Recovery of soil and fertiliser nitrogen in irrigated cotton in Australia

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Abstract
Lint yield of irrigated cotton is typically responsive to the application of fertiliser nitrogen (N). However, the applications of high rates of fertiliser N that exceed crop requirements result in unnecessarily low nitrogen recovery efficiency (N_{RE}). Three field experiments with eight N application rates were established across overhead and flood-furrow irrigation systems to determine N response curves for lint yield in irrigated cotton. Lint yield was considered to be at its maximum where there was no further statistical increase from additional N application, this occurred between 145-245 kg/ha of total N supply (mineral N at planting + applied fertiliser N) with plant N uptake levels of 134-170 kg/ha. N_{RE} was determined by dividing crop N uptake at defoliation by the total N supply. Where starting soil N levels were similar, overhead irrigation offered 34% higher N_{RE} compared to flood. The N_{RE} at maximum lint yield was 6-28% higher than that achieved using farm practice at each site.

Key Words
Nitrogen recovery efficiency, cotton N uptake, irrigated cotton, furrow irrigation, overhead irrigation

Introduction
Nitrogen nutrition is an important determinant of the growth and yield of irrigated cotton (*Gossypium hirsutum* L.) (Rochester et al. 2001) and recently there has been increasing focus on the use of N within the Australian cotton industry. This focus is because of the link between inefficient fertiliser N use and emissions of the potent greenhouse gas nitrous oxide, which has a global warming potential 298 times that of carbon dioxide (Myhre et al. 2013) and contributes to the depletion of the ozone layer in the stratosphere (Ravinshankara et al. 2009).

Growers continue to use high rates of fertiliser N with the aim of achieving higher lint yields despite N representing one of the highest components of crop variable costs under their control (NSW DPI 2015). In the 2014/15 cotton production season greater than 300 kg N/ha was applied to approximately 64% of crops surveyed by Crop Consultants Australia (Anonymous 2016). Producers can afford to apply chemical fertilisers to overcome nutrient limitations because of the high value of cotton lint (Rochester 2007), despite the risk of over application leading to low N_{RE}.

This research was the first in a planned series of experiments to assess the impact of irrigation method on crop N recovery within N fertiliser rate experiments. This work is part of Cotton Research and Development Corporation (CRDC) funded research higher degree scholarship.

Methods
Measuring N recovery efficiency
Nitrogen recovery efficiency was determined in four field experiments conducted during the 2014/15 cotton season on the Darling Downs region of Southern Queensland, Australia (151°20'E, 27°25'S). Two field sites were established in each of two irrigation systems, overhead and flood-furrow, although only three field sites were used in the analysis due to the impact of disease at one of the overhead irrigation sites.

At each site, eight N fertiliser treatments were applied approximately 10 weeks prior to sowing the cotton, with plots 8 rows wide (1 m row spacing) and 20 metres long. The pre-sowing N rates ranged from 0 to 300 kg N/ha in the overhead system and from 0 to 360 kg N/ha in the flood-furrow system. The field sites had additional N applied evenly over all plots by the grower during the season, with 60, 50 and 20 kg N/ha applied on the overhead (OH) and two flood sites (F1, F2) respectively. The upfront N treatments were replicated either five or six times depending on the site.

The soil at each site was classified as a Vertosol with soil mineral N levels (0 – 90 cm) of 100 kg N/ha, 115 kg N/ha and 45 kg N/ha for OH, F1 and F2, respectively.

Above ground biomass was sampled within one week prior to the first defoliation spray being applied with 1m of plant row from four of the eight N treatments in 3 replications collected. The sample was dried, weighed, mulched, ground and analysed for N concentration using Dumas combustion (LECO analyser). After chemical defoliation two rows of each plot from all replications were mechanically picked and a subsample of seed cotton ginned to determine lint content and lint yield.

Nitrogen $_{RE}$ at defoliation was calculated using the following equation (adapted from Ladha et al. 2005):

$$\frac{Crop\ N\ uptake\ at\ defoliation\ (kg\ N/ha)}{Total\ N\ supply\ (starting\ soil\ N + applied\ fertiliser);\ kg\ N/ha}$$

This calculation does not take into account additional plant available N derived from in-season mineralisation or organic N sources. As each site received an unplanned in-crop application of N by the grower, resulting in no trial containing a treatment where there was no applied N estimates of in-season mineralisation could not be derived from any of the sites.

