1379 Integrated Disease Management for Fusarium Wilt of Cotton in Australia

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ABBREVIATIONS: FOV (*Fusarium oxysporum* f sp. *vasinfectum*)

IDM (Integrated Disease Management)

Fusarium wilt of cotton, caused by *F. oxysporum* f sp.*vasinfectum*, was first recognized in Australia in 1993. The pathogen can be seed borne and it can also be dispersed in soil and crop residues attached to vehicles and machinery and carried in irrigation and flood water. Infection is favored by cool, wet spring conditions and shallow development of roots. The rapid increase in the distribution of the disease prompted a comprehensive response by the Australian cotton industry. A free central diagnostic service was funded by industry to confirm and record new outbreaks; major plant breeding programs were established to identify better host plant resistance; a protocol was established to provide growers with a quantitative ranking of cotton cultivars based on host plant resistance; fungicide seed treatments were tested for efficacy against seed borne inoculum; a seed production protocol was developed to minimise the chance of dispersing the pathogen in planting seed; cotton extension personnel and local grower associations promoted the importance of farm hygiene and wash-down facilities for vehicles and machinery; a research program was established to determine the origins of the pathogen in Australia and the potential for further adaptation. At the farm level, an extensive research program has evaluated a large number of strategies that could be incorporated into an Integrated Disease Management plan. The resulting plan includes the following recommendations to cotton growers: 1. Sow a resistant cultivar with Bion® seed treatment, 2. Delay sowing to the end of October, 3. Avoid cultivating with knives, 4. Retain cotton residues on the surface for 60 d, 5. Bare fallow rotation is best, 6. If using a cereal rotation, then burn, bury, or bale residues, 7. Minimise run-off of excess irrigation water, 8.Always practice good farm hygiene, 9. Flood in summer (if possible) to reduce the inoculum in soil.

Keywords:

Control, *F. oxysporum* f sp. *Vasinfectum*

Introduction

Fusarium wilt of cotton (*Gossypium hirsutum* L.), caused by *Fusarium oxysporum* Schlecht f sp. *vasinfectum* Atk., Sny. & Hans., was first recognized in Australia in 1993 (Kochman, 1995). By the end of 1999, the disease was present in six of the ten cotton production areas in Eastern Australia and widespread in two of those areas (Allen and Lonergan, 2000). Fusarium wilt has now been confirmed on 80 farms in NSW (Fig. 1) and is now widespread in seven of the cotton production areas in Eastern Australia.

Figure 1 shows a logarithmic increase in the number of affected farms in NSW from 1992/93 to 2002/03 and an obvious decline in new reports over the last few years. Possible reasons for this decline include (i) the severe drought conditions, (ii) the availability of new cultivars with better host plant resistance, (iii) the reticence of some growers to report that the disease has been detected on their farm, and (iv) the impact of increased attention to farm hygiene.

The results of annual disease surveys over the last five seasons show that Fusarium wilt is most common on farms in the Darling Downs area of Queensland, where it has been found in 75% of fields inspected with an average incidence of 6.7% of plants infected (Allen, 2006b).

The rapid spread of the pathogen from region to region, as well as between and within farms, caused great concern among growers and consultants in Australia. Allen (2004) noted that there were 17 pathologists, molecular biologists, and cotton breeders currently directing all, or at least part of their research effort to the Fusarium wilt problem.

The Pathogen

Some basic information on the characteristics of FOV and Fusarium wilt in Australia is essential before considering the development of an IDM strategy.

Colyer (2003) compared Fusarium wilt of cotton in the USA and Australia. He noted that the root knot nematode was frequently associated with wilt in the USA but not associated with wilt in Australia. Symptoms appeared mid-season with no mortality in the USA while considerable mortality with consequent poor stands was often apparent at the seedling stage in Australia. Isolates of FOV from Australia have been classified as race 6 with two new strains distinguished on the basis of vegetative compatibility and DNA fingerprinting, while races 1 and 2 are most common in the USA. New classification systems group races 1, 2 and 6 all in group A. Hillocks (1992) describes Fusarium wilt as a warm temperature disease with optimum temperatures of 30 ^{0}C to 32 ^{0}C and little development of the disease at temperatures below 23 ^{0}C. In contrast, Wang et al. (1999) found that the optimum temperature range for FOV in Australia was 18 ^{0}C to 23 ^{0}C with little development of symptoms above 23 ^{0}C.

In Australia infection is favored by cool, wet spring conditions. The disease incidence as assessed at the end of the season was closely associated (R^2 = 0.9836) with the amount of rainfall recorded for October and November (Allen, 2005). Disease incidence was highest (92%) following a wet spring in 2001 and lowest (51%) following a relatively dry spring in 2002. Inoculum is usually concentrated in the top 16cm of the soil profile and conditions that favor shallow development of roots can result in increased disease incidence (Allen, 2005).

