

COTTON RESEARCH AND DEVELOPMENT CORPORATION



FINAL REPORT

Diseases of cotton VI

DAN121C

July 1998 to June 2001

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ISBN 0 7347 1325 8

B-2001

DISEASES OF COTTON VI

CONTENTS

<i>Plain English Summary</i>	3
<i>Full Report</i>	4
BACKGROUND	4
OBJECTIVES AND EXTENT TO WHICH THEY HAVE BEEN ACHIEVED	5
COTTON R&D CORPORATION OBJECTIVES	6
METHODOLOGY AND JUSTIFICATION	7
Disease surveys	7
Experiments	7
RESULTS AND DISCUSSION	8
Disease surveys	8
Experiments	22
CONCLUSIONS (RESEARCH OUTCOMES VERSUS OBJECTIVES)	35
LIKELY IMPACT OF RESEARCH OUTCOMES (COST BENEFIT)	38
RECOMMENDATIONS AND APPLICATION TO INDUSTRY	39
COMMERCIAL DEVELOPMENTS	40
TECHNICAL DEVELOPMENTS	40
FURTHER DEVELOPMENT	41
TECHNOLOGICAL	41
OUTCOME DEPLOYMENT	41
COMMUNICATION OF RESULTS	42
PUBLICATIONS	42
APPENDIX - BUDGET	44

PLAIN ENGLISH SUMMARY

Regular disease surveys have highlighted the changing status of cotton diseases over time and provided valuable insights into the factors affecting their distribution and severity.

- Seedling mortality across NSW declined from a high of 40% during the early 1990s, leveled off at close to 20% in the late 1990s and increased sharply in the 2000-01 season. Environmental conditions have an overriding influence on seedling mortality.
- The incidence of black root rot has increased dramatically during the 1990s and if it continues to increase at its current rate, then 95% of the fields on farms that are regularly surveyed in NSW will have the disease by 2004.
- Fusarium wilt is increasing and further cases are likely to occur. The disease continues to increase with successive cotton crops, even if the less susceptible varieties are grown.
- The widespread adoption of resistant varieties has resulted in a dramatic decline in the incidence of Verticillium wilt.
- The dominant factor affecting the incidence of boll rots is precipitation; Localised rainfall events have resulted in major losses to Phytophthora boll rot in some areas.
- Alternaria leaf spot occurs across the cotton industry but usually its severity is low, except in crops of Pima.
- 'Bunchy top' was widespread and sometimes severe in the 1998-99 season but has been present in low levels since then (0.06% of plants affected in NSW in 2000-01).
- Bacterial blight still occurs in Pima and at low levels in the few varieties of upland cotton that are susceptible.

Experiments were conducted to develop and/or evaluate control strategies for Verticillium wilt, Fusarium wilt, Alternaria leaf spot and seedling diseases:

- No fungicides or other treatments were consistently better at controlling seedling disease than the standard PCNB/Apron seed treatment.
- Continuous monoculture of Verticillium wilt-resistant varieties may select for more virulent strains of the pathogen. Active populations of Verticillium are still widespread in cotton growing soils and will quickly increase with a return to susceptible varieties.
- The severity of Fusarium wilt is reduced by: summer flooding; bare fallow in comparison to rotation with cereals where the residues are incorporated in the soil; leaving cotton trash on the soil surface for two months rather than incorporating immediately; inducing systemic acquired resistance with a chemical activator applied to the seed.
- A protocol to screen for resistance to *Alternaria macrospora* was developed.

Results of these experiments and observational studies have been incorporated in strategies for integrated disease management and disseminated to the cotton industry by way of publications, media releases, field days and meetings with growers and consultants.

Full Report

BACKGROUND

In the late 1980s and early 1990s, Verticillium wilt was the most widespread and important disease of cotton in Australia. The widespread adoption of CSIRO cultivars with resistance to Verticillium wilt has effectively reduced the incidence and importance of the disease in recent years. In California, where there are several different and more virulent strains of the pathogen, the repeated use of resistant cultivars resulted in the selection of more virulent strains and an effective breakdown in the level of cultivar resistance to the disease. For this reason it is of great importance to monitor the incidence of Verticillium wilt with repeated cultivation of a resistant cultivar.

At the commencement of this project, Fusarium wilt was widespread in the McIntyre valley and had been recorded on two farms in the Gwydir valley. It is essential that the spread of this disease be minimised and that the pure seed production programs should be kept free of the disease if possible. Alternaria leaf spot is regarded as one of the major factors affecting Pima cotton production and several of the commercial upland cultivars are very susceptible. Effective control of seedling diseases is important so that the costs and problems associated with replanting can be avoided.

The disease surveys will allow the changing distribution and potential importance of diseases of cotton to be monitored. The proposed experimental studies will allow the development and confirmation of recommendations to growers for the more effective control of cotton diseases.

OBJECTIVES AND EXTENT TO WHICH THEY HAVE BEEN ACHIEVED

- (i) To monitor the distribution and importance of diseases in Australian cotton by regular disease surveys.**

Disease surveys were conducted in November and March in each year of the project, including the Lachlan valley and Menindee for the first time. Survey data was added to the existing database to analyse changing trends in the severity and/or distribution of seedling disease, black root rot, *Alternaria* leaf spot, *Verticillium* wilt, *Fusarium* wilt, boll rots and 'bunchy top'.

The incidence of *Fusarium* wilt across transects of infested fields was assessed in each year of the project and trends were identified.

- (ii) To continue to develop and/or evaluate control strategies for *Verticillium* wilt, *Fusarium* wilt, *alternaria* leaf spot and seedling diseases of cotton.**

Seed treatment experiments were completed at Narrabri and Dalby in each year of the project, including evaluation of the potential of fungicides and some 'biological' products. Experiments on the effect of seed treatment/planting date on cotton yield were completed in each year of the project.

The long-term experiment on the potential for repeated use of resistant varieties to select for more-virulent strains of *Verticillium* was completed, along with evaluation resistance in a number of variety trials.

Experiments on crop rotation, crop residues and systemic acquired resistance for the control of *Fusarium* wilt were completed, as well as an observational study of the potential for control by summer flooding.

A technique for creating artificial infection of cotton by *Alternaria macrospora* in the field was developed and a protocol for screening for host-plant resistance was developed.

Results of these experiments and observational studies have been incorporated in strategies for integrated disease management and disseminated to the cotton industry by way of publications, media releases, field days and meetings with growers and consultants.

COTTON R&D CORPORATION OBJECTIVES

The research conducted in this project has led to changes in agronomic practices for disease management that have contributed directly to the strategy to improve chemical and non-chemical management of diseases; a strategy in Output 1; Sustainability of Natural Resources. These changes in agronomic practices include:

- Widespread adoption of measures to minimise the further spread of soil borne diseases, including Fusarium wilt, by all participants in cotton production and research.
- Increased awareness by growers and consultants of the need to avoid environmental conditions that favour seedling diseases by having good bed preparation, sowing cotton when soil temperatures are on a rising trend and pre-irrigating in preference to irrigating after sowing.
- Preliminary use by growers of summer flooding to limit the spread of Fusarium wilt, particularly in the initial stages of new outbreaks.
- Continued use of resistant varieties to maintain low incidence of Verticillium wilt.
- Prolonged retention (i.e. two months) of cotton residues on the soil surface to minimise the saprophytic increase of the Fusarium wilt pathogen during the inter-crop period.

METHODOLOGY AND JUSTIFICATION

Disease surveys

The distribution, incidence and importance of diseases of cotton in NSW production areas were determined by disease surveys in November and March of each season. Field history, trash carryover, ground preparation, cotton variety, planting date and seed rate were recorded for each of the fields surveyed. Estimates of the number of seeds planted per metre were compared to the number of plants established per metre. This comparison produces an estimate of seedling mortality, which includes the impact of seedling disease (*Rhizoctonia* and *Pythium*) as well as seed viability, the activity of soil insects such as wireworms and physical problems such as fertiliser burn.

Changes in the incidence and severity of Fusarium wilt over time were monitored along transects across infested fields.

Experiments

Replicated long-term field trials at the Australian Cotton Research Institute were continued to evaluate the efficacy of a combined range of cultural practices for the control of Verticillium wilt. These long-term experiments, which also included monitoring disease incidence under repeated cultivation of either a resistant or a susceptible cultivar, were continuations of experiments commenced in 1991/92 as part of a previous project.

A summer flooding experiment to control Fusarium wilt was established and was monitored in subsequent years. The incidence of Fusarium wilt in fields near Boggabilla was assessed to determine the effectiveness of current control strategies. Field experiments in the Macintyre valley were used to evaluate options for crop rotation, trash management and the potential to induce systemic acquired resistance against Fusarium wilt.

Methods were developed to allow more reliable field screening of cultivars to identify resistance to *Alternaria* leaf spot.

Fungicide seed treatments for seedling disease control were evaluated at Narrabri and on the Darling Downs in collaboration with Cotton Seed Distributors Ltd and Deltapine Australia Ltd.

RESULTS AND DISCUSSION

Disease surveys

Seasonal conditions

1998-99

Common observations during the November 1998 survey included deep wheel-tracks from planting in wet conditions, extensive tipworm damage and cotton regrowth from stalks surviving from the previous season. There were several reports of tractors being towed across tail drains and getting bogged in the rotor-buck area near the head ditch during planting. The compaction problems caused by planting in these conditions were evident in many crops at maturity when plants in rows under the tractor were noticeably shorter than the plants in the guess rows. Cool wet conditions were experienced in many areas of NSW during the 1998-99 season.

1999-00

Weather conditions throughout much of the 1999-00 season were cooler and wetter than average resulting in increased problems with seedling disease, black root rot, Verticillium wilt, Fusarium wilt and the boll rots.

2000-01

Very wet weather conditions and associated flooding during October, 2000 and early February, 2001, combined with periods of very hot, dry weather during summer, impacted significantly on the health of cotton crops; seedling diseases were particularly severe while diseases occurring later in the season tended to be less prominent than in the previous two years.

Seedling disease

Despite the wet conditions prior to planting in 1998, the incidence of seedling diseases was generally low and the mean seedling mortality was 21.1% across NSW. In other words 78.9% of seed sown produced apparently healthy seedlings. Seedling mortality is derived from the difference between the number of seed planted per metre and the number of plants established per metre.

In 1999, crops planted in mid to late September generally established much better than crops planted in October, which reflects the warm conditions experienced in late September and the cool wet conditions that occurred throughout much of October. Mean seedling mortality for the 94 crops visited across NSW was 22.8%. Mean seedling mortality for the McIntyre, Gwydir, Namoi and Macquarie valleys varied from 19.0% to 24.6% while the mean for the Lachlan valley was 30.4%.

In 2000, crops planted in mid to late September generally established much better than crops planted in October and early November. This reflected the

warm conditions experienced in late September and the cool, wet conditions throughout much of October. In the crops inspected, mean seedling mortality across NSW was 31.9%; a level considerably higher than in the previous season. Mean seedling mortality was particularly high in the Gwydir, Namoi and Macquarie valleys where it exceeded 34% and where significant areas of replant were required. Seedling mortality was increased in association with severe black root rot. Seedling mortality in the Lachlan valley (26.3%) was lower than in the previous year (30.4%) because, although the Lachlan valley also experienced the warm conditions in September followed by cooler conditions in October, rainfall in the Lachlan valley in October was less than in other areas.

Seedling mortality declined by approximately 50% during the early 1990s, leveling off at close to 20% in the late 1990s (Figure 1). Many factors other than seedling disease contribute to seedling mortality. Since the fungicides used in the standard seed coatings during this period did not change, the observed decline probably represents better farming practices, such as improved bed preparation, planting accuracy, and avoidance of herbicide damage and fertiliser burn.

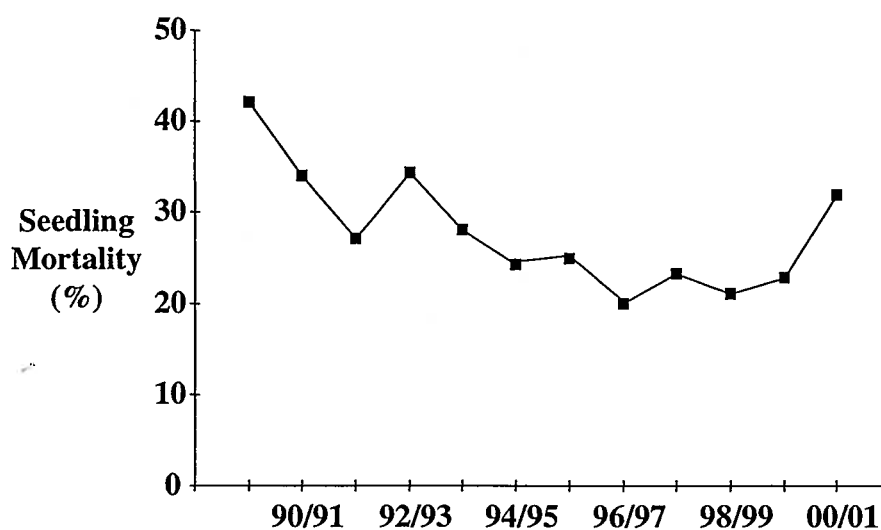


Figure 1. Changes in seedling mortality in fields surveyed in the Macintyre, Gwydir, Namoi, Macquarie and Lachlan valleys in NSW. The Lachlan valley was included in the surveys for the first time in 1999-00.

The sharp increase in seedling mortality in the 2000-01 season clearly demonstrated that environmental conditions have an overriding influence on seedling mortality. It is likely that higher seedling mortality will be observed as the severity and distribution of black root rot increases. Furthermore, the expanding area of cotton in southern NSW will be at greater risk of adverse environmental conditions at planting than the established areas in north west NSW.

