2001 Current Status of Fusarium Wilt in the United States and Future Challenges

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ABSTRACT

Fusarium wilt was first observed in the United States in 1892. With the observance of the disease in Australia in 1992, it is now present in all major cotton producing areas of the world. During this time, much research has been conducted on the biology and ecology of the pathogen, and on the management of the disease. While tremendous advancements have been made in our knowledge of the pathogen and the disease, there are still many areas that need to be researched. The interaction with the root-knot nematode plays a significant role in disease severity and management, but the nature of the interaction is not completely understood. The damage to Pima cotton in California being caused by race 4 emphasizes the importance of identifying races of the pathogen in the United States. Associated with the identification of races, a set of cotton differentials is needed to be used in conjunction with DNA-based techniques. Effective disease management is still an elusive goal. Resistance of cotton cultivars to Fusarium wilt and the root-knot nematode has improved, but higher levels of resistance are needed. Some of the most effective management strategies, crop rotation and chemical control, are directed at the root-knot nematode. But these strategies are not effective against isolates of the pathogen that cause considerable disease without the nematode. Fusarium wilt has been a problem for over 100 years and will continue to provide challenges for the future.

Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *vasinfectum*, was first observed in Alabama in 1892 (Atkinson, 1892). The disease now occurs in all of the major cotton producing areas of the world and occurs on all four of the domesticated cottons, *Gossypium arboretum* L., *G. barbadense* L., *G. herbaceum* L., and *G. hirsutum* L. Although losses are variable within a country or region, losses in heavily infested fields planted to susceptible cultivars can be high. In 2005, over 81,000 bales were lost in the United States based on disease loss estimates prepared by the Cotton Disease Council (Blasingame, 2006).

Although much has been learned over the last 100 years about the pathogen, the disease, and how to manage the disease, there is still much to learn. The identification of a virulent strain of the pathogen in Australia, the presence of race 4 of the pathogen in California and its effect on Pima cotton, and increased incidence of Fusarium wilt in some areas of the United States have stimulated a renewed interest in the pathogen and the disease.

Interaction with the root-knot nematode. Since the first observation of Fusarium wilt, it was also observed that the disease is more severe in the presence of the root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood (Atkinson, 1892). This interaction is probably the most widely recognized disease complex in the world. Although much has been learned about this complex, the exact nature of this interaction is not understood.

It has been suggested that the nematode may be responsible for transmitting the fungus. Although it is possible that fungal spores are transmitted on the cuticle of the nematode, this has not been documented (Mai and Abawi, 1987). The ability of nematodes to vector the pathogen through feeding does not appear to be plausible, because the stylet is too small for fungal spores to enter (Mai and Abawi, 1987).

There is still widespread belief that the root-knot nematode provides entry sites for the fungus through wounds produced during feeding, despite research that indicates the relationship is more complex. Inoculation studies determined that wilt was greater when nematodes were inoculated 2 to 4 weeks prior to the fungus, which indicates that wounding is not critical (Powell, 1971). Other studies have shown that wilt severity was less from mechanical wounding than from wounds caused by the root-knot nematode (Jenkins and Coursen, 1957), and some nematodes, despite their ability to feed on cotton, do not form a complex with the fungus (Holdeman and Graham, 1954). Anatomical studies of roots infected by the root-knot nematode demonstrated that there was no increase in fungal colonization at the site of nematode feeding (Perry, 1963). These studies indicate that the nature of the interaction is more complex than physical wounding providing entry.

Stem layering studies showed that the factors responsible for predisposing plants to Fusarium infection were translocatable (Webster, 1985). Increased susceptibility of plants to wilt appears to be systemic, because plants infected with the nematode are more susceptible to stem inoculation (Hillocks, 1985). It is now understood that the interaction is related to complex biochemical and physiological changes, but the exact nature is still not clearly understood.