The pathogen can be seed borne and it can also be dispersed in soil and crop residues attached to vehicles and machinery and carried in irrigation and flood water (Allen and Lonergan, 2000; Allen and Kochman, 2001; Allen, 2002).

Integrated Disease Management

It was recognized that no single control strategy could provide an adequate level of control of Fusarium wilt of cotton in Australia. Integrated Disease Management requires the selection and application of a harmonious range of control strategies that minimize losses and maximize returns. These strategies may be applicable across the whole industry or specific for individual farms.

Actions with Industry-wide Benefits

1. A free central diagnostic service provided by the Queensland Department of Primary Industries and Forestry was funded by industry to confirm and record new outbreaks of Fusarium wilt and identify to strain using vegetative compatibility grouping (Allen, 2006b). Between 1999 and 2006 973 samples were submitted, and 46% of those samples were found to be positive for FOV (L.J. Smith, Personal communication). Results are treated as confidential, unless confidentiality is waived by the grower.

2. A 'Fusarium wilt research coordination committee' (FUSCOM) was established under the auspices of the Australian Cotton Cooperative Research Center (Allen, 2002). The committee includes pathologists, growers, consultants, and representatives of the seed industry and funding bodies. The threefold objective of FUSCOM was to (i) encourage collaboration between the various research groups, (ii) develop an integrated disease management strategy for Fusarium wilt, and (iii) communicate results of research activities to growers. FUSCOM has also been responsible for developing the resistance ranking protocol and maintaining the seed production protocol.

3. Major plant breeding programs were established to identify better host plant resistance (Constable et al., 2007. *In These Proceedings*). The CSIRO and Deltapine programs have made considerable improvement to the level of resistance to FOV in commercial cotton cultivars.

4. A protocol was established by FUSCOM to provide growers with a quantitative ranking of the resistance of cotton cultivars (Allen, 2003). The ranking is based on the number of plants that survive to the end of the season with vascular discoloration restricted to an area less than 5% of the stem cross section at ground level as a proportion of the initial stand counted within 3 wk of sowing. This proportion of plants surviving is expressed relative to survival in an industry standard cultivar that is assigned a value of 100 and is included in all comparisons. The number of field comparisons contributing to the ranking is indicated in brackets. An 'F.rank' less than 100 indicates that a cultivar is more susceptible than the standard, while an 'F.rank' above 100 indicates more resistant than the standard. The resistance ranking protocol is still undergoing some refinement. The original protocol allowed an open ended scale for cultivars more resistant than the standard. This has now been modified to limit the ranking to a maximum of 200, which represents complete resistance or immunity.

5. Since FOV can be seed-borne, a seed production protocol was developed to minimize the chance of dispersing the pathogen in planting seed (Kay, 2003) The protocol covers all stages of seed production from breeder's plots to commercial seed crops and includes site selection, planting, in-season checks, harvesting, and ginning.

6. The efficacy of fungicide seed treatments for the elimination of the pathogen from within infested seed was investigated as a precaution against the possibility of seed transmission. Carbendazim, TCMTB and PCNB – metalaxyl were found to be effective in eliminating seed-borne inoculum of FOV from acid-delinted, graded seed (Allen and Kochman, 2001). When PCNB and metalaxyl were tested separately, only metalaxyl gave repeated complete control. Pathogen growth from treated seed was completely suppressed by metalaxyl treatments in six separate experiments.

7. A farm hygiene policy has been developed under the slogan 'Come clean – Go clean'. Cotton extension personnel and local grower associations have promoted the importance of

farm hygiene and wash-down facilities for vehicles and machinery (Allen, 2002). Contractors and agronomists and their vehicles and machinery should be cleaned before leaving one farm, so that they can arrive clean at the next farm that they visit.

8. A research program has been established to determine the origins of the Australian strains of FOV and the potential for further adaptation (Wang et al., 2007. *In These Proceedings*)

Developing an Integrated Disease Management Plan

At the farm level an extensive research program has evaluated a large number of strategies that could be incorporated into an Integrated Disease Management plan.

Resistant cultivars (Constable, 2007. *In these Proceedings)*. New cultivars with greatly improved resistance to FOV are now available to growers.

Seed treatments that induce resistance (Allen et al., 2004). The cotton plant has natural defense mechanisms that can be activated by the application of acibenzolar-S-methyl (ASM) to the seed at, or prior to, planting. The use of ASM as a seed treatment has consistently reduced the incidence of Fusarium wilt of cotton throughout the season. While not providing complete control, the use of such seed treatments is seen as a potentially important component of an integrated disease management strategy for Fusarium wilt of cotton.

Delayed sowing (Allen, 2005). As mentioned previously, Fusarium wilt is favored by cooler temperatures and rainfall in spring. Several field experiments have investigated the impact of delaying the time of planting to avoid the less favourable environmental conditions early in the season. In one of these studies, total survival was increased by 80.5% ($P<0.001$) by delaying the planting from mid-October to the end of October. In a second study, there was no rainfall early in the season and no significant difference in survival between earlier and later plantings.

