# Optimising nitrogen fertiliser in high yielding irrigated cotton:

# A benefit-cost analysis and the feasibility of participation in the ERF

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## Abstract

Maximising nutrient use efficiency and minimising emissions of the powerful greenhouse gas nitrous oxide, could enable Australian producers of high yielding irrigated cotton to participate in the Emissions Reduction Fund. This paper reviews nitrogen (N) use in the cotton industry in Australia to date and the challenges of achieving optimal N use in commercial growing practices. The study quantifies both the social and economic parameters in a benefit-cost analysis using two scenarios: an optimal use of N fertiliser and an overuse of N fertiliser in irrigated cotton production. Results of sensitivity analysis for social and economic costs have implications for policy makers focusing on improved N management and an industry supplying an increasingly environmentally aware global market. The study also contains preliminary modelling using industry research of a cotton-N emissions abatement project under the Australian Government's Emissions Reduction Fund.

Keywords: nitrogen, N, nitrogen use efficiency, cotton, fertiliser, emissions, extension, Emissions Reduction Fund.

## Introduction

Current nitrogen (N) management practices for worldwide cropping and horticultural production systems are characterised by low N use efficiency, environmental contamination and considerable ongoing debate regarding what can be done to improve N fertiliser management (Shanahan *et al.* 2008). Interest in N fertiliser efficiencies has been renewed with the development of cotton-specific N methods for the Emissions Reduction Fund (ERF) that could result in a financial reward for reducing emissions. This study aims to identify the benefits and costs of fertiliser use in irrigated cotton and investigate the viability of cotton growers participating in the ERF.

Agricultural producers have limited ability to influence either output or input prices, and as a result, improving input use efficiency in production is a key strategy for profitability and survival (Segarra 1990). Cotton is one of many agricultural industries where N is a key input to maintaining high levels of production; it is therefore at greater risk of system losses through denitrification and nitrate leaching (Rochester *et al.* 2008). Sustainable soil and crop management practices that reduce soil erosion and N losses, conserve soil organic matter and optimise cotton yields are important issues for growers (Sainju *et al.* 2006).

Australian cotton industry research, development and extension organisations and providers as well as growers are acutely aware of the knowledge gaps in relation to N use. Over the years, a significant amount of research and development has been done to address these gaps. Despite this, challenges still remain in understanding the complex nature of N use and loss in the cotton system and also achieving best practice across the industry in relation to optimal N use. Research conducted on recovery rates of N in cotton also show a high proportion of applied N remains unaccounted for (Chen *et al.* 2008). Studies by Humphreys et al. (1990), Freney et al. (1993) and Janat (2008) conclude that between 43-92% of applied N is lost from the system from ammonia volatilisation, nitrification and denitrification. In a normal season, the Australian cotton industry uses up to 100,000 tonnes of N fertiliser and some researchers estimate up to half of this fertiliser may be lost from the system (Grace *et al.* 2003). Nitrous oxide loss from denitrification increases exponentially as fertiliser rates increase, achieving up to 3.5% of these losses when N rates are applied between 280-320kg N per hectare (Scherbak *et al.* 2014). Research is currently underway to determine exact proportions of losses from all other types of N compounds from the furrow irrigation system as a whole, including supply channels, head ditches, tail water and storage dams (Macdonald *et al.* 2015). Nitrous oxide has 310 times the global warming potential of carbon dioxide (EPA 2013). Environmental policy in agriculture generally has committed to incentives designed to improve management practices of N focusing on reducing losses and increasing efficiency of applied N products. As well as the environmental concerns with greenhouse gas emissions, run-off and nitrate leaching, overuse of N fertilisers is costly in terms of wasted fertiliser (McDonald *et al.* 2012).

The Australian cotton industry's research, development and extension investors are currently focused on collating all the N research to date into decision making processes regarding N management.

## Background

Nitrogen is the most difficult nutrient to manage in cotton production; it has more impact on yields, crop maturity and lint quality than any other primary plant nutrient (Hons *et al.* 2004). The Cotton Research and Development Corporation (CRDC) Grower Practices Survey 2013 found most irrigated cotton growers spent between $300 and $600 per hectare on nutritional inputs (Roth Rural 2014). This is consistent with findings in the 2014 Boyce Australian Cotton Comparative Analysis (Boyce & Co 2014) that reported nutrition as the largest cost line item ($591/ha) ahead of wages ($462/ha) and fuel and oil ($439/ha). Within the nutrition category, N is the highest input cost (Boyce & Co 2014).

