Earl B. Minton
ARS, USDA, Cotton Physiology and Genetics Research Unit, Stoneville, MS

Richard H. Garber
ARS, USDA, U.S. Cotton Research Station, Shafter, CA

Controlling the Seedling Disease Complex of Cotton

Seedborne and soilborne organisms, both flora and fauna, acting singly or in combination, produce the seedling disease complex of cotton (17) (Fig. 1). Most of the pathogens involved are ubiquitous fungi that are associated with many other hosts as well as with cotton wherever it is grown. Pathogenic nematodes are often associated with these fungi, and the combination of these organisms can cause more severe disease problems than fungi alone. Each pathogen produces effects that become a complex of interrelated symptoms caused by several organisms simultaneously attacking seed and seedlings. The disease syndrome includes various amounts of preemergence rotting of seed and seedlings, chlorosis and necrosis of seedlings both before and after emergence, stunting, and wilting. The incidence of seedling disease is influenced primarily by adverse temperature and soil moisture. Any condition favoring faster development of the pathogen than the host, however, can be detrimental (9).

Pathogens

Pythium ultimum Trow, *Rhizoctonia solani* Kühn, *Thielaviopsis basicola* (Berk. & Br.) Ferr., and *Fusarium* spp. are the most important soilborne pathogens associated with diseased seed and seedlings in the United States. Many additional but less virulent seedborne and soilborne organisms may influence the disease intensity. The prevalence and virulence of causal organisms differ from field to field and from one area of the cotton belt to another.

Bacteria and species of *Rhizopus*, *Alternaria*, *Aspergillus*, and *Fusarium*, either alone or in combination, are often associated with seed rot. *Glomerella gossypii* Edg., a seedborne and soilborne fungus, causes seedling blight. *Fusarium oxysporum* Schlecht. f. sp. *vasinfectum* (Atk.) Snyd. & Hans., sometimes a seedborne pathogen but more frequently a soil inhabitant, often causes seed and seedling losses. Nematodes, especially *Meloidogyne incognita* (Kofoid & White) Chitwood, damage the roots of cotton and increase their susceptibility to infection by *F. oxysporum* f. sp. *vasinfectum* and other pathogens (4). The foliar fungus *Ascochyta gossypii* Woron. and the bacterial blight organism *Xanthomonas campestris* pv. *malvacearum* (Smith) Dye often affect older cotton plants but can also cause significant seedling losses.

Symptoms

The symptoms associated with each organism that causes deterioration of cottonseed and infection of seedlings are not unique, and visually diagnosing the primary causal pathogen is often difficult. A poor stand may be the first evidence that the seed were infected before or soon after they were planted (Fig. 2). Many seed fail to germinate after an attack by one or more seedborne or soilborne pathogens. A diseased seed is usually completely deteriorated and when squeezed between the fingers, the contents ooze from the tip.

Many seedlings that fail to emerge are destroyed very quickly after the radicle grows beyond the seed coat (Fig. 3). This type of damage may range from destruction of the radicle tip, resulting in cessation of elongation at various stages before emergence, to complete deterioration of the radicle. If the radicle is not completely destroyed or if radicle elongation is stopped but lateral roots develop, the seedling may have enough energy to emerge slowly. Severely diseased plants that survive even though part or all of the taproot is killed and produce lateral roots above the stub of the taproot are called "nub root" plants (Fig. 4). The lateral roots that form may grow deep into the soil and partially replace the taproot, but ordinarily only shallow-growing lateral roots develop. Although plants with only shallow lateral roots can survive when soil moisture and heat stress are minimal, excessive midseason heat may either kill them or cause severe fruit shedding even though the available soil moisture is adequate for development of plants with normal root systems. For adequate production, nub root plants usually require small amounts of water at frequent intervals.

The hypocotyl of cotton seedlings forms a crook during emergence, and this crook usually reaches the soil surface before the cotyledons (Fig. 5). As the hypocotyl straightens in the process of rapid elongation and emergence, the cotyledons are almost literally dragged through the covering soil. During this period, the cotyledons are subject to attack by pathogens. Symptoms of attack range from marginal to complete necrosis of the cotyledons. It is not uncommon for cotton seedlings to have healthy root systems but diseased hypocotyls (Fig. 6). The disease syndrome ranges from yellowish brown necrotic streaks 0.5–1 cm long to complete girdling of the hypocotyl. The girdled tissues may vary in appearance from a soft, watery tan, to shades of brown tinted with red or orange, to a dark brownish black.

The taproots of plants infected by *Thielaviopsis* are often reduced in diameter and shriveled. Frequently, the central stele of a diseased plant is not destroyed. The plant may recover, slough off the necrotic epidermal and cortical tissues, and produce lateral roots.