Cultivation. Five field experiments have evaluated the effects of cultivation on the incidence of Fusarium wilt. Disease incidence was not increased by using rolling cultivators. Cultivation with knives significantly increased (by 15% and by 27%) disease incidence in two of the experiments.

Herbicides. Mixed results were obtained in field experiments to study the impact of herbicides on disease incidence. In the 2001/02 season (wet Spring) survival was reduced by 41% in the Trifluralin + Fluometuron + Prometryn treated plots, while in the 2002/03 season (dry Spring) the Metolachlor + Fluometuron + Prometryn treatment had no effect at all on plant survival. It is suggested that these mixed results from cultivation and herbicide treatments may reflect seasonal conditions. When spring conditions are dry, there is no shallow root development and no movement of herbicide into the root zone and consequently cultivation and herbicide treatments have no impact.

Trash management (Allen and Lonergan, 2000; J.K. Kochman, Personal communication). Crop residues are an important source of pathogen inoculum. In two out of three field experiments, there has been a 30% reduction in disease incidence when residues have been pulled and mulched and retained on the surface and exposed to wet weather for 6 – 8 wk compared with immediate incorporation soon after mulching. There was no significant difference between the two treatments in the third experiment, where weather conditions remained dry during exposure of the residues.

Crop rotation (Allen, 2006a). Winter cereals, such as wheat, oats, and barley are the preferred rotation crops for over 80% of Australian cotton growers and cereal residues appear to have a significant impact on the epidemiology of Fusarium wilt of cotton. Results of a previous study showed that there was a significant increase in the incidence of Fusarium wilt in the subsequent cotton crop after either a wheat or barley rotation when compared with a long bare fallow. The use of long, bare fallows is not considered to be an economic or practical option, and therefore the management of cereal residues is an important issue. The results of two trials near Brookstead suggest that cereal residues should be burnt, baled, or incorporated into the soil as soon as possible after harvest to minimize the saprophytic build-up of the pathogen.

Summer flooding has been recommended as an effective control strategy for soil borne diseases of cotton in California. Summer flooding has been applied to at least five cotton fields in the Gwydir and Macintyre valleys in recent years. While disease incidence is drastically reduced the pathogen is not eliminated. A field near Boomi was flooded during the summer of 2000/01. Only 0.8% of plants in the 2001/02 season and 1.9% of plants in the 2002/03 season were found to be infected in an area where previously nearly all plants were killed. In 2005/06, after two crops of cotton, a barley fallow rotation and two further crops of cotton, Fusarium wilt was detected at 56% of the 63 assessment points and 9.8% of plants were infected.

Soil fumigation. Although fumigation with metham sodium produced some encouraging results, there were difficulties with application and problems with re-colonisation. The soils used to grow cotton in Australia have high clay content and tend to smear and suffer structural damage when operations are attempted over moist soil. In dry soil, the fumigant escapes to the surface too quickly.

'Other' treatments. Numerous other products have been tested and tried in replicated small plot field experiments without producing any disease control benefits. These treatments include fertilizers, such as gypsum, sulphate of potash, urea, calcium cyanamide, products based on seaweed, feedlot and poultry manure, humates, micronutrients, radionic homeopathic treatments, compost tea, herbal treatments, ti-tree oil, biocontrol treatments (including four isolates of *Trichoderma* sp. and a *Bacillus* sp.), mustard meal, mustard oil, etc.

Recommended IDM for Fusarium Wilt of Cotton in Australia.

Based on numerous field experiments the following IDM strategy has been recommended to Australian Cotton growers faced with the challenge of Fusarium wilt on their farm.

1. Sow a resistant cultivar with Bion® seed treatment,

2. Delay sowing to the end of October,

3. Avoid cultivating with knives,

4. Retain cotton residues on the surface for 60 days,

5. Bare fallow rotation is best,

6. If using a cereal rotation then burn, bury or bale residues,

7. Minimise run-off of excess irrigation water,

8. Always practice good farm hygiene,

9. Summer flooding (if possible) reduces the inoculum in soil.

IDM Works!

The incidence of Fusarium wilt of cotton was monitored in a field near Boggabilla in 1997/98 (20%), 1998/99 (52 %), 1999/00 (41%), 2002/03 (43%). The grower imposed a crop rotation, delayed planting until 21 Oct. 2005, planted Sicot F-1 (the most resistant cultivar available in Australia), and used the Bion seed treatment. The incidence of Fusarium wilt in the 2005/06 cotton crop was 5%.

Integrated Disease Management for Fusarium wilt of cotton in Australia includes the combination of both actions with an industry-wide application and strategies that a grower can adopt as part of his farm management.

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Figure 1. Increasing distribution of Fusarium wilt of cotton in NSW as indicated by the number of farms where the disease has been confirmed as present. (Courtesy of D.B. Nehl, NSW Department of Primary Industries)