It is difficult to accurately predict the applied N a crop needs because N compounds can undergo chemical changes that influence N retention and mobility in the soil, as well as its availability to plants (Hons, M.L. et al. 2004). Applied N use efficiency as a measure for performance has its limitations, with as much as two-thirds of the N plant uptake occurring from soil organic carbon and mineralisation (Australian Cotton CRC 2001).

There remains a division between cotton industry best practice recommendations and commercial practice. Researchers, agronomists and economists are still debating the issue of correct rates of N, as they base their insights on different production functions. Economists assume decreasing returns of input use, whereas the response curve used by agronomists (and their cotton grower clients) is often described as linear with a plateau (de Koeijer *et al.* 2003).

## Nitrogen Research

Nitrogen fertilisers and farmer decision making

Various N response experiments on a number of agricultural crops have shown variability in the shape of N response curves between trials, not only in cotton (Vold 1998). Within the Australian cotton industry there is a particular focus on N use, due to divergence between commercially applied N rates and researcher recommendations. From 2004 to 2007, the National Cotton Extension Team initiated an N use efficiency program in several regions to gain some understanding of N use efficiencies and trends in N management. At 34 sites in major growing areas from central Queensland south to Wee Waa in New South Wales, crop N uptake, crop N use efficiency and N fertiliser recovery was calculated. The data indicated that there is considerable scope to reduce N fertiliser inputs to cotton fields without reducing yields (Rochester *et al.* 2007). Averaged over all sites, Rochester et al. (2007) found approximately 40kg N/ha too much N fertiliser was applied, based on a N uptake efficiency range (calculated by dividing the lint yield by the crop N uptake). Experimental data from CSIRO Plant Industry provided the basis for determining the optimal range for N use efficiency.

More recent industry trials indicate rates are still applied well in excess of optimum values. A modified Nitrogen Fertiliser Use Efficiency (NFUE) calculation based on the lint yield divided by applied N fertiliser developed by Rochester (2011) identified a new optimum range for N rates. In the five years from 2009-2014, data taken from 147 irrigated commercial cotton sites revealed 74.1% of sites were considered to have over-applied N fertiliser based on the NFUE calculations (Smith *et al.* 2014).

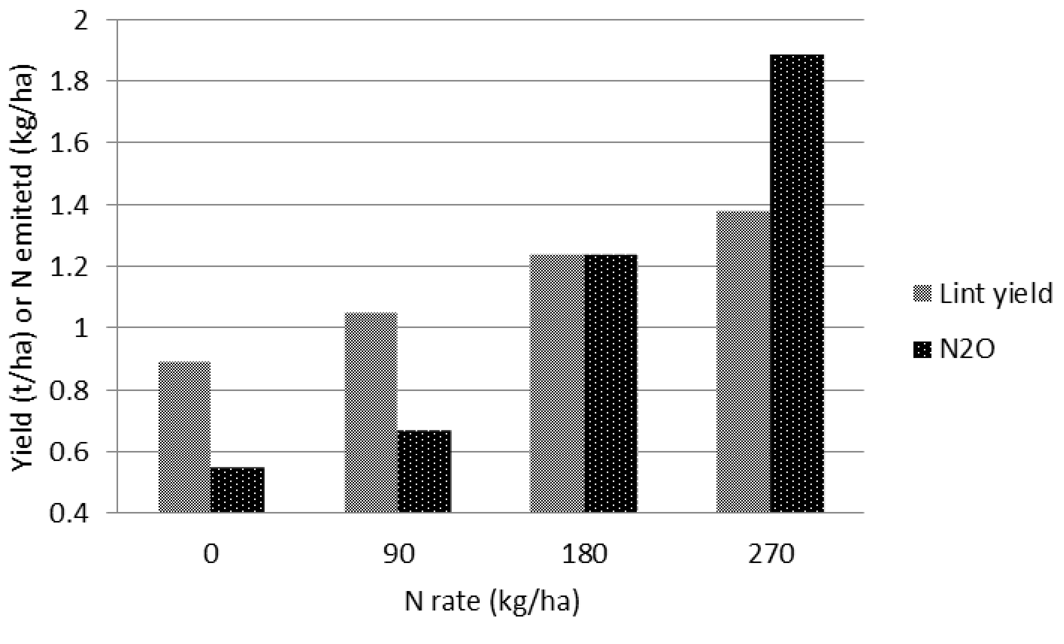
The economic implications for the cotton industry and cost to the environment, given the status of nitrous oxide as a harmful greenhouse gas, require further investigation. Historically, it has been a difficult task to resolve the poor N use efficiency issue and to implement lasting practice change. Nitrogen use campaigns focusing on rate, timing, placement and product have been a feature of extension in the cotton industry consistently for almost twenty years (Rochester 1998). Extension based on simple recipes is perceived to be inadequate for complex productivity issues (Lawrence 2006). The key management challenge is to determine the optimal amount of N fertiliser to apply at a particular site in a particular season in advance of sowing the crop.