Race designation. Using a differential set of hosts that include plants other than cotton, 8 races of the pathogen have been identified (Armstrong and Armstrong, 1978; Chen et al., 1985). Since hosts other than cotton have been used to distinguish between these races, there are some questions about the significance of these designations. Race is meant to describe a genetic relationship between a pathogen and a host. Techniques using DNA are now available to distinguish between races and have provided important information about the genetic relationship between races of the pathogen. Most of these techniques indicate that races 1, 2 and 6 are similar (Assigbetse et al., 1994; Kim et al. 2005, Skovgaard et al., 2001), which coincides with pathogenicity to cotton hosts in the differential tests. Despite the availability of DNA-based techniques to characterize races, there is a need for a standard set of differential hosts to correlate the conclusions of these DNA techniques with host susceptibility.

The appearance of a new strain of the pathogen in Australia has renewed interest in the distribution of races of the pathogen in the United States. Historically, different races of the pathogen have been associated with specific areas of the world. Only races 1 and 2 were identified in the United States, and race 2 was restricted to a small area in South Carolina (Armstrong and Armstrong, 1960; Kappelman, 1983). Recent research has identified races 1, 3, 4, and 8 in California, and described severe losses to Pima cottons caused by race 4 (Kim et al., 2005). Races 1, 3, and 8 have also been identified from the mid-South of the United States (unpublished data, 2004). Given that fact that races have differential reactions to cotton cultivars, a thorough survey of races is needed. The distribution of races will be important in breeding for resistance and in developing management strategies from different cotton growing regions.

Disease management. Although some advances have been made in the managing Fusarium wilt, the disease is still difficult to manage. Because of the close association with the root-knot nematode, some success in management of wilt has been obtained by focusing management strategies at the nematode.

Host resistance offers the best opportunity to manage Fusarium wilt. Many of the early wilt resistant cultivars produced lower yield and fiber qualities than wilt susceptible cultivars (Ebbels, 1975). Cultivars with moderate levels of resistance and agronomically favorable traits have been developed. Kappelman (1980) evaluated planting material from 1969 to 1978 and determined that the most significant improvements in wilt resistance occurred since 1975. In 1986, Shepherd and Kappelman (1986) evaluated 18 cultivars and breeding lines and noted that lines developed after 1965 had higher resistance than lines developed prior to 1965. None of these lines had high levels of resistance. The cotton cultivar Siscot F1, which has improved resistance to strains of the fungus in Australia, was released in Australia in 2004 (Reid et al., 2004).

Because the root-knot nematode can increase the incidence of Fusarium wilt in both resistant and susceptible cultivars, planting cultivars with resistance to the nematode can reduce disease severity. Unfortunately, the development of cultivars with high levels of resistance and agronomically favorable traits has been disappointing (Davis et al., 2006; Starr and Smith, 1993). Only moderate resistance to the root-knot nematode is available in only a few commercial cultivars (Koenning et al., 2001; Robinson et al., 1999). It is also important that transgenic cultivars be screened for resistance. The transgenic relative of a resistant cultivar was more susceptible to the nematode and resulted in greater disease severity (Colyer et al., 2000).

It has been suggested that wilt resistance could be developed by breeding for high levels of nematode resistance (Shepherd, 1974), but breeding for wilt resistance could make an impact on disease control even though nematodes increased wilt severity on both resistant and susceptible cultivars (Hillocks, 1992). Kappelman and Bird (1981) suggested that indirect selection for nematode resistance could be based on wilt symptoms. Starr and Veech (1986) caution that indirect selection for nematode resistance might not be adequate in some cultivars because the interaction might be cultivar specific. The lack of an interaction between nematodes and strains of the pathogen in Australia (Davis et al., 1996) and race 4 in California (Kim et al., 2005) emphasizes the importance of screening germplasm and cultivars for wilt resistance independently from nematode resistance.

Crop rotation is often recommended as a management strategy, but rotations may not be adequate, the fungus usually persists indefinitely in infested soils (Smith et al., 2001; Wood and Ebbels, 1972). The pathogen was able to survive in fields not planted to cotton for over 10 years (Armstrong and Armstrong, 1948; Smith et al., 2001). Survival is enhanced by the ability to colonize the roots of several weed hosts (Smith and Snyder, 1975; Wood and Ebbels, 1972). These studies indicate that rotation would have a limited impact on disease management.

