IMPROVING NITROGEN USE EFFICIENCY IN COTTON

DR CHRIS DOWLING HAS UNDERTAKEN A COMPREHENSIVE STUDY OF THE INTRICACIES OF NITROGEN USE IN COTTON CROPS, AND HAS RESEARCHED METHODS TO IMPROVE EFFICIENCY.

Nitrogen (N) nutrition of high yielding cotton crops remains one of the biggest production costs with improvement of nitrogen use efficiency (NUE) being somewhat of an enigma when trying to ensure that profitability and efficiency are both optimised.

When attempts to improve NUE are centred on tweaking N rates, application timing and products only, the outcomes are frequently fruitless, confusing and seasonally contradictory. This is generally because they are made in the absence of close consideration of the other major factors that control NUE.

NUE is not just related to N fertiliser practices but is intimately related to soil characteristics and condition, their reaction to irrigation practices, and weather conditions (Figure 1).

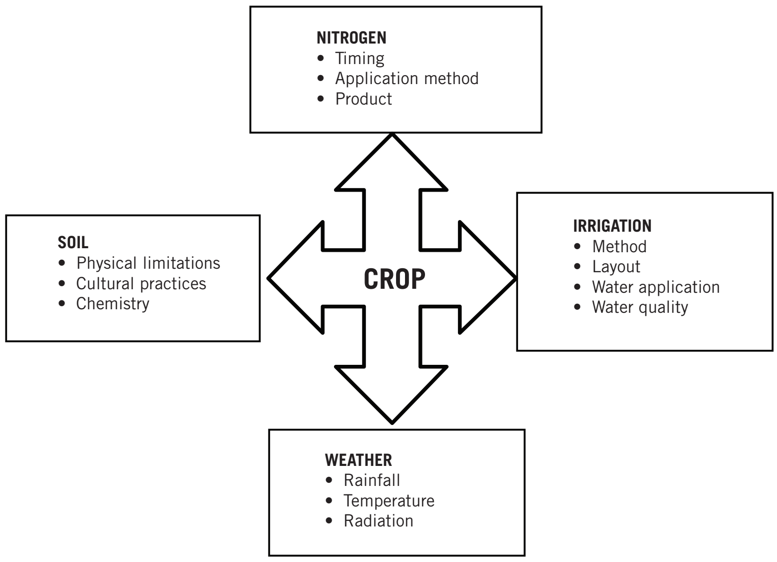

Figure 1 - Factors controlling nitrogen use efficiency in cotton

Measuring NUE

In scientific literature there are numerous methods used to describe NUE. The easiest to calculate is generally fertiliser nitrogen use efficiency (NUEf) which is the lint yield (kg/ha) divided by the total amount of fertiliser N applied.

CSIRO's Dr Ian Rochester has suggested that NUEf between 13 and 18kg lint/kg N denotes efficient N use. NUEf above 18 kg lint/kg applied N may indicate insufficient N was available to the crop and yield would most likely have been increased by extra N. NUEf below 13kg lint/kg applied N suggests that N applied was inefficiently used or in some circumstances, may indicate extra N was applied.

The trade-off between NUEf and net fertiliser margin remains one of the biggest challenges in improving NUEf. This was clearly demonstrated in N demonstration strips at "Yambocully" Goondiwindi, QLD, in 2014 (Figure 2). These results (NUEf < 13 at economic best N rate) suggest that an underlying soil or water factor may be adversely affecting NUEf. Addition of extra N at rates above 303 kg/ha to overcome system inefficiency not related to N application was not profitable.

There was however a severe economic penalty for under fertilising. Soil sampling for N post-harvest showed increasing soil residual N with higher N application rates but there was also a parallel increase in N that was not able to be accounted for presumably lost as gaseous emissions or leaching.

Improving NUE

Improvement in NUE requires a good understanding of the causes of inefficiency to make consistent improvement without sacrificing profitability. In some cases there may be more gain in NUE from making changes to soil and /or irrigation practices than attacking N management directly.

Inefficiency can arise from a range of factors related to soil, irrigation, weather and nitrogen tactics and they can be classified into some broad categories. These categories provide some insight into loss pathways and practice change that leads to higher NUE.

Identification of the likely causes of N use inefficiency through an audit of current FNUE and practices can help define the strategies and tactics that are most relevant in addressing improvement in NUE in a particular situation.

Sources of N use inefficiency

Low NUE has its origins in both the soil environment and within the plant. In both cases the interaction with growing season conditions make single season measurements of NUE unreliable; measurements should always be contrasted across different management practices in the same season or assessed as part of a longer term trend.

The need for fertiliser N stems from a lack of contribution from mineralising soil organic pools of fresh labile (low legume frequency and duration in rotations), older labile and humic fractions (being rundown). Where oversupply occurs there is a high probability of increased denitrification losses and decreased NUE (Figure 3).

Supply greater than demand - chronic oversupply

Oversupply occurs where N availability is greater than crop demand. This does not mean that high N rates are not seasonally justifiable, for example where there has been unseasonably wet weather and despite best efforts to avoid loss, extra N is added to maintain crop profitability.

When NUEf is assessed from an annual

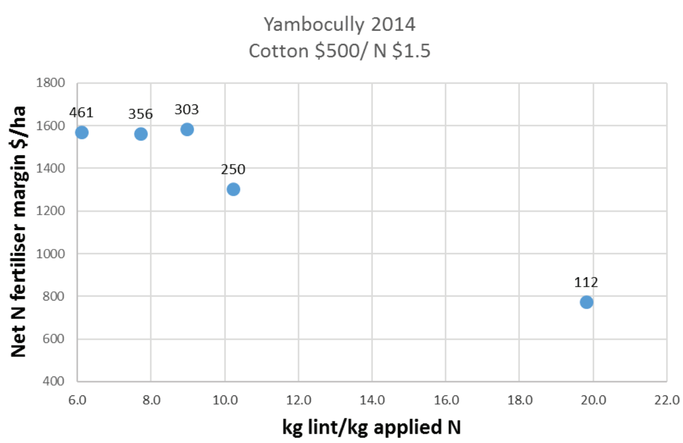

Figure 2- NUEf and fertiliser margin trade-off "Yambocully" 2014 (number above the dot is the total rate of N applied in kg/ha).

Acknowledgements
Thanks to Nigel Corish and Sally Dickinson for kindly making available the results of the "Yambocully" trial.

COMMON FACTORS CONTRIBUTING TO LOW NUE

perspective, if residual N from an "over-application" is subsequently lost, low NUEf is likely but where N loss of residual N is negligible (such as in dryland production), annual NUEf is low but rotational NUEf may still be acceptable.

Oversupply frequently occurs as a result of factors such as:

- over-estimation of yield potential
- lack of consideration of soil N that will become available (mineralisation potential)
- under- estimation of residual soil mineral N
- overcompensation for less than optimal soil condition (compaction) and irrigation practices
- poor calibration of application equipment

Indications that N supply may have be higher than yield requirements include:

- high late season plant tissue and petiole nitrogen concentrations (Figure 4)
- late season vigour leading to difficulty with defoliation
- high seed N percentage kg lint/kg fertiliser N in the low range (<13)
- kg lint / kg crop available N (soil + fertiliser) in the low range (<10)
- high residual soil mineral N immediately post picking (>80 kg/ha, 0-80 cm)

Management options

Use of objective measurement of nitrogen supply such as soil testing can at the minimum help rank paddocks with respect to their mineral-N content and plant tissue analysis around first flower provide the plants view of how much N it can see with its roots approaching maximum depth for the season. Adherence to a well-designed sampling protocol is key to getting these tools to provide interpretability and consistency. (Nutrient Sampling Guidelines for cotton - www.cottoncrc.org.au/files/0b13f3af-7ac6-4c68-910f.../SamGL06.pdf)

Causes of inefficient nitrogen uptake

Poor NUE from both pre and in-crop N application is a result of loss mechanisms such as volatilisation, denitrification and leaching, or temporary unavailability due to soil processes such as immobilisation. In-crop applications of N (particularly those between squaring and peak bloom) reduce the time that applied N is subject to loss processes and increases the chance of interception, being applied when a significant root structure is present and aboveground biomass demand is increasing rapidly (Figure 5, see over page).

Fertiliser N efficiency is also affected by the amount of soil available N at sowing (residual applied N from the previous season and mineralised N). High fertiliser efficiency is most common where soil residual N and the contribution from in crop mineralisation is low, losses are minimal and other management factors such as weeds, disease, sowing date, rate and cultivar optimised.

There is no doubt that inappropriately high biomass production early in the season due to high N availability may create poor NUEf but having the crop too low in N as it enters the reproductive stage (squaring to flowering) poses a production risk if N supply cannot be effectively made adequate by early flowering. Strategies for split application of N therefore need to consider both the amount and location of residual soil N to ensure adequacy pre-flowering and product supply and multiple application options for in-crop applications.

KEY THINGS YOU SHOULD KNOW

- Four broad factors influence nitrogen use efficiency (NUE): soil type, irrigation practices, weather conditions and N application management.
- Improvements to NUE should not centre on tweaking N rates, timings and products only.
- Major factors that control NUE in any cotton production setting include management decisions that affect the loss mechanisms arising from interactions between nitrogen application, soil, irrigation and weather.
- Long term measurement and monitoring strategies are important to distinguish between seasonally unavoidable low NUE and chronic production system related causes.
- High NUE, high yield and high profitability can co-exist.

Applied but temporarily unavailable

Immobilisation of soil N occurs when there is competition between soil microbes and the crop for soil mineral-N. It is likely to occur where large quantities of cereal stubbles (wheat, maize) are incorporated close to sowing, for example in dryland or where irrigated crops are sown into standing sprayed out wheat crops. Net immobilisation reduces available N to the growing crop in the incorporation layer. In the short term up to 18kg N/tonne of cereal stubble soil incorporated can be consumed in the immobilisation process.

Applied or mineralised, but lost from soil

Leached (summer mineralised N and residual mineral N) is more of a risk in lighter textured soils.

Ammonia volatilisation is generally a loss of N associated with applied N, particularly products that at some stage create ammonium-N after application (eg urea, DAP, chicken manure or fresh animal manure with high N content).

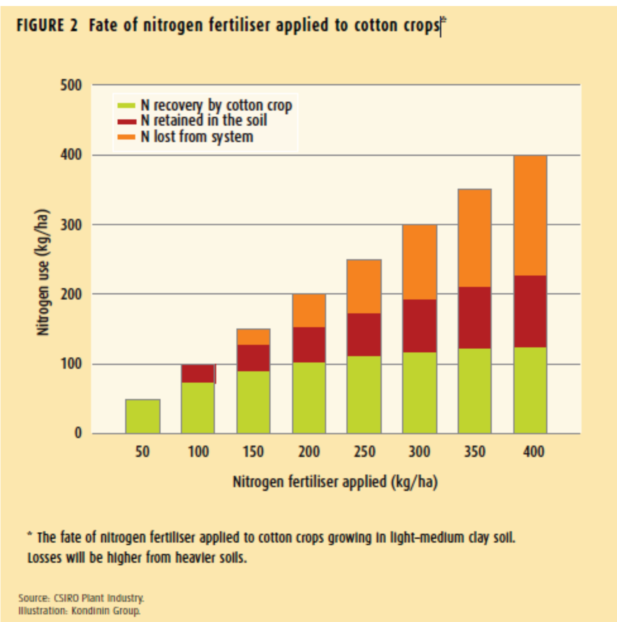

Figure 3 - NUE declines rapidly as N rate exceed that required by the crop. Source: Dr Ian Rochester, CSIRO.

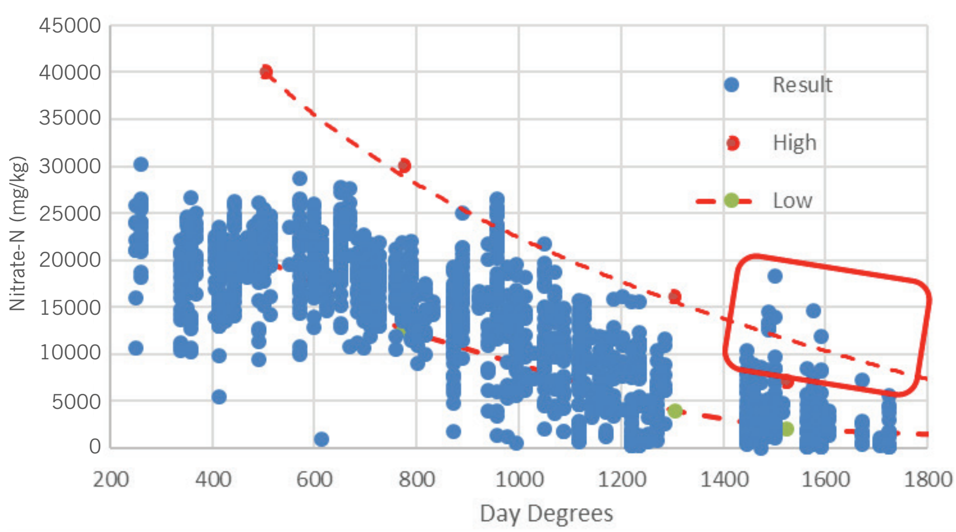

Figure 4 - High levels of N in petioles indicating high availability of soil N in late season (source Back Paddock Company)

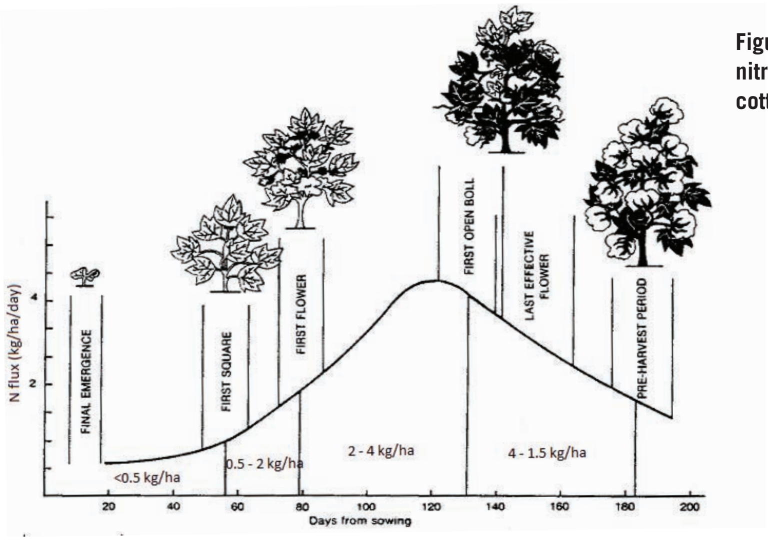

Figure 5 Seasonal nitrogen fluxes in cotton

Under favourable loss conditions, 10 to 20 percent of applied N may be lost in a four-day period (after application) but the effect on yield of this loss is not always proportional.

Management options

Recent research has indicated that urease inhibitors such as those containing the active ingredient NBPT are able to reduce the rate of urea hydrolysis and potentially reduce volatilisation losses. To be useful in increasing NUE this method needs to reliably produce higher yield or improved profitably to cover the extra cost.

Incorporation of manure (as for urea) is the most effective means of reducing N losses.

Denitrification

Significant denitrification losses are mostly related to conditions of high soil moisture. Research in recent years suggests that:

- Dry seasons create minimal waterlogging in dryland production so most denitrification losses are due to nitrification of urea and anhydrous ammonia in the fertiliser bands. In irrigated crops, losses can be significant where soil structure, irrigation practices and N fertiliser management are less than optimal.
- Wet periods producing water-filled soil porosity (WFSP) greater than 60 percent results in higher rates of denitrification. The intensity of loss is related to the quantity of nitrate and labile carbon co-located in soil layers, high soil temperature and duration of WFSP greater than 60 percent.
- Some nitrification-inhibitor treated and polymer-coated products have shown potential for reducing losses but the effect of factors such as soil temperature on application timing and persistence need to be further investigated to increase their reliability and profitability.

Management options

Changes to N fertiliser application tactics that are central to reducing denitrification losses:

- keep the N in the ammonium form for longer e.g. use of nitrification inhibitors
- minimise the amount of nitrate-N exposed to each irrigation (split application)
- minimise the duration of inundation and area of fields where soil moisture is above 60 percent WFSP.

Horizontal Movement

N movement from the soil into irrigation water as it flows down the field is a feature of flood irrigation systems. Losses occur from horizontal movement of nitrate-N carried down field and into table-drains and channels, and directly from the water (denitrification).

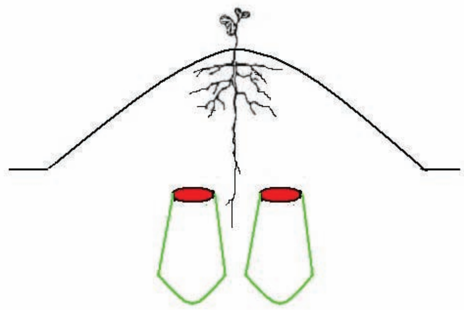

Figure 6. Preferred placement of pre-plant N

Management options

Ensuring fertiliser nitrogen is applied in a manner that creates downward movement rather than toward the surface of beds is recommended (Figure 6). This is particularly important where a high proportion of the N is applied pre-plant in hot production areas where irrigation and evaporation during the season can bring soluble salts such as nitrate to the surface from considerable soil depth via a soil process called hydraulic lift.

Available in soil but not taken up

Positional unavailability occurs when the active root mass is at distance from mineral N sources for a significant period of crop growth. This has occurred in low in-crop rainfall seasons where a significant N application is surface broadcast and then furrow irrigated. The upward movement of the wetting front carries urea and nitrate to the dry surface of the bed rendering some of it unavailable until rain falls or is lost via horizontal movement down the furrow when irrigated.

When the timing of release or transformation of the applied product (organic matter, enhanced efficiency N fertiliser) to a plant-available mineral N form does not match crop demand, it is more exposed to losses and low NUEf .

Factors that create a limitation to root mass, root depth and density such as by chemical (eg phosphorus deficiency), physical (eg compaction) or biological (root disease) can reduce NUEf.

Taken up to biomass but not transferred to harvestable parts

The relationship between N supply and that in the harvested material is more complex in cotton than in cereal crops. This complexity arises from cotton's indeterminate growth habit (vegetative and reproductive development occurring together) and the indirect relationship between the major saleable commodity, the lint, and the location of nitrogen that is removed at harvest, the seed.

Nitrogen use efficiency is reduced as a result of the indeterminate growth where loss of fruiting structures is related to an increase in vegetative growth, hence maintenance of a sustainable fruit load is key to high NUE.

Some of the factors that can influence NUE in relation to indeterminate growth include varietal selection, climatic conditions and agronomic management.

THE LINT-SEED RELATIONSHIP

Cotton lint contains no appreciable quantity of N, it is in the seed. This means gin turnout (GTO) is also a factor in manipulation of NUE. The N concentration in the harvested seed of some of the new smaller seeded varieties is frequently in the range 3.5 to 4.5 percent as compared to 3.2 to 3.9 percent for older varieties. At first glance this would logically suggest that it was taking more N to produce a bale of lint.

However a parallel increase in GTO has maintained a relatively stable position of N removal per bale (Table 1). With some of the newer small seeded varieties optimised NUE appears to be indicated when when seed N is around 3.9 percent (Rochester 2014) suggesting removal of 11 to 12 kg N /bale for GTO round 42 to 44 percent as compared to a similar range for seed N of 3.5 percent and GTO around 38 percent.

	GTO %			
Seed N %	**38**	**40**	**42**	**44**
3	11	10.1	9.3	8.5
3.5	**12.7**	11.7	10.8	9.9
4	14.5	13.4	**12.3**	11.3
4.5	16.2	15	13.8	**12.7**

Table 1 Effect of seed N content and gin turnout (GTO %) on nitrogen removed per bale of lint (kg N/227 kg lint).

Nutrient Sampling Guidelines for cotton - www.cottoncrc.org.au/files/0b13f3af-7ac6-4c68-910f.../SamGL06.pdf)

Rochester I, 2014. Growing high-yielding nitrogen-efficient cotton. www.australian-cottonconference.com.au/2014_Proceedings.htm

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