SEED PRODUCERS AND THE TEXAS AGRICULTURAL EXPERIMENT STATION AS MEASURED AT BERCLAIR, TEXAS, 1972

Firm	No. of hybrids tested	Reaction class (% SDM) 1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
A	8	0	3	2	2	1					
B	10	3	1	3	0	1	1	1			
C	5	1	2	0	2	0					
D	7	0	1	1	0	1	1	2	0	1	
E	9	1	1	1	1	2	2	1	0		
F	10	0	2	2	1	3	1	1			
G	7	1	1	0	3	1	0	0	1		
H	12	1	1	2	2	1	1	1	2	0	1
I	4	1	1	0	1	1					
J	10	1	1	1	1	1	1	1	1	0	2
TAES	9	2	2	3	2						
TOTAL	91	11	16	15	15	12	7	7	4	1	3



A Rogued diseased plants.
B Not rogued.
C Rogued healthy plants.
1, 2 and 3 are different hybrids.

Figure 9. Yield and downy mildew percent for three grain sorghum hybrids and three treatments at Berclair, Texas, 1971.

have higher incidences of SDM; consequently, the damaging effects of the disease with these cultivars will increase as the season progresses.

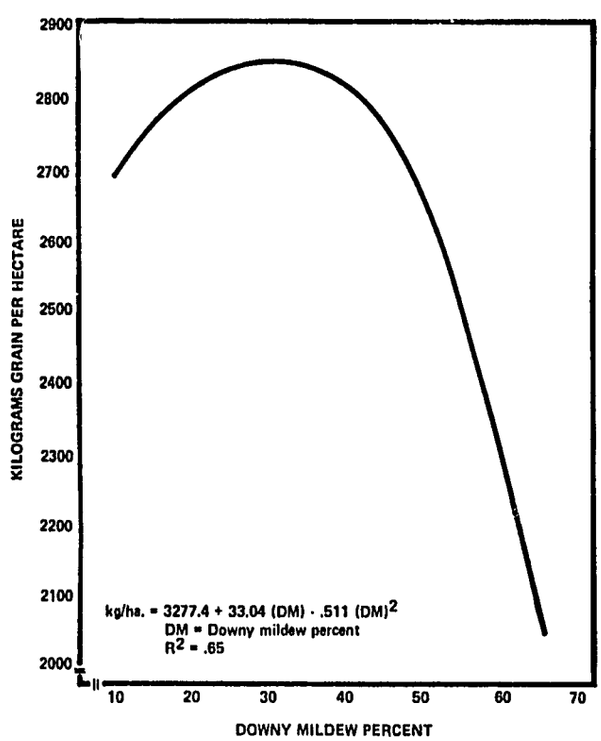


Figure 10. Effect of downy mildew on yields of grain sorghum at Berclair, Texas, 1971.

Effect of Seed Quality

Seed quality, as used here, refers to the physiological condition of the seed that contributes to either high or low germination. High quality seed are those which have a relatively high percent germination compared to low quality seed which have a low percent germination.

It is normally accepted that low quality seed are more susceptible to attack by seed rotting and damping-off organisms; however, it is rare that the physiological condition of seed affects the reaction of plants to a disease such as SDM that is expressed on well-established plants 3–4 weeks old. To test this phenomenon, three grain sorghum hybrids, each with two levels of seed quality, were planted at College Station in 1969 (7). One-month-old plants from low quality seed (76-percent laboratory germination; 78-percent emergence in the field) had almost twice the incidence of SDM as those from high quality seed (93-percent germination; 91-percent field emergence) (Table 7). Differences between high and low quality seed exceeded the 1-percent level of significance, and all three hybrids exhibited the same relative susceptibility as in numerous other field tests.

Because of the low incidence of infection in the field test, the experiment was repeated in the greenhouse under conditions conducive to higher levels of infection. Remnant seed from the same seed lots as those used in the field test were inoculated with oospores collected from leaves of infected sorghum plants (Table 4, technique 1).

TABLE 7. REACTION OF HIGH AND LOW QUALITY SEED OF THREE GRAIN SORGHUM HYBRIDS TO SORGHUM DOWNY MILDEW UNDER FIELD CONDITIONS AND IN THE GREENHOUSE, COLLEGE STATION, TEXAS, 1969

Hybrid	Percent SDM in field test			Percent SDM in greenhouse		
	High	Low	Mean	High	Low	Mean
RS625	1.8	3.3	2.5	6.6	11.3	9.0
RS626	1.3	2.6	2.0	4.0	11.9	8.0
RS671	0.8	1.1	1.0	2.1	4.9	3.5
Mean	1.3	2.3		4.2	9.4	

The greenhouse data showed increased SDM infection with approximately the same relative differences between high and low quality seed as the field test data with hybrids ranked in the same order of susceptibility (Table 7). Viability of RS626 low quality seed declined sharply during the 6-month storage period between field planting and greenhouse testing. Emergence of low quality seed was 49 percent with 11.9-percent infection, whereas emergence of high quality seed was 89 percent with 4-percent infection. This represents a threefold difference in SDM infection between high and low quality seed, while only a twofold difference occurred in the field test.

Seven grain sorghum hybrids were tested at Berclair in 1970 to further establish the relationship between SDM and sorghum seed quality. Commercial seed companies furnished two hybrids with high, intermediate and low levels of seed quality and two with only high and low quality seed; three Texas hybrids had three levels of seed quality. Mean germination of high, intermediate and low quality seed was 92, 81 and 69 percent, respectively; field emergence was 74, 68 and 53 percent.