Black root rot

In 1998, the wet weather prior to planting and the relatively cool conditions after planting provided ideal conditions for black root rot. The disease was found on all of the properties inspected in the Macquarie valley and on all but one of the properties inspected in the Namoi valley. Black root rot was also reported from the Bourke, Brewarrina and Carinda areas. There was also considerable expansion of affected areas on a property near Mungindi. Black root rot was observed on seedling roots in 52% of the fields that were inspected in November, 1998. The mean incidence of the disease where it was present was only 1.1% and varied from a trace up to 10 % of plants in a field affected.

In 2000, black root rot was again present in over 50% of fields that were inspected in NSW. Up to 40% of plants were affected in some fields and badly affected fields were present in all production areas including the McIntyre valley. Despite a relatively short history of cotton production black root rot was found for the first time in several commercial cotton crops in the Lachlan Valley near Hillston. Black root rot is favoured by cooler conditions and is usually prevalent early in the season, with symptoms on the roots usually disappearing by the end of December as temperatures rise. However, the 1999-00 season didn't warm up sufficiently and symptoms of black root rot persisted throughout the entire season in some crops. These symptoms included severe stunting and delayed maturity with some plants retaining a black 'core' of infected tissue in stem just below ground level (Figure 2). Significant yield reductions occurred in these areas.

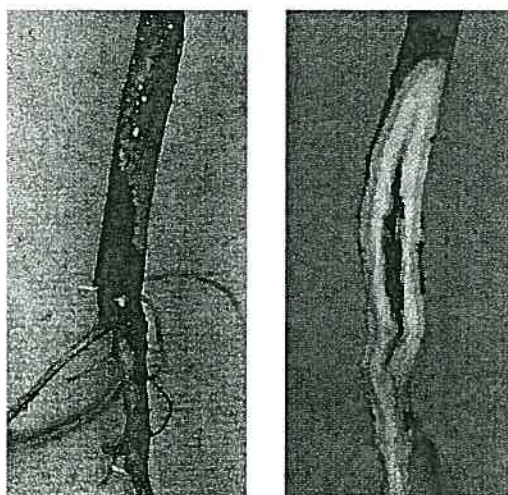


Figure 2. Late-season symptoms of black root rot of cotton, caused by *Thielaviopsis basicola*, include an external canker (left) and internal stem rot (right).

In 2000, black root rot was present in over 46% of fields that were inspected in NSW in late November and early December, 2000. The disease was present in all fields examined in the Macquarie valley and in 78% of fields examined in the Namoi valley. The symptoms of this disease disappeared quickly as weather conditions became fine and warm in December. Consequently, in fields that were surveyed later than usual due to the flooding in November, the presence

of black root rot may have gone undetected; with these fields excluded, the proportion of fields across NSW with black root rot in 2000 was 65%. Despite these delays in the surveys, black root rot was found on a number of farms where it was not previously observed. Although the black root rot pathogen does not generally kill cotton seedlings by itself, the weakened seedlings were rendered more susceptible to other seedling pathogens and mortality was increased. One farm in the Macquarie valley reported that of 20 fields, that were known to have substantial levels of black root rot, 18 had to be replanted due to the associated seedling losses. Fortunately, the long period of warm weather after the flooding in November 2000 enabled many crops to recover substantially.

In summary, the incidence of black root rot has increased exponentially in NSW and the disease has now emerged as a major threat to the sustainability of the cotton industry. Black root rot has now been recorded on 93% of the farms surveyed annually in the Macquarie, Namoi, Gwydir and Macintyre valleys (Figure 3a) and occurs in all cotton growing regions of NSW except Menindee and the Murrumbidgee valley. Black root rot is also widespread in south west Queensland and the Darling Downs (J. Kochman, personal communication). If black root rot continues to increase at its current rate, then 95% of fields on the farms that are regularly surveyed in the Macintyre, Gwydir, Namoi and Macquarie valleys will have the disease by 2004 (Figure 3b).

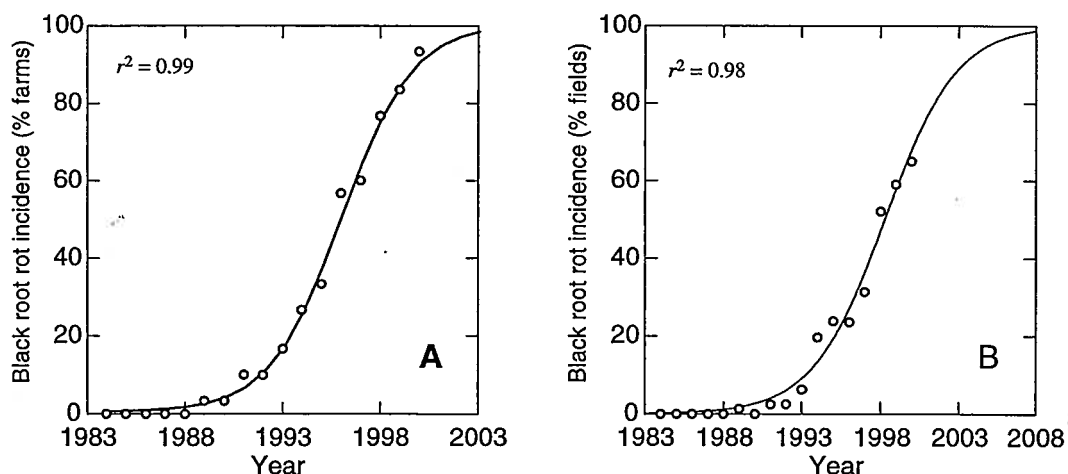


Figure 3. Observed (circles) and predicted (curves) increase in the distribution of black root rot of cotton, caused by *Thielaviopsis basicola*, in irrigated fields in the Macintyre, Gwydir, Namoi and Macquarie valleys.

Fusarium wilt

In the 1998-99 season, *Fusarium wilt* was reported and confirmed at two new sites near Mungindi and Boomi in NSW. *Fusarium wilt* on the Queensland side of the border near Mungindi and at St George (J.Kochman, pers. Comm.).

During the 1999-00 season the disease was newly reported and confirmed on five farms in the Macquarie valley, two farms in the upper Namoi valley, one farm at Bourke, on 13 more farms in the Gwydir valley as well as on several more farms throughout the McIntyre valley. Dr Joe Kochman reported more outbreaks of the disease in the St George and Theodore areas of Queensland

and the results of a survey of farms on the Darling Downs of Queensland conducted by Greg Salmond indicated that *Fusarium* wilt was present in approximately 30% of fields in that area. These newly detected outbreaks varied in size from a few square metres to up to 12 hectares. In almost all cases the disease occurred in an obvious patch extending along the furrows towards the tail drain. On several occasions the affected patch had been noticed but had been attributed to cultivation errors. In three of the new outbreaks in NSW the disease occurred as scattered, single wilting plants. All but one of the new reports involved strain 01111 of the *Fusarium* wilt pathogen (the 'Downs' strain). One new farm in the Boggabilla area was found to have strain 01112 (the 'Boggabilla' strain).

In several fields where both Ingard and conventional cultivars were grown side by side certain Ingard varieties appeared to be more susceptible to *Fusarium* wilt than the conventional parent. The susceptibility of these varieties has now been clearly identified by the seed producer.

In the 2000-01 season there were five new reports of *Fusarium* wilt on farms in NSW. One of these new reports was from a farm near Narromine in the Macquarie valley while the other four new reports were from farms in the Moree, Garah and Boomi areas of the Gwydir-McIntyre. There were several newly affected fields on farms where the disease had previously been reported.

Fusarium wilt is now recognized as being widespread in most cotton production areas of Australia. Only Emerald in Queensland and the lower Namoi, Menindee, Lachlan and Murrumbidgee areas of NSW have been free from reports of the disease; so far! *Fusarium* wilt is currently increasing in an exponential manner (Figure 4) and further cases are likely to occur. The rapid increase in reported cases in 1999-00 represents dispersal in previous seasons; the favourable seasonal conditions during that year allowed the prominent expression of symptoms and, hence, a large number of new cases were reported. It must be assumed that the disease is much further widespread than is currently recognised.

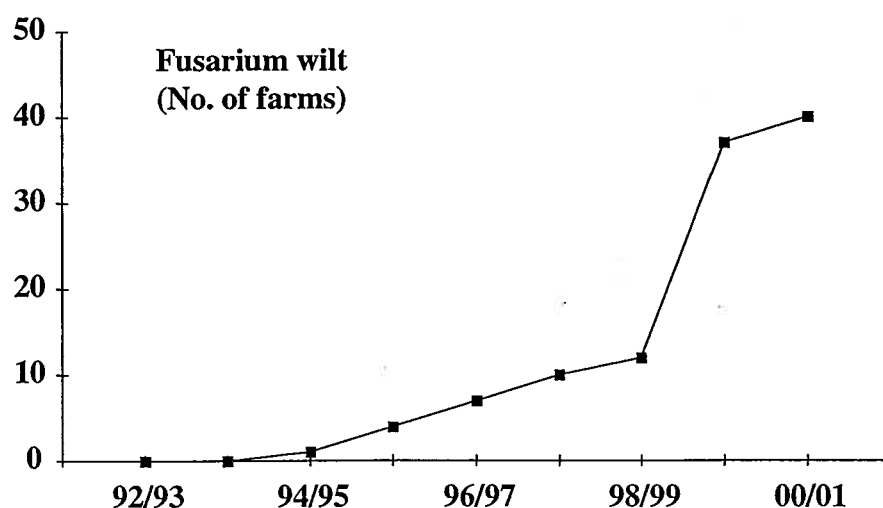


Figure 4. The increase in reported cases of *Fusarium* wilt of cotton, caused by *Fusarium oxysporum* f.sp. *vasinfectum*, in NSW.

Questions arising from these observations include:

- Why were there 25 new records of Fusarium wilt in NSW in the 1999/2000 season and only between one and five new records in each of the other seasons since the disease was first reported in NSW?
- Was one of the wettest harvests on the Darling Downs in 1996, and the subsequent movement of pickers, related to the peak in cases of Fusarium wilt reported four years later?

To prevent further spread of Fusarium wilt, it is important that growers, consultants and contractors declare if the disease is present in an area. This will enable implementation of appropriate measures to minimise the further spread of the pathogen.

Verticillium wilt

In the 1998-99 season, the cool weather conditions experienced in many of the cotton growing areas of NSW were favourable for Verticillium wilt and symptoms were apparent in November in some fields. The incidence of Verticillium wilt exceeded 10% in 7 of the 90 fields inspected in March 1999 with one crop in the Bourke area having 32% of plants infected. The mean incidence of the disease was only 2.94% for crops in NSW and 3.56% for crops in the Namoi valley. This represented the lowest recorded incidence for the Namoi valley since surveys began in 1983-84.

In the 1999-00 season, conditions were cooler and wetter than average, Verticillium wilt was obvious in many crops and symptoms were severe, even in crops of the supposedly resistant varieties. Host-plant resistance to Verticillium wilt is temperature sensitive and temperatures throughout most of the 1999-00 season were significantly below average. Resistant varieties become susceptible when conditions are cool. A 1973 USDA review entitled "Verticillium Wilt of Cotton" edited by C. D. Ranney gives several examples of the influence of temperature on the expression of resistance, as follows.

"When a defoliating strain of the fungus is present, the critical range for disease development is 25C to 30C. At a mean temperature of 30C most wilt tolerant cultivars are totally resistant; as temperature decreases, resistance decreases until total defoliation occurs at a mean temperature of 25C. With the mild strain...the cotton reaction still changes from resistance to susceptibility over a range of about 5C."

*"Both resistant and susceptible cultivars of cotton were susceptible at greenhouse mean air temperatures of 22C and resistant at 32C. At 25C to 29C susceptible cultivars reacted as susceptible and resistant as resistant, **whereas tolerant cultivars were susceptible at 25C, tolerant at 27C and resistant at 29C.**"*

"The incidence of Verticillium approached 100% in the 1950 growing season which was unusually cool and rainy (25-26C). Conversely wilt averaged 3% in the 1954 growing season which was unusually hot and dry (29-31C)."

Researchers have suggested that “The marked increase in resistance as temperatures increase from 23C to 30C appears to be due to an increase in the rate of the host’s defense metabolism and a concurrent decrease in the growth and sporulation rates of the fungus.”

Despite the cooler than average season in 99/00 and the consequent severe expression of symptoms of Verticillium wilt in some crops, the mean incidence in commercial crops was relatively low at 5.75%, which is well below the incidence of the disease several years earlier.

In the 2000-01 season, the cool weather conditions in October and November 2000 did favour Verticillium wilt and severe stunting was observed in some fields early in the season. However, these symptoms abated with the fine, hot summer weather experienced later in the 2000-01 season. In a few crops a high incidence of Verticillium was observed as infection in cotton stems in February and March but foliar symptoms were weak or absent. This observation is consistent with the climatic conditions, which favoured infection early and then arrested further spread up the stems of plants. Over all, the 2000/2001 season did not favour the Verticillium wilt pathogen and the mean incidence of the disease in commercial crops in NSW was only 2.98% of plants.

The widespread adoption of resistant varieties has resulted in a dramatic reversal of the exponential increase in Verticillium wilt that was occurring in the late 1980s (Figure 5). In four out of the last five years, the incidence of Verticillium wilt in NSW was lower than when disease surveys began in 1983 and, consequently, Verticillium wilt is slipping towards obscurity in the minds of many growers. While the number of crops sown with varieties that are resistant to Verticillium has fallen by 14 percentage points during the last two years, this trend was not reflected by an overall increase in the incidence of the disease (Figure 5).

