The influence of nitrogen fertiliser rate and irrigation management on crop nitrogen uptake, lint yield and apparent fertiliser recovery in sub-surface drip irrigated cotton

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Key findings

- Nitrogen fertiliser management influences crop nitrogen uptake at defoliation and cotton lint yield.
- Irrigation management did not influence crop nitrogen uptake at defoliation, but significantly influenced cotton lint yield.
- The apparent nitrogen fertiliser recovery was 46% where the optimum fertiliser nitrogen rate was applied.
- Seed nitrogen concentration and nitrogen removal was influenced by nitrogen fertiliser application rate, but the effect was not consistent with rate.

Introduction

Cotton growers cannot afford to allow their cotton crop yields to be limited by nitrogen (N) deficiency (or other nutrients) and tend to manage this risk by over applying N fertiliser relative to the lint yield achieved (Rochester & Bange 2016). Analysing data from 147 irrigated commercial cotton crops over 2009–2014 revealed that 74% of the sites were considered to have over-applied N fertiliser (Smith et al. 2014). This assessment was based on the industry standard, nitrogen fertiliser use efficiency (NFUE) measure in which lint yield (kg/ha) is divided by applied N fertiliser (kg/ha) (Rochester 2011).

Irrigation opportunity time and soil type can have a substantial impact on the level of waterlogging, redox conditions and potential loss of N from the soil (Jamali, Quayle & Baldock 2015). However, information on the interaction of these is limited. The work described here was the first of its type undertaken in the cotton production area of southern NSW.

This research aimed to identify the impact of irrigation opportunity time and fertiliser N rates on fertiliser N response, lint yield and fertiliser N recovery in a sub-surface drip irrigation system.

Site details

Location	Whitton NSW (146°18'E, 35°54'S)
Soil type	Transitional red–brown earth
Previous crop	Cotton
Fertiliser planting date	25 September 2015
Cotton planting date	16 October 2015
Variety	Sicot 74BRF
Irrigation	The site was irrigated using a sub-surface drip irrigation system with the drip line placed approximately 300 mm below the soil surface in the middle of a 1.83 m bed. Normal practice is to water the cotton every day. After planting, siphon irrigation was used to water-up the crop. A second siphon irrigation was conducted at first flower to incorporate the nitrogen fertiliser that was spread on the field outside the experiment areas.
Harvest	3 rows × 2 m of row was hand harvested between 12–20 April 2016

Soil test results (0–30 cm)		
	Nitrate–N	7.9 mg/kg (0–30 cm)
	P (colwell)	28.9 mg/kg
	pH (water)	7.1
	OC	6.4 g/kg
	CEC	20.6 cmol/kg
Soil test results (30–90 cm)		
	Nitrate–N	6.2 mg/kg (30–90 cm)

Treatments

Structure

The field experiment was designed as a randomised split plot design with irrigation treatments as the main plots (six main plots) and N rate as the sub-plot. Nitrogen was sown in blocks of five N rates applied before planting the crop. Three of the main plots had four blocks of N rates and three had two blocks of N rates (Figure 1). This variation in N rate blocks within the irrigation treatment was done because of uncertainty at planting around the capacity of the irrigation system to be able to apply the desired irrigation treatment across so many valves. The blocks of N rates were used as replicates of the N treatments in the statistical analysis.