As new cultivars are developed and commercialised, yields have increased substantially and removal rates of N and recommendations for applied N have also increased (Roth Rural 2013). The grower-advisor decision making process on N management is currently a focus area of CRDC. Industry surveys suggest growers and advisors have low confidence in N budgeting decision support tools used to determine applied N rates, once starting soil nitrate values are known. Moreover, growers and advisors assembling a ‘balance sheet’ for N in the crop planning stage see uncertainty in quantifying potential in-crop mineralised N, sources of N fixed from the atmosphere by legumes and soil carbon testing (CRDC 2014). Interestingly, those researchers surveyed reported high confidence in the N decision support tools indicating gaps in extension and knowledge brokering in N management.

Due to the low cost of N of around $1.45/kg (including application costs), an overspend on this item is often interpreted as an insurance policy for losses from the system and to cover potential errors in calculation methods in respect to the rate required to achieve maximum yield. However, the more N fertiliser applied, the greater the losses from the system and the lower the proportion of applied N available to the plant. Studies from the National Agricultural Nitrous Oxide Emissions Research Program has shown emissions of nitrous oxide (losses of applied N) greatly increase when applied rates of N fertiliser increase (Schwenke *et al.* 2013).

Figure 1 shows the cumulative emissions or losses from an irrigated cotton field on the Darling Downs. Where the N rate increases, so too do emissions relative to lint yield (Schwenke, Grace et al. 2013).

**Figure 1. Cumulative nitrous oxide ($N_2O$) emissions and lint yield in response to N application on cotton at Kingsthorpe (Qld) on a heavy black clay in 2010-11**




*Source: Schwenke et al.(2013)*

A recent industry grower and advisor survey on N (Welsh 2014) suggests growers take the view that they cannot afford to under fertilise with N (or other nutrients) and tend to manage risk by ensuring their cotton crop yields are not limited by N availability. The sample data indicates 66% of surveyed respondents (n=82) applied more than 250 kg per hectare of N fertiliser in the 2013-14 season. This is consistent with surveys completed by Roth (2014), Crop Consultants Australia Incorporated (2014) and industry commercial trial data (Smith, Devlin et al. 2014). A grower knows that suggested industry rates are unlikely to be tailored to their location, soil type and climate, so they err on the side of caution by applying additional N compared to industry suggestions. The grower also uses their previous N experiences on their own farms to help make N decisions, in many cases this is from decades of experience. In a recent survey (Roth Rural 2014) found that 80% of respondents had over 10 years' experience, 62% had over 20 years' experience and 21% had over 30 years' experience within the cotton industry.

Nitrogen Response Curves

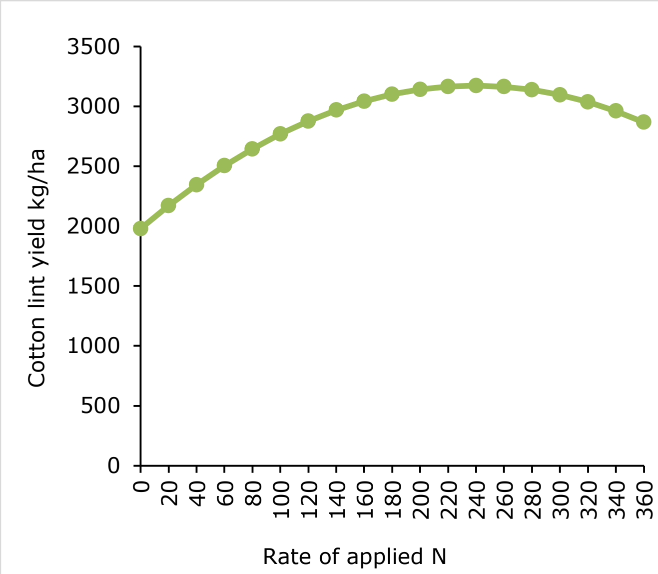
From the economist's point of view, N response curves are production functions. The purpose of a production function is to summarize the production process with a simple analytical description (Vold 1998). Nitrogen response curves are used to analyse N efficiency and to support fertiliser decisions (Fageria and Baligar 2005). The use of N response curves has been of great value in assessing N requirements of crops (Angus 1995). Once the general shape of a response curve is known, several meaningful thresholds can be obtained to assist in management decisions, including the maximum yield achievable and optimal rate of fertiliser. The economic optimum rate is the rate at which the extra yield produced is the same value as the extra N applied (Rochester and Filmer 2007) i.e. when marginal benefits equate to marginal costs. After this point, the value of the extra yield is not enough to cover the cost of the extra N.