The percent of infected plants, counted at 4 and 12 weeks after planting and averaged over seed quality levels, showed that the hybrids had different levels of resistance and that the percent SDM increased during the year in approximately the same relative amount for each hybrid (Table 8). SDM in commercial hybrid #2 increased proportionately more than in the other hybrids. Considering only the high and low quality seed of all seven hybrids, a significantly higher percent SDM occurred in plants from low quality seed (14.9 at 4 weeks and 13.2 at 12 weeks). In the five hybrids with three levels of seed quality, high quality seed produced plants with 7.0 and 8.8 percent SDM at 4 and 12 weeks after planting, intermediate quality seed resulted in 9.6 and 11.4 infection and low quality seed showed 11.5 and 13.5 percent, respectively.

TABLE 8. REACTION OF SELECTED GRAIN SORGHUM HYBRIDS TO SORGHUM DOWNY MILDEW AT BERCLAIR, TEXAS, 1970

Hybrid	Percent SDM 4-wk-old plants	Percent SDM 12-wk-old plants
RS671	3.9	4.9
RS626	7.7	9.3
RS625	8.0	9.7
Commercial #1	9.8	12.2
Commercial #2	14.5	21.4
Commercial #3	17.5	19.8
Commercial #4	27.6	32.1

Eight inbred lines of maize with two levels of seed quality and varying degrees of susceptibility to SDM were similarly evaluated (Table 9) (6). Germination of high and low quality seed was 95 and 80 percent, respectively, with average field emergence of 86 and 71 percent. There was a significant inbred line-seed quality interaction in maize resulting from the reaction of two lines (Tx173D and Tx303). These two lines showed a relationship between seed quality and SDM infection similar to that which occurred in sorghum.

TABLE 9. REACTION OF SELECTED INBRED MAIZE LINES TO SORGHUM DOWNY MILDEW AT BERCLAIR, TEXAS, 1970

Inbred line	Percent SDM at 4 weeks			Percent SDM at [illegible] weeks		
	High	Low	Mean	High	Low	Mean
Tx61M			1			1
Tx441			1			1
Tx508			15			31
Tx303	15	21	18	74	80	77
Tx203-2			21			41
Tx173D	44	61	53	84	91	88
Tx585			56			83
Tx501			68			99

6 Control

Resistance in Sorghum

Sorghums with resistance to SDM field infection were reported as early as 1965 by Futrell (27). Later reports (21, 22, 39) also indicate a number of resistant sorghums. These sorghums were all in the World Sorghum Collection, were screened under tropical conditions and were tall and would not mature when grown in the temperate zone daylengths of the United States. Zummo (51) reported resistance in some tall, late-maturing sweet sorghums; however, these are of limited use (directly) in breeding for resistance in grain sorghums.

None of the old standard U.S. varieties or breeding lines, except perhaps Acme Broomcorn and Tx2519, possess sufficient levels of field resistance to be very useful in breeding programs (38). As a result, commercial grain and forage hybrids were previously all moderately to highly susceptible (24). Therefore, there was a critical need for agronomically desirable, SDM-resistant lines.

The Texas Agricultural Experiment Station (TAES)-U.S. Department of Agriculture (USDA) cooperative sorghum conversion program (37) provided the source of new materials which, upon screening, revealed a number of agronomically desirable, SDM-resistant grain sorghum lines. In the conversion program, a backcross procedure is used to convert tall, late-maturing tropical varieties to early-maturing, combine-height sorghums (47).

The first materials released from the conversion program in 1969 were partially converted bulks selected because of their new, diverse germ plasm and disease resistance (11, 15). Eight bulks (Table 10) were highly resistant to SDM and were the first agronomically desirable, SDM-resistant lines available to U.S. breeders in a usable condition. Additional fully converted lines were released in 1970 and 1973 (11, 30) (Table 10). Only one TAES released line (Tx2519, a Kafir derivative) other than those derived through the conversion program, has been found to possess field resistance to SDM (22).

The first SDM-resistant grain sorghum hybrids became available for commercial use in 1972. A few others were available in 1973, and there should be rapidly increasing supplies available soon, because some of the new sources of resistance are being utilized in breeding programs throughout the United States.

Inheritance Studies

In 1967, approximately 100 F_3 rows from each of four crosses among four standard lines (CI243, CI71, Tx09 and CI556) were planted in a replicated trial at College Station (Table 11). In succeeding studies, a SDM-resistant line (BTx406 x IS2816^2) F_4(R), selected from the sorghum conversion program, was crossed with two susceptible cultivars, (BTx406 x IS5676^2) F_4(S) and Tx2536(S). Random selections were made from an F_2 population of (BTx406 x IS5676^2) F_4(S) x (BTx406 x IS2816^2) F_2(R) and an F_2 population of (BTx406 x IS2816^2) F_6(R) x Tx2536(S). Selections were planted in a completely randomized block design with four replications near Berclair. The tests were planted in soil on which sorghum with a high level of SDM infection had grown the previous year.

Stand counts and the number of systemically infected plants were recorded in both the seedling and adult plant stages of growth. No systemically infected plants were observed in the resistant parent in either the 1971 or 1972 test (Table 12).

The F_1 and F_3 data indicate that resistance is partially dominant or dominant, depending on the genetic background (Tables 12 and 11), and that more than one gene is involved (Table 11). The resistance in CI243 (Acme Broomcorn) appears superior to that in CI71 (Standard Blackhull Kafir) in terms of the proportion of resistant F_3 rows obtained. The 1971 and 1972 data indicate that the portion of resistant F_3 rows obtained is influenced by the relative susceptibility of the susceptible variety used in the cross. These data suggest that multiple genes or one major dominant gene with modifiers controls the inheritance of resistance in the line derived from IS2816.