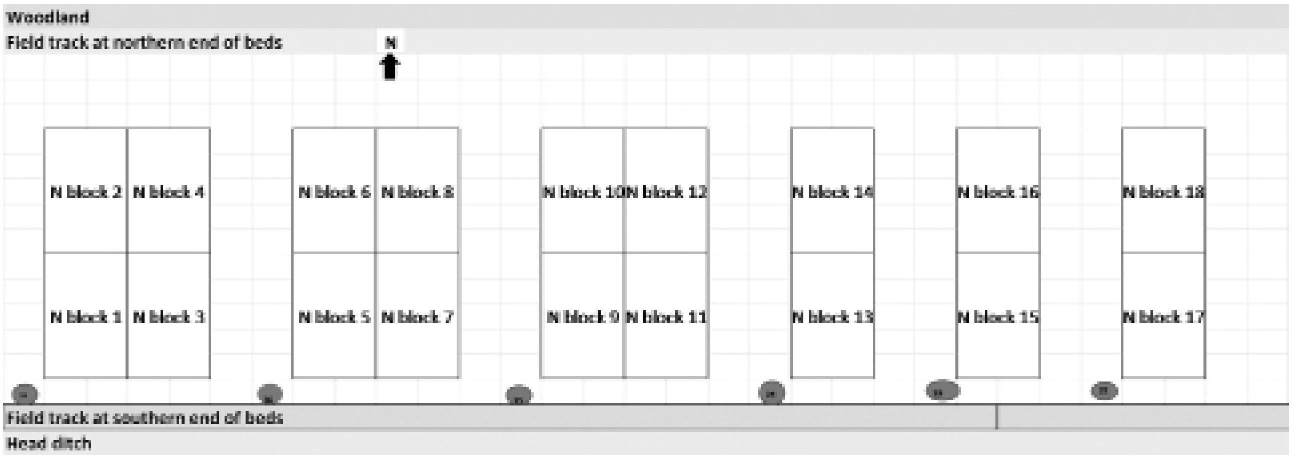

Figure 1. Field layout of the irrigation and nitrogen rate field experiment in cotton conducted at Whitton NSW in the 2015–16 cotton season. The circles represent the control valves of the sub-surface drip systems that controlled the irrigation treatment applied to each area. The nitrogen blocks consisted of five rates of nitrogen (0, 80, 100, 150, 250 kg N/ha) applied before planting.

Fertiliser and irrigation treatments

The two irrigation treatments applied were: irrigation every day (standard practice) and irrigation every second day. The irrigation control valves used to divide the fields into irrigation shifts were used to apply the irrigation treatments, based on the designed flow rate of the sub-surface drip irrigation system. The water was from an irrigation supply channel. The irrigation treatments were replicated three times across the field using six control valves in the field (Figure 1). The irrigation treatments were only imposed during the period from first flower to first cracked boll. Outside this period, the whole field was watered using the standard practice.

Five N fertiliser treatments were applied at 0, 80, 100, 150 and 250 kg N/ha. The N was applied as Anhydrous ammonia (82% N) approximately three weeks before planting of the cotton crop. No in-crop N applications were made to the experimental areas in the field.

Crop agronomy and measurements

Cotton was planted into beds on 90 cm row spacing with two rows per bed. Insect and weed control was managed by the farm consultants and carried out as needed. Plant growth regulators were used to control plant growth and provide a timely cut-out; the timing was based on decisions by the farm consultants. Above ground biomass was measured three times:

at first flower, first cracked boll and defoliation (within one week before the first defoliation spray being applied).

Nitrogen concentration of whole plants was calculated using the Dumas combustion method. Samples were collected by cutting one metre of plants along a row at the cotyledon node. The samples were then dried, weighed, mulched, ground and analysed. Crop N uptake was calculated by multiplying the N concentration (%) by the dry matter production (kg DM/ha). Apparent N fertiliser recovery (ANFR) was calculated by dividing the difference in crop N uptake between N-fertilised and unfertilised plots by the N fertiliser applied.

Crop N uptake was measured in the 0, 150 and 250 kg N/ha fertiliser N treatments at first flower and measured in the 0, 100, 150 and 250 kg N/ha fertiliser N treatments at defoliation. The internal nitrogen use efficiency (iNUE) was calculated using the formula; kg lint ÷ kg crop N uptake.

Lint yield was determined by hand picking 2 metres of three adjoining rows in each plot following the second chemical defoliation. Turn-out was determined by hand ginning a sub sample of the hand-picked seed-cotton. Nitrogen concentration of the cotton seed was determined using the Dumas combustion method to calculate seed N removal across the N rates.

Statistical analyses

Nitrogen uptake, lint yield and ANFR was analysed as an unbalanced two-way ANOVA test using GENSTAT 18.

The economic optimum N fertiliser rate and the N rate at maximum lint yield were estimated using the polynomial N fertiliser response curve. The economic optimum N fertiliser rate was defined as when the marginal cost of applying additional N fertiliser ($1.50/kg of N) equalled the marginal increase in returns from increased lint production ($2.20/kg) (Rochester & Bange 2016).

Results

Lint yield

Watering every second day produced a significantly (P<0.001) higher lint yield of 9.6 bales/ha than watering every second day, which produced 8.8 bales/ha. Applying N fertiliser significantly (P<0.001) increased lint yield from 7.4 bales/ha to a predicted maximum yield 10.13 bales/ha with 190 kg N/ha applied (Figure 2). The predicted economic optimum fertiliser N rate was 171 kg N/ha, producing a lint yield of 10.10 bales/ha.