In considering how N rates may be modified, it is clear that there are very complex interactions throughout plant metabolism and considerable impacts of environment, which combine to determine the growth of the plant and its composition. Nitrogen may come from rainfall and soil reserves as well as from applied fertilisers, therefore greatly affecting the apparent response derived from applied N. Similarly, losses of N due to leaching, bacterial metabolism, variable seasonal affects and emissions from soils and plants affect N response curves (Lawlor 2002).

The N response curve used within this model is from the Australian Cotton Research Institute in the Lower Namoi Valley near Narrabri, New South Wales. The response curve is derived from a local experimental site for the cotton season 2013/2014. The field agronomic history is consistent with common industry rotation practice for the region; cotton, winter wheat, summer fallow, winter fallow and returned to cotton. As applied N increases, the curve (see Figure 2) shows a diminishing response to cotton lint yield. The shape of the curve is of key importance. In Figure 2 the yield response to N is initially strong and increases at a decreasing rate with each fertiliser unit to the point of maximum yield. After this point the yield decreases with each N unit. If a linear N response curve or a plateaued curve at the point of maximum yield was used, the results from this analysis would be significantly different.

The 2014 Cotton Seed Distributors (2014) variety trials show marked differences in yield N response within valleys and across climatic zones. This variability contributes to a level of uncertainty in extending results to farm advisors and growers in different regions. It should be noted that using agronomic models with site-specific microclimatic conditions and soil data can assist with a broad description of environmental behaviour (Godard *et al.* 2008). However, when the goal is to infer agronomic results to a regional level, such models will be limited at a larger geographical scale without applying generalised assumptions on the physical data used potentially compromising the findings (Jayet and Petsakos 2013). Economic analysis of farm level production often assumes that homogenous agents efficiently move along response curves when changes in relative input prices occur. Studies by Hertel et al. (1996) found considerable heterogeneity between farm managers in regards to N fertiliser use in maize production due to differing rates of profitability and differing entrepreneurial capacity. Econometric modelling of aggregate data series also ignores compositional affects (entry/exit) owing to price changes. However, capturing heterogeneity in local environmental conditions at a regional level can be achieved by positive mathematical programming for use in agri-environmental policy evaluation (Mérel *et al.* 2014). Nitrogen response curves are rarely used on a broad scale to estimate industry trends or crop production (Godard, Roger-Estrade et al. 2008).

**Figure 2. Nitrogen yield response curve supplied by I Rochester (2014)**




## Opportunities under the ERF

The Australian Government's current climate change policy includes a focus on providing opportunities and support for the agriculture sector to implement emission mitigation activities as part of farming and land management. It aims to reward land managers for providing abatement. The policy approach prioritises activities which also deliver additional practical environmental benefits (co-benefits). This study will investigate the revenue and costs associated with a hypothetical ERF emissions abatement project using current industry research under two scenarios of in-field N management.

Farmers and land managers considering greenhouse gas abatement or sequestration activities can potentially earn and trade Australian Carbon Credit Units (ACCUs) from an approved method. Each ACCU represents one tonne of carbon dioxide equivalent ($CO_2$e) net abatement (through either emissions reductions or carbon sequestration) achieved by eligible activities (Clean Energy Regulator 2013). ACCUs can provide additional income to farming businesses that choose to participate in the ERF.

Once a project is registered under an approved method with the Clean Energy Regulator, the project proponent can bid into an ERF auction and if successful, enter into a Carbon Abatement Contract which details the number of ACCU that will be generated and over what time frame. The Department of the Environment is currently working with the Clean Energy Regulator and the cotton industry on an N management method designed to provide incentives for growers to improve N use efficiency from a baseline scenario. By using this method emissions abatement resulting from changed practices to avoid nitrous oxide emissions due to excessive applied N would generate ACCUs under the ERF. Typically, N fertiliser methodologies in the United States have focused primarily on reducing the rates of applied N in the field (Climate Action Reserve 2013; Verified Carbon Standard 2013). This method under development by the Department of the Environment aims to measure future improvements and allows crediting for continuous improvement in NFUE. NFUE improvements can be achieved by increasing yield from the existing historical rates of N or maintaining yield from reduced rates of N. Under guidelines from the Clean Energy Regulator, ERF abatement projects can surrender ACCUs for a maximum crediting period of seven years.