Since root-knot nematodes increase the incidence of wilt, crop rotations to reduce nematode populations may be helpful in reducing wilt. Root-knot resistant soybeans, grain sorghum, and peanuts are good rotation crops for managing populations of the root-knot nematode in the soil (Kirkpatrick and Sasser, 1984). Fallowing is not an effective strategy unless weeds are controlled, since many weeds are also hosts of the root-knot nematode (Davidson and Townshend, 1967; Davis and Webster, 2005). These data suggest that long rotations would be necessary to reduce populations of the nematode and the fungus, and some rotations might not be economically feasible for producers.

Chemical management of wilt has not been successful. Seed treatments have been reported to eliminate the pathogen from seed (Allen and Kochman, 2001; Hillocks, 1992), and might be effective in limiting the spread of the pathogen on planting seed. These treatments most likely would be ineffective in infested fields, because of the ability of the fungus to survive in the soil and invade hosts after the active ingredient has dissipated.

The contact nematicide aldicarb reduced root galling and stem discoloration across eight cultivars with different levels of resistance to the disease complex (Colyer et al., 1997). Fumigants that reduce root-knot nematode populations have been shown to reduce the incidence and severity of Fusarium wilt (Hyer at al., 1979; Jorgenson, et al., 1978; Smith, 1948). Fumigation is generally regarded as being too expensive to provide a return, but recent data indicates that 1-3 dichloropropene can provide an economic return (Williams et al., 2002).

Soil solarization reduced the survival of the pathogen in the soil and reduced the incidence of wilt (Ben-Yephet et al., 1987). Although solarization appears to be effective, it is not economically feasible for large-scale cotton production. In addition to the costs associated with implementing solarization, treated fields are out of production for 1 year during the solarization. Tillage practices impact both fungal and nematode pathogens in the soil (Minton, 1986; Sumner at al., 1981), but the impact on Fusarium wilt has not been thoroughly researched. Because of the ability of the fungus to survive in the soil for extended periods, tillage is expected to have little impact. Reduced tillage procedures may reduce the spread of the pathogens within a field (Minton, 1986).

Future challenges. Knowledge about the *Fusarium oxysporum* f. sp. *vasinfectum* and wilt has improved in the 100 years since it was first observed, but significant challenges remain. A survey of races of the pathogen is needed, particularly in the United States. Since there are potential differences in the response of cotton cultivars to different races of the pathogen, information about the distribution of races will be important for breeding programs and the development of resistant cultivars. Associated with the survey of races, a standardized set of host differentials is needed to correlate pathogenicity with DNA techniques. The failure of cultivars with moderate resistance to the disease in the United States to provide resistance against strains of the pathogen from Australia emphasizes the need for a standard set of differential hosts.

Screening techniques for resistance to the pathogen need to be rigorous. Plants are often observed with few or little foliar symptoms, but are colonized by the pathogen and do exhibit stem discoloration (Colyer and Vernon, 2002; Davis et al., 2006). The role of this non-symptomatic parasitism on yield is not well understood, but it is possible that plants are being selected for the absence of foliar symptoms, but not for infection. Failure of plants to show obvious symptoms may also lead to an underestimation of disease losses.

With the lack of host resistance, management remains elusive and additional research is needed in this area. Most of the management studies in the United States were based on the assumption that they involved race 1 of the pathogen. With the recent reports of the existence of other races in the United States, these management strategies may not be sufficient. Race 4 in California and the strains from Australia, which do not interact with the root-knot nematode, cannot be managed by strategies directed at the nematode. These isolates provide an additional challenge for management.

Fusarium wilt has been an interesting problem for producers and scientists for over 100 years. Recent developments indicate the problem will continue for years to come and justifies the need for continued research.

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