Fusarium and Nematodes on Cotton

Albert L. Smith

Wilt of cotton resembles the wilt disease of tomato, cowpeas, watermelons, cabbage, and several other crops. It is primarily a disease of the water-conducting vessels of the woody or stem part of the plant and is caused by a fungus that inhabits the soil.

The disease is complicated by nematodes, the celllike microscopic worms that also inhabit the soil and provide the openings through which the wilt fungus enters cotton roots. Nematodes reduce the root growth and increase the susceptibility of cotton plants to fusarium wilt. Thus the disease is considered a wilt-nematode complex.

Some nematodes enter the tip end of young roots. Others enter and feed on the root tissue some distance back from the tip. The root knot nematode makes galls, or knots, on roots, which later decay and leave the ends of the water-conducting vessels open and exposed to soil-borne organisms. The meadow nematode, feeding some distance from the root tips, may cause a pruning off of the small rootlets.

The wounds made by those and other species of nematode provide numerous openings for the wilt fungus, Fusarium oxysporum f. vasinfectum. Once the wilt pathogen gets into the vascular system, which conducts water to all parts of the plant, it can grow and spread throughout the woody portion. In the vascular ducts it may be found in pure culture, and appears especially
adapted to grow in this tissue while most other organisms from the soil are excluded.

The wilt disease of cotton is distributed throughout the world wherever American cottons are grown in acid alluvial sandy soils. Pathologists believe the disease originated in Mexico or Central America in the same locality as upland cotton. The wilt fungus is carried inside cotton seeds and has been transported by the seed to new cotton-growing areas. In the United States the disease occurs in all States from Virginia to eastern Oklahoma and Texas. It is limited in those States by low rainfall and alkaline soils. Greatest losses occur in Coastal Plain soils of the Carolinas, Georgia, and Alabama. Wilt is also an important disease in Arkansas, Louisiana, Mississippi, and southeastern Texas. Although the disease is more severe in the sandy soils, it occurs in the lighter soils scattered throughout some of the heavier soils series of the Piedmont and Mississippi Delta regions.

Losses to the cotton crop from the wilt-nematode disease complex have been greater than those caused by any other disease except possibly Texas root rot. Losses in yields result from reduced stands, stunted plants, small bolls, and poor-quality lint. Before the development, distribution, and general use of wilt-resistant varieties, losses to individual growers often amounted to 75 to 90 percent of the crop. The growing of sea-island cotton had ceased on many acres before 1902, when Rivers, a resistant variety, became available. The first wilt-resistant upland variety, Dillon, was released in 1905. Estimates of crop losses beginning in 1920 indicate wilt losses from 1 to 5 percent for the different States. Additional losses from the root knot nematode ranged from a trace to 3 percent. Between 1940 and 1950 the release of improved wilt-resistant varieties brought further reductions in wilt losses. Now the losses from nematodes and wilt together probably do not exceed 3 or 4 percent in any State.

Symptoms of wilt may appear on cotton plants at any stage of development. The earliest symptoms to be seen on seedlings and small plants are the yellowing and browning of cotyledons and leaves. The affected parts ultimately die and fall off. The bare stem soon blackens and dies. The first symptom in older plants may be stunting, followed by yellowing, wilting, and dropping of most of the leaves. Leaf discoloration first appears near the margin of the blade near a vein. The affected areas enlarge, and an abscission layer may form at the base of the petiole, causing the leaf to drop.

An outstanding symptom is the browning and blackening of the woody tissue. When a stem or branch is cut crosswise, the discoloration is usually found in a ring just beneath the bark. Sometimes the discoloration is dispersed through the woody cylinder. In advanced cases, discoloration may extend throughout the plant from the roots through the stem, branches, leaf petioles, and peduncles and into the bolls.

Wilting mostly occurs gradually, but after a rain, following a dry period, plants may wilt suddenly and in large numbers. Wilted plants may produce some bolls, which usually are smaller and open prematurely. Plants may die one at a time until the stand is reduced or largely eliminated, depending on the susceptibility of the variety and the amount of infestation.

