The effects of various agronomic practices on the incidence of bacterial blight of cotton.

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Summary
Bacterial blight is an important disease of cotton in Australia, but little is known of the influence of agronomic practices on its incidence. The effects of field slope, duration of furrow irrigation, soil and foliar application of nitrogen fertilizer, and irrigation method on the incidence and severity of bacterial blight infection were studied in four field experiments at Narrabri, New South Wales, Australia. Increasing the duration of furrow irrigation from 4 to 32 hr on a field slope of 1:1000 increased the incidence of bacterial blight on bolls from 32% to 53%. Decreasing the field slope from 1:1000 to 1:2000 and furrow irrigating for 4 hr per irrigation increased the incidence of blight on bolls from 32% to 46%. Application of nitrogen fertilizer to the foliage at rates up to 120 kg N ha^{-1} did not increase disease severity despite severe burning of the leaves. The incidence of blight was not affected by soil applications of anhydrous ammonia at rates up to 120 kg N ha^{-1}. Drip irrigation increased or decreased bacterial blight infection relative to furrow irrigation in different experiments, depending on which irrigation method produced the most waterlogging or leaf area, which varied between seasons. The study showed that the incidence of bacterial blight was increased mainly by factors conducive to waterlogging or high humidity of the crop canopy, including reduced field slope, extended furrow irrigation, rain following irrigation, and high leaf area index. All of these factors except rainfall can be optimized by adjusting the agronomic management of the crop.

Introduction
Bacterial blight caused by *Xanthomonas campestris* pv *malvacearum* (Smith) Dye (*Xcm*) is an important disease of cotton (*Gossypium hirsutum* L.) in Australia. Severe epidemics have been observed throughout New South Wales cotton growing areas with up to 60% of bolls infected in some fields (Allen 1986, Allen and West 1987). Blight has been a major factor in the declining popularity of cv. Deltapine 90, which is susceptible to the disease and cultivars with immunity to blight are now widely accepted. Bacterial blight occurs as dark green, water-soaked, angular lesions on the leaves and bracts of cotton. Boll infections are characterized by dark green, raised, circular, greasy lesions, especially common at the base of the boll. The 'Blackarm' symptom of the disease, where whole branches are killed, is not common on cotton in Australia unless associated with hail damage. The disease is seed borne (Allen and Scott 1985), favoured by warm and humid conditions (Stoughton 1931, 1932) and spread within a crop by rain-splash. Agronomic practices which promote high humidity within the crop canopy are expected to increase the disease, but little or no evidence has been reported previously.

Most of the Australian cotton crop is furrow irrigated in fine textured soils that are prone to waterlogging following irrigation or heavy rainfall (Hodgson and Chan 1982). Monthly rainfall in excess of 100 mm is common during the cotton growing season, and high levels of relative humidity within the crop canopy also result from extended furrow irrigations and poor surface and sub-surface drainage. Cotton yields are reduced on average by 29 to 33 kg lint per hectare per day of waterlogging (Hearn and Constable 1984, Hodgson 1986), and much of the yield loss is associated with reduced uptake and utilization of nitrogen from the soil (Hearn and Constable 1984, Hodgson and MacLeod 1988). Reduced uptake of nitrogen is attributed to root disfunction (Sojka and Stolzy 1980) and denitrification (Freney *et al*. 1985) during the period of waterlogging. Hodgson and MacLeod (1987, 1988) showed that much of the yield loss from the waterlogging associated with furrow irrigation could be prevented by applying urea to the cotton foliage one day before irrigation. Commercial adoption of this practice usually involves the application of concentrated solutions of urea or urea-ammonium nitrate mixtures, which sometimes burn leaf tips and margins. The leaf burn has been confused with symptoms of bacterial blight infection, and applications of foliar nitrogen have been considered by farmers to increase the disease. However, this contention has not been validated.

Findlay (1928) claimed that waterlogging in roots increased the susceptibility of Sea Island cotton (*Gossypium barbadense* L.) to infection by *Xcm*. He observed that the disease "progressed further in those pots where the water table was high and the soil almost or completely waterlogged than in those which were wet but had the water table some distance below the surface". He suggested that asphyxiation of the roots decreased the resistance of plants to infection. Findlay (1928) also reported that side-dressing with ammonium sulphate increased the susceptibility of Sea Island cotton to infection by the blight pathogen. Conversely, Bird and Joham (1959) reported that the resistance of Upland cotton (*G. hirsutum* L.) to infection by *Xcm* was increased by the application of nitrogen and that nitrate nitrogen was more efficient in increasing resistance than was the ammonium form.