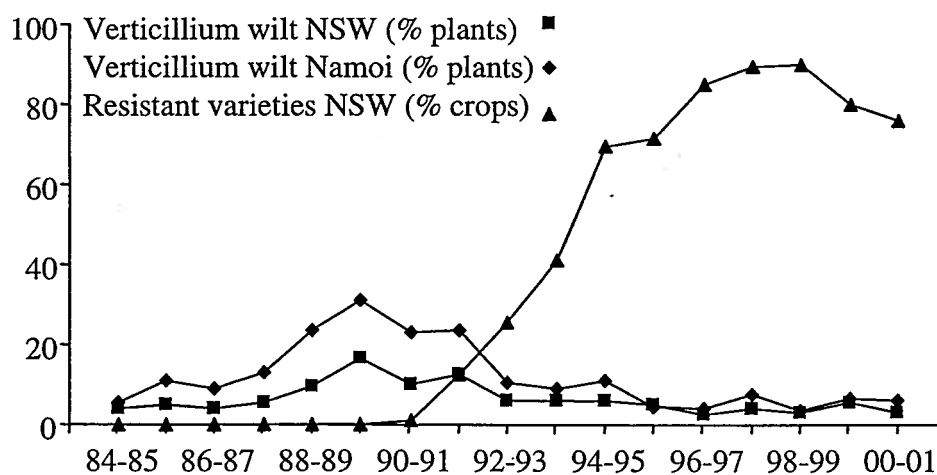


Figure 5. The rise and fall of Verticillium wilt of cotton, caused by *Verticillium dahliae*, in irrigated fields in NSW.

Boll rots

Phytophthora boll rot occurs when wet soil is splashed onto low bolls that are about to open or when mature bolls are temporarily submerged either in water in the furrow or when water backs up from the tail drain. A well-established and closed canopy minimises the chance of soil splash onto low bolls. Other boll rots develop when bolls are exposed to extended damp conditions as a result of wet weather and confinement in a dense or rank canopy.

In the 1998-99 season, Phytophthora boll rot was found in 73% of the fields inspected in March 1999 and incidence varied from a trace up to 4%. Other boll rots were found in 54% of the crops inspected and the incidence varied from a trace up to 8%. The absence of low bolls in many crops may have been a contributing factor to this low incidence of boll rots.

In the 1999-00 season, the incidence of boll rots was generally low, averaging 5% across NSW production areas. However, wet weather late in the season in the Macquarie valley and Bourke area provided ideal conditions for boll rots. In late April when the Macquarie survey was finally completed the mean incidence of boll rot was found to be 12.7% with up to 37% of bolls affected in one crop. This figure does not include bolls initially damaged by grubs but does include those bolls affected by Phytophthora boll rot. Sclerotinia boll rot was observed in three fields with 2% of bolls affected in one field in the Gwydir valley.

In the 2000-01 season, the incidence of boll rots was generally low, averaging 2.8% of bolls across NSW production areas. The local flooding in the Gwydir valley following the early February rain resulted in significant losses to Phytophthora boll rot in that area. The incidence of other boll rots was less than 0.5% in most areas.

The dominant factor affecting the incidence of boll rots appears to be climatic conditions. The number of fields affected was lowest during the drought in 1995 and higher during wetter seasons (Figure 6).

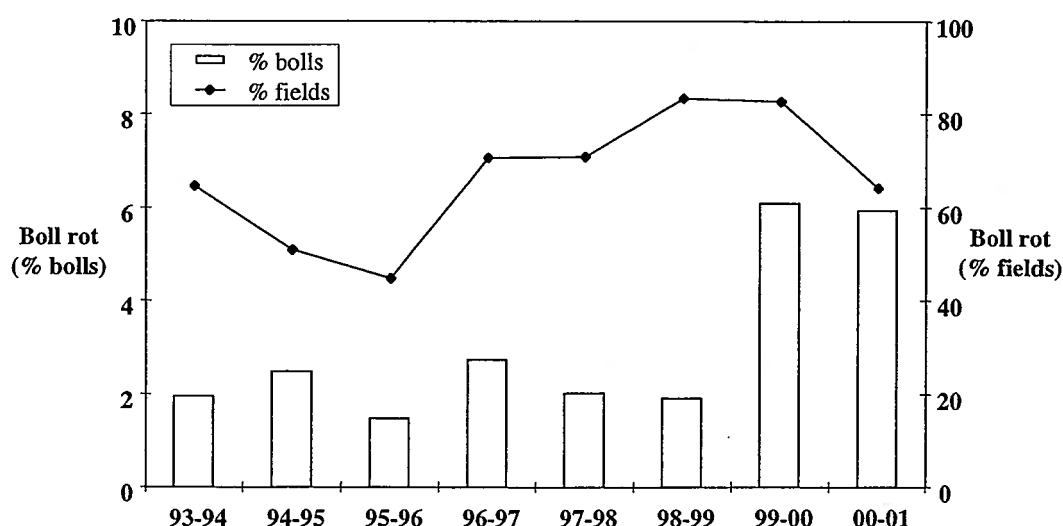


Figure 6. The incidence of cotton boll rots, caused by *Phytophthora nicotianae* var. *parasitica* and other fungi, in NSW. Bars represent means from only those fields where boll rots were present.

Variation in the number of fields affected across NSW does not necessarily reflect the incidence of boll rot within those fields (Figure 6) because climatic events have an overriding influence, as described above.

Alternaria leaf spot

The pathogen that causes *Alternaria* leaf spot survives on crop residues from the previous season. *Alternaria* leaf spot is favoured by wet weather conditions coupled with the use of susceptible cultivars, retention of crop residues from one season to the next and physiological stresses on the host crop such as those caused by a heavy fruit load or nutritional imbalances etc. The development of premature senescence and reddening can be associated with severe epidemics.

In both the 1998-99 and the 1999-00 seasons, *Alternaria* leaf spot was observed at very low levels in virtually all crops of upland cotton that were inspected. In both seasons, several Pima crops in the Bourke area were severely affected and suffered some defoliation.

The dry 2000 winter and the cool wet start to the 2000-01 cotton season provided ideal conditions for *Alternaria* leaf spot on seedling cotton, especially in fields where there was significant carryover of crop residues from the previous season. In severe cases seedlings were partially defoliated by the disease. The growing tip was generally unaffected in these plants and crop growth recovered after the onset of warmer conditions. *Alternaria* leaf spot was found in most fields surveyed in February-March, 2001 but the incidence was generally low. The mean incidence across all areas was 0.19% of leaf area affected.

Alternaria leaf spot became widespread in the cotton-growing areas of NSW in the early 1990s (Figure 7). Despite its almost universal occurrence, the severity (i.e. % leaf area affected) of this disease in upland cotton has remained at negligible levels during recent years. Pima crops ~~are~~ remain at risk.

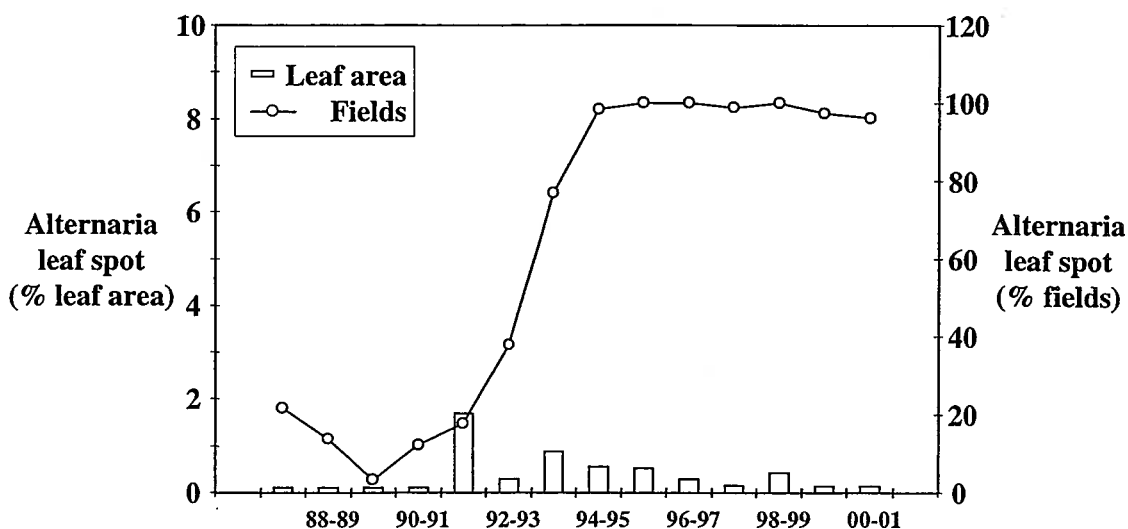


Figure 7. The incidence and severity of *Alternaria* leaf spot of cotton, caused by *Alternaria macrospora*, in irrigated fields in NSW.

Bunchy top and/or bunchiness

There appears to be considerable confusion with regard to the symptoms of bunchy top. A 'bunchiness' of terminal growth can also result from late season regrowth, prolonged activity of sucking insects or overuse of growth regulants and may affect large areas of the crop. Bunchy top symptoms include small bolls, small leaves and short internodes, usually accompanied by a distinctive leaf mottle occurring around the margins of the leaves (the leaf mottle may be masked if infestation by aphids or mites is severe), and usually confined to a few plants or a distinct patch. The leaf mottle symptoms may occur unaccompanied by the bunchy growth habit. A causal agent for the disease has not yet been identified.

In the 1998-99 season, the symptoms were observed early in some crops on the Darling Downs of Queensland and plants never recovered. In many fields the symptoms only became apparent toward the end of the season and were confined to the tops of the plants. In some situations whole fields were affected with only 1% or 2% of plants unaffected while in other areas the fields were generally unaffected with only 1% or 2% of plants showing symptoms. In some fields only patches of plants or plants near the margin of a crop were affected. While aphids were commonly linked to the occurrence of bunchy top cotton there were several examples where fields which experienced high aphid populations were found to be free of the condition.

In the 1999-00 season, 'bunchy top' was observed in nine (8.2%) of the 109 fields inspected during the disease surveys in NSW. The incidence was generally low and patches varied in size from one or two plants up to a four hectare patch in a field in the Gwydir where, according to the grower, "the crop struggled early and had problems with aphids".

In the 2000-01 season, 'bunchy top' was observed in only four (3.9%) of the 103 fields inspected during February and March, 2001. The incidence of bunchy top was low (0.06% of plants overall) and patches varied in size from one or two plants up to 10 square metres. Bunchy top appears to be associated with sucking pests. Of the four fields where patches of bunchy top were observed, two had Ingard® varieties and two had conventional varieties and, hence, the role of conventional insecticide regimes in preventing spread of the disorder is uncertain. The leaf mottle symptoms were observed without any bunchiness in six (5.8%) of the 103 fields inspected, and the incidence was low: 0.5% of plants in three of these fields and trace amounts (<0.01%) in the other three fields.

Bacterial blight

Nearly all varieties of upland cotton grown in Australia are immune to the bacterial blight pathogen. However, a few of the older varieties are susceptible and Pima is also very susceptible. In the 1998-99 season, the mean incidence of bacterial blight on bolls in the four susceptible crops that were inspected was found to be 5.7%, with 15% boll blight in a crop near Moree and 7.5% boll blight in a Pima crop near Bourke. In the 1999-00 season, the mean incidence of

blight on bolls in five susceptible crops inspected was 0.2%, ranging from 0 to 1.0%. In the 2000-01 season, six susceptible crops were inspected and boll blight averaged 0.12%. The highest level of infection was with 0.5% of bolls in a Pima crop at Menindee. Bacterial blight remains a threat to Pima crops, especially when climatic conditions are favourable for infection.

Other diseases and disorders

In the 199-00 season, a condition that has been called 'sunscald' was observed across significant areas of the Darling Downs of Queensland in February 2000. Affected crops appeared as if they had been sprayed with a desiccant or caught by an early frost and severely affected crops defoliated prematurely. It was concluded that the condition was a physiological response to environmental conditions. Symptoms were observed in some crops in the McIntyre, Gwydir and Namoi valleys, generally at trace levels.

In the 2000-01 season, sudden wilt was observed as isolated plants or small patches in several crops during mid February as well as in the disease surveys during late February to March. The very wet conditions early in February were followed by fine hot weather and these conditions favour the disease. Sudden wilt is caused by 'ordinary' species of *Fusarium* that are usually non-pathogenic and it is often associated with waterlogging. Affected plants wilt, defoliate and die. Plants may produce regrowth in some situations. Sudden wilt does not re-occur in the same places in the following crop.

The condition that has been called 'sunscald' was observed in small areas of two fields in mid-February 2001. The very warm weather during summer of 2000-01 was favourable for the charcoal rot pathogen and several infected plants were observed in one field in the Gwydir valley. This disease is normally rare in irrigated cotton crops. A stem rot associated with the fungus *Sclerotium rolfsii* was observed in dying plants in one field in the Gwydir valley. This pathogen has a wide host range and is characterized by a white fungal growth and the presence of small (1-2mm) brown survival structures (sclerotia) at the base of the stem.

Crop residues

Some pathogens may survive on crop residues and cotton residues on the soil surface have been quantified each year since the inception of the disease surveys in 1983. There have been no significant correlations between trash carryover and the incidence of Verticillium wilt, boll rots, late-season Alternaria leaf spot, black root rot or seedling mortality.

Fusarium wilt transects

The incidence of Fusarium wilt in several fields has been assessed annually for the several years in the Macintyre valley. Changing from a very susceptible variety to a less susceptible can result in an initial drop in the incidence and distribution of Fusarium wilt across fields (Figures 8 and 9) but not in all cases (Figure 10). However, even with continued deployment of the less-susceptible varieties, the disease has continued to increase (Figures 8, 9 and 10).