Plants that survive attack from seedling diseases are usually weakened, unthrifty, and less productive and more susceptible to other pathogens than

Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

healthy plants. Seedling diseases can kill a high percentage of the seed and seedlings and cause low yields because of plant skips and nonuniform stands (Fig. 2). Often in these cases, replanting the field is warranted. Lush weed growth also may occur in the skips. Insects can build up on the weeds and may migrate to the cotton. Cotton plants adjacent to the skips produce long heavy branches that are difficult to harvest mechanically.

Control

The first step in controlling seedling diseases of cotton is the selection of high-quality planting seed produced under optimum conditions for full development of the embryo and without field deterioration. During processing, some seed with low density and reduced vigor are removed from seed lots by mechanical separation, leaving primarily the more vigorous medium-density seed for planting. Seed exposed to high moisture and high temperature either before or after harvesting may deteriorate rapidly. Seed damaged mechanically or chemically during harvesting, ginning, or processing should not be planted.

Traditionally, cotton cultivars have been selected for rapid germination and emergence under mild to adverse disease conditions. Bird (2), however, has selected MAR (multi-adversity-resistant) cultivars on the basis of slow germination of seed and emergence of seedlings at low temperatures. The seed of MAR cultivars are more resistant to mold growth and rot than the seed of most commercial cultivars. The seedlings of MAR cultivars are resistant to many pathogens, have high cold tolerance, and normally produce taproots rather than nub roots. Because of their cold tolerance and resistance to seedling pathogens, MAR cultivars can be planted earlier in the season than non-MAR cultivars. Under the Leach (9) concept, the suboptimum temperatures tolerated by MAR cottonseed should restrict the advantage of the pathogens, as the seed germinate and emerge at temperatures less favorable for the pathogens. The seedlings, therefore, escape infection, which provides us with another dimension for controlling seedling diseases. A 1981 test was conducted with three MAR cultivars in California (E. B. Minton, R. H. Garber, L. S. Bird, and J. E. DeVay, *unpublished*) in a field naturally heavily infested with *R. solani*, *P. ultimum*, and *T. basicola*. The number of surviving seedlings was significantly higher with the MAR cultivars than with Acalas developed locally and a Mississippi commercial cultivar (Fig. 7).

In the rain belt, seed should be planted when temperatures and moisture of the soil are favorable for cotton. In irrigated soils, cotton should be planted after the soil moisture at planting depth has drained to field capacity. Also, the forecast should be for sunny, dry weather for several days after planting.

One of the most important factors influencing seedling disease losses is planting depth. Seedling emergence from seed planted at great depths is delayed because soil temperature decreases with depth. In addition, the seedlings must grow through more soil before reaching the surface, and hypocotyl tissue is exposed to pathogen attack for longer periods. Therefore, seed should be planted only as deep as necessary to ensure adequate moisture for seed germination and seedling growth. Planting depth, therefore, varies according to the moisture-holding capacity of each soil and from one area of the country to another.

Soil temperature at seed depth is important and is directly influenced by air temperature, seed covering depth, and exposure to sunlight. Raised seedbeds expose more soil surface to the sun's rays and seed and seedlings grow more rapidly because the sun warms and dries the soil more quickly than on flat land. Plant debris from the previous crop should be destroyed and buried immediately after

Fig. 1. Group of seedlings dying from seedling diseases (left) compared with healthy seedling (right).

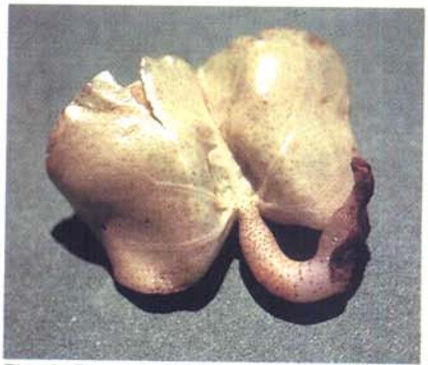

Fig. 3. Preemergent cotton seedling with completely diseased radicle.

Fig. 4. "Nub root" seedlings resulting from disease, chemical, or mechanical damage to taproot.

Fig. 2. Poor stand of seedlings resulting from severe seedling disease.

Fig. 5. Cotton seedling hypocotyl emerging before cotyledons.

Fig. 6. Cotton seedlings with surface soil removed to expose profile of hypocotyls. The seedling on the left is healthy. The other seedlings are still alive even though girdled by *Rhizoctonia*. The seedling second from left appears healthy above the ground but is diseased below the ground.

Fig. 7. Cotton seedlings in soil infested with *Rhizoctonia solani*, *Pythium ultimum*, and *Thielaviopsis basicola*. MAR (multi-adversity-resistant) cultivar (third from left) is more resistant than commercial cultivars in adjacent rows.

harvesting and seedbeds should be uniformly firmed to minimize seedling disease.