Resistance Incorporation

Sorghum varieties with SDM resistance can be obtained in several ways. The most reasonable

TABLE 10. SOURCES OF RESISTANCE TO SORGHUM DOWNY MILDEW IN SORGHUM RELEASED BY THE TEXAS AGRICULTURAL EXPERIMENT STATION

Designation	Variety, kind or derivation	Conversion[1] number	Group	Year released
Tx 2519	Kafir derivation			1964
TAM Bk-15	IS 2266	SC 93	Caudatum	1969
TAM Bk-21	IS 2573	SC 64	Caudatum/Kafir	1969
TAM Bk-24	IS 1335	SC 418	Caudatum/Kafir	1969
TAM Bk-25	IS 12608	SC 108	Zerazera	1969
TAM Bk-26	IS 12609	SC 109	Zerazera	1969
TAM Bk-27	IS 2816	SC 120	Zerazera	1969
TAM Bk-28	IS 12611	SC 170	Zerazera	1969
TAM Bk-40	IS 3569	SC 502	Durra/Nigricans	1969
IS 2266C	PI 217684	SC 93	Caudatum	1970
IS 2403C	PI 239441	SC 103	Caudatum	1970
IS 2482C	PI 152593	SC 311	Dochna	1970
IS 2483C	PI 152594	SC 309	Dochna	1970
IS 2573C	PI 152736	SC 64	Caudatum/Kafir	1970
IS 2579C	PI 152750	SC 423	Zerazera	1970
IS 2816C	PI 267474	SC 120	Zerazera	1970
IS 3579C		SC 425	Caudatum/Durra	1970
IS 7009		SC 268	Conspicuum/Nigricans	1970
IS 7064C		SC 420	Caudatum/Kafir	1970
IS 12608C	PI 257595	SC 108	Zerazera	1970
IS 12609C	PI 257598	SC 109	Zerazera	1970
IS 12610C	PI 257599	SC 110	Zerazera	1970
IS 12617C	PI 276772	SC 126	Durra/Subglabrescens	1970
IS 12622C	PI 276782	SC 131	Durra/Dochna	1970
IS 12662C	PI 276838	SC 171	Caudatum/Nigricans	1970
IS 12664C	PI 276840	SC 173	Zerazera	1970
IS 12666C	PI 276842	SC 175	Zerazera	1970
IS 2508C		SC 414	Caudatum/Kafir	1973
IS 3574C		SC 239	Zerazera	1973
IS 12563C	PI 151303	SC 44	Dochna/Amber	1973
IS 12568C	PI 152702	SC 56	Caudatum/Nigricans	1973
IS 12612C	PI 257603	SC 112	Zerazera	1973
IS 12656C	PI 276828	SC 165	Caudatum/Nigricans	1973
IS 12658C	PI 276830	SC 167	Durra/Bicolor	1973
IS 12685C		SC 224	Dochna/Leoti	1973
IS 12553	PI 148101	SC 33		

[1]The "SC" number denotes the code by which these sorghums were identified during conversion.

TABLE 11. PERCENT OF F_3 ROWS WITH DIFFERENT NUMBERS OF PLANTS SYSTEMICALLY INFECTED WITH SDM, COLLEGE STATION, TEXAS

	1967 Study						
	Percent systemically infected plants						
Designation	0.0	0.1–2.0	2.1–4.0	4.1–10.0	10.1–20.0	20.1–30.0	30.1–40.0
(Acme Broomcorn x Standard Blackhull Kafir)F_3	48.1	32.1	10.4	9.4	0.0	0.0	0.0
(Tx 09 x Acme Broomcorn)F_3	35.2	34.0	16.0	9.3	3.7	1.2	0.6
(Standard Broomcorn x Acme Broomcorn)F_3	13.3	26.5	17.3	29.6	8.2	4.1	1.0
(Standard Broomcorn x Standard Blackhull Kafir)F_3	4.6	9.2	27.6	33.3	17.2	4.6	3.5
	1971 Study						
	0.0	0.1–10.0	10.1–20.0	20.1–30.0	30.1–40.0	40.1–60.0	60.1–90.9
[(B Tx 406 x IS 5676[2])F_4 x (B Tx 406 x IS 2816)[4]F_4]F_3	9.4	25.0	27.0	16.2	9.4	9.4	3.4
	1972 Study						
	0.0	0.1–2.0	2.1–4.0	4.1–7.0	7.1–20.0	20.1–40.0	40.1–46.2
[(B Tx 406 x IS 2816[3])F_4 x Tx 2536]F_3	24.7	18.2	18.2	16.9	14.3	5.2	2.6

approach is to improve adapted varieties through plant breeding. The ways by which a gene or genes influencing disease reactions are inherited become important, not only in the host but in the pathogen as well, as development of plants resistant to disease is attempted.

Resistance, as used here, means any reduction in damage associated with the specific host-pathogen interaction. This may include any or all terms defined elsewhere for tolerance, field resistance, hypersensitivity or immunity. Regarding the sorghum-SDM complex, it is known that

1. Sorghum is a self-pollinated species which can be manipulated as a cross-pollinated species.
2. Within *Sorghum* sp. there is good resistance to SDM. It is found in most classification groups of sorghum; exists, to a degree, in some U.S. materials; and appears, at high levels, in both exotic and converted forms of sorghum.
3. Resistance to SDM presently in use is known to be inherited as a partially dominant trait and conditioned by at least one major gene with several modifiers.
4. Field, greenhouse and laboratory inoculation procedures exist which will separate varietal reactions to SDM.

By combining these bits of knowledge, researchers have the necessary key information which can be used to build a plant breeding program which incorporates SDM resistance into high-yielding sorghum lines.

Most male-sterile and normal Kafir varieties grown in the United States possess a degree of resistance to SDM (38). Most male parents or R-lines of U.S. hybrids (that is, milos, feteritas, Shallus and yellow endosperm feterita types) are susceptible to the disease. The resulting hybrids vary in their degree of susceptibility but are generally less susceptible than their male parents (Table 13).