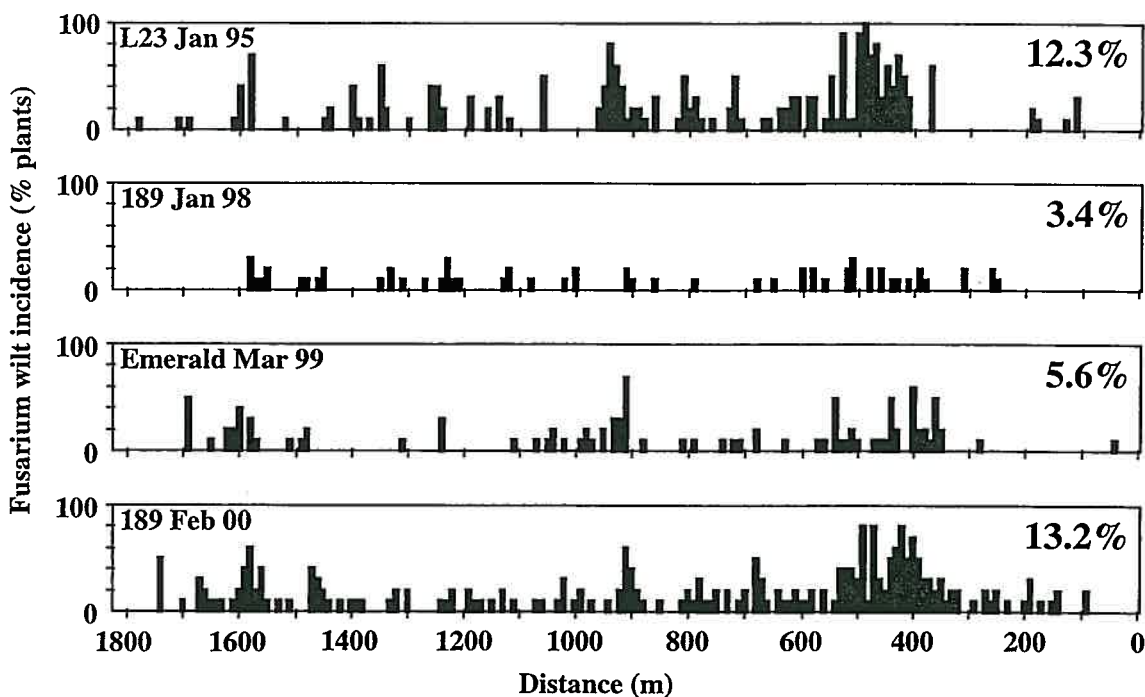


Figure 8. Incidence of Fusarium wilt of cotton across a transect of a field at Boggabilla. This field was the first to be diagnosed with the disease in NSW. L23 is a susceptible variety, 189 and Emerald are less susceptible varieties. Transect means at right.

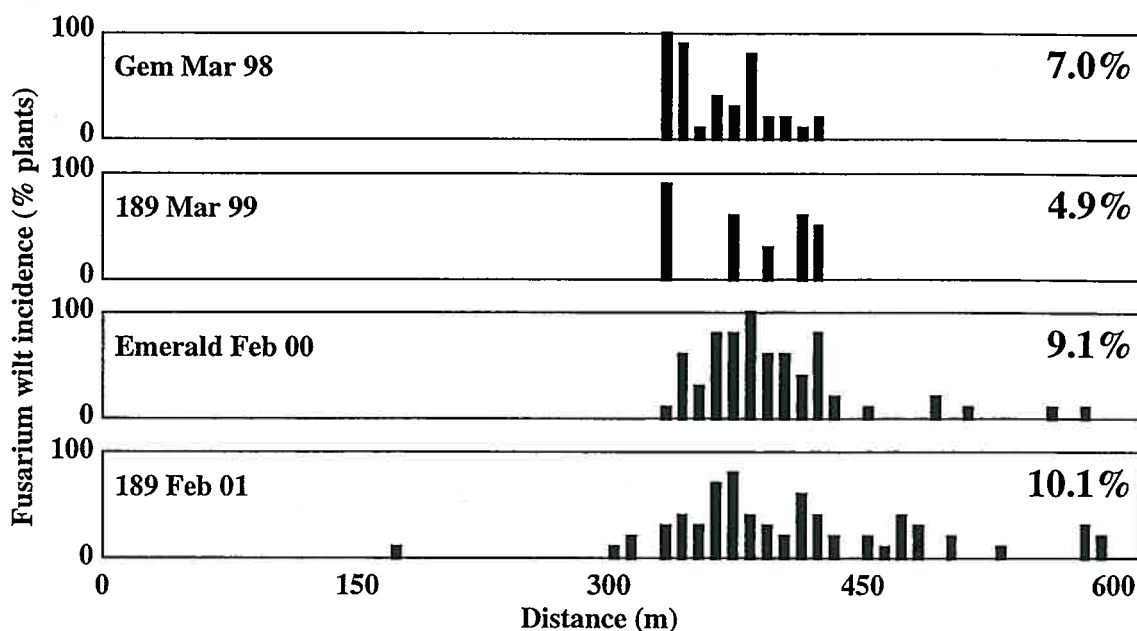


Figure 9. Incidence of Fusarium wilt of cotton across a transect of a field near Boomi. Gem is a susceptible variety, Emerald and 189 are less susceptible varieties. Transect means at right.

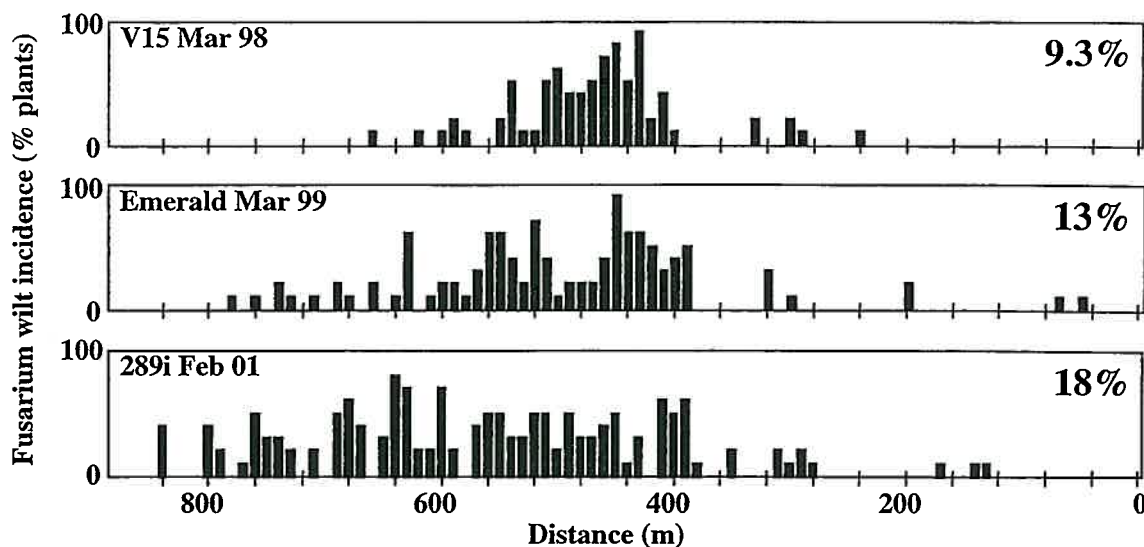


Figure 10. Incidence of Fusarium wilt of cotton across a transect of a field near Boomi. V15 is a susceptible variety, Emerald and 289i are less susceptible varieties. Transect means at right.

In a field that had three consecutive cotton crops the incidence of Fusarium wilt increased by 119% (Figure 10). In a nearby field, where two cotton crops had been separated by a double winter crop rotation (wheat followed by a green-manured legume crop), the incidence of Fusarium wilt increased by 39% (Figure 10).

In a field near Boggabilla, in which susceptible varieties were grown, the severity of the disease increased to the point where cotton cropping is no longer viable (Figure 11). In February 2000 another transect was established across another field near Boggabilla. The presence of Fusarium wilt was relatively constant at one end of the field (Figure 12) and experiments using biofumigation and rotation crops were subsequently established in this area.

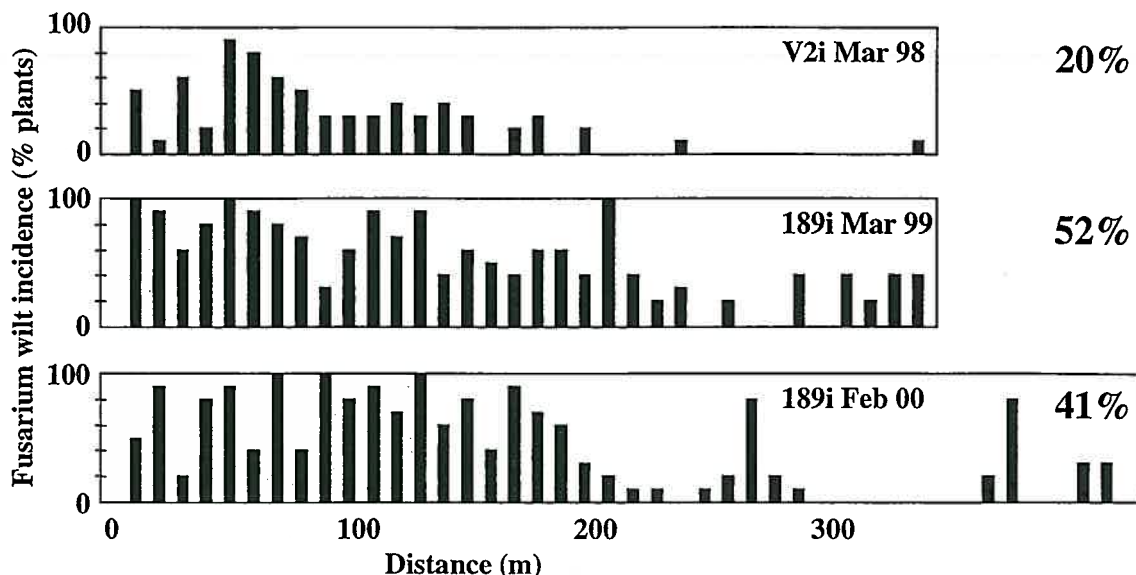


Figure 11. Incidence of Fusarium wilt of cotton across a transect of a field near Boggabilla. All varieties used are susceptible. Transect means at right.

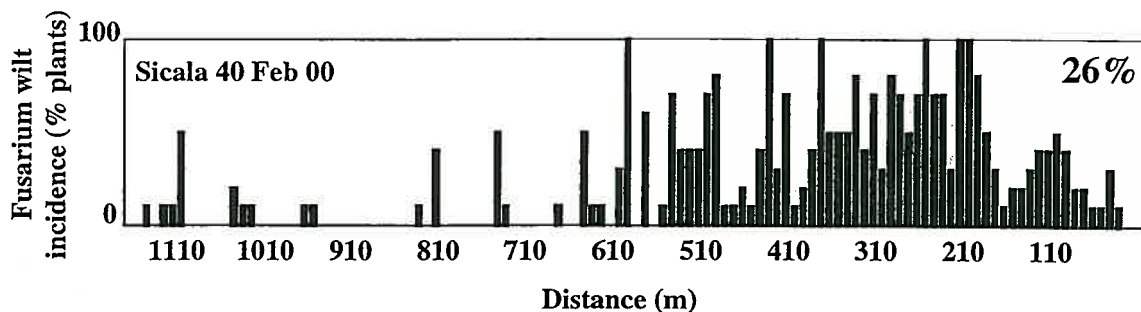


Figure 12. Incidence of Fusarium wilt of cotton across a transect of a field near Boggabilla. Transect mean at right.

While the transects have provided good information on the progress of Fusarium wilt in the border rivers region, it is uncertain whether the disease will progress more quickly in the cooler cotton-growing areas of NSW. Consequently, new transects were established in one field in the upper Namoi (Figure 13) and in two fields in the Macquarie valley. These fields will be monitored in future.



Figure 13. Incidence of Fusarium wilt of cotton across a transect of a field near Gunnedah. Transect means at right.

In summary, changing to a less-susceptible variety usually results in an immediate reduction in the incidence and severity of Fusarium but the disease will continue to increase in successive crops, even when the less susceptible varieties are grown. Effective control will ultimately require the deployment of varieties and/or treatments that result in zero increase in inoculum in the soil. The distribution of Fusarium wilt in all the established transects will continue to be monitored as part of CRDC project DAN154C (Diseases of cotton VII).

Experiments

Seedling disease

Two fungicide seed treatment trials were completed during the 1998-99, 1999-00 and 2000-01 seasons. These experiments were made possible by the collaboration of Cotton Seed Distributors, who kindly provided, treated and packaged the seed, and Deltapine Australia who kindly planted and assessed the trials at Dalby on the Darling Downs.

In the 1998-99 season, there were no significant differences between any of the treatments (Tables 1 and 2) despite significant seedling mortality, even though the Narrabri trial was subjected to rain and some low morning temperatures during the week after planting.

Table 1. Cotton seedling establishment at Dalby in 1998-99 with various fungicides applied as seed treatments.

Fungicide Seed Treatment	Plants/100 seeds	% of mean
Nusan/Nuflow/Apron200LS	80	109
PCNB(std)/Apron200LS/Baytan	77	105
PCNB(std)/Apron200LS	77	104
Vitavax/PCNB/Apron200/Thiram42	77	104
Vitavax 200FF/Apron200LS	76	104
PCNB(US)/ApronXL350ES	76	103
Thifluzamide/Apron200LS	75	101
PCNB(std)/Apron200LS/Kodiak	75	101
ApronTriple104ES	74	101
Baytan/Thiraflo/Kodiak/Apron200	74	101
PCNB(std)/ApronXL350ES	74	100
Apron200LS	73	99
Rizolex/Apron200LS	73	99
Apron XL350ES	73	99
Baytan/Apron200LS	73	99
Vitavax/PCNB/Apron200LS	72	98
PCNB(US)/Apron200LS	72	97
Untreated	70	96
HumicExtra	69	94
CropExtra	64	87

#Not significant

*Coefficient of Variation = 14.7. Std = standard rate, US = USA rate.