## Analysis

The environmental cost of N fertiliser volatilising after application is now gaining increasing scrutiny by policy makers, environmental groups and fertiliser companies. In addition, processors and consumers need reassurance that the system used to grow the product is environmentally sustainable (Maraseni *et al.* 2010).

The social or environmental cost of emitting nitrous oxide into the atmosphere can be quantified by a defined series of equations and assumptions (Table 1). For simplicity this analysis will concentrate on the social and economic benefits and costs of N fertiliser use as a standalone practice and within a potential ERF project. It will analyse the social and economic benefit/cost from two N management practices, with emissions and product costs as key variables. The two scenarios in the analysis will be modelled over four cotton crops (seven years) to identify economic differences between a research-based optimal rate and general industry practice within the cotton industry.

- Farmer A (Optimal rate): Nitrogen application rate determined by the price of cotton lint and cost of applied N to the crop in a range where marginal cost of N equals marginal revenue of cotton lint yield.

- Farmer B (General Industry practice): Nitrogen application rate set at 280 kg N/ha, which includes additional fertiliser to allow the grower reassurance that N will not be yield limiting.

**Table 1. Equations used to calculate social benefits and costs of changes in N fertiliser use in irrigated cotton**

| Equation | Formula | Reference |
|---|---|---|
| Cotton Nitrogen Response Curve | Lint Yield = 1979+0.0209(N Rate)$^2$ | Rochester Pers Comms (2014) |
| Emissions Factor (EF) | $N_2O$. (treatment)-$N_2O$.N(control)<br>Fertiliser applied (kg/ha) | McDonald et. al. (2012) |
| Cotton Nitrogen Emissions Response Curve | Emissions = 0.3926 x (Nrate/10)$^2$ + 18.927 x (Nrate/10) | Visser et al. (2014) |

An applied rate of 280 kg per hectare of elemental N is used in the industry practice scenario based on data from a recent grower N workshop survey (Welsh 2014) and the 2013 post season cotton survey by Crop Consultants Australia Incorporated (CCA 2014).

The prices received for lint in the analysis is \$450/bale (\$1.98/kg) based on the average 5 year lint price and gin for seed assumption (Namoi Cotton 2013).

The cost of applied elemental N of \$1450/t (\$1.450/kg of N) is calculated using the five year average price of urea fertiliser (ABARES 2013) of \$646/tonne at 46% N, plus an application cost of \$0.045/kg of N.

Some variable costs are linked to yield (i.e. wrap, freight, ginning and levies). These costs (\$0.40/kg) are calculated using NSW Department of Primary Industries (2015) and are multiplied by the yield increases (or decreases) associated with N application.

The discount rate used in the Net Present Value (NPV) calculations is set at seven per cent (New South Wales Treasury 2007). As the annual net benefit only occurs every second year, the discount factor is only applied in the year the cotton crop is planted. Discount factors have been applied using the equation from Sinden and Thampapillai (1995);

$$PV = Bt \times WTt \text{ or } PV = \frac{Bt}{(1+i)^t}$$

where *Bt* is the benefit received in time t and *i* is the discount rate over time period *t*.

## Economic Benefits and Costs of N application rates

The economic optimum N fertiliser rate can be determined based on the cost of each kg of N fertiliser, plus/minus yield based costs and the return for each kg of lint. Total lint yield has been derived from the N response curve (Rochester 2014) showing a non-linear response as N rates increase beyond optimum levels (Figure 2). This formula has been calculated using data from the Australian Cotton Research Institute's commercial trials in the 2013/14 summer cropping year, which reflects common industry practice. The results would be markedly different if a response curve with a different shape was used.

The economic benefit identifies the yield produced by the selected rate of N (in these scenarios, optimal rate and industry practice) and multiplies the yield by the value of the lint ($1.98/kg of cotton lint). The economic costs are calculated by multiplying the N rate by the cost of product and application ($1.45/kg of N), plus the costs associated with the yield increase ($0.40 multiplied by the additional lint compared to no N). There are many other costs to produce one hectare of cotton, however this analysis is a partial cost budget which focuses only on N. There may be other potential agronomic costs associated with the over use of N. For example, Rochester (2012) outlines some possible costs that may be a result of over use of N, however these costs have not been considered within this analysis due to a scarcity of reference material and trial data.

## Social Benefits and Costs of N application rates

A number of equations have been identified to enable calculations of the social benefits and costs with respect to varying N management practices. The analysis will assume the social cost as the environmental cost of the two defined scenarios. An emissions factor (EF) has been derived using an equation identified by McDonald et al. (2012) where the proportion of N lost to the atmosphere varies according to the rate of N fertiliser applied. Visser et al. (2014) acknowledge that whilst there are other emissions sources in soils, nitrous oxide is the dominant emissions source. The changing nature of emissions from fertiliser as rates increase is represented as an equation shown with other formulae in Table 1.