TABLE 12. PARENTS AND F_1 HYBRIDS USED IN SORGHUM DOWNY MILDEW RESISTANCE INHERITANCE STUDIES AND THEIR REACTION TO SORGHUM DOWNY MILDEW, COLLEGE STATION, TEXAS

Designation	Percent infection
1967 Study	
CI243 (Acme Broomcorn)	0.0
CI71 (Standard Blackhull Kafir)	1.1
Tx09 (Double Dwarf White Feterita)	3.0
CI556 (Standard Broomcorn)	21.6
1971 Study	
(BTx406 x IS2816[3])F_4 (SC120-6sel)	0.0
(BTx406 x IS5675[4])F_4 (SC474-6sel)	64.0
1972 Study	
Tx2536	36.0
A378 x Tx2536	27.6
A399 x Tx2536	10.0
(BTx406 x IS2816[3])F_4 (SC120-6sel)	0.0
A3197 x (BTx406 x IS2816[3])F_4	0.0

TABLE 13. AVERAGE INCIDENCE OF SYSTEMIC SORGHUM DOWNY MILDEW IN SELECTED HYBRIDS AND THEIR MALE PARENTS AT BERCLAIR, TEXAS

Hybrid	Percent SDM	
	Hybrid	Male parent
A378 x Tx2536	19	30
A399 x Tx2536	20	30
A3197 x Tx414	7	13
A378 x Tx414	5	10
A378 x Combine Shallu	13	12

With recent releases of SDM-resistant elite lines and the accessibility of different sources, resistant material is now available for developing resistant lines and hybrids. Such techniques as selection, hybridization, reselection and performance testing are being used to develop and evaluate resistant lines and hybrids.

Converted and partially converted selections from the sorghum conversion program have been field tested to determine their respective levels of SDM resistance. Those superior grain types with resistance have been selected and hybridized with elite parents of present grain sorghum hybrids. Basically, the program in Texas is a backcross and pedigree-selection method with field screening. Several sources of resistance have been used in making the original crosses, but occasionally a different source was used for a second cross to resistant stocks. Most of the material has had only one, or occasionally two, crosses to the SDM-resistant lines, followed by selection for acceptable agronomic characteristics.

Vertical resistance is often associated with one or certainly few genes imparting resistance to specific races of pathogens, whereas horizontal resistance results from many modifiers or multiple genes conditioning reaction to disease. Vertical resistance can be transferred easily by utilizing the backcross breeding method, but breeding for horizontal resistance is more difficult. If one can associate a particular character with horizontal resistance per se (that is, few rust pustules with high levels of generalized resistance versus many pustules with low levels), selection for that trait can be exercised, and normal breeding procedures will suffice. Probably the most practical method of developing horizontal resistance is to select for "field resistance" and not be concerned with the individual components of resistance. Field resistance in the kafir group, for instance, is higher than in the feterita group as a whole.

Previously, sorghum breeders relied heavily on the use of vertical resistance for control of diseases such as head smut (race 1 and 3), milo disease, kernel

smut and rust. Resistance was easy to transfer from one variety to another but sometimes became ineffective. Horizontal resistance is often polygenic and more difficult to manipulate in a breeding program, but the advantages of prolonged protection and the reduction of inoculum at the end of each season warrant consideration. There are strong indications that a horizontal or generalized resistance to SDM exists in sorghum.

The inheritance of SDM resistance appears to be relatively simple (42) and should be easily transferred to any stable line using the backcross procedure with selection. The fact that inheritance patterns have not been well established leads to a degree of concern if horizontal resistance to SDM is desired. Field screening of resistant lines, their hybrids and their progeny indicates that the resistance could be vertical. However, greenhouse inoculations of these same resistant sources (Table 5) indicate that resistance may not be vertical. Although TAES researchers are using resistant materials which have been tested in many areas of the world, vertical resistance may be masking the desired horizontal resistance. They are prepared to circumvent this by using different techniques of disease resistance transfer. One technique consists of selection and backcrossing of presently available materials.

TAES researchers have obtained a high degree of resistance in progeny rows, and it effectively controlled SDM in the F_1 hybrid (Table 14). Selection and field testing are continuing.

Disease resistance is concurrently being transferred in random mating populations of sorghum which contain various sources of SDM resistance. Materials tested in other areas of the world which show resistance are incorporated with materials which develop only a few diseased plants, thereby increasing the genic base of resistance to SDM. As these populations are random mated and become more heterogenous, the disease-resistant germ plasm is not only maintained, it becomes recombined. These populations can be selected for resistance using either direct selection or cyclic-selection methods. The chances of

TABLE 14. UTILIZATION OF CONVERTED MATERIALS IN TRANSFER OF SORGHUM DOWNY MILDEW RESISTANCE TO ELITE LINES[1]

Pedigree	No. of check plants		No. of rows (lines)		No. of rows (hybrids)	
	Total	Susceptible	Susceptible	Resistant	Susceptible	Resistant
A399 x Tx2536	28	6				
A378 x Tx2536	36	7				
A3197 x Tx414	33	1				
Tx412	25	25				
Tx7078	16	4				
Tx7000	40	2				
Tx2536	20	8				
Tx415	35	3				
IS12610C	46	0				
IS12661C	48	0				
IS12608C x Tx7078			21	31	2	10
Tx414 x IS12608C			9	26	0	7
Tx414 x IS12608C			8	16		8
IS12610C x Tx414				6		
Tx414 x IS12610C			5	8		
IS2816C x Tx414			17	31	8	13
Tx414 x IS12661C			17	23	2	10
Tx09 x IS12661C			8	11	3	2
IS12610C x Tx7000			18	13	1	1
IS2816C x Tx7000			21	29	2	5
Tx7000 x IS12661C			11	30	1	3
Tx2536 x IS12609C			4	10	1	
IS12610C x Tx2536			13	11	1	1
Tx2536 x IS12610C			21	14	2	
IS12661C x Tx2536			43	120	5	19
Tx2536 x IS12661C			26	16	4	4
Tx2536 x IS12664C			13	28	2	1
SA9101 x IS12610C			9	5	4	
IS12661C x SA9101			2	2		
SA9101 x IS12664C			7	10	2	3
Rio C x IS12610C			6	20		4
IS12568C x IS12661C			5	30		11
IS12553 x IS2816C			1	11		
BTx378 x IS12610C			17	45	2	16
IS2816C x BTx617			2	17		

[1]Observations based on selected F_3 heads grown as F_4 rows at Beeville and Berclair under natural field infections of sorghum downy mildew.

realizing horizontal resistance from direct selection and pedigree breeding are not as good as from a cyclic-selection procedure. There are selection schemes which should be employed to search the heterogenous disease-resistant populations for horizontal resistance to SDM. These include recurrent selection and S_1 line and half-sib testing.