The relationship between waterlogging, soil and foliar application of nitrogen, and the incidence and severity of bacterial blight was studied in two field experiments at Narrabri, New South Wales, Australia. The objectives of these experiments were to (i) investigate the relationship, if any, between soil and foliar application of nitrogen fertilizer and bacterial blight infection, and (ii) to investigate the possibility of reducing blight infection by rapid irrigation and surface drainage. Two field experiments comparing furrow irrigation with two types of drip irrigation were also assessed to determine the effect of the irrigation system on the incidence and severity of bacterial blight.

Materials and methods
All field experiments were done at the Agricultural Research Station, Narrabri, New South Wales, Australia (30° 13′ S ; 149° 47′ E) during the summer seasons of 1985–86 and 1986–87. The soils are cracking grey clays or vertisols classified as Ug 5.25 by Northcote (1979). The susceptible cotton cultivar Deltapine 61 (*G. hirsutum*) was used in all field experiments reported here except in experiment II, in which the susceptible cv. Deltapine 90 was used. The occurrence of bacterial blight in all experiments resulted from natural epidemics.

Waterlogging and nitrogen fertilizer experiments
In experiments I and II we assessed the influence of soil and foliar nitrogen fertilizer applications on bacterial blight of cotton and the relationship between bacterial blight and waterlogging. Waterlogging was varied by running irrigation siphons in the furrows of a cotton field for periods ranging from 4 to 32 hr. A more complete description of experiment I, is given by Hodgson and MacLeod (1988). The incidence and severity of bacterial blight was assessed in the nil nitrogen, foliar nitrogen only and soil applied nitrogen only treatments and not in the soil plus foliar nitrogen treatment. In experiment II, field slope, which affects the rate of drainage and hence

waterlogging, was also varied by grading a field to slopes of 1:500, 1:1000, 1:1500 and 1:2000 (replicated). Only slopes of 1:1000 and 1:2000 were included in the present study. Table 1 summarizes and compares the cultural and experimental treatments in experiments I and II. Foliar sprays were applied at the rates and times shown in Table 1 as a high volume/low concentration (8.33 g N L^{-1}) mixture, using a commercial boom sprayer with high clearance to straddle the cotton plants. Soil applications of nitrogen (Table 1) were in the form of anhydrous ammonia incorporated before planting at a depth of 0.2 m below the surface of the ridges in which the crop was subsequently sown.

Comparison of drip and furrow irrigation systems

The incidence and severity of bacterial blight of cotton was also assessed in field experiments in 1985–86 (experiment III) and 1986–87 (experiment IV), which compared two drip irrigation systems with standard furrow irrigation. Growth and yield of cotton in these experiments have been reported elsewhere (Constable *et al.* 1990, Constable and Hodgson 1990, Hodgson *et al.* 1990). The irrigation systems were: (i) surface drip irrigation: polythene tube laterals 200 m in length placed on the soil surface in alternate furrows; (ii) buried drip irrigation: laterals 200 m in length placed at 20 cm depth under every crop row; and (iii) standard furrow irrigation: water applied to furrows using siphons run for 4 hr as in experiments I and II. Plot size was 12 rows by 200 m. There were four replications.

Drip irrigation treatments were irrigated to maintain a soil water deficit of approximately 45 mm. Nitrogen fertilizer (urea, ammonium nitrate) was also applied through the drip system during the first half of each crop season. The furrow irrigation treatment was irrigated to maintain a soil water deficit of approximately 90 mm and nitrogen fertilizer (anhydrous ammonia) was applied before sowing.

Assessment of bacterial blight

The incidence of bacterial blight on bolls was assessed late in the growing season when the first low bolls began to open. Five sampling points were selected in each plot using a step point method and ten bolls were checked at each point. The bracts were pulled back to expose the base of the boll and the presence or absence of blight lesions was noted. Bolls ranged in maturity from mature bolls that had just opened to relatively immature bolls at the top of the plant. Results were expressed as the percentage of bolls with symptoms of bacterial blight.

Disease severity was estimated using a standard pictorial assessment key illustrating 0.5, 1, 2, 5, 10 and 20% of the leaf area infected. The pictorial key was drawn on squared graph paper to give 3000 squares per leaf. The relevant number of squares were filled in to represent the required levels of infection for the key. The pictorial assessment key was tested on 20 plants and the mean percentage of leaf area infected for all leaves (up to 55 leaves) was compared by regression with the mean percentage of leaf area infected for those leaves directly attached to the main stem only (up to 12 leaves). As a result of the good correlation between the two values (r^2 = 0.801) all field assessments were confined to an inspection of all main stem leaves on each of five plants per plot. Plants were selected at random using a step point method. Results were expressed as the mean percentage of leaf area infected per plot.