The wilt fungus survives in the soil on organic matter. It grows as a threadlike mycelium and produces two kinds of spores. One type, known as conidia, is relatively short-lived. The second type, chlamydospores, is a resting stage, which may live longer. Both types give rise to a mycelium that infects the roots of the host plants.

Dissemination by spores probably accounts for the rapid spread of the disease to all parts of a field once the disease is introduced by cotton seed. Spores may be washed about in the field or blown about by the wind or
transported by many other means. The wilt fungus lives in the soil indefinitely once it is introduced even though cotton and other susceptible plants are not grown. Fields not planted to cotton for as long as 25 years have shown severe wilting the first year after cotton planting was resumed. No method of eradicating the organism economically from fields is known.

Many laboratory experiments indicate that with large amounts of inoculum the fungus enters healthy cotton roots in the absence of openings made by nematodes. Field experiments show that the openings caused by nematodes largely account for the infections occurring naturally. In experiments at the Alabama Agricultural Experiment Station, I found that wilt is readily controlled with soil fumigants, which reduce or eliminate nematodes before planting.

After entering the small roots, the fungus inhabits the water-conducting vessels and spreads by growth of the mycelium and by movement of spores upward in the water stream. The vascular tubes become browned and later blackened by the formation of gum-like substances and by growth of tyloses. Plugging or partial plugging of the vessels lowers the flow of water and uptake of salts from the soil and stunts the plant or causes wilting. Toxic products, which injure the host cells, are also produced by the fungus. Browning, drying, and killing follow; the ultimate falling of most leaves is a symptom largely produced by toxic materials. When bolls are present, the mycelium may grow through the peduncle into the seed. After the plant dies, the organism invades all its tissues; if enough moisture is present, spores are produced, which may be spread to all parts of fields.

The root knot nematode is the most common of the nematodes that affect cotton roots. It occurs on cotton roots in all lighter soils of the Cotton Belt. The immature larvae infest cotton plants by invasion through the soft root tips. After entering the tip, the larvae push their way between the cells. Then they become stationary and feed by puncturing all the cell walls within reach with a spearlike stylet and sucking out the juices from inside the cell. The affected cells grow much larger and proliferate to form knots, or galls. With susceptible varieties and the feeding of large numbers of nematodes, the knotlike enlargements may become a half-inch in diameter. Tissues in the galls are quite soft and are likely to decay and leave the ends of vascular bundles exposed to the wilt fungus. The enlarged worms are filled with eggs, which hatch and release numerous young nematodes. They, in turn, feed on any new cotton rootlets in the vicinity. Some cotton plants become infected by wilt when quite young; perhaps the mycelium enters the root tissue with the young larvae as well as later when the galls decompose.

If nematodes have made many points of entry for the fungus, multiple infections gradually envelop the root system, even in fusarium-resistant plants of upland cotton. The meadow or root rot nematode (Pratylenchus pratensis) multiplies rapidly on corn, crabgrass, and other fibrous rooted crops, following which it might become the predominant species on cotton. The meadow nematode is also found abundantly in some soils too heavy in texture to support the root knot nematode. It may enter the soft cortical root tissue at any point near the growing zone. In feeding, the female moves about, destroying cells and depositing eggs throughout a short segment of the root. The young larvae intensify the destruction of the cortical tissues so that usually the rootlet is cut off. Many openings are thus left for the wilt organism to enter directly into the vascular tubes.

The sting nematode or coarse root nematode (Belonolaimus gracilis) is a third type that provides openings for the wilt fungus. The sting nematode
does not enter roots but feeds on cortical root cells from the outside. It is one of a group of ectoparasites, or free-living nematodes, which complete their life cycle outside the root, entirely in the soil. The fine roots are pruned off leaving many openings accessible to the wilt fungus.