Statistical Analysis
A general analysis of variance was conducted using Genstat 17th edition. Within each analysis the fertiliser rates were used as the treatment structure and replication used as the block structure. Least squares regressions were used to determine response functions that best described the reslationships between soil N supply, crop N uptake and lint yield or N recovery efficiency.

Results and Discussion
Lint yield
No further statistical increase in lint yield was achieved when total N supply reached 185 kg N/ha, 245 kg N/ha and 145kg N/ha for the OH, F1 and F2 sites (Figure 1) – equivalent to fertiliser N applications totalling 85, 130 and 100kg N/ha, respectively. A multi-year cropping system trial in northern NSW showed similar effects with maximum yields achieved with relatively low applications of N in some years and cropping systems (Rochester 2011). These results across different locations and years were unexpected given current industry practices, where high rates of N are often used to ensure yield is maximised. At these field sites fertiliser N application for the rest of the commercial fields were 112 kg N/ha, 300 kg N/ha and 240 kg N/ha for OH, F1 and F2, respectively.

Plant N uptake
Despite the plateau in lint yield the crop continued to take up N as the rate of applied N increased at OH and F2, which was consistent with the relationship identified by Rochester (2007). The same relationship existed at F1 but was not significant (data not shown).

There was a strong positive correlation between crop N uptake and lint yield at each site (Figure 2) with lint yield maximised at crop N uptakes of 163, 170 and 134 kg N/ha at OH, F1 and F2 sites, respectively. The levels of N uptake at these sites were lower than the 200 kg N/ha identified by Rochester (2011) as necessary to achieve optimal crop yield, although the levels of uptake at OH and F1 were similar to the average obtained from a survey of commercial fields (177 kg N/ha) reported in Rochester (2011).

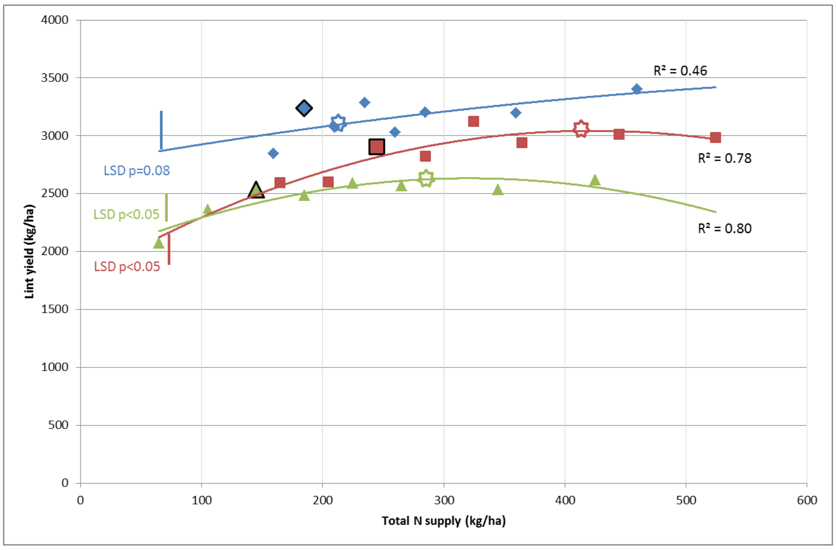

Figure 1: The relationship between the total N supply (starting soil N + fertiliser N) and lint yield at OH (blue), F1 (red) and F2 (green). The large outlined symbols at each site represent the maximum lint yield while coloured open stars represent the total N supply available in the rest of the commercial field. The small coloured vertical lines represent the least significant differences for each trial.