All cottonseed used for planting is cleaned, delinted, graded, and coated with one or more protectant and systemic fungicides. Protectant fungicides are applied to all planting seed to kill or inhibit the growth of pathogens that are seedborne and those that occur in the soil near the seed. Systemic seed treatments are absorbed by the roots of seedlings and then translocated to the hypocotyl. Seed protectants together with systemic fungicides provide protection against both preemergence and postemergence diseases. Most fungicides have been selected for their capacity to control specific pathogens. Therefore, for maximum protection against the organisms anticipated in a given location, two or more specific fungicides are usually used in combination (Fig. 8). Plant stands were similar when seed from the same seed lots were coated with the same fungicides by commercial seed treatment applicators and by application in a small cement mixer (15).

In 1971, when fungicides containing mercury were withdrawn from registration for use as seed treatments, effective replacements were available because of the efforts of the Cottonseed Treatment Committee of the Cotton Disease Council (11,16). The list of fungicides suggested for coating cottonseed for each state is revised periodically on the basis of performance data (12).

Recent development of fungicides formulated as flowable suspensions has improved application over that of wettable powders (13). These new formulations usually are easier to handle, provide more uniform coverage, and adhere to the seed coat more readily than the wettable powders.

Pentachloronitrobenzene (PCNB) was one of the first fungicides reported to control the specific fungus *R. solani* (1,3,10). In the following years, several chemicals, including chloroneb (Demosan) and carboxin (Vitavax), were identified and used commercially to control this pathogen. Fenaminosulf (Lesan, formerly Dexon) was identified in the mid-1950s to control *P. ultimum*. Since then, ETMT has also been shown to be highly effective against *P. ultimum*. Several broad-spectrum fungicides are also used as seed and supplemental treatments for cotton, both singly and in combination with more specific compounds. For example, captan, thiram, TCMTB (Busan), captafol (Difolatan), and the zinc ion-maneb complex mancozeb (Dithane M-45) are not as effective for controlling *R. solani* and *P. ultimum* as the specific fungicides mentioned and are usually combined with other fungicides.

The above compounds do not effectively control *T. basicola*, a fungus that is a problem on cotton in the irrigated western states and in some areas of the rain belt. This fungus rarely kills seedlings but usually delays their growth. Several fungicides that show promise in controlling *T. basicola* were developed recently but are not available commercially. For example, seed treated with benomyl (Benlate), imazalil, CGA-64250, and CGA-65251 have produced seedlings with significantly improved disease ratings (6).

The number of new experimental fungicides has been reduced by the high cost of developing pesticides. Nevertheless, some very promising new fungicides to control *P. ultimum* and *R. solani* have been tested for several years. One of these is metalaxyl (Apron, Ridomil), which has shown excellent control of *Pythium* in both greenhouse and field trials. BAS 389 and CGA-64251, which is also effective against *T. basicola*, are promising new materials to control *R. solani*. These materials are not available for commercial use. However, octhilinone (Kathon), a relatively new broad-spectrum fungicide, was recently registered for use on cottonseed.

Fig. 8. Seed of row on left were not treated. Seed of row on right were coated with two fungicides to protect against *Rhizoctonia solani* and *Pythium ultimum*.

Most soils are infested with several seedling pathogens. The diversity of both seedborne and soilborne pathogens warrants the use of a combination of several fungicides to control seedling diseases (10). Severe disease outbreaks may not be controlled even with combinations of seed treatments. Additional protection can be obtained from supplemental fungicides that are similar to the ones used as seed dressings. These fungicides are applied either as dusts mixed with the seed or as sprays or granules in the seed furrow during planting. The addition of dilute fungicide dusts, such as captan plus PCNB or similar fungicides, to the seed as they are packaged for planting or put into the seed hopper of the planter can significantly increase protection from diseases over that obtained with the use of seed dressings only. Because these dust fungicides fall by gravity at variable rates along with the seed into the seed furrow, disease control may not be uniform. Many combinations of fungicides sold as seed treatments to control *Pythium* and *Rhizoctonia* are also available as granules or sprays to be applied in the seed furrow at planting (5,7). Dust, granule, and spray fungicide formulations are used at higher rates than, and in addition to, the seed dressings; thus greater protection is obtained but at increased cost. In addition, the granule and spray formulations require specialized application equipment that must be closely monitored for optimum results.

Seedling diseases are largely controlled by fungicides, although crop rotations with grass or grain crops help to lower inoculum levels of pathogens in the soil. A direct relationship occurs among inoculum levels, disease incidence, and fungicide performance (8,14). Seedling disease control by selection of disease-resistant cultivars has not been emphasized in the development of most commercial cottons. A notable exception is the release of the MAR cultivars developed and released in Texas by Bird (2). Among the most exciting research being actively pursued by university, government, and industry scientists is the field of biological control of diseases. The aim of their research is to increase the populations or activities of nonpathogenic organisms that compete with or are antagonistic to pathogens. It remains to be seen whether plant pathologists can learn to manipulate bacterial and fungal populations to minimize seedling diseases of cotton.