Direct losses in yield from nematodes alone may be of greater importance in some soils than losses resulting from the wilt-nematode complex. Serious losses occur in some irrigated soils where fusarium wilt is unknown. Losses occur throughout the lighter soils of the rain belt but often go unnoticed by growers.

The main effect of nematodes is a reduced rate of growth, which means smaller plants and lower yields. Growers are inclined to attribute them to other causes. The effect of nematodes on yield can best be demonstrated by using soil fumigants: Often they double yields in severely infested fields in both the western irrigated and eastern rain belt soils. Nematode-reducing rotations also demonstrate how great are the losses caused by nematodes. In some western soils the root knot nematode becomes the limiting factor to profitable cotton production and rotation or soil fumigation becomes necessary.

The host range of the cotton wilt fungus is limited. It may enter the roots of a number of different crops, but it produces wilt symptoms only on cotton, okra, coffee weed (Cassia tora), and some varieties of burley tobacco. The host range of the root knot nematode is extensive. It attacks and reproduces in the roots of more than 1,200 different species of plants.

Studies made by V. H. Young and W. H. Tharp at the Arkansas Agricultural Experiment Station show that the maximum growth rate of the fungus and maximum disease development require relatively high soil temperature and moisture. Soil temperatures between 80° and 90° F. were favorable for maximum disease development. Although some wilt occurs in seedlings and small plants in the field in April and May, maximum appearance of symptoms is in late June or July and August when soil temperatures are highest. In greenhouse studies, maximum wilt development was obtained at 80 to 90 percent of the water-holding capacity of the soil.

High soil temperatures also are favorable for nematode development. The soil moisture conditions that are favorable for plant growth usually are favorable for nematodes. Field observations indicate that maximum wilt development occurs during years of highest soil temperatures, which also favor maximum nematode development. High soil moisture tends to lower soil temperatures. Alternate dry, hot periods of rather long duration followed by rains provide conditions favorable for maximum wilt development.

Measures to control wilt consist of practices directed at both the wilt organism and nematodes. Resistant varieties and the use of balanced fertilizers to produce healthy plants help control Fusarium. The planting of varieties resistant to root knot, the use of root knot reducing crops in rotation with cotton, and the application of soil fumigants are important in the control of nematodes.

The early history of the wilt disease illustrates the early participation of the Department of Agriculture in the study and control of a disease threatening a major farm crop. Cotton wilt was first described by George F. Atkinson at the Alabama Agricultural Experiment Station in 1892. Atkinson also clarified the effects of wilt, which farmers confused with rust or potash deficiency. Atkinson also described the root knot nematode on cotton and found that it provided openings through which the wilt fungus entered cotton roots. The Department of Agriculture was requested to help on the wilt problem in 1895, when the disease became serious on the sea-island plantations off the coast of South Carolina. Erwin F. Smith visited the area at that time and began his studies on the wilt diseases of cot-
ton, watermelon, and cowpeas. E. L. Rivers, a sea-island plantation operator, in 1895 began the selection work that ultimately led to the production of the wilt-resistant sea-island variety that bears his name.

W. A. Orton, of the Department of Agriculture, entered the work in South Carolina in 1899. He cooperated in the later breeding phases and distribution of the Rivers variety. Orton also initiated a successful breeding program with upland cottons in 1899. The early breeding work of Rivers and Orton was the forerunner of the breeding programs that ultimately led to the practical control of cotton wilt and the wilts of other crops.

The importance of wilt-resistant varieties was demonstrated by the release of Rivers. It saved the industry that centered on the islands off the South Carolina coast and extended along the coast.

The early work by Rivers and Orton also established the plant-to-row selection method essentially as it is used by modern breeders. They picked out individual plants that had survived on severely infested soils. The following year the seed from each plant was planted in a single row. The rows that combined the best resistance and agronomic characters were then increased to establish the variety. Orton extended this method to include hybridization to improve upland varieties in work that he and associates initiated in 1899. The method was adopted by other workers in breeding flax, peas, and watermelons resistant to fusarium wilt.