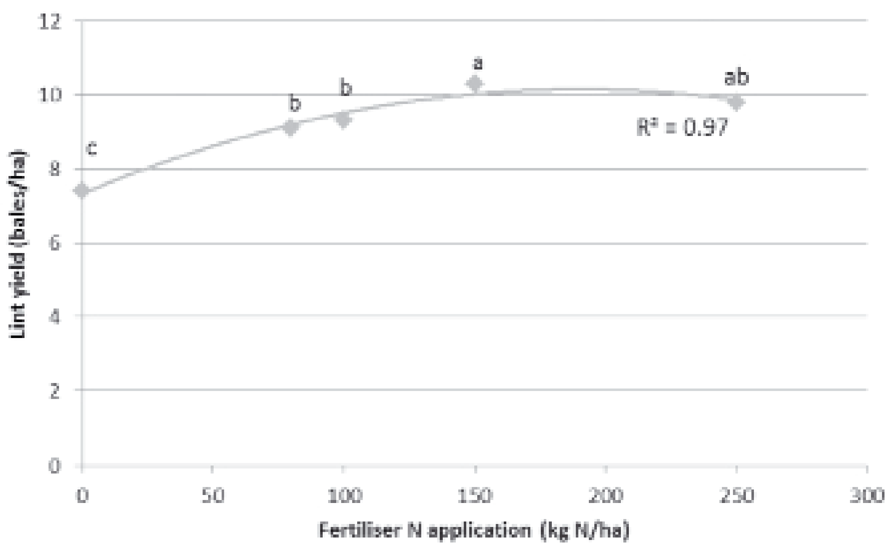

Figure 2. The response of cotton lint yield to applied nitrogen fertiliser.

The NFUE ranged from 25.8 at 80 kg N/ha to 8.9 at 250 kg N/ha. NFUE at the optimum N rate of 171 kg N/ha was 13.4.

Irrigation & climate

Crop nitrogen uptake

Nitrogen rate had no significant effect on crop N uptake at first flower. The irrigation treatments had not been imposed before first flower and consequently no irrigation treatment effects on crop N uptake at first flower can be reported.

Irrigation management had no significant effect on crop N uptake at defoliation. Crop N uptake increased significantly (P<0.001) with increased N fertiliser application (Figure 3). There was no significant interaction between irrigation treatment and N application rate.

Crop N uptake was predicted to be 188 kg N/ha at the economic optimum N fertiliser rate of 171 kg N/ha. The difference between this amount and the crop N uptake from the unfertilised plots (109 kg N/ha) indicates that the deficit in soil supply of N was 79 kg N, which was met by fertiliser application.

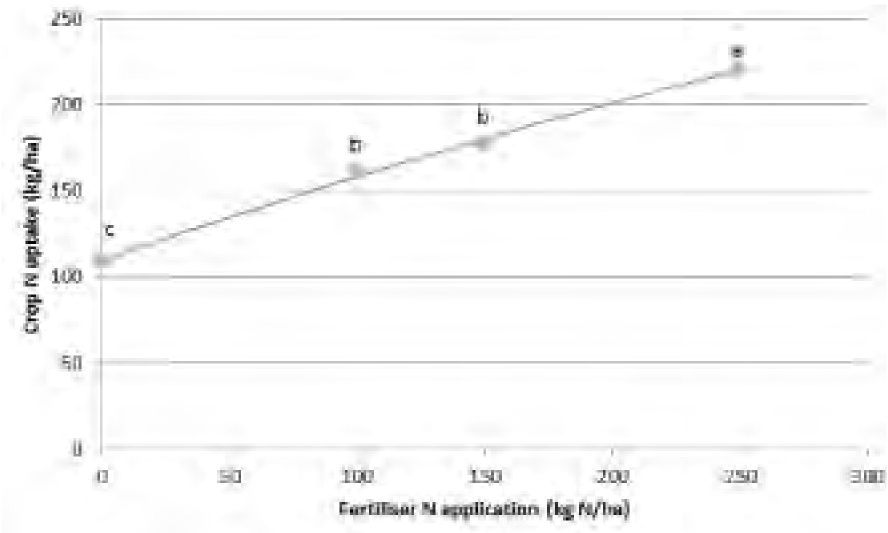

Figure 3. Crop N uptake response to fertiliser N application rates.