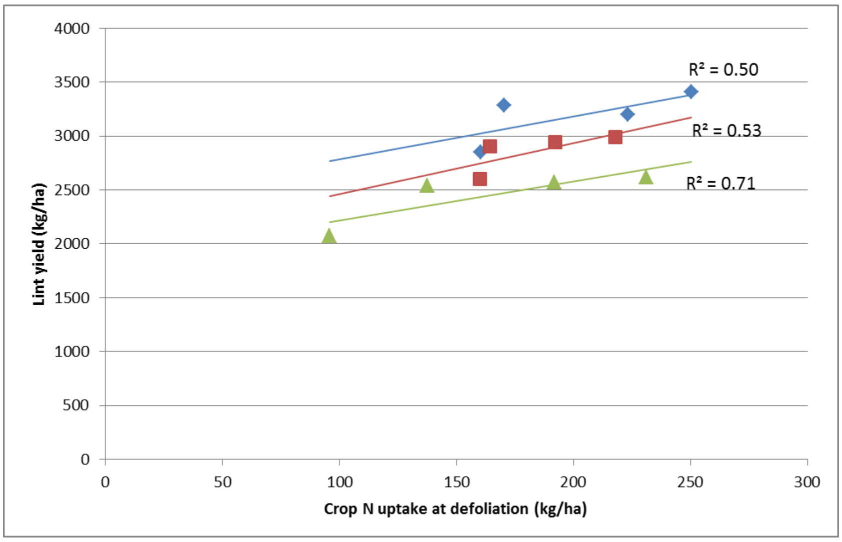

Figure 2: The relationship between cotton crop N uptake at defoliation and lint yield for OH (blue), F1 (red) and F2 (green) field experiment sites.

Conversion of N uptake to lint yield

The efficiency with which the crop was able to convert additional N uptake into lint yield was very low. At OH it took 4 kg of additional crop N uptake / kg of additional lint produced, while at F1 it took 4.7 kg extra crop N / extra kg lint and at F2 it took 3.6 kg extra crop N / extra kg lint. Only at F2 was there an increase in seed N concentration with increased N availability, meaning that N removal was driven primarily by increases in seed yield at all sites. The accumulation of N in the crop without an associated lint yield increase represents an inefficient use of N in the season of application, while large proportions of available N remaining in the soil profile or returned in crop residues represent a potential for loss from the cropping system prior to the next crop sowing.

Nitrogen recovery efficiency

The N_{RE} declined significantly as the total N supply increased at each site ranging from 1.00 to 0.54 at OH, 0.97 to 0.42 at F1 and 1.47 to 0.54 at F2 (Figure 3). Where there were similar levels of starting N (at OH and F1) the overhead site provided a 34% higher N_{RE} at maximum yield. At F2, where there was less than half the starting soil N of the other two sites, the N_{RE} at maximum yield was 0.95. The additional N applied to the commercial crop at each site contributed to a reduction in N_{RE} of 6% at OH, 27% at F1 and 28% at F2.

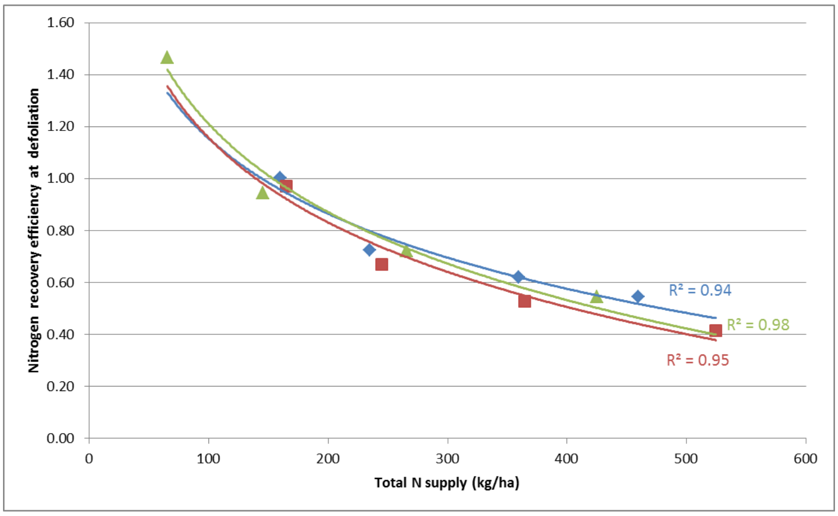

Figure 3: Decline in nitrogen recovery efficiency (kg crop N / kg of total N supply) as the total supply of N increases at OH (blue), F1 (red) and F2 (green) sites.

Optimising N supply to field and crop requirements by manipulating fertiliser N rates offers the opportunity for significant increases in the recovery of applied N. However, the majority of irrigated cotton growers apply at least 50% of the estimated crop N requirement prior to planting (Roth Rural 2013), placing some limitations around the ability to fine-tune crop N applications in response to site and seasonal conditions.

Conclusion

This work is consistent with other studies within the Australian cotton industry in that adequate levels of N uptake to achieve maximum lint yield can be achieved from lower levels of N fertiliser application than are currently being applied commercially. The application of large amounts of fertiliser N to cotton crops to increase total N supply results in a significant reduction in N_{RE}, compared to when total N supply was sufficient to achieve maximum lint yield. Improving low N_{RE} across the industry by manipulating the applied N rate to reflect both starting soil N and likely crop requirement is a significant opportunity for the industry, but one that has to be balanced against the financial risk of lower lint yields.

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