Seedling diseases can be controlled by integrating our knowledge of the effects of cultural practices, environmental factors, chemical and biological agents, and the genetics of cotton on both the host and the pathogens. Cotton producers must select those practices that best apply to their specific problems and economic threshold.

Earl B. Minton

Dr. Minton is a research plant pathologist with ARS, USDA, working in cooperation with the Mississippi Agricultural and Forestry Experiment Station at Stoneville. He received his Ph.D. degree in plant pathology in 1964 from Auburn University. He began his cotton research in 1952 with the USDA at Stoneville and has conducted research in cooperation with the Alabama Agricultural Experiment Station (1956–1964) at Auburn, the Texas Agricultural Experiment Station (1964–1979) at Lubbock, and the Mississippi Agricultural and Forestry Experiment Station (1979 to present). He is a past secretary and chairman of the Cotton Disease Council and has been consulted internationally.

Richard H. Garber

Dr. Garber is research plant pathologist project leader at the U.S. Cotton Research Station, Shafter, California. He obtained his B.S. degree from Geneva College, his M.S. degree from Colorado State University, and his Ph.D. degree from the University of California, Davis. His professional career in the USDA began in 1954 at Davis and has continued at Shafter, where he is working with soilborne and seedborne plant pathogens of cotton. His research interests have included Verticillium and Fusarium wilts, seed and soil fungicide treatments, and the ecology of soilborne pathogens. He is a past chairman of the Cotton Disease Council and has consulted and lectured internationally.

Literature Cited

1. Arndt, C. H. 1953. Evaluation of fungicides as protectants of cotton seedlings from infections by *Rhizoctonia solani*. Plant Dis. Rep. 37:397-400.
2. Bird, L. S. 1978. TAMCOT CAMD-E A multi-adversity resistant cotton variety. Tex. Agric. Exp. Stn. L-1720.
3. Brinkerhoff, L. A., Oswalt, E. S., and Tomlinson, J. T. 1954. Field tests with chemicals for the control of *Rhizoctonia* and other pathogens of cotton seedlings. Plant Dis. Rep. 38:467-475.
4. Brodie, B. B. 1964. The seedling disease complex as influenced by plant parasitic nematodes. Page 83 in: Proc. Cotton Dis. Council. National Cotton Council, Memphis, TN.
5. Chambers, A. Y. 1977. Report of the soil fungicide committee—1976. Pages 9-10 in: Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.
6. DeVay, J. E., Garber, R. H., Weinhold, A. R., and Wakeman, R. J. 1981. Comparisons of selected fungicide seed treatments against *Rhizoctonia solani, Pythium* and *Thielaviopsis basicola*. Pages 24-28 in: Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.
7. Garber, R. H. 1961. Improving cotton stands through in-furrow treatments. Pages 2-4 in: Proc. West. Cotton Prod. Res. Conf.
8. Garber, R. H., DeVay, J. E., Weinhold, A. R., and Matheron, D. 1979. Relationship of pathogen inoculum to cotton seedling disease control with fungicides. Plant Dis. Rep. 63:246-250.
9. Leach, L. D. 1947. Growth rates of host and pathogen as factors determining the severity of pre-emergence damping-off. J. Agric. Res. 75:161-177.
10. Leach, L. D., Garber, R. H., and Lange, W. H. 1959. Cottonseed treatment trials in California, 1954–1958, with special reference to specific fungicides. Plant Dis. Rep. Suppl. 259:213-221.
11. Minton, E. B. 1974. Status of non-mercurial seed treatments, 1967–73. Pages 5-9 in: Proc. West. Cotton Prod. Res. Conf.
12. Minton, E. B. 1980. Report of the cottonseed treatment committee for 1979. Pages 12-15 in: Proc. Beltwide Cotton Prod. Res. Conf. National Cotton Council, Memphis, TN.
13. Minton, E. B., and Green, J. A. 1980. Germination and stand with cottonseed treatment fungicides: Formulations and rates. Crop Sci. 20:5-7.
14. Papavizas, G. C., Lewis, J. A., Minton, E. B., and O'Neil, N. R. 1980. New systemic fungicides for the control of cotton seedling disease. Phytopathology 70:113-118.
15. Paulus, A. O., Nelson, J. A., Shibuga, F., and Garber, R. H. 1976. Treating cotton seed cuts losses to damping-off. Calif. Agric. 30(10):15.
16. Ranney, C. D. 1971. Effective substitute for alkyl mercury seed treatments for cottonseed. Plant Dis. Rep. 55:285-288.
17. Watkins, G. M., ed. 1981. Compendium of Cotton Diseases. American Phytopathological Society, St. Paul, MN. 87 pp.