Table 1. A summary of designs and treatments for field experiments to evaluate the effects of soil and foliar nitrogen applications and waterlogging on cotton.

	Experiment I	Experiment II
Season	1985-86	1986-87
Design	split plot (2 × 2 × 2)	split plot (2 × 2 × 2)
Replicates	4	3
Field slope	1:2290	1:1000, 1:2000
Duration of irrigation	4 hr and 32 hr per irrigation	4 hr and 32 hr per irrigation
Soil applied nitrogen	0 and 120 kg N ha^{-1} as anhydrous ammonia	120 kg N ha^{-1} as anhydrous ammonia
Foliar applied nitrogen	0 and 120 kg N ha^{-1} as a 50/50 (w/w) mixture of urea and ammonium nitrate	0 and 74 kg N ha^{-1} as a 50/50 (w/w) mixture of urea and ammonium nitrate
Size of main plots	32 rows × 200 m	24 rows × 200 m
sub-plots	16 rows × 40 m	12 rows × 200 m
sub-sub-plots	8 rows × 20 m	12 rows × 20 m
Date of sowing	18th Oct.	20th Oct.
Dates of irrigations	31 Dec., 22 Jan., 11 Feb., 28 Feb.	31 Dec., 23 Jan., 7 Feb., 27 Feb.
Foliar nitrogen applications	17 Dec., 30 Dec., 14 Jan., 21 Jan., 31 Jan.	30 Dec., 22 Feb.
Blight assessment	25 Feb.	5 Mar.
Harvest	21 Apr.	13 May

Table 2. Influence of the duration of furrow irrigation and soil and foliar application of nitrogen fertilizer on the incidence and severity of bacterial blight of cotton in Experiment I (1985-86).

Duration of irrigation hr	Rate of soil N kg ha^{-1}	Rate of foliar N kg ha^{-1}	Incidence of blight on bolls[a] %	Severity of blight on leaves[b] %
4	0	0	26.0	1.34
	0	120	27.0	1.53
	120	0	25.5	1.57
		mean	26.2	1.48
32	0	0	22.5	1.91
	0	120	30.0	2.10
	120	0	24.0	1.86
		mean	25.5	1.96
overall mean		25.8	1.72	
		se(interaction)	5.3	0.36

[a] mean percentage of bolls with symptoms of bacterial blight [b] mean percentage of leaf area showing symptoms of bacterial blight

Results

Waterlogging and nitrogen fertilizer experiments

Symptoms of bacterial blight were found on 26% of bolls, on average, in experiment I, but there was no significant treatment effect (at $P < 0.05$) on the incidence and severity of the disease despite obvious leaf burn from the high rate of foliar applied nitrogen (Table 2). There was no effect of waterlogging on the incidence of blight on bolls and a non significant trend toward greater leaf infection under waterlogging.

The average incidence of bacterial blight on bolls in experiment II was 45%. The least waterlogged treatment (1:1000 slope, 4 hr irrigations) was least infected with blight (Table 3). Increasing the duration of irrigation increased the incidence of the disease ($P = 0.035$), by 65% on the steeper slope and by 9% on the lesser slope (interaction P = 0.118). The latter increase was relatively small because waterlogging and disease were severe on the flatter slope, even when irrigation was rapid. Increasing the duration of irrigation consequently increased disease incidence less than on the steeper slope.

Comparison of drip and furrow irrigation systems

Drip irrigation treatments increased the incidence and severity of bacterial blight relative to furrow irrigation in experiment III, but the opposite trend occurred in experiment IV (Table 4). In experiment III, the leaf area index, and presumably the humidity of the canopy, was higher under drip irrigation (Constable *et al.* 1990). In experiment IV, conditions were more conducive to waterlogging under furrow irrigation than under drip irrigation – the furrow irrigated treatment had a higher leaf area (Constable *et al.* 1990) and extra waterlogging associated with a heavy rain storm just after the first irrigation (Hodgson *et al.* 1990). These results are consistent with those in experiment II.

Discussion

The association between waterlogging and bacterial blight is consistent with the requirements of the pathogen for warm, humid conditions, and supports the results obtained by Findlay (1928) in his pot experiments. The disease is favoured in Australian cotton growing areas by high summer temperatures during the growth of the crop (daily means range from 22–29°C); high relative humidity varying between 60 and 100% within the crop canopy; the dense foliage of high-yielding irrigated crops (the leaf area index may exceed 4, though 3–3.5 is common); and frequent summer storms (monthly totals in excess of 100 mm rainfall). It follows that management practices which minimize waterlogging should also minimize the disease. These include: high application rate of water to furrows; short fields in the direction of the furrows; deep, clean furrows; increased field slope; and accurate scheduling of irrigations to reduce the frequency of waterlogging and consequently the number of opportunities for rain after irrigation.