The inheritance of fusarium resistance in sea-island cotton later was found to be determined by two dominant pairs of factors. The resistance in sea-island, when pure, approaches immunity. Such high resistance greatly simplified the problem of selecting for resistance; it was fortunate that the earliest breeding work was done with sea-island. Upland cotton does not possess factors for the same high degree of resistance and has not yet been bred to compare with the resistance of Rivers sea-island.

From the breeding of wilt-resistant upland varieties initiated by Orton and his associates came Dillon, which was developed from a wilt-resistant selection of Jackson's Limbless in South Carolina and released in 1905. They developed a second variety, Dixie, in Alabama. A cross between Dixie and Triumph yielded a third variety, Dixie-Triumph, which was widely grown and used extensively in later selection and crossing. Beginning in 1913 the Alabama Agricultural Experiment Station made available to growers Cook 307 and other related varieties, which were developed by H. B. Tisdale. Additional varieties released before 1940 were Cleveland, Miller, Express, Lightning Express, Super Seven, Clevewilt, Toole, and Lewis 63. Most of them matured rather late and yielded less than the best nonresistant kinds.

The long effort of breeders to produce agronomically superior wilt-resistant varieties was climaxed in 1942 with the introduction of Coker 100 wilt. It was as productive as nonresistant varieties and had other desirable characteristics such as a medium staple length, earliness, and adaptability to a wide range of growing conditions. It quickly became popular in southeastern and south central regions where wilt is a factor. Other superior wilt-resistant varieties, Empire, Stonewilt, Pandora, White Gold, and Plains, were introduced in 1940–1950.

Breeders have started efforts to transfer the greater resistance of sea-island to upland. Greater resistance is also available in the wild, or 13-chromosome, cottons of Asia and the Americas. Geneticists doubled the chromosome numbers of wild species and were then able to cross them with upland varieties. Attempts are being made to improve the wilt resistance of modern varieties by using crosses with the wild, or 13-chromosome, cottons.

A moderate amount of root knot resistance is associated with fusarium
resistance in varieties developed in the Southeast and selected on wilt- and nematode-infested soils. In the process of selecting for fusarium resistance and high yield in segregating progenies, moderate resistance to root knot is obtained without specific effort on the part of the breeder. This resistance contributes to the fusarium resistance and to the yield of such lines. High resistance to root knot is not present in any upland varieties. However, there are considerable differences between the most susceptible and the most resistant ones. Varieties combining both fusarium resistance and moderate root knot resistance are Stonewilt, Coker 100 wilt, and Plains. Several varieties considered susceptible to root knot are Rowden, Miller, Deltapine, Bobshaw, Stoneville, Empire, and Pandora.

A search for high resistance to root knot was made at the Alabama Agricultural Experiment Station in 1951. A number of the world cotton species and many types and varieties were planted, and the roots were later examined for size and abundance of galls. Several sources of resistance were found, the most promising of which were Gossypium barbadense var. darwinii and two wild cottons from Mexico. The latter two introductions from Mexico are much like upland (G. hirsutum) but are not productive. These three were crossed and backcrossed to productive upland varieties. The segregating progenies will be selected for root knot resistance and further backcrossed. Eventually high root knot resistance in combination with desirable agronomic characters will be obtained. Improved root knot resistance will increase the yields of varieties grown on infested soils and should also improve the resistance to fusarium wilt.

The use of balanced fertilizers to maintain a vigorous growth of cotton plants is an important cultural practice to prevent losses from cotton wilt. Potash tends to reduce wilt losses. Nitrogen and phosphorus tend to increase wilt within certain limits. The proper balance of nitrogen, phosphorus, and potash gives the maximum yields and best control of wilt when no one of the three elements is deficient. Cotton rust, or potash deficiency, was early confused with cotton wilt. George F. Atkinson discovered that ample application of potash prevented the occurrence of rust. Rust on cotton continued to cause serious losses and increased the losses from wilt until 1926, when American sources of potash were developed, which provided ample supplies at a reasonable cost.