Several populations utilizing partially converted and converted downy mildew and other disease resistant lines along with agronomically elite germ plasm have been started by The Texas Agricultural Experiment Station. These populations use MS_3 to obtain random mating contain individual plants with resistance to all the . jor sorghum diseases, greenbug and midge resistance and lodging resistance in elite, high-yielding germ plasm. These populations differ from the two Kansas-developed populations described later in that they were developed from good agronomic lines only, while the Kansas populations used many original sources of resistance that were undesirable agronomically.

A cooperative program between The Texas Agricultural Experiment Station, the Kansas Agricultural Experiment Station and the U.S. Department of Agriculture for the development of SDM-resistant broad-based populations of grain sorghum and sudangrass was started in 1973. Research personnel of The Texas Agricultural Experiment Station, Kansas State University and the Federal Experiment Station in Puerto Rico are participating in this program.

In the grain sorghum populations, attempts will be made to combine resistance to *S. sorghi* with resistance to Periconia root rot, anthracnose, maize dwarf mosaic and greenbugs by alternating cycles of selection and recombination. Development of this population was started with selection among half-sib families for resistance to greenbugs and SDM. Duplicate sets of the S_1 lines produced in Puerto Rico will be used to provide a separate population for

1. Selection for resistance to SDM in Texas and greenbugs in Kansas
2. Yield trials in Kansas
3. Selection for resistance to anthracnose in Mississippi
4. Selection for resistance to maize dwarf mosaic in Kansas
5. Selection for resistance to SDM in Texas
6. Production of S_2 lines and selection for agronomic characters with S_1 parents in Kansas

The S_2 progeny of S_1 lines selected by the tests for yield and pest and disease resistance will be planted in a recombination nursery in Puerto Rico to provide material for the next cycle of selection.

The development of an SDM-resistant sudangrass composite utilizes an antherless type of sudangrass to achieve the required genetic recombination. Half-sib families from antherless plants grown in Puerto Rico are tested for SDM resistance in the greenhouse in Kansas, and families which appear resistant are used to plant a seed production plot.

The half-sib families and S_1 lines produced in this plot are tested for resistance to *S. sorghi* in downy mildew nurseries in Texas. Remnant seed of the resistant half-sib families and S_1 lines will be used to plant a recombination nursery in Puerto Rico. At harvest, seed from antherless plants are selected to provide half-sib families for the next cycle of selection for SDM resistance.

Resistance in Maize

It appears inevitable that SDM will eventually become established in the Corn Belt. A large number of U.S. leading maize inbreds are susceptible to this disease (16, 17) (Table 15). Of the ten leading U.S. inbreds, the majority (B37, W64A, B14, A632, A239, H84 and CI66) were rated as susceptible. Only Oh43,

TABLE 15. REACTION OF POPULAR MAIZE INBREDS TO SORGHUM DOWNY MILDEW (*SCLEROSPORA SORGHI*) AS EVALUATED UNDER FIELD CONDITIONS AT BEEVILLE AND BERCLAIR, TEXAS

Designation	Number of seasons tested	Highest incidence of downy mildew
A239	1	11
A251	1	60
A257	1	39
A509	1	78
A554	1	40
A619	1	4
A632	1	45
A634	1	100
A635	1	92
B14	1	100
B14A	3	100
B37	4	83
B57	5	45
C103	1	2
C123	1	3
CI21E	3	76
CI44	1	100
CI64	3	99
CI66	1	56
H49	4	100
H84	2	60
K55	1	4
K64	1	30
Ky226	1	10
Mo5	3	100
Mo17	3	22
N28	3	100
Oh7B	1	85
Oh43	2	6
Oh51A	1	68
Va35	3	94
W59N	1	81
W64A	1	41
W117	1	0
W153R	1	75
W182B	1	55

W117 and C103 were resistant with A619 showing moderate resistance.

Most of the inbred lines available in the United States have been screened for SDM resistance in Texas. Of the Corn Belt lines, W117, Oh43, C103, C123, Ky201, A297 and A619 can be classified as resistant; Ga209, SC152, SC154, T232, Tx441, Tx601 and CI31A (Southern lines) also showed resistance (Table 16).

Two diallele tests were grown in 1972 to investigate the inheritance of SDM (5). Test I was composed of Texas lines (Table 17); in all cases resistance appeared to range from dominant to intermediate. Test II was composed of Texas and other selected Southern lines (Table 18). Again resistance appeared to be dominant with the exception of the crosses with AR200. AR200 is extremely susceptible and tends to carry its susceptibility into crosses; it either carries an additional gene for susceptibility or its susceptibility is dominant.