Industry research on soil carbon sequestration rates under irrigated cotton have ranged from a potential sequestration of 700-800 kg carbon dioxide per hectare per annum (Rochester 2011) to a zero or possibly negative sequestration level (Hulugalle 2000). These findings led Visser et al. (2014) to assume that a 550kg carbon dioxide per hectare is sequestered during the growth cycle for irrigated cotton. One factor affecting sequestration rates is stubble management. Burning cotton stubble used to be a common practice which would have released carbon back into the atmosphere resulting in a low or even negative sequestration for the plant, however an industry education campaign on soil health in the 1990s has led to the common practice of incorporating stubble (Conteh *et al.* 1998). A sequestration of 550kg per hectare per annum is used within this analysis. Due to the large differences between research findings, the implications of variability in the sequestration rate is analysed using sensitivity testing.

To complete the analysis on environmental cost, we assume that the emissions produced in the manufacturing of granular urea fertiliser are 2.19kg/ha of $CO_2$e (IFA 2009). Therefore, the net emission per hectare will be calculated by adding the emissions from manufacturing the fertiliser plus the emissions during crop growth less the assumed soil carbon sequestration rate during the growth cycle.

The range of the price of one unit of carbon dioxide equivalent estimated by the Parliament of Australia (2014) for the upcoming Emissions Reduction Fund is between $5.35 and $18 per tonne. Therefore an emissions cost of $10/tonne for carbon dioxide equivalent is used to value the social benefits, costs and net position of each scenario.

## Whole farm results and emissions abatement project under the ERF

(Roth Rural 2014) reports that the average irrigation area per farm, planted to cotton in Northern NSW in 2012-13 was 718 ha. To consider the whole farm results, per hectare figures will be multiplied by 718. The net present value over a seven year time frame is assessed to be consistent with maximum contract lengths within the ERF.

The whole farm results are then aggregated to a project level to consider how these results may be applied to the N fertiliser method under development by the Department of the Environment. In this analysis, we assume an ERF project consists of 10 farms growing an average size (718ha) crop forming a 7180ha aggregation. 2000t of $CO_2$e equivalent emissions are mitigated biennially when cotton crops are grown and project administrative costs are shared between multiple businesses. The minimum bid size for a project is 2000 ACCUs per year to participate in the ERF. Using the cotton-wheat-fallow cropping sequence in this study it is assumed four cotton crops will be eligible to generate ACCUs during the project period (Years 1, 3, 5 & 7). Wheat nutrition is assumed to be a stand-alone independent calculation in regards to N management and is not considered within the proposed N fertiliser method for cotton, so is not considered within this partial budgeting exercise. ERF project feasibility costings have been sourced from the Federal Government, the Australian Farm Institute, registered ERF auditors and existing ERF project proponents.

# Results

The results shown in Table 2 illustrate the optimum fertiliser application rate where the marginal return from the last unit of N declines as N fertiliser rate increases to a point where at the optimum rate, it equals the marginal cost of N.

## Economic Benefits and Costs

Based on the response curve used, the optimal rate of application is 200kg of N per hectare (Table 2), producing a yield of 3,141kg of cotton lint (13.83 bales/ha). At $1.98/kg of lint, this is an economic benefit of $6,220 per hectare. The cost of applying 200kg of N (at $1.45/kg of N) is $290 per hectare and the costs associated with yield (additional freight, ginning, levies, etc, $0.40/kg) is $465. This is a net benefit of $5,465 per hectare.

The rate of N required for maximum yield is 240kg, however the cost of the additional 20kg of N is greater that the value of the additional lint yield produced.

The industry practice of applying 280kg of N per hectare would produce 3,138kg of cotton lint (13.28 bales/ha). At $1.98/kg of lint, this is an economic benefit of $6,214 per hectare. The cost of applying the 280kg of N is $406 per hectare and the costs associated with the yield increase is $464, resulting in a net benefit of $5,344.

The general industry practice of applying additional N fertiliser (and assuming a linear relationship between N and yield), in this analysis has resulted in virtually no change in yield than would have been achieved using the optimal rate of N but a 2.2% lower ($121/ha) net economic benefit.

Considering the very small reduction in yield and net economic benefit, it is not surprising the current practice is for a grower to tailor N management to their own farm or to over-compensate on applied N rates, compared to industry recommendations. One of the likely reasons is that the additional N is perceived to be a cheap insurance policy to ensure plant nitrate levels remain above agronomic thresholds necessary to achieve maximum yield. Von Blottnitz et al. (2006) also concluded that the cost of N is small relative to the value of the crop produced, so the farmer is not very sensitive to the cost of fertiliser.