Nematocides can control fusarium wilt and nematodes and thereby can double yields of resistant varieties and triple and quadruple the yields of susceptible varieties grown on soils heavily infested by both pathogens. In experiments in Alabama in 1947, I learned that wilt is controlled indirectly by destroying the nematodes. The yields are increased as a result of control of both the wilt and nematodes. On treated plots better stands are maintained, the plants grow off more rapidly, grow larger, and produce greater yields.

Most economical control is obtained by applying the material in the row at the rate of 6 to 8 gallons an acre a few days before planting. Materials giving satisfactory control are ethylene dibromide and a mixture of dichloropropene and dichloropropane. Their trade names are Dowfume W-40 and D-D. Row application gives control of nematodes in a zone near the young plants. Once the plants are established and growing rapidly, later nematode infections do little damage to the crop. Annual applications are necessary if only the row application is made.

Rotating cotton with crops that reduce the amount of root knot is a cultural practice of value in reducing wilt losses and increasing yields. Crops
that reduce root knot nematodes are grasses, sorghum, small grains, corn, peanuts, crotalaria, velvetbeans, alfalfa, and nematode-resistant cowpeas.

Several crops that are particularly susceptible to root knot tend to intensify wilt and nematode losses. Among them are cowpeas susceptible to root knot, annual lespedezas, sweet-potatoes, and tobacco.

Crops grown during mild winters for green manure sometimes increase populations of root knot to the extent of causing increased losses in the cotton crop that follows them. Blue lupine, Austrian winter peas, and vetch are examples. On the contrary, increased organic matter is beneficial in improving yields and reducing wilt losses.

Rotations help to control other diseases of cotton. An example is ascochyta blight of young plants, which sometimes becomes epidemic. Rotation is likewise of value against bacterial blight infections in the Southwest and irrigated valleys, where plant refuse is not decayed over winter.

The rotation of cotton with other crops has not become a widely used practice. Farmers are reluctant to follow some other crops with cotton, particularly peanuts and hay crops, which exhaust the soils of some minerals to the extent that yields of cotton may be reduced. Other reasons may have to do with the accessibility of the land to the house, weeds, and the tendency to select the most productive land for cotton.

ALBERT L. SMITH is a graduate of Oklahoma Agricultural and Mechanical College and the University of Wisconsin. He joined the Department of Agriculture as a pathologist in 1936 to work on cotton diseases and breeding for disease resistance. Most of his time has been devoted to studies on fusarium wilt and nematode disease of cotton. Plains, a wilt-resistant variety of cotton was developed by him and released in 1949. He is stationed at the Alabama Polytechnic Institute in Auburn.

The Rot That Attacks 2,000 Species

Lester M. Blank

Cotton root rot, caused by the soil-inhabiting fungus Phymatotrichum omnivorum, flourishes on more than 2,000 species of wild and cultivated plants. Cotton grows in most of the area where the fungus is present, and the disease is usually designated as cotton root rot, although it also attacks the roots of trees, shrubs, fruits, and vegetables. The monocots—grasses, corn, sorghum, and such—are considered immune to it.

The fungus occurs naturally in the alkaline soils of the southwestern United States and northern Mexico. It has not been found in other parts of the world. The disease is serious in parts of Texas, Oklahoma, New Mexico, Arizona, and northern Mexico. It has been reported in California, Nevada, Utah, Arkansas, and Louisiana. It is particularly damaging in the blackland prairie of central Texas.

It has been alarmingly destructive. In Arizona, the average yearly loss between 1924 and 1929 was 10.3 percent. Losses in Texas were estimated at 130,000 bales in 1918, 314,000 in 1919, 630,000 in 1920, 444,000 in 1928, 300,000 in 1937, and 191,000 in 1939. Those were reductions in yields of 5 to 15 percent.

The losses fluctuate from year to year according to acreage in cotton and the moisture conditions under which the crop is grown. High temperature and high soil moisture favor the development of the disease.