TABLE 16. SOME MAIZE INBREDS MODERATELY OR APPARENTLY RESISTANT TO SORGHUM DOWNY MILDEW (*SCLEROSPORA SORGHI*) AS EVALUATED UNDER FIELD CONDITIONS AT BEEVILLE OR BERCLAIR, TEXAS

Designation	Highest observed incidence or sorghum downy mildew in year tested		
	1970	1971	1972
A297		1	
A619		4	
B46	0		
B54		6	0
B70			4
B71			4
B75			4
C103	2		
C123		4	
CI31A		0	0
C190A			0
GA209		2	
H52	0		
K61-1	2		
K148	2		
K175		0	
Ky201		5	
Ky228		0	
Mo13		5	
MP317			0
N7A		0	
N7B		0	
Oh43	0	6	
SC152		0	
SC157			0
SC254		0	
SC343			6
SynD1-1		0	
T222			5
T234			6
T236			6
Tx127C		4	
Tx441	0	1	9
Tx601	0	0	0
W117			0
33-16	2	46	5
38-11	4		

TABLE 17. AVERAGE INCIDENCE SORGHUM DOWNY MILDEW IN TEXAS MAIZE HYBRIDS AND THEIR PARENTS AT BEEVILLE, TEXAS, 1972

Line	Percent SDM					
	Tx303	Tx325	Tx508	Tx127C	Tx441	Tx601
Tx303	100	51	26	17	14	9
Tx325		80	75	25	40	10
Tx508			100	27	12	5
Tx127C				0	3	13
Tx441					5	5
Tx601						0

On the basis of observations of these and other crosses, it is concluded that there are at least two and possibly three genes controlling resistance or susceptibility to SDM. In double-cross hybrids, each addition of a resistant line in the hybrid will increase the resistance of the hybrid. Breeding systems based on individual plant selections generally are not effective in breeding for SDM resistance since large numbers of escapes occur under conditions dependent on natural infection.

Maize lines and hybrids, developed for downy mildew resistance in Southeast Asia, were evaluated at Berclair in 1970 (Table 19). Some of these also showed good resistance to SDM in South Texas.

Cultural Control Methods

Cultural control of plant diseases refers to those methods by which man indirectly reduces disease severity by manipulation of plant growth patterns and the environment without the direct use of biological or chemical agents. With chemical control currently under public scrutiny, emphasis on cultural methods to enhance the biological or genetic resistance to disease has reappeared.

Since oospores of *S. sorghi* overwinter in the soil and in plant debris, sanitation or destruction of crop residues as soon after harvest as possible is prudent when economically feasible. Another method of attack at the infection court, the destruction of soil-borne oospores by ultrahigh-frequency electromagnetic fields, is currently being investigated. This new technique shows great promise for control of weeds and nematodes (9); the subsequent reduction of the incidence of SDM in infested soil by UHF fields promises an exciting bonus from this revolutionary technological development (18). Frederiksen *et al.* (19) reported that deep-plowing (burying the surface soil and debris to a depth of 10–12 inches) reduced the incidence of SDM. Grain sorghum hybrids grown under conditions of reduced inoculum exhibited a 5-percent disease incidence compared with 20-percent infection in control plots.

The probability that a damaging epiphytotic will occur is reduced when improved grain sorghum hybrids with higher levels of resistance are grown in

TABLE 18. AVERAGE INCIDENCE OF SORGHUM DOWNY MILDEW IN SOUTHERN MAIZE HYBRIDS AND THEIR PARENTS AT BEEVILLE, TEXAS, 1972

	Percent SDM					
Line	AR200	GA172	Mo12	SC152	Tx441	Tx601
AR200	100	99	100	81	69	48
GA172		96	100		12	26
Mo12			100		60	31
SC152				4	3	1
Tx441					4	6
Tx601						2

place of sorghum-sundangrass hybrids. These grain hybrids yield less inoculum and, when subjected to lower inoculum pressure, usually escape damaging losses.

Based on the assumption that continuous monoculture allows the fungus to continue its life cycle uninterrupted, resulting in a gradual buildup in the soil, crop rotation may be a feasible method of control. The disease averages from a number of hybrids examined in Wharton County illustrate inoculum buildup during a 3-year period of continuous sorghum cropping (15). The average incidence of systemically diseased plants rose from 2.4 percent in 1967 to 17.6 percent in 1969 (Figure 11). Reports vary as to soil-borne oospore persistence. *S. sorghi* oospore survival has been monitored by Frederiksen and Tuleen (25). When susceptible sorghum cultivars were planted in infested soil stored at room temperature, no infection appeared after 3 years, whereas the same soil stored at 1° C continued to yield infected plants under test conditions. Soil moisture did not appear to affect oospore persistence under room temperature storage (Figure 12). Purified oospores from ground and sieved leaves (Table 4, technique 1) similarly lost their ability to infect after 3 years' storage at room temperature, but remained viable when stored at 1° C and 10° C.

TABLE 19. PERCENT INFECTION OF MAIZE PLANTS IN THE INTERNATIONAL DOWNY MILDEW NURSERY GROWN IN THREE REPLICATES AT BERCLAIR, TEXAS, 1970

Entries	Country of origin	No. of plants	Percent SDM
CM 105	India	99	53
Taiwan DMR Composite 1	Taiwan	77	7
Taiwan DMR Composite 2	Taiwan	91	3
Taiwan DMR Composite 3	Taiwan	93	10
MIT x Cuba Gr. 1	Philippines	96	6
Chain DMR Synthetic	Philippines	83	2
College White x Tuxpeno	Philippines	100	2
Ph 9 DMR	Philippines	83	1
MIT x Flint	Philippines	75	1
Composite AMAR			
Bogor Synthetic II	Indonesia	114	7
Peer Rehovot	Israel	10	100
TX 441	Texas, USA	102	0
TX 601	Texas, USA	100	0
Caribbean Composite	Mexico	100	52
Susceptible Controls			
CM 110	India	78	56
Taiwan #5	Taiwan	68	94
La Granja yellow popcorn	Philippines	111	57
TX 303	Texas, USA	71	76

Chemical Control

Soil fumigants have been used to control brown stripe downy mildew of maize caused by *Sclerospora rayssiae* (46), but earlier attempts to control SDM by soil-incorporated fungicide was unsuccessful (15). Recently, Matocha *et al.* (36) obtained striking control of SDM by using low rates of potassium azide (KN_3).