Irrigation treatment had no significant (P = 0.05) effect on iNUE. The iNUE declined (P<0.001) with higher N fertiliser rates ranging from 18.5 kg/kg with 0 N applied to 10.7 kg/kg when 250 kg N/ha was applied. The iNUE was 12.2 kg/kg at the predicted optimum fertiliser N rate.

Apparent nitrogen fertiliser recovery

The effects of irrigation treatment and N fertiliser rate on ANFR were not significant in this study. Across the range of N fertiliser rates from 100 to 250 kg N/ha, there was a declining trend of 60–48% ANFR, respectively.

The ANFR was 46% at the predicted optimum fertiliser N rate.

Seed N and N removal

Irrigation treatments had no significant (P = 0.05) effect on seed N concentration or N removal in seed. Applying N fertiliser significantly (P = 0.001) increased the amount of N removed in seed (Table 1).

Table 1. Comparison of seed N concentration with N fertiliser rate applied. Different letters within each column signify a significant difference between the N fertiliser rates that were applied.

N fertiliser rate (kg N/ha)	Seed N concentration (%)	N removal (kg N/ha)
0	3.8 b	68.8b
100	4.5ab	105.7a
150	4.9a	121.5a
250	4.6ab	114.2a

Discussion

Irrigation strategy

Lint yield was greater when water was applied every day compared with applying water every second day, suggesting that there was a period of moisture stress when water was applied every second day with the sub-surface drip irrigation system.

The irrigation strategy had no effect on crop N uptake or iNUE. No difference in crop N uptake suggests that there were similar levels of plant-available N even when there was more water applied when the crop was watered every second day. This highlights the benefit of drip irrigation systems where there is high irrigation efficiency (Burt et al. 2000) with minimal losses of water from deep drainage, thereby minimising any N leaching loss.

When water was applied every day, approximately 1.4 megalitres (ML) of water was applied during the treatment period compared with 1.7 ML when the water was applied every second day. Inappropriate or poor management of an irrigation system reduces water productivity by reducing yield and increasing water use. For example, Dunn et al. (2016) found a 55% reduction in water productivity in irrigated wheat when water was ponded for 48 hours during spring irrigation.

N fertiliser application

Lint yield, crop N uptake and iNUE were all influenced by the rate of applied N.

Crop N uptake increases with N fertiliser application (Rochester 2011), and high crop N uptake is required for high lint yields (Rochester & Bange 2016). The level of crop N uptake at the optimum N rate in this study (188 kg N/ha) is very similar to the 200–220 kg N/ha determined in commercial and experimental crops by Rochester (2011).

The iNUE at the optimum fertiliser N rate of this study (12.2 kg/kg) was within the optimum range established by Rochester (2011). More recently, it has been shown that cotton yields have increased in the order of 40% and crop N uptake has increased by approximately 140%, meaning that the ideal iNUE would have declined (Rochester & Bange 2016).

Apparent N fertiliser recovery

The ANFR when the optimum fertiliser was applied was 46%, but ranged between 60% and 48% across the N fertiliser rates in the present study. The ANFR at optimum fertiliser is consistent with that of Rochester and Bange (2016), which is higher that than of previous studies, but consistent with the increases in crop N uptake that have been recorded in recent crops.

Seed N and N removal

Seed N concentrations of 3.9% in the treatments where N was applied are higher than that considered adequate for the variety Sicot 74BRF (Rochester & Gordon 2014). Seed N was increased by N application, although the only significant differences were between the plots with no N applied and those with N applied.

A similar relationship existed between seed N and crop N uptake (data not shown) where there was a difference in the effect between the plots with no nitrogen and those with N applied. The relationship between seed N and crop N uptake shows some variability. Rochester (2012) was able to show a relationship suggesting it could be used as a measure of NUE. However, others have found that it is only effective in depicting deficiency (Malavolta et al. 2004), which is more consistent with the results here.

Although there was a continual increase in crop N uptake, the increased plant N was not translocated to the seed and N removal declined as applied N rates increased. It seems that more N remains in the vegetative parts of plant residues. Therefore, while N is not completely lost from the system, there is inefficient N use for lint production in the season of application. Nitrogen remaining in field residues is exposed to a greater risk of loss through mineralisation, denitrification and leaching.

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