In the 1999-00 season, the trial was not implemented at Dalby and the trial at Narrabri had no significant differences among the treatments (Table 3). The standard treatment (PCNB/Apron), which was replicated in this experiment, had the highest and lowest scores. However, this reflected a relatively small range of variation among treatments that year (Table 3).

Table 2. Cotton seedling establishment at Narrabri in 1998-99 with various fungicides applied as seed treatments.

Fungicide Seed Treatment	Plants/100 seeds	% of mean
Vitavax 200FF/Apron200LS	52	112
PCNB(std)/Apron200LS	52	111
PCNB(std)/Apron200LS/Kodiak	51	110
PCNB(US)/Apron200LS	50	108
Baytan/Thiraflo/Kodiak/Apron200	50	107
PCNB(std)/Apron200LS/Baytan	50	106
PCNB(US)/ApronXL350ES	49	106
Vitavax/PCNB/Apron200/Thiram42	48	103
Baytan/Apron200LS	47	101
Thifluzamide/Apron200LS	46	99
Nusan/Nuflow/Apron200LS	46	98
Untreated	45	97
Apron Triple 104ES	45	97
Crop Extra	44	95
Apron200LS	44	95
Vitavax/PCNB/Apron200LS	44	95
PCNB(std)/ApronXL350ES	44	94
Rizolex/Apron200LS	44	94
ApronXL350ES	42	89
Humic Extra	40	86
Not significant		

Coefficient of Variation = 24.3. Std = standard rate, US = USA rate.

Table 3. Seedling establishment at Narrabri in 1999-00 with various fungicides applied as seed treatments.

Fungicide Seed Treatment	Plants/100 seeds	% of mean
PCNB(Std)/Apron	78	108
PCNB(US)/Apron	76	105
Vitavax 200FF/Apron	76	105
Nusan/Nuflow/Apron	75	104
Apron	74	103
Baytan/Thiraflo/Apron	73	101
PCNB(std)/Apron/Baytan	73	101
Rizolex/Apron	71	99
Baytan/Apron	70	97
Vitavax/PCNB/Apron/Thiram42S	70	97
Untreated	69	96
Maxim/Apron	69	95
Vitavax/PCNB/Apron	68	95
PCNB(Std)/Apron	68	94
Not significant		

Std = standard rate, US = USA rate. Apron = Apron XL350 ES. Vitavax 200FF includes Thiram.

In the 2000-01 season seed treatment with fungicides did increase seedling establishment significantly at both Dalby and Narrabri (Tables 4 and 5). At Dalby, Apron had no effect on seedling disease, suggesting that *Rhizoctonia* was the dominant pathogen at that location (Table 4). At Narrabri, seedling establishment was increased dramatically by Apron alone and almost all treatments with Apron were significantly better than untreated seed (Table 5), suggesting that *Pythium* had the dominant effect at that site in 2000-01. In both experiments, the standard seed treatment was best or equal best.

Table 4. Cotton seedling establishment at Dalby in 2000-01 with various fungicides applied as seed treatments.

Fungicide Seed Treatment	Plants/100 seeds	% of mean
Baytan/Thiraflo/Apron	72	112
PCNB(std)/Apron/Baytan	70	108
Ascend 30	69	106
Ascend 30/Apron	67	104
PCNB(US)/Apron	67	104
Rizolex/Apron	66	103
Vitavax/PCNB/Apron	66	102
Vitavax/PCNB/Apron/Thiram42S	64	99
PCNB(std)/Apron	63	97
Untreated	61	94
Spinfo/Apron	61	94
Baytan/Apron	60	94
Apron	59	92
Vitavax 200FF/PCNB/Apron	59	92

LSD = 7.4

Std = standard rate, US = USA rate. Apron = Apron XL350 ES. Vitavax 200FF includes Thiram.

Table 5. Cotton seedling establishment at Narrabri in 2000-01 with various fungicides applied as seed treatments.

Fungicide Seed Treatment	Plants/100 seeds	% of mean
PCNB(US)/Apron	69	116
Apron	66	112
Vitavax/PCNB/Apron	65	111
PCNB(std)/Apron/Baytan	65	110
PCNB(std)/Apron	63	107
Baytan/Thiraflo/Apron	62	106
Vitavax 200FF/PCNB/Apron	61	103
Spinfo/Apron	60	102
Baytan/Apron	60	102
Vitavax/PCNB/Apron/Thiram42S	67	96
Rizolex/Apron	54	92
Ascend 30/Apron	51	87
Ascend 30	50	84
Untreated	42	72

LSD = 12.3

Std = standard rate, US = USA rate. Apron = Apron XL350 ES. Vitavax 200FF includes Thiram.

Experiments on the effects of fungicide seed treatment and cotton yield were completed in 1998-99, 199-00 and 2000-01. In each year, seed treatment (PCNB and metalaxyl) had no significant impact on cotton yield (Table 6).

Table 6. Lack of effect of seed treatment or planting date on cotton yield at the Australian Cotton Research Centre.

Year	Sowing date	Seed treatment*	Yield (ba/ha)
1998-99	Early	Untreated	8.5
		QA	8.3
		QAS	8.5
	Late	Untreated	9.4
		QA	8.8
		QAS	8.7
			Not significant
1999-00	Early	Untreated	5.3
		QA	5.1
2000-01	Early	Untreated	6.5
		QA	6.6
	Late	Untreated	6.0
		QA	6.0

*Q = Quintozene (PCNB at standard rate), A = Apron (metalaxyl at standard rate); S = Semevin.

In recent years a plethora of 'cures' for cotton diseases have been offered to growers, ranging from magnetised water to the "miracle of the ages". In many cases these remedies are offered under the banner of improving soil health and do not give credit to the fact that pathogens have evolved to be aggressive colonisers of plants. In some cases such treatments may make disease worse. Amendment of soil infested with *Thielaviopsis* with a number of formulations of a product claimed to control cotton diseases caused substantial increases in cotton seedling mortality (Figure 14). *Rhizoctonia* multiplies on crop residues, particularly residues that are high in nitrogen, and this may explain the enhanced level of seedling disease with the herbal amendment. The herbal treatment had no impact on the severity of black root rot (data not presented).

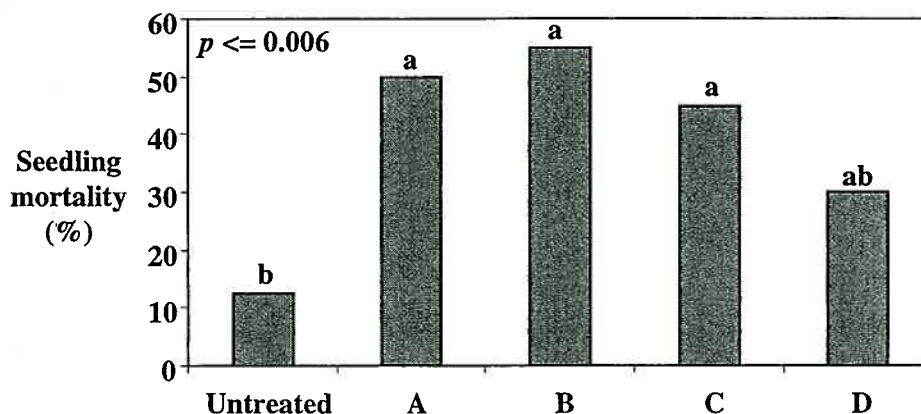


Figure 14. Increase in cotton seedling mortality in potted soil amended with four formulations (A, B, C and D) of an unknown herbal 'remedy'. Bars with the same letter are not significantly different by pairwise comparison of means using Fisher's LSD test at the stated probability level.

Seed treatment with the 'biological' products Humic Extra and Crop Extra tended to increase seedling mortality in both the seed treatment experiments in 1998-99 (Tables 1 and 2). While these differences were not significant, neither were the effects of the fungicide treatments in that particular year. Humic Extra and Crop Extra could potentially increase seedling mortality in other circumstances. It is essential that biological products used as seed treatments and soil amendments be evaluated in a scientific manner to preempt potential enhancement of seedling diseases.

In conclusion, the seed treatment trials in this project and preceding projects at Narrabri and Dalby clearly indicate that no fungicide seed treatments are substantially and consistently better than the standard PCNB/Apron treatments. These results were reflected by the absence of effects in the yield experiments. However, seedling disease is likely to be an important issue as cotton production in southern NSW expands, especially after pathogen populations increase during the first few cotton crops on 'new country'. The future duplication of the seed-treatment experiment in the Lachlan should give a valuable assessment of the impact of seedling disease and the potential for their control under conditions of greater disease pressure than occurs at Narrabri and Dalby.

Verticillium wilt

In the 1998-99 season, a variety trial was established near Collarenebri, using four replicates of ten commercial cultivars. Symptoms of *Verticillium* wilt became obvious across much of the trial where tail water backed up into the field. Plants were assessed prior to harvest by splitting stems along two transects that were approximately 40 and 80 metres in from the tail drain and parallel to it. The results (Table 7) indicate that Sicala V2, DeltaSapphire, Sicot 189, Sicot 40 and Siokra V16 have the best resistance to the *Verticillium* wilt pathogen.

Table 7. The incidence of *Verticillium* wilt in cotton varieties assessed as vascular discolouration in a field near Collarenebri in 1998-99.

Variety	Incidence(%)	% of site mean
Sicala V2	5	21
DeltaSapphire	10	41
Sicot 189	11	43
Sicala 40	14	58
Siokra V16	15	62
DeltaOpal	31	126
Siokra V15i	32	132
DeltaEmerald	36	149
DeltaPearl	43	177
DeltaTopaz	47	192

#LSD = 16.94

The coefficient of variation was high (34.9) which indicates considerable variability associated with the distribution of the disease in the field.

The incidence of *Verticillium* wilt was assessed in three variety trials in 1999-00. These experiments confirmed the resistance of several of the current varieties under significant disease pressure (Table 8).

Table 8. Incidence of *Verticillium* wilt in cotton at three sites in 1999-00.

Merah North		Merah North		Warren	
Variety	Disease (% plants)	Variety	Disease (% plants)	Variety	Disease (% plants)
Siokra V16i	6.1	Sicala V2	15.0	Exp. 459	15.5
Sicot 289i	7.7	Exp. 0858	17.3	Sicala V2	16.5
Sicala V3RRi	14.5	Siokra V17	17.7	Sicala 40	18.0
Siokra V15i	16.9	Sicot 189	20.0	Siokra V16	18.4
Sicala V3i	17.9	Sicala 40	24.7	Exp. 321	19.9
Nucotn37	21.6	Exp. 321	24.7	Siokra V17	20.8
Nupearl	22.2	Siokra V16	32.7	DeltaOpal	23.9
		DeltaOpal	40.0		
LSD	9.28		8.42		4.62

The repeated use of resistant varieties, along with limited crop rotation, has resulted in dramatic reductions in the incidence of *Verticillium* wilt in commercial cotton crops (Table 9). This is consistent with the declining incidence of *Verticillium* wilt that has been observed across all cotton growing areas of NSW (see surveys section).

Table 9. Declining incidence of *Verticillium* wilt of cotton due to the repeated use of resistant varieties on a commercial farm near Narrabri.

Field	Incidence* (season)	Number of resistant cotton crops	Incidence (1997-98)
12	70% (1988-89)	6 crops in 9 seasons	4.5%
31	67% (1988-89)	5 crops in 9 seasons	6.5%
33	74% (1990-91)	5 crops in 7 seasons	7.0%
21	72% (1993-94)	3 crops in 4 seasons	22.5%

* Incidence was assessed as the percentage of plants with vascular symptoms.

In collaboration with this project, it was shown in CRDC Project US37C that systemic acquired resistance against *Verticillium* wilt could be induced using chemical activators (Colson-Hanks et al., 2000).

A replicated field experiment was established in the *Verticillium* nursery at ACRI to confirm the observations of declining incidence of *Verticillium* wilt in commercial cotton crops. The incidence of *Verticillium* wilt in the susceptible variety, Siokra 1-4, was 95 per cent in the first year and increased to over 99 per cent in each of the last four seasons of the experiment (Figure 15). The incidence of the disease in the resistant variety, Sicala V2, declined substantially during the course of the experiment. This decline was relatively rapid during the first three years, then slower and then rapid again in the final year of the experiment (Figure 15). The experiment was terminated after the 1998-99 season. Siokra 1-4 was sown across the whole field in the following season. In plots that previously had Sicala V2 with a very low disease incidence (16%, Figure 15), the incidence of *Verticillium* wilt in 1999-00 in Siokra 1-4 was 72%, indicating that given appropriate seasonal conditions the pathogen can increase rapidly on susceptible varieties.