The incorporation of KN_3 into oospore infested soil significantly reduced the disease incidence in greenhouse trials (Table 20). Although no infection was present at application rates over 67 parts per million (ppm), high concentrations of KN_3 had an adverse effect on seed germination and plant growth. Concentrations of 200 and 1,000 parts per million resulted in almost total loss of seed germination.

In field trials at Beeville, KN_3 markedly reduced SDM. At 0.56 kilogram per hectare (kg/ha) the disease incidence was reduced to 7 percent from 25.4 percent in the untreated plots; 1.12 kilograms per hectare decreased the incidence of the disease by a factor of 10 when compared with the control. As the rate of KN_3 increased beyond 1.12 kilograms per hectare, the incidence of disease was lowered further;

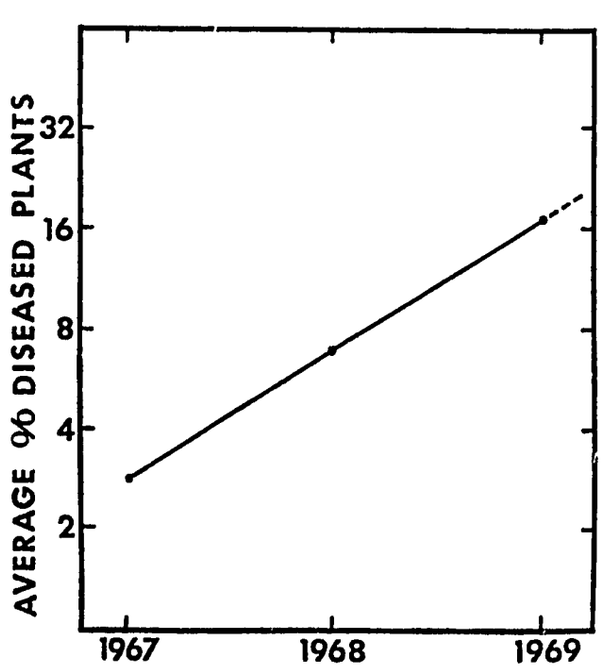


Figure 11. Average incidence of sorghum downy mildew observed in 86 sorghum hybrids grown 3 consecutive years on a Wharton County site.

however, at these higher rates KN_3 became more phytotoxic. A rate of 1.12 kilograms per hectare of KN_3 could be considered sufficient for practical control of SDM when applied in the drill row.

Fungicide activity of an azide is influenced by soil pH (40). Adams *et al.* (1) report increased phytotoxicity of KN_3 when pH was increased from 5.0 to 7.0. Goliad fine sandy loam (pH 6.7) and Orelia sandy clay loam (pH 7.2) appeared not to alter the phytotoxicity of KN_3 in these trials. Since many South Texas soils have a pH in excess of 7.8, further tests in other soil types will be necessary to determine whether KN_3 fungicidal activity or phytotoxicity is altered.

Although there is no evidence for the mode of action of KN_3 in these studies, it appears to reduce oospore inoculum in the field effectively at low rates and thus provide temporary protection from infection by soilborne inoculum.

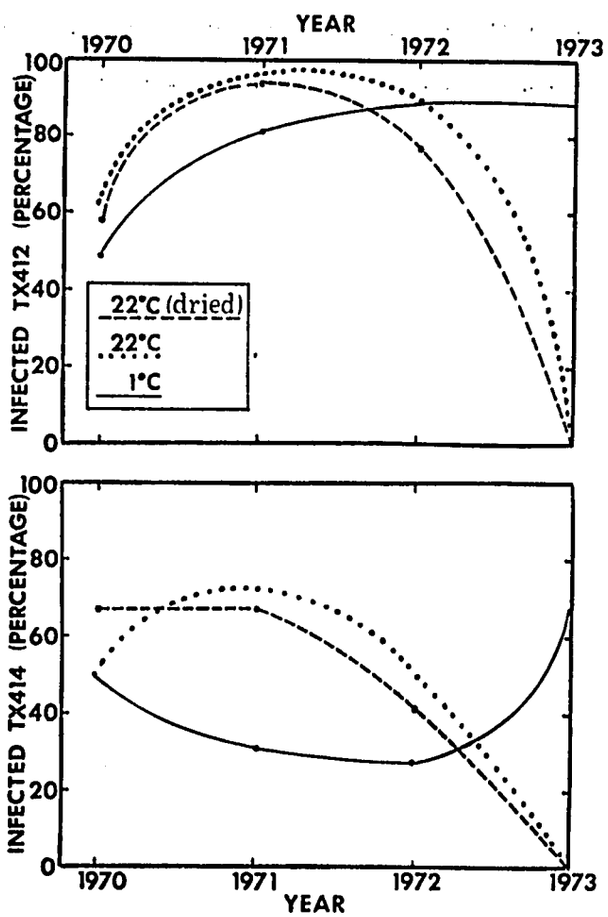


Figure 12. Means of two sorghum cultivars infected by soilborne oospores of *S. sorghi* stored for 3 years at 22° C, dried and stored at 22° C and stored at 1° C (soil not dried maintained approximately 1 percent moisture).

TABLE 20. EFFECT OF POTASSIUM AZIDE ON STAND COUNT AND SORGHUM DOWNY MILDEW INCIDENCE

Amount KN_3	Test method	No. of plants	Avg ht	Percent SDM
	Greenhouse[1]			
0		32	13.2 cm	60.7
17 ppm		30	9.1 cm	7.1
67 ppm		22	4.9 cm	0
200 ppm		3	2.5 cm	0
1000 ppm		0		0
	Field trial[2]			
0				25.4[a,3]
0.56 kg/ha				7.0[b]
1.12 kg/ha				2.6[bc]
2.24 kg/ha				2.1[bc]
4.48 kg/ha				0.4[bc]

[1]Tx412 and Tx414 planted in infested soil (Table 4, technique 2) at 27° C.