## Social Benefits and Costs

The effect of N fertiliser on $CO_2$e emissions is outlined in Table 3. The optimal application rate of 200kg of N results in a total of 974kg of $CO_2$e per hectare (438kg from the production of the fertiliser and 536kg from application). The industry practice of applying 280kg of N (40% higher than optimal) results in a total of 1,451kg of $CO_2$e per hectare (49% higher than optimal). The sequestration rate of 550kg/$CO_2$e per hectare remains constant between the two scenarios. The cost of net emissions can be seen in Table 3. At the optimal application rate, the net emissions of 424kg $CO_2$e per hectare is 53% lower than the net emissions of 901kg $CO_2$e hectare produced with the common industry practice. With an ACCU price of $10/tonne, this equates to $4.24/ha for the optimal rate and $9.01/ha for general industry practice; a difference of $4.77/ha. In terms of yield, $4.77/ha is equivalent to approximately 1.9kg/ha (0.082%) yield increase. These costs are at an insignificant level in terms of production costs for one hectare of cotton considering variable costs are approximately $3700/ha (NSW Department of Primary Industries 2015).

**Table 2. Nitrogen fertiliser cotton lint yield response function**

| N applied | Total lint produced | Additional lint availability compared with no N | Additional lint availability compared with no N | Average lint produced per kg N | Lint produced from last unit of N applied (marginal return) | Value of lint produced from last unit of N applied (lint = $1.98/kg) | Cost of last unit of N applied | Costs associated with yield increase ($0.40/kg) from last unit of N applied | Net revenue from last unit of N applied | Rate of return on last $ invested in N (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| kg/N | kg/ha | kg | % | kg/ha | Lint kg | $ return | $ Cost | $ Cost | $ revenue | % |
| 0 | 1979 | 0 | | | | | | | | |
| 20 | 2170 | 191 | 10 | 109 | 9 | 18.2 | 1.45 | 3.67 | 13.05 | 900 |
| 40 | 2345 | 366 | 19 | 59 | 8 | 16.5 | 1.45 | 3.34 | 11.73 | 809 |
| 60 | 2503 | 524 | 26 | 42 | 8 | 14.9 | 1.45 | 3.00 | 10.41 | 718 |
| 80 | 2645 | 666 | 34 | 33 | 7 | 13.2 | 1.45 | 2.67 | 9.09 | 627 |
| 100 | 2769 | 790 | 40 | 28 | 6 | 11.5 | 1.45 | 2.33 | 7.77 | 536 |
| 120 | 2877 | 898 | 45 | 24 | 5 | 9.9 | 1.45 | 2.00 | 6.45 | 444 |
| 140 | 2968 | 989 | 50 | 21 | 4 | 8.2 | 1.45 | 1.66 | 5.12 | 353 |
| 160 | 3043 | 1064 | 54 | 19 | 3 | 6.6 | 1.45 | 1.33 | 3.80 | 262 |
| 180 | 3100 | 1121 | 57 | 17 | 2 | 4.9 | 1.45 | 1.00 | 2.48 | 171 |
| 200 | 3141 | 1162 | 59 | 16 | 2 | 3.3 | 1.45 | 0.66 | 1.16 | 80 |
| 220 | 3166 | 1187 | 60 | 14 | 1 | 1.6 | 1.45 | 0.33 | -0.16 | -11 |
| 240 | 3173 | 1194 | 60 | 13 | 0 | 0.0 | 1.45 | -0.01 | -1.48 | -102 |
| 260 | 3164 | 1185 | 60 | 12 | -1 | -1.7 | 1.45 | -0.34 | -2.80 | -193 |
| 280 | 3138 | 1159 | 59 | 11 | -2 | -3.3 | 1.45 | -0.68 | -4.12 | -284 |
| 300 | 3096 | 1117 | 56 | 10 | -3 | -5.0 | 1.45 | -1.01 | -5.44 | -375 |
| 320 | 3036 | 1057 | 53 | 9 | -3 | -6.7 | 1.45 | -1.35 | -6.76 | -466 |
| 340 | 2960 | 981 | 50 | 9 | -4 | -8.3 | 1.45 | -1.68 | -8.08 | -558 |
| 360 | 2867 | 888 | 45 | 8 | -5 | -10.0 | 1.45 | -2.01 | -9.41 | -649 |