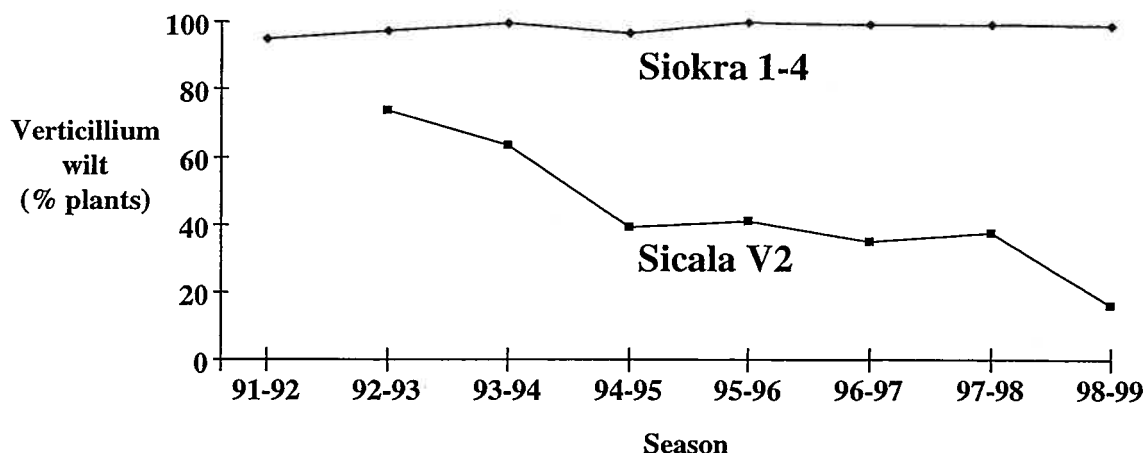


Figure 15. The incidence of *Verticillium* wilt of cotton in a resistant variety (■) and a susceptible (▲) variety when grown repeatedly in the same plots for six consecutive seasons.

Closer examination of the plots revealed that there were areas within the plots where the incidence of *Verticillium* wilt had increased (Figure 16). Consequently the assessments of disease incidence in the plots of the resistant variety, Sicala V2, were more detailed in the 1996-97 and 1997-98 seasons. In the 1996-97 season, when the mean incidence of *Verticillium* wilt across the three replicates of the resistant cultivar was 35 per cent, there were seven areas where the incidence was greater than, or equal to, 70 per cent (Figure 16). In the 1997/98 season, when the mean incidence of *Verticillium* wilt across the three replicates of the resistant cultivar was 37.5 per cent, there were thirteen areas where the incidence was greater than, or equal to, 70 per cent (Figure 15). There appeared to be no increase in the severity of the disease symptoms in plants where the incidence of *Verticillium* wilt was high.

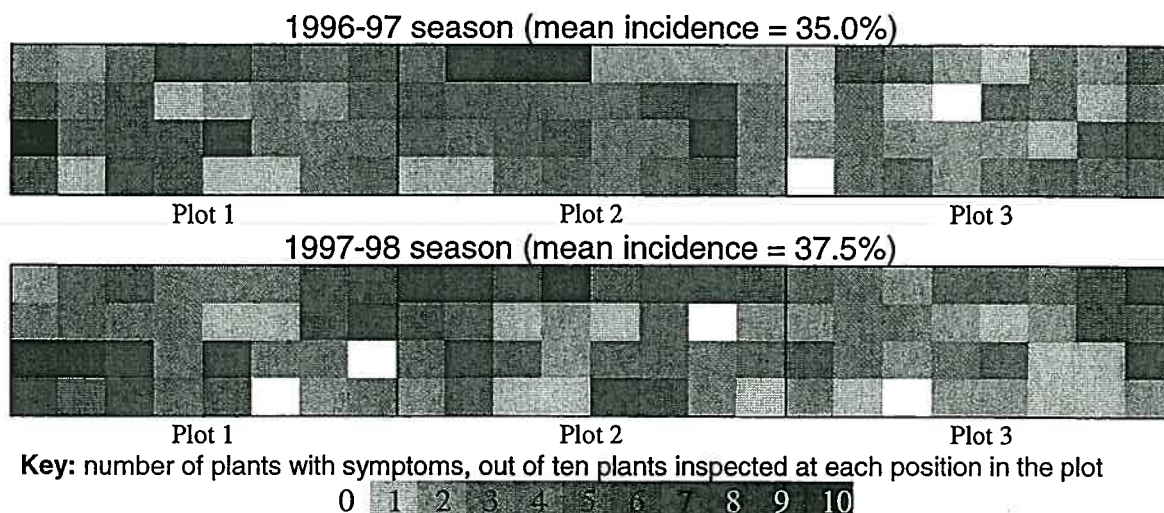


Figure 16. Spatial distribution of *Verticillium* wilt in plots with the resistant variety (Sicala V2) in the resistance-susceptibility experiment. Each plot contained eight rows of cotton (vertical in figure) that were 45 m long. Shading represents disease incidence (see key) for four groups of ten plants that were assessed in each row at the end of the season.

Schnathorst and Mathre (1966) and Ashworth *et al.* (1983) in California found that the repeated use of cotton varieties with resistance to *V. dahliae* resulted in the selection of more virulent strains of the pathogen and a consequent breakdown in the level of cultivar resistance. The occurrence of small areas in the *Verticillium* wilt nursery experiment, where the incidence of disease is increasing, indicated that the selection of more virulent strains of the pathogen may be possible under Australian conditions. However, it should be noted that the environmental conditions provided in this experiment favoured the pathogen and there were no crop rotations included with either treatment.

Despite the widespread and repeated use of resistant cultivars in Australia there has been no conclusive evidence of the development of more virulent strains of the pathogen in commercial cotton fields to date. However, during the 2000-01 disease survey, a site with severe *Verticillium* wilt was found in the upper Namoi valley in a crop of Siokra V16i, which has a relatively good level of resistance to *Verticillium* wilt. Plants were defoliating and dying and showed severe symptoms of vascular discoloration. The affected area was approximately 24 rows wide by 100 m long, with scattered patches between it and the tail ditch. The *Fusarium* wilt pathogen was not present in repeated samples that were sent to QDPI for testing. Isolates of *V. dahliae* collected from the upper Namoi site and from the areas of higher incidence in the *Verticillium* wilt nursery experiment need to be characterized and evaluated further.

In conclusion, *Verticillium* wilt was once the most widespread and important disease of cotton in Australia until the advent of resistant varieties. Active populations of *Verticillium* are still widespread in cotton growing soils. Continuous monoculture of resistant varieties in Australia may be selecting for strains of *Verticillium* with greater virulence. It is essential that the incidence of *Verticillium* wilt in commercial cotton crops continue to be monitored.

***Fusarium* wilt**

Summer Flooding

Three fields have been subjected to summer flooding for the control of *Fusarium* wilt of cotton. The disease was detected in three large patches in a field between Boomi and Mungindi in December 1994 and the field was flooded for 60 days during the following summer. The field was planted to one of the 'more resistant' cotton cultivars in 1996-97, 1997-98 and 1998-99. *Fusarium* wilt was not observed in either the 1996-97 or the 1998-99 seasons and only four isolated infected plants were found in the 1997-98 season.

Three large areas of *Fusarium* wilt were detected in two cotton crops near Moree in January 1997. These two fields were flooded during the 1997-98 summer. High rainfall during winter of 1998 prevented the fields from drying out and they were not sown to cotton again until 1999, when less susceptible varieties were planted in October. A few isolated plants with symptoms of *Fusarium* wilt were observed at one end of one field, well away from the original areas of severe disease. No symptoms of *Fusarium* wilt were observed in the

original patches. Summer flooding will be constrained by the topography of fields and the availability of water. However, strategic use on new outbreaks of the may be the most useful way to deploy summer flooding.

Managing Crop Residues

F. oxysporum f.sp. *vasinfectum* is able to survive as chlamydospores in association with crop residues. A large scale field experiment was established to determine if there was an advantage in retaining cotton crop residues on the soil surface for eight weeks prior to incorporation rather than incorporating them into the soil as soon as possible after harvest and slashing. Crop residues retained on the soil surface were exposed to sunlight and repeated wetting and drying cycles. Cotton was planted across the trial area in the following season and seedling mortality was assessed in the two treatments (Table 10). Fusarium wilt seedling mortality was reduced by 31% when infested cotton crop residues were retained on the surface for eight weeks prior to incorporation.

Table 10. Fusarium wilt of cotton seedling mortality at six weeks after planting where infested crop residues were either retained on the soil surface for 8 weeks prior to incorporation or incorporated as soon as possible after harvest. ($p = 002$)

Treatment	Dead seedlings/100m
Residues incorporated immediately	634a
Residues retained on soil surface for 8 weeks	436b

Crop Rotation

The most common rotation used in Australian cotton production systems is a winter cereal planted soon after the cotton harvest followed by a summer-winter fallow. According to Smith and Snyder, (1975) *F. oxysporum* f.sp. *vasinfectum* is able to survive and sometimes increase on residues of some cereal crops. A large scale field experiment was established to investigate the effect of a wheat fallow, barley fallow or long bare fallow crop rotation on the incidence of Fusarium wilt in a subsequent cotton crop. The rotations were established in May 1998 and managed according to commercial practice in plots 8 m wide and 75 m long. Cotton was planted across the trial area in October 1999 and seedling mortality was assessed six weeks later (Table 11). The incidence of seedling mortality resulting from Fusarium wilt was significantly lower following a long bare fallow than after either of the cereal fallow rotations.

Table 11. Fusarium wilt of cotton seedling mortality at six weeks after planting following three different winter crop rotations. ($p = 0.01$)

Crop rotation	Seedling mortality (%)
Long bare fallow	29.9 a
Wheat fallow	42.4 b
Barley fallow	41.6 b

Systemic acquired resistance (SAR)

Plants have natural defense systems that may be activated to provide a broad spectrum increased resistance to pathogens. Colson et al., (1997) showed that chemically induced SAR could provide significant control of both foliar and vascular wilt pathogens of cotton. Benzothiadiazole (BTH) is a chemical activator of SAR that has been developed by Novartis (Gorlach et al., 1996).

It was suggested that the pre-soaking of seed in 25ppm BTH for 5 hours could provide induced resistance to cotton pathogens during the seedling stage of growth (A. H. Mondal *pers. comm.*). A small plot field experiment with 12 replicates and 24 seeds per plot was established to determine if manipulation of the natural plant resistance mechanisms could provide significant control of Fusarium wilt of cotton. The pre-soaking treatment with BTH significantly increased the survival of seedlings (Table 12).

Table 12. The effect of pre-soaking seed with 25ppm BTH (an activator of systemic induced resistance) on the incidence of Fusarium wilt of cotton at six weeks after planting. ($p = 0.002$)

Treatment	Seedling survival (%)
Untreated control	21.7 a
Presoaked in water	19.2 a
Presoaked in BTH	37.9 b

In collaboration with this project, it was shown in CRDC Project US37C that systemic acquired resistance against *Verticillium* wilt could be induced using chemical activators (Colson-Hanks et al., 1999).

In conclusion, no single control measure will provide a satisfactory solution to the problem of Fusarium wilt of cotton in Australia. An integrated control strategy using a range of approaches must be developed to minimize the impact of this disease on Australian cotton production.

Alternaria leaf spot and Alternaria boll rot

Alternaria leaf spot is widespread in most cotton growing areas but usually at low levels (see survey section). However, with favourable environmental conditions instances of defoliation of leaves on mature plants and boll rots have been observed in association with wet weather and nutritional stress. Defoliation of the leaves of seedlings has been observed occasionally in association with the carry-over of inoculum on cotton residues.

Severe boll rot caused by *A. macrospora* was observed in a variety trial near Boggabilla in the 1995-96 season. There were no open bolls at the time of assessment. Lesions 2 mm in diameter were the most frequent in size, followed by lesions 3 mm in diameter (Figure 16). The severity of *Alternaria* boll rot was assessed by summing the number of 2 and 3 mm lesions on 50 bolls in each replicate. (Figure 17a,b). Some varieties were more susceptible than others were and the pattern for 2 mm lesions did not match the pattern for 3 mm lesions. However, lesions 3 mm in diameter would give a better measure of the

ongoing expansion of lesions and, hence, the degree of resistance by the plant. Accordingly, the incidence of 3 mm lesions (Figure 17b) matches quantitative observations of the performance of these varieties against *A. macrospora* over time (G. Constable, pers. Comm.).

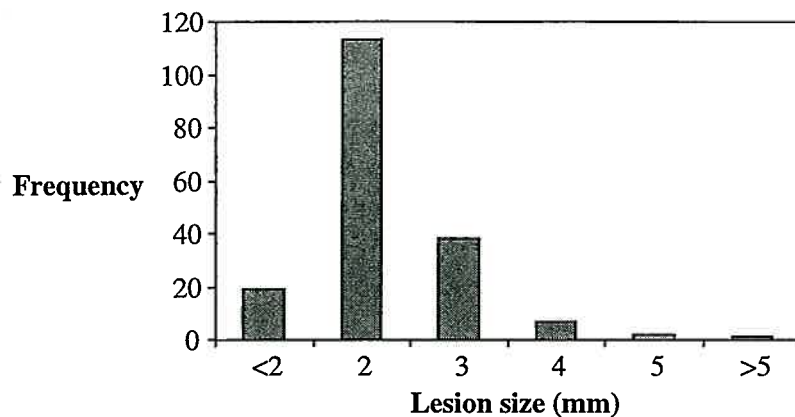


Figure 16. Frequency distribution of different sized lesions, caused by *Alternaria macrospora*, on bolls of cotton (cultivar CS8S) in a variety trial near Boggabilla in the 1995-96 season (totals for 50 bolls).

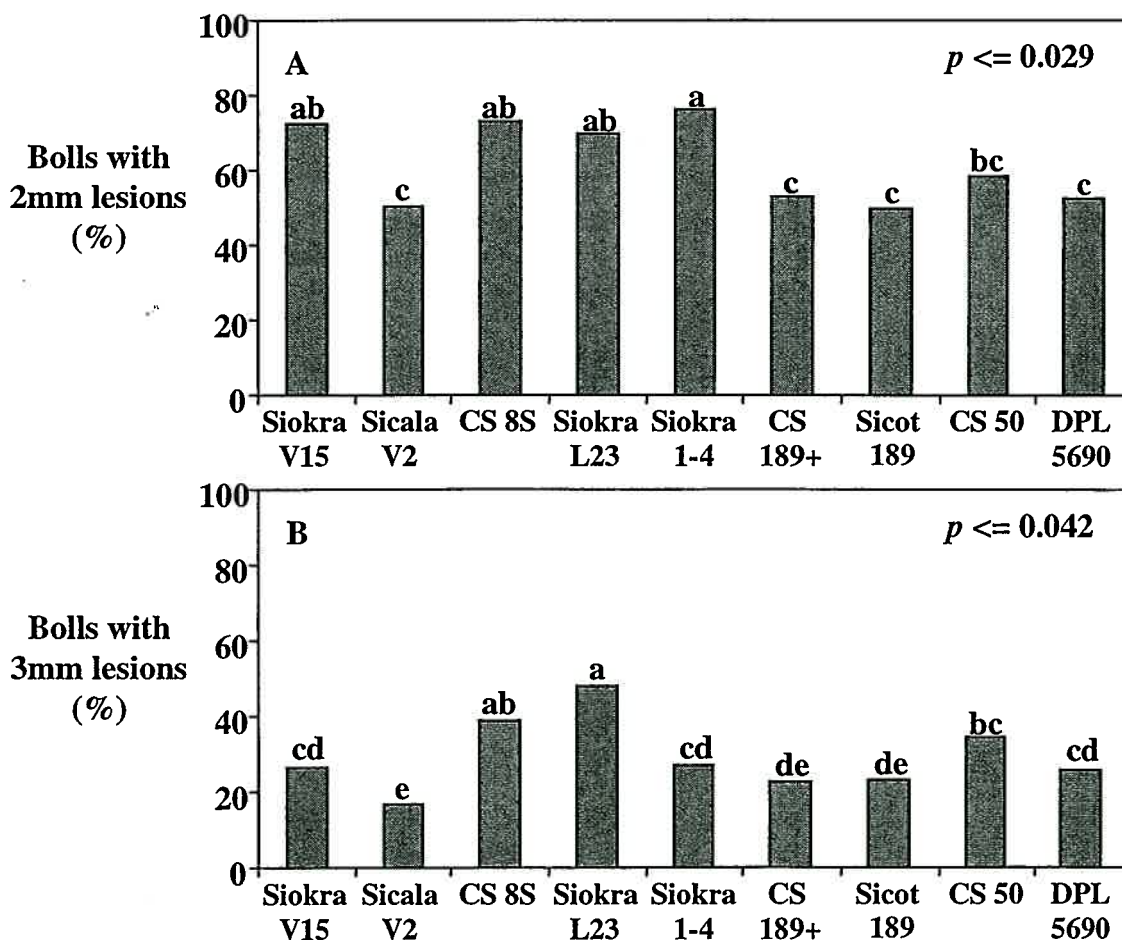


Figure 17. Incidence *Alternaria* boll rot in a cotton variety trial near Boggabilla in the 1995-96 season. Bars with the same letter are not significantly different at the stated probability level by pairwise comparison of means using Fisher's LSD test.

In the light of these observations, experiments were initiated at ACRI to develop a suitable screening technique for evaluating resistance against *A. macrospora* under field conditions.

The screening technique involved planting varieties in replicated plots between buffers of susceptible varieties of cotton. The buffers consisted of two rows of cotton with a misting line running between them for the length of the plots. The misting line was suspended 1.2 m above the ground, with mist jets placed every 0.5 m. The misting was initiated near the end of January, when the crop canopy was substantial, and was applied for 15 minutes each hour, over a period of approximately six weeks. A few days prior to the initiation of misting, the buffer rows were inoculated with *A. macrospora* by dusting with a chaff made from infected cotton leaves (Pima) that were collected the previous season. After misting was completed, the severity of Alternaria leaf spot was assessed on 10 randomly selected plants within each replicate plot. Assessment included counts of the number of primary leaves remaining on each plant and estimates of the percentage leaf area with necrotic lesions that were made using a disease key constructed for this purpose. In the 1998-99 season, CS50 and Pima were used for the buffer rows and in subsequent seasons only Pima was used due to its greater susceptibility.

In the 1998-99 season, 62% of the variation in the severity of defoliation of primary leaves could be explained by variation in the severity of leaf necrosis on the lowest primary leaf (Figure 18).

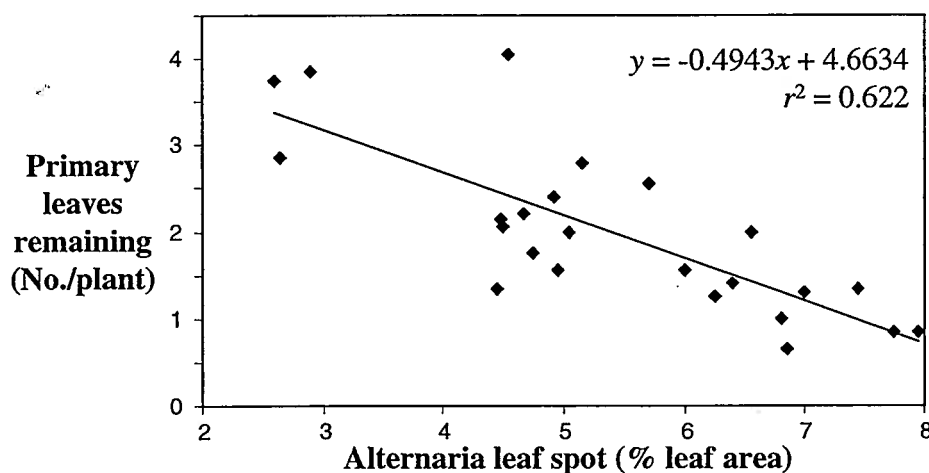
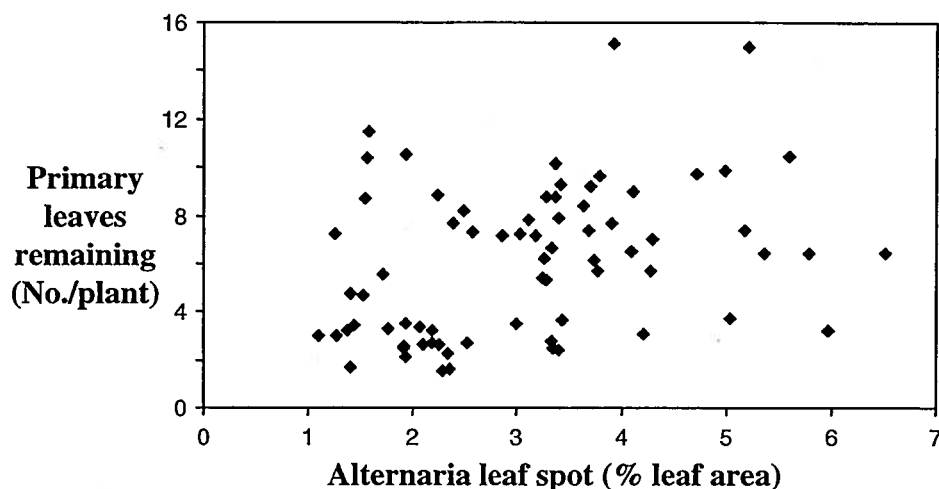


Figure 18. Relationship between the severity of Alternaria leaf spot and defoliation of primary leaves in cotton lines in a screening experiment at ACRI in the 1998-99 season. (Assessed 24 March 1999).

In the 1999-00 season, the severity of defoliation of primary leaves was not related to the severity of leaf necrosis on the lowest primary leaf (Figure 19). Both experiments were assessed relatively late in the season when plants were beginning to senesce and would have been more susceptible to infection by *A. macrospora*. Although the first experiment (Figure 18) did appear to discriminate between different cotton lines, factors such as crop maturity will

influence susceptibility. In both screening experiments there was no relationship between symptoms and cotton yield. Lesions on bolls will have a direct effect on yield potential and should be a more valuable measure of resistance against *A. macrospora* than foliar symptoms or defoliation of primary leaves. Yield loss will be more likely if the onset of infection occurs early rather than late. Assessment of Alternaria boll rot should be conducted at an early stage of fruit maturity, when few bolls are open.



CONCLUSIONS (RESEARCH OUTCOMES VERSUS OBJECTIVES)

- (i) **To monitor the distribution and importance of diseases in Australian cotton by regular disease surveys.**

The disease surveys identified the following trends:

Seedling mortality across NSW declined by approximately 50% during the early 1990s, leveling off at close to 20% in the late 1990s with a sharp increase in seedling mortality in the 2000-01 season. Environmental conditions have an overriding influence on seedling mortality. It is likely that higher seedling mortality will be observed as the severity and distribution of black root rot increases. Furthermore, the expanding area of cotton in southern NSW will be at greater risk of environmental conditions that favour seedling disease than the established areas in north west NSW.

The incidence of black root rot has increased exponentially in NSW and the disease has now emerged as a major threat to the sustainability of the cotton industry. Black root rot has now been recorded on 93% of the farms surveyed annually in the Macquarie, Namoi, Gwydir and Macintyre valleys and occurs in all cotton growing regions of NSW except Menindee and the Murrumbidgee valley. If black root rot continues to increase at its current rate, then 95% of fields on the farms that are regularly surveyed in the Macintyre, Gwydir, Namoi and Macquarie valleys will have the disease by 2004.

Fusarium wilt is increasing exponentially and is widespread in most cotton production areas of Australia and further cases are likely to occur. The rapid increase in reported cases in 1999-00 represents dispersal in previous seasons; the favourable seasonal conditions during that year allowed the prominent expression of symptoms and, hence, a large number of new cases were reported. It must be assumed that the disease is much further widespread than is currently recognised. Monitoring of infested fields showed that changing to a less-susceptible variety usually results in an immediate reduction in the incidence and severity of Fusarium but the disease will continue to increase with successive cotton crops, even when the less susceptible varieties are grown.

The widespread adoption of resistant varieties has resulted in a dramatic reversal of what was an exponential increase in Verticillium wilt during the late 1980s. In four out of the last five years, the incidence of Verticillium wilt in NSW was lower than when disease surveys first began in 1983 and, consequently, Verticillium wilt is slipping towards obscurity in the minds of many growers. While the use of resistant varieties has been decreasing over the past two seasons, this trend was not reflected by an increase in the incidence of the disease overall.

The dominant factor affecting the incidence of boll rots is precipitation; the incidence of boll rot across NSW ranged from 3 to 5% accordingly during

the last three seasons. Localised rainfall events have resulted in major losses to *Phytophthora* boll rot in some areas.

Alternaria leaf spot became widespread in the cotton-growing areas of NSW in the early 1990s. Despite its almost universal occurrence, the severity of this disease in upland cotton has remained at very low to negligible levels during recent years. Pima crops are remain at risk.

The incidence of 'Bunchy top' is very sporadic. In the 1998-99 season 'bunchy top' symptoms were widespread and sometimes severe, although in many fields the symptoms only became apparent toward the end of the season and were confined to the tops of the plants. In the following two seasons the incidence of bunchy top was low, with small isolated patches being observed nine fields in 1999-00 and in four fields in 2000-01 (0.06% of plants across NSW). Leaf mottle symptoms were observed without bunchiness in six fields in 2000-01.

Bacterial blight still occurs in and in Pima and at low levels in the few varieties of upland cotton that are susceptible. Bacterial blight remains a threat to susceptible crops, especially Pima, when climatic conditions are favourable for infection.

(ii) To continue to develop and/or evaluate control strategies for *Verticillium* wilt, *Fusarium* wilt, *alternaria* leaf spot and seedling diseases of cotton.

Seed treatment trials in this project and preceding projects at Narrabri and Dalby clearly indicate that no fungicides are substantially and consistently better than the standard PCNB/Apron treatments. These results were reflected by the absence of effects in the yield experiments. Some of the 'biological' products and organic amendments currently being marketed for the control of cotton diseases actually increased seedling mortality. It is essential that such products be evaluated in a scientific manner to preempt potential enhancement of seedling diseases and quantify any benefits.

The long-term field trial with susceptible and resistant varieties of cotton indicated that continuous monoculture of resistant varieties may potentially select for strains of *Verticillium* with greater virulence. Active populations of *Verticillium* are still widespread in cotton growing soils and this field trial demonstrated that populations will quickly increase if susceptible varieties are grown. The use of resistant varieties is still the key to control of this disease.

No single control measure will provide a satisfactory solution to the problem of *Fusarium* wilt of cotton in Australia. Field experiments indicated that:

- Summer flooding is very effective against *Fusarium* wilt but does not eradicate it;
- Rotation with cereals can increase the severity of *Fusarium* wilt in comparison to bare fallow.

- Leaving cotton trash on the soil surface for two months before incorporation results in less disease in the subsequent crop than if the trash is incorporated immediately
- Systemic acquired resistance against Fusarium wilt can be induced by seed treatment with chemical activators to give a degree of protection.

An integrated control strategy using a range of approaches will be the best approach to minimise the impact of this Fusarium wilt on Australian cotton production.

The *Alternaria* screening experiments at ACRI demonstrated that an artificial level of infection by *A. macrospora* can be created to screen cotton breeding lines in the field. Assessment of the incidence of boll lesions 3 mm in diameter or more will give the best discrimination between cotton varieties or breeding lines and should be conducted while most of the fruit are still closed. Although host resistance is a powerful control measure for *A. macrospora*, it should be deployed in an integrated manner with other control strategies, such as systemic acquired resistance.

Results of these experiments and observational studies have been incorporated in strategies for integrated disease management and disseminated to the cotton industry by way of publications, media releases, field days and meetings with growers and consultants.

LIKELY IMPACT OF RESEARCH OUTCOMES (COST-BENEFIT)

Verticillium wilt has potential to cause large yield losses. Continued awareness of the importance of using varieties with good resistance to Verticillium wilt will control the existing populations of this pathogen. The experiments and observations of this project have clearly indicated a risk that more-virulent strains of the Verticillium wilt pathogen could develop. Investigation of any potential new strains will enable appropriate responses to minimise their impact and spread.

Fusarium wilt is a major threat to cotton production in Australia. The adoption of measures to control and constrain Fusarium wilt will be invaluable to both prevent disease progress and enable breeders and researchers to build upon the existing control strategy for Fusarium wilt. Some growers have already adopted control measures such as summer flooding and leaving cotton trash on the soil surface. Heightened awareness of the potential for further spread of Fusarium wilt has contributed to the successful deployment of the "come clean, go clean" strategy across NSW.

While *Alternaria macrospora* does not usually cause substantial losses, the capacity to identify resistance in cotton varieties will enable the industry to minimise the damage very effectively.

The disease surveys have highlighted the changing status of cotton diseases over time and provide valuable insights into the factors affecting disease incidence and severity. This information enables research directions and the deployment of research outcomes (i.e. disease control measures) to be prioritised.

RECOMMENDATIONS AND APPLICATION TO INDUSTRY

The annual disease surveys and observational studies of the incidence of Fusarium wilt should be continued.

The use of varieties with disease resistance, where available, and the minimisation of the spread of soilborne pathogens has been beneficial, and should remain a high priority for the industry.

An integrated control strategy will be the best approach to minimise the impact of this Fusarium wilt on Australian cotton production.

- Summer flooding is an effective option for the control, but not eradication, of Fusarium wilt. Summer flooding will be constrained by the topography of fields and the availability of water. Strategic deployment of summer flooding on new outbreaks of the disease may give the greatest return in terms of slowing the spread of the disease.
- Leaving cotton trash on the soil surface for two months before incorporation may minimise the carryover of the Fusarium wilt pathogen to subsequent crops.
- Investigation of appropriate rotation crops for Fusarium wilt should continue.
- Investigation of the potential for inducing systemic acquired resistance should continue.
- It is important that growers and consultants confirm and declare if Fusarium wilt is present in an area. Early detection of the disease is essential in the establishment of an effective control strategy.

The impact of seedling diseases in the new cotton areas in southern NSW should be monitored and the current control measures should be assessed, including duplication of seed treatment trials conducted by NSW Agriculture.

Screening for resistance to *Alternaria macrospora* should include assessment of the incidence of boll lesions 3 mm in diameter, before bolls open. Assessments can be made with naturally occurring infection or by inoculating buffers of Pima cotton and applying an artificial mist to enhance the spread of *A. macrospora* to the test plots.

Novel 'biological' products and organic amendments should be evaluated in a scientific manner to preempt potential enhancement of seedling diseases and quantify any benefits.

COMMERCIAL DEVELOPMENTS

There are no commercially significant developments, patents or licenses arising from the research in this project.

TECHNICAL DEVELOPMENTS

The technique of soaking cotton seed in acibenzolar-S-methyl (BTH) represents a new development in the use of chemical agents to induce resistance against Fusarium wilt. Cotton seed is soaked in a solution of BTH ($25 \mu\text{g mL}^{-1}$) for three to five hours, allowed to dry, and sown as soon as possible. BTH has not been previously used to induce resistance against pathogens of plant roots. This technique was developed by the Technical Officer with CRDC project DAN122C, Mr Anowar Mondal, and has also proved to be effective against black root rot.

The development of a protocol for screening for resistance to *Alternaria macrospora* will enable uniform comparison of the relative resistance of cotton varieties. Screening for resistance to *Alternaria macrospora* should include assessment of the incidence of boll lesions 3 mm in diameter, before bolls open. Assessments can be made with naturally occurring infection or by inoculating buffers of Pima cotton and applying an artificial mist to enhance the spread of *A. macrospora* to the test plots.

FURTHER DEVELOPMENT

Technological

Further refinement and development of the use of rotation crops, biofumigation crops, rotation strategies and systemic acquired resistance for control of various cotton diseases, including black root rot, seedling disease, Fusarium wilt and Verticillium wilt, is being conducted as part of the CRDC projects DAN153C (Managing black root rot) and DAN154C (Diseases of cotton VII) with NSW Agriculture.

Further research on the pathogenicity and genetic diversity of Australian populations of *T. basicola* is the subject of the CRDC postgraduate scholarship CRC29C, with the University of Queensland and NSW Agriculture.

Further research on the role of soil microbial diversity ('soil health') in soils that are suppressive or conducive to black root rot is the subject of the CRDC postgraduate scholarship CRC18C, with the University of Sydney, NSW Agriculture and the University of New England.

Outcome deployment

The research outcomes of this project are being included in the Integrated Disease Management (IDM) Manual currently being compiled by the Australian Cotton Cooperative Research Centre. At a recent meeting of the Cotton CRC's Fusarium Wilt Coordination Committee (FUSCOM) it was agreed to investigate the feasibility of (i) incorporating the IDM Manual into CottonLOGIC and (ii) developing protocols for growers to use CottonLOGIC to record disease incidence and provide decision support for disease management.

Information on the current disease management strategies for cotton diseases has already been disseminated to the industry by various means, including: Cotton CRC information sheets, articles in *The Australian Cottongrower*, presentations and papers in the proceedings at Australian Cotton Conferences in 1998 and 2000 and at the Cotton CRC Research Conference in 1999, presentations at numerous grower meetings and field days, media releases and radio and television interviews.

COMMUNICATION OF RESULTS

Publications

Refereed Papers

- Colson-Hanks, E. S., Allen, S. J. & Deverall, B. J. (2000). Effect of 2,6-dichloroisonicotinic acid or benzothiadiazole on *Alternaria* leaf spot, bacterial blight and *Verticillium* wilt in cotton under field conditions. *Australasian-Plant-Pathology* **29**, 170-177.
- Nehl, D. B., Allen, S. J. & Brown, J. F. (1998). Slow arbuscular mycorrhizal colonisation of cotton caused by environmental conditions in the soil. *Mycorrhiza* **8**, 159-167.
- Hulugalle, N. R., Entwistle, P. C., Cooper, J. L., Allen, S. J. & Nehl, D. B. (1998). Effect of long-fallow on soil quality and cotton lint yield in an irrigated, self-mulching, grey Vertosol in the central-west of New South Wales. *Australian Journal of Soil Research* **36**, 621-639.
- Hulugalle, N. R., Entwistle, P.C., Cooper, J.L., Scott, F., Nehl, D.B., Allen, S.J. & Finlay (1999). Sowing wheat or field pea as rotation crops after irrigated cotton in a grey Vertosol. *Australian Journal of Soil Research* **37**, 867-89.
- Nehl, D. B., McGee, P. A., Torrisi, V., Pattinson, G. S. & Allen, S. J. (1999). Patterns of arbuscular mycorrhiza down the profile of a heavy textured soil do not reflect associated colonisation potential. *New Phytologist* **142**, 495-504.
- Wang, B., Dale, M. L., Kochman, J. K., Allen, S. J. & Obst, N. R. (1998). Variations in soil population of *Fusarium oxysporum* f. sp. *vasinfectum* as influenced by fertiliser application and growth of different crops. *Australasian Plant Pathology* **27**, 174-181.

Book chapters

- Allen, S. J. (1999) Black Root Rot. In Kirkpatrick, T. & Rothrock, C. (Editors) '*Compendium of Cotton Diseases*' American Phytopathological Society
- Nehl, D. B., Brown, J. F. & Allen, S. J. (2001). Bacterial stunt. p. ? In: T. Kirkpatrick & C. Rothrock (Eds), *Compendium of Cotton Diseases, 2nd Edition*, APS Press: St Paul, Minnesota.

Refereed Conference Papers

- Nehl, D. B., Brown, J. F. & Allen, S. J. (1999). Rhizobacteria: friend or foe? In *First Australian Soilborne Disease Symposium* pp. 31-32. Ed. R. C. Magarey. Bureau of Sugar Experiment Stations: Broadbeach.
- Allen, S. J. & Nehl, D. B. (1999). The dilemma between sustainable soil management and controlling soilborne diseases of cotton. In *First Australian Soilborne Disease Symposium* vol. pp. 9-11. Ed., R. C. Magarey. Bureau of Sugar Experiment Stations: Broadbeach.

Australian Cottongrower articles

- Allen, S. J. (1998) Crop residues and diseases of cotton. *The Australian Cotton Grower* **19(2)** 40-41.

Conference proceedings

- Allen, S. J. and Lonergan, P. A. (1998) Trends in diseases in Australian Cotton. (*Invited Paper*) *Proceedings of the Ninth Australian Cotton Conference*, Broadbeach, Qld. p541-547.
- Putcha, S. Barker, K. and Allen S.J. (1998) Biocontrol of cotton diseases. (*Invited Paper*) *Proceedings of the Ninth Australian Cotton Conference*, Broadbeach, Qld. p555-559.
- Allen, S. J. (1998) The development of new strains of *Verticillium dahliae* in Australia. *Proceedings of the Second World Cotton Research Conference*, Athens, Greece September 1998.

- Reid, P.E., Allen, S.J., Constable, G.A. and Thomson, N.J. (1999) Breeding for Disease Resistance in Cotton - Successes and Challenges. *Proceedings of the Australian Plant Breeding Conference*.
- Allen, S.J. and Lonergan, P.A. (1999) Thermal imagery for the detection of Fusarium wilt of cotton. *Proceedings of the 12th biennial Conference of the Australasian Plant Pathology Society, Canberra, 1999*, p47.
- Colson-Hanks, E.S., Deverall, B.J. and Allen, S.J. (1999) Systemic acquired resistance in cotton. *Proceedings of the 12th biennial Conference of the Australasian Plant Pathology Society, Canberra, 1999*, p241.
- Allen, S.J. (2000) Control strategies for fusarium wilt of cotton in Australia. *Proceedings of the 2002 Beltwide Cotton Conferences – Cotton Disease Council, San Antonio, Texas*.
- Allen, S. J. (2000) Integrated Disease Management – How are we doing?. (Invited Paper) *Proceedings of the Tenth Australian Cotton Conference, Brisbane, Qld.* p439-442.
- Putcha, S., Allen, S.J., Tingay, S. and Mitchell, A. (2000) Biological control of Fusarium wilt of cotton – Scope and prospects. (Invited Paper) *Proceedings of the Tenth Australian Cotton Conference, Brisbane, Qld.* p507-511.
- Allen, S.J. and Kochman, J.K. (2001) Eliminating seed-borne inoculum of *Fusarium oxysporum* fsp *vasinfectum* in cotton. *Proceedings of the 2001 Beltwide Cotton Conferences – Cotton Disease Council, Anaheim, California*.
- Allen, S.J. (2001) Genetic and induced resistance strategies for controlling Fusarium wilt of cotton. ?. *Proceedings of the Second Australasian Soil-borne Disease Symposium - Lorne, Vic.*, p59-60.
- Gulino, L.M., Pattermore, J.A., Bentley, S., Moore, N.Y., Kochman, J.K., Allen, S.J. and Irwin, J.A.G. (2001). Fusarium wilt of cotton: Diversity and diagnostics. *Proceedings of the 13th biennial Conference of the Australasian Plant Pathology Society, Cairns, Qld.*, p380.
- Allen, S.J. (2002) The impact of disease incidence and severity on the yield of cotton in Australia. *Proceedings of the 2002 Beltwide Cotton Conferences – Yield Stagnation Symposium, Atlanta, Georgia*.
- Allen, S.J. (2002) The Australian Cotton Industry response to the Fusarium wilt problem. *Proceedings of the 2002 Beltwide Cotton Conferences – Cotton Disease Council, Atlanta, Georgia*.

Cotton CRC Information sheets

- Kochman, J., Allen, S., Moore, N. and Salmond, G. (1998) WILT ALERT - Fusarium wilt of cotton.
- Cotton CRC Pathologists and Weed Scientists (2000) Farm hygiene for disease and weed control. *Cotton Information Sheet, Australian Cotton Cooperative Research Centre*.
- Salmond, G. and Cotton CRC Pathologists (2000) Fusarium wilt update. *Cotton Information Sheet, Australian Cotton Cooperative Research Centre*.
- Cotton CRC Pathologists (2000) A tractor driver's view of Fusarium wilt. *Cotton Information Sheet, Australian Cotton Cooperative Research Centre*.
- Allen, S.J., Moore, N.Y. and the CRC Extension team. (2001) Now that Fusarium wilt has been confirmed on your farm. *Cotton Information Sheet, Australian Cotton Cooperative Research Centre*.

Other non-refereed publications

- Allen, S. J. and Lonergan P.A. (1998) Cotton Pathology 1997-98. *Cotton Seed Distributors 1998 Trial Results. AND Deltapine Trial Results*
- Allen, S. J. and Lonergan P.A. (1998) Disease Surveys 1997-98. In Kelly, D. (Editor) *Macquarie Valley Cotton Trial Reports* .
- Allen, S. J. and Lonergan P.A. (1999) Cotton Pathology 1998-99. *Cotton Seed Distributors 1999 Trial Results. AND Deltapine Trial Results*
- Allen, S. J. and Lonergan P.A. (2000) Cotton Pathology 1999-2000. *Cotton Seed Distributors 2000 Trial Results. AND Deltapine Trial Results*
- Nehl, D. B., Allen, S. J. and Lonergan P.A. (2001) Cotton Pathology 2000-01. *Cotton Seed Distributors 2001 Trial Results. AND Deltapine Trial Results*

APPENDIX - BUDGET

Total funds contributed to DAN122C by the CRDC.

Year	DAN122C
1998-99	57,838
1999-00	63,414
2000-01	67,071
Total	\$188,323