Lack of correlation between application of foliar N fertilizer and the severity of bacterial blight suggests that farmers can apply N to cotton leaves without disease penalty. Symptoms of bacterial blight were not associated with damage to leaf tissue resulting from foliar fertilizer burn which usually is most apparent on leaf margins and tips.

In some environments, drip irrigation reduces waterlogging relative to furrow irrigation by maintaining a relatively stable soil water deficit which does not cause anoxia of the root zone (Nir 1981). However, Hodgson *et al.* (1990) found that heavy rain can reverse this advantage when it falls on a furrow irrigated field which is drier than in a drip irrigated field. In this condition, furrow irrigated fields can absorb more rain water than drip irrigated fields before waterlogging occurs. The frequency of such occasions varies between seasons, and between fields, as is shown by the variable incidence of bacterial blight under the two irrigation systems found in this study.

Cotton cultivars which are resistant to bacterial blight are available in Australia, and are adapted to local conditions. These can be grown in any area where the disease is a problem (Reid *et al.* 1989). Transmission of the blight pathogen in the seed of susceptible cultivars is being reduced as a result of the adoption of a clean seed scheme by the Australian cotton seed industry (Allen 1990).

An important effect of cultivar resistance to bacterial blight and the association between bacterial blight and waterlogging, is that cultivars resistant to the disease appear to be more tolerant of waterlogging than susceptible cultivars when the disease is prevalent. In experiments comparing the waterlogging responses of cotton cultivars (A.S. Hodgson, unpublished data, 1987, 1990), extending the duration of furrow irrigation from 4 to 32 hr per irrigation on a field slope of 1:1500 decreased lint yields of resistant and susceptible cultivars by 6.6 and 16.4% ($P < 0.05$), respectively, in 1986–87, a heavy blight season (30–54% of bolls infected). In 1989–90, with almost no disease, respective yield losses were not significantly different between cultivars. Apparent tolerance of cultivars to waterlogging should therefore be corrected for cultivar interactions with diseases that are associated with waterlogging.

Table 3. Influence of field slope, duration of furrow irrigation and rate of foliar application of nitrogen fertilizer on the incidence of bacterial blight on bolls of cotton in Experiment II (1986-87).

Field slope	Duration of irrigation hr	Rate of foliar N kg ha^{-1}	Incidence of blight [a] %
1:1000	4	0	30.7
		74	33.3
		mean	32.0
	32	0	54.0
		74	51.3
		mean	52.7
MEAN			42.3
1:2000	4	0	43.3
		74	48.7
		mean	46.0
	32	0	48.0
		74	53.3
		mean	50.7
MEAN			48.3
GRAND MEAN			45.3
se(irrigation)			4.0
se(slope x irrigation)			5.7
se(slope x nitrogen)			4.1
se(irrigation x nitrogen)			4.1
se(slope x irrigation x nitrogen)			5.5

[a] mean percentage of bolls with symptoms of bacterial blight

Table 4. Effect of irrigation system on incidence and/or severity of bacterial blight of cotton in experiments III and IV.

	Experiment III (1985-86)		Experiment IV (1986-87)
Irrigation treatment	Severity of blight on leaves (%)[a]	Incidence of blight on bolls (%)[b]	Incidence of blight on bolls (%)[b]
Surface drip	1.82	27.0	37.1
Buried drip	2.55	28.0	30.9
Furrow	1.50	17.5	43.9
se	0.334	4.31	5.20
lsd	0.76	9.8	11.8

[a] mean percentage of leaf area showing symptoms of bacterial blight
[b] mean percentage of bolls with symptoms of bacterial blight

Conclusions

Results indicate (i) that bacterial blight infection is favoured by waterlogged conditions; (ii) that foliar applications of heavy rates of nitrogen fertilizer do not increase infection, despite burning of the leaves in some cases; (iii) that drip irrigation can increase or decrease infection relative to furrow irrigation, depending on which irrigation method produces the most waterlogging or leaf area; (iv) that leaf area probably influences bacterial blight infection by affecting the relative humidity of the crop canopy; and (v) that cotton cultivars that are resistant to bacterial blight may appear to be more tolerant of waterlogging in seasons when the disease is prevalent, because waterlogging exacerbates the effects of the disease on susceptible cultivars. We conclude that the incidence and severity of bacterial blight is increased mainly by factors conducive to waterlogging or high humidity of the crop canopy, including reduced field slope, extended furrow irrigation, rain following irrigation, and high leaf area index. All of these factors except rainfall can be optimized by adjusting the agronomic management of the crop.

Acknowledgments

We gratefully acknowledge the financial support of the Australian Cotton Research Council.

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