[2]Planted at Beeville, 1971; fertilized with 20–15–0 at 336 kg/ha.

[3]Means not followed by the same letter differ significantly at the 5% level of probability, Duncan's Multiple Range Test. Data are means from four replicates of approximately seven meter plots.

TABLE 21. REDUCTION IN THE INCIDENCE OF SORGHUM DOWNY MILDEW IN MAIZE (Tx28A) BY INCORPORATION OF ZINC IN THE SEED BED[1]

Zn (kg/ha)[2]	Percent SDM[3]
0.0	36.4[a,4]
1.12	24.6[b]
3.36	16.0[c]
10.08	13.6[c]
30.24	11.2[c]

[1]Data from unpublished Regional Project S-80, courtesy of Warren Anderson.

[2]Zinc applied as $ZnSO_4$.

[3]Based on an average of five replicates of 50–60 plants each.

[4]Means not followed by the same letter differ significantly at the 1% level.

Fertility levels appear to influence SDM incidence also. Higher levels of available soil nitrogen favor disease incidence in sorghum (36). Low levels of zinc reduce the incidence of SDM in maize (Table 21). The effect of low levels of zinc ($ZnSO_4$) was first observed by Matocha (35) in a nursery designed to study the effect of zinc on maize development. The zinc probably affects plant growth and development in some manner which reduces the probability of systemic infection by *S. sorghi*.

7 Outlook

Internationally, downy mildews represent one of the more damaging diseases of maize and sorghum; consequently more, rather than less, cooperative research should be initiated if the real and potential threat of further introduction or international distribution of downy mildew pathogen species is to be understood and circumvented. The rapid expansion of maize acreage in the tropical and temperate regions further increases the concern for knowledge of downy mildews and their control. In addition, an understanding of the downy mildews can elucidate plant disease in general and the interactions of living organisms.

Just how far SDM will spread within the continental United States is difficult to estimate. While it was observed in limited areas in both Kentucky and Missouri in 1972 (M. C. Futrell, personal communication), the rate of spread should have been slowed considerably for several reasons.

Foremost, sorghum for seed production is infrequently grown on fields with histories of SDM; thus, the likelihood of long distance spread by infested seed should be reduced. Soil temperature at planting appears to influence significantly the susceptibility or severity of SDM in maize. As the disease continues north, this parameter will exert greater influence on reducing both severity and ultimate distribution of SDM.

Those portions of the Corn Belt which have relatively warm summers and indigenous populations of johnsongrass should not expect to escape the disease. SDM already may have appeared in an occasional field in southern Illinois, Indiana and Ohio but remained undetected because it does not spread rapidly in these areas.[1] Even in areas, such as South Texas, which are well adapted to the disease, the spread has been slow. However, caution is warranted since the introduction of a new genotype has been known to trigger an epidemic. The introduction of a new grain sorghum hybrid to northern Mexico in the spring of 1973 was sufficient stimulus to make a previously stabilized disease rampant. Unfortunately this hybrid had only one obvious shortcoming: it was extremely susceptible to SDM. Even though this area of Mexico had for many years experienced very little SDM in sorghums, the introduction of a new cultivar made SDM a major disease.

The threat of SDM to grain sorghum and maize acreage in Texas is lessened because cultural practices have been altered to control the disease. Even along the Gulf Coast, where grain sorghum monocultures constitute the major cropping sequence, the incidence of SDM has remained low. This is attributed to 1) use of resistant and moderately resistant hybrids, 2) reduced cultivation of susceptible green manure sorghum-sundangrass hybrids and 3) planting maize early in the season.

With the advent of resistant cultivars, variation in the pathogen becomes a greater menace. Data from Thailand suggests a possibility that physiologic races of *S. sorghi* exist. The threat of the introduction of *S. philippinensis, S. sacchari* and new races of *S. sorghi* to the Western Hemisphere necessitates a continued surveillance of maize and sorghum germ plasm under present rigorous conditions until satisfactory levels of resistance are attained for cultivars adapted to other regions.

Etiology of *S. sorghi,* particularly in regard to survival, germination and physiology of both sexual and asexual spores, poses many unanswered questions. Oospore germination under laboratory conditions is erratic and needs more careful study. Conidia are short lived and fragile and can be produced in quantity only from infected sorghum leaves. Consequently, adequate methods for assaying plant resistance with equal levels of viable inoculum are lacking. Further observations concerning maturation and conditioning of inoculum as it overseasons should provide insight

[1]Sorghum downy mildew was identified in at least two new areas in the Corn Belt during the summer of 1973: Southern Indiana, personal communication, W. H. Warren; and Northwestern Kentucky, personal communication, A. S. Williams.

into its dormancy and survival. This information could provide confidence for cultural control recommendations.

Biological agents probably account for destruction of tremendous quantities of inoculum. Oospores and conidia observed in the laboratory are readily invaded by bacteria. Cultural control of this downy mildew pathogen may be enhanced by slight modifications in agricultural practices. These practices, in turn, may be useful in controlling other downy mildew diseases.

Research is needed to further clarify the nature of the host-parasite interaction. An understanding of SDM resistance will aid in the development of techniques for screening and testing and subsequent development of superior sources of genetic resistance.

Recent advances in the development of systemic fungicides suggest possibilities regarding chemical control of downy mildew. These possibilities, vigorously pursued, could result in an ability to check the spread of downy mildew by use of fungicides if it is found in new regions of the Corn Belt.

New, different and unexpected diseases and disease problems will occur. The histotry of SDM in Texas is an example of only one threat to maize and sorghum cultivation. SDM, as well as diseases of the future, can be controlled only through the continued efforts of many concerned individuals.

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