**Table 3. Nitrogen fertiliser rates and emissions**

| N applied | Emissions N2O | Emissions from fertiliser production (Urea 2.19) | Sequestration Rate | Net Emissions | Cost of net emissions |
|---|---|---|---|---|---|
| kg/N | $kgCO_2e/ha$ | $kgCO_2e/ha$ | $CO_2e/kg/ha$ | $CO_2e/kg/ha$ | $/ha |
| 0 | 0 | 0 | 550 | -550 | -5.50 |
| 20 | 39 | 44 | 550 | -467 | -4.67 |
| 40 | 82 | 88 | 550 | -380 | -3.80 |
| 60 | 128 | 131 | 550 | -291 | -2.91 |
| 80 | 177 | 175 | 550 | -198 | -1.98 |
| 100 | 229 | 219 | 550 | -102 | -1.02 |
| 120 | 284 | 263 | 550 | -4 | -0.04 |
| 140 | 342 | 307 | 550 | 99 | 0.99 |
| 160 | 403 | 350 | 550 | 204 | 2.04 |
| 180 | 468 | 394 | 550 | 312 | 3.12 |
| 200 | 536 | 438 | 550 | 424 | 4.24 |
| 220 | 606 | 482 | 550 | 538 | 5.38 |
| 240 | 680 | 526 | 550 | 656 | 6.56 |
| 260 | 757 | 569 | 550 | 777 | 7.77 |
| 280 | 838 | 613 | 550 | 901 | 9.01 |
| 300 | 921 | 657 | 550 | 1028 | 10.28 |
| 320 | 1008 | 701 | 550 | 1158 | 11.58 |
| 340 | 1097 | 745 | 550 | 1292 | 12.92 |
| 360 | 1190 | 788 | 550 | 1429 | 14.29 |

## Total Benefits and Costs

A summary of the total (social and economic) benefits and costs with the focus on emissions, lint yield and N input is provided in Table 4. There is a difference of $126/ha between the net position of Farmer A ($5,461) and Farmer B ($5,335). By assuming a linear relationship between N and yield, when, in this case the yield response was diminishing, the industry standard practice of applying fertiliser in excess of the crops requirements has resulted in a 2.23% reduction in net benefit.

**Table 4. Summary of social and economic costs for two scenarios of N management**

| Scenario | Benefits | | Costs | | Net Position/ha |
|---|---|---|---|---|---|
| | Social | Economic | Social | Economic | |
| Farmer A (optimum rate) | $5.50 | $6,220 | $9.74 | $755 | $5,461 (0) |
| Farmer B (industry standard rate) | $5.50 | $6,214 | $14.51 | $870 | $5,335 (-126) |

## Whole farm, seven year results and emissions abatement project under the ERF

When the total results are considered at a farm scale (with an average cotton crop of 718ha) over a seven year period (the current contract term of an ERF mitigation project), the results can be seen in Table 5.

In a seven year period, where cotton is grown every second year, there are four cotton crops. During this time, the difference in applying the optimal N rates versus over-applying N (as shown by the industry standard rate) amounts to a saving of $278,861 (2.3% of total NPV).

**Table 5. Calculation of net present values for two alternative N management practices at a farm scale**

| | | Alternative A: Optimum Yield | | Alternative B: Industry Standard Rate | |
|---|---|---|---|---|---|
| Year | Discount Factor | Annual Net Return from N fertiliser ($) | PV ($) | Annual Net Return from N fertiliser ($) | PV ($) |
| 1 | 0.9346 | 3,920,837 | 3,664,415 | 3,830,492 | 3,579,977 |
| 2 | 0.8734 | | | | |
| 3 | 0.8163 | 3,920,837 | 3,200,580 | 3,830,492 | 3,126,830 |
| 4 | 0.7629 | | | | |
| 5 | 0.713 | 3,920,837 | 2,795,557 | 3,830,492 | 2,731,140 |
| 6 | 0.6663 | | | | |
| 7 | 0.6227 | 3,920,837 | 2,441,505 | 3,830,492 | 2,385,247 |
| Net Present Values | | | 12,102,057 (0) | | 11,823,195 (-278,861) |

The benefits and costs are calculated at an ERF project level, where ten farms growing the average cotton area, create a project total of 7,180ha of cotton, four times in seven years. As per the results in Table 3; an average emissions abatement of 477kg of $CO_2$e/ha occurs per cotton crop by applying optimum rates of N fertiliser rather than the common industry practice rate (method baseline) of 280kg/ha. The potential revenue from each crop grown within the project is calculated by the project area (7,180ha) times the abatement (0.477t $CO_2$e/ha) and ACCU price ($10/t/$CO_2$e), as shown in Table 6. The project revