Optimising nitrogen application in a cotton farming system

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Abstract
The Australian Cotton industry in the last decade has enjoyed extraordinary growth in cotton lint yields, increasing from 1680 kg/ha in 2003 to 2610.5 kg/ha in 2014-15. Higher yields have been driven by both improved varieties and crop management strategies. One issue rising from the increase in yields is the recent industry trend of applying high rates of nitrogen (N) fertiliser to cotton crops. Industry audits are reporting many growers are applying in excess of 300 kg N/ha, in order to achieve yields greater than 2724 kg/ha, in spite of research suggesting these yields are achieve able with applied N rates of 220-250 kg N/ha.
To address the issue, two field experiments were conducted over two years on a commercial cotton farm in the Liverpool Plains of Northern NSW. Experiment treatments included varied N and irrigation rates, with the aim to quantify research outcomes conducted within a research institute experiment. The investigation found N rate and to a lesser degree irrigation rate significantly impacted on cotton yield, NUE and the economic optimum N rate. On average there was a 7% increase in yield at every additional 50 kg N/ha increment from 150 to 300 kg N/ha (2552 to 3040 kg/ha of cotton lint).The economic optimum N rate was determined to be 237 kg N/ha over the two seasons. This trial was conducted within the Upper Namoi region of Northern NSW and thus optimum management systems should be developed for other regions that are specific to their growing environments.

Key Words
Cotton, Nitrogen, Irrigation, Nitrogen Use Efficiency (NUE), Economic Optimum

Introduction

The trend for nitrogen (N) management in the Australian cotton industry indicates an increase in the amount of N fertiliser applied by Australian cotton producers and a decline in nitrogen use efficiency. Previous Research (Rochester, 2010) has shown that high yields can be achieved with applied N rates of 200-220kg/ha, while industry surveys reveal that a significant proportion (44%) of cotton growers are applying N rates in excessive of 250 kg N/ha and up to 400 kg N/ha (Roth 2013). Based on the science of the N cycle in an agricultural system, excess N is being lost from the farming system via a number of different pathways which includes denitrification, volatilisation and run-off or the leaching process. These processes can lead to the production of gaseous forms of N including nitrous oxide (N_2O). Critically for the cotton industry is that N_2O is classified as a potent greenhouse gas with a lifespan of 120 years and a global warming potential 310 times carbon dioxide (UNFCCC, 2016). Rochester (2003) stated that cotton production could be losing just over 1% of applied N as N_2O. Reducing the production of N_2O from agriculture systems is considered of high importance and necessary to reduce the footprint agriculture may have on the environment.

Methods

Experimental Design

Field experiments were set up to investigate the influence of N and irrigation management on N use efficiency (NUE) in cotton. The experimental site was situated at Gunnedah (150.3°E, 31°S) within the Upper Namoi valley of New South Wales. The experiments were conducted in 2014-15 and 2015-16 cotton season. The irrigation rates were set at 50, 70 and 100 mm soil water deficits, and the N rates included 0, 150, 200, 250 and 350 kg N/ha applied to the crop. The experiment was set up as a split plot design with the irrigation treatment being the main plot (320 x 28 m) and the N rates being the subplots (320 x 8 m). There were three replicates. The 100 mm irrigation rate was excluded during the second cotton season. The deletion of the 100 irrigation rate allowed for a greater number of varied N rates without increasing the footprint of the trial on the commercial farm
To alleviate potential interference by the trial on in-crop operations, all the N was applied prior to planting in the form of anhydrous ammonia, except for 30 kg N/ha which was applied by fertigation during both season. The cotton cultivar grown was CSD Sicot 74BRF, sown at 150,000 seeds/ha and planted on 1 m hills. Irrigation was delivered by 50 mm diameter siphons from a supply channel. The outflow from the siphons initially flowed down every second furrow in the field (typical of a siphon-flood furrow irrigation system).

The site contained a uniform vertosol profile that was heavy grey clay (NSW Office of Environment & Heritage, 1991).

Irrigation Scheduling
The varied irrigation rates were set as a soil water deficit (refill point) from the dried upper limit of the field location (field capacity). Soil characterisation was required to evaluate the drained upper limit and the crop lower limit which resulted in the total plant available water capacity (PAWC) of the soil. Neutron Moisture Meters (NMM) were used to measure the soil water capacity during the growing season on a weekly basis and before and after irrigation events to measure the crop water use and determine the schedule of the forthcoming irrigations.

Crop N Uptake
Crop maturity plant mapping and above ground biomass was conducted at approximately 30% open bolls and two weeks before chemical defoliation. One linear metre of complete plants were removed from each experiment plot. The collected plants were weighed (wet and dry), milled and analysed for N concentration using a Lachat QC8500 Series 2 flow injector.

Experiment Harvest
Experiment harvest was conducted by a John Deere 7760 “baler” cotton harvester. One bale was produced from each plot, and weighed separately. The picker was cleaned to ensure no carryover of excess lint to the next plot. A subsample was collected from each plot bale, ginned at the Australian Cotton Research Institute (Narrabri), with the turnout percentage used to determine final plot yields.

N Use Efficiency (NUE)
NUE was calculated from the following equation (Bronson 2008) and (Rochester 2010).
Applied NUE (aNUE) = Yield/ (Applied N rate)

Economic Optimum N rate
The optimum economic N rate is that which maximises net revenue, with all other requirements of the crop at an adequate, constant level. It is that level of input usage where revenue from an extra kilogram of N fertiliser applied (the marginal revenue) just exceeds the cost of the extra kilogram of N fertiliser applied (the marginal cost). It can be determined by equating the ratio of the ‘as spread’ cost of N fertiliser ($/kg) and the price of cotton lint ($/kg) (referred to as CP by Belanger, 2000) to the derivative of an N response function that exhibits diminishing returns. Standard prices for both seasons were used for the project’s purposes ($1.12/kg for N and $2.20 /kg for cotton lint). A quadratic function was fitted to the yield results of the treatments in regards to N rate application. The quadratic model is;
$Y = a + bx + cx^2$
And the economic optimum N rate is calculated by;
Ec. Opt = (CP – b)/ 2c

Statistical analysis was conducted using the Genstat program and included the ANOVA analysis, least significant difference values, and the linear and non-linear lines of best fit.

Results
Yield
The varied N rate had a significant impact on experiment yield in the two seasons, 2014/15 and 2015/16 ($P<0.1$ & $P<0.05$ respectively). The maximum yield in the 2014/15 season was achieved at the 250 kg N/ha (3100 kg/ha), while the greatest yield in the 2015/16 season was found at the 350 kg N/ha N rate with 2801 kg/ha. For both seasons there was no significant advantage in applying a N rate above 250 kg N/ha, this supports a recent study in Australian cotton farming system (Rochester,2010) which suggest the optimum applied N rate to be between 220 and 250 kg N/ha.
The varied irrigation rate had a significant ($P<0.01$) impact on yield in the 2014/15 season but there was no impact in the 2015/16 season. This was due to having three irrigation rates in the first season and only two in the later season due to the deletion of the third irrigation rate of 100 mm.

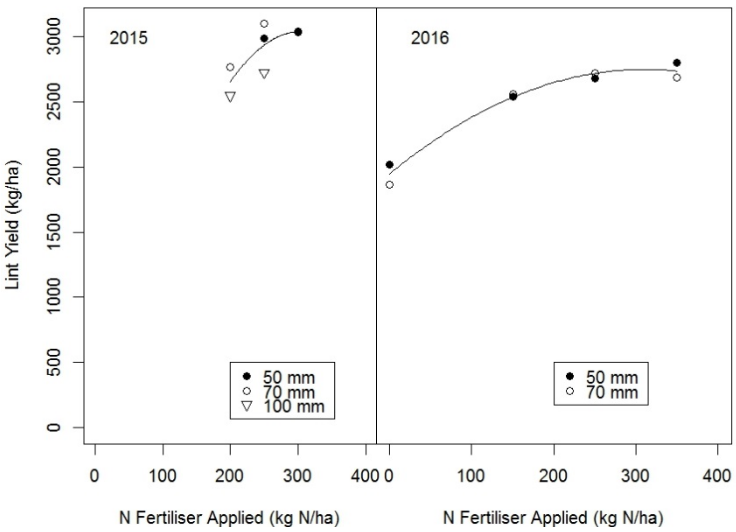

Figure 1. Irrigation x N rate experiment yield from Gunnedah, Northern NSW (2015-16). Spline lines are best fit polynomial curves of both rates of irrigation.

Ecomonic Optimum N rate

The economic optimum N applied rate for the 2014/15 season was calculated to be 230 kg N/ha while for the 2015/16 season the economic optimum rate was 252 kg N/ha. Over the two seasons of this investigation, the combined economic optimum was 237 kg N/ha, again these results support recent research conducted on cotton N fertiliser efficiency. As stated beforehand, the highest yield (3100 kg/ha) produced in the experiment was achieved with 250 kg N/ha in the 2014/15 season. While the 350 kg N/ha achieved the highest yield in the 2015/16 season with 2802 kg/ha, although the 250 kg N/ha N rate was within 5%. When the economic optimum N rate is applied, the average lint yield of the two seasons would be 2806 kg/ha. This provides greater confidence in the researched results and reiterates that Australian cotton growers can improve their on farm NUE and continue to grow highly productive crops.

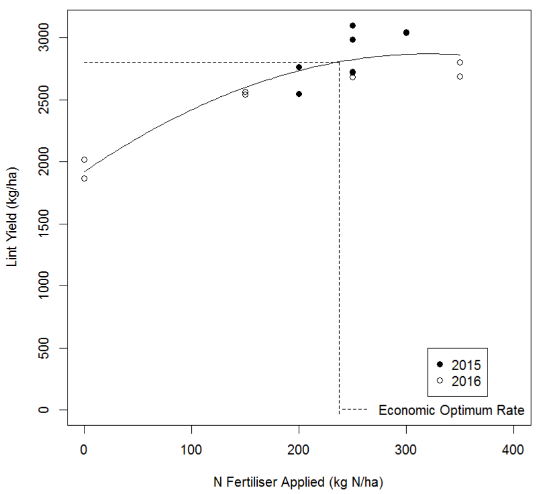

Figure 2. Cotton yield from Gunnedah, Northern NSW from the 2015 and 2016 seasons in relation to the economic optimum N rate (shown as the dotted line).

Nitrogen Use Efficiency (NUE)-Applied NUE

The applied NUE (aNUE- sometimes referred to as fertiliser NUE) is simplistic equation that is commonly used by general industry surveys as a comparative index between management systems. The equation's only required measurements are lint yield and the amount of applied N fertiliser. The experiment aNUE obviously was strongly aligned with the varied N rates ($P<0.001$) but across the two seasons irrigation rate did not have an influence on aNUE. A common trend occurred over the two seasons as the increase in N rate decreased the aNUE. Applying the economic optimum N rate to the aNUE response curve, we find that the optimum aNUE over the two seasons to be 11.95 kg lint/kg N applied.

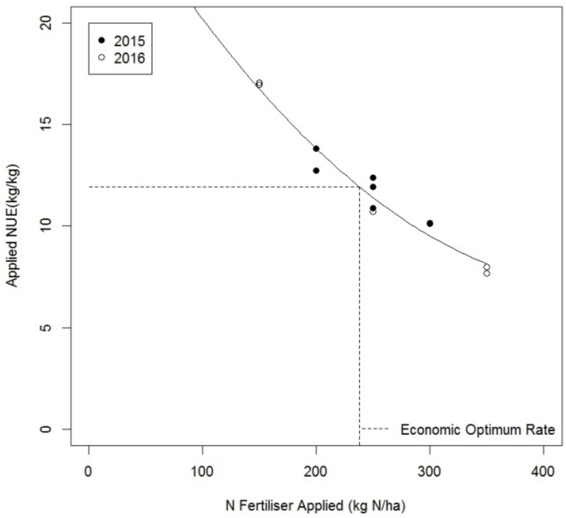

Figure 3. N fertiliser rate impact on Applied Fertiliser NUE (aNUE) from the 2015 and 2016 cotton seasons, based at Gunnedah, Northern NSW. The economic optimum N rate and aNUE is shown by the dotted line.

Conclusion

The experiment concluded that the economic optimum N applied rate for 2014/15 was 232 kg N/ha and 252 kg N/ha for the 2015/16 season. When we combine the two seasons the economic optimum applied N rate was found to be 237 kg N/ha. This supports claims from Rochester (2010) that the recent trend of applying excessive rates of N fertiliser (>300 kg N/ha) is unwarranted and not required to produce high lint yields. By applying higher than crop required N rates, it decreases farm efficiency (especially NUE), erode potential crop profits and increase the loss of N into the environment.

There was a linear relationship between N rate and lint yield when application rates were under 200 kg N/ha. The linear relationship starts to decrease over the 200 kg N/ha, closely aligning with a quadratic curve. The derivative equation from the curve suggests that there was no advantage in applying more than 250 kg N/ha onto a cotton field.

As expected when working on a field trial over two different growing seasons, there was seasonal variability caused by change in weather conditions, rainfall, and impacts from mechanical operations. The variability led to a significant gap in the experiment yields of the two years, and proves that in order to better understand N use within commercial farming systems requires multiple years of data. Although what was clear is that researched optimum input rates can be used by commercial growers to build their management strategy in order to be nutrient efficient and continue to grow exceptional cotton lint yields. By adopting recommended N rates, growers would have less input wastage, become more sustainable and improve their crop net returns by reducing non-required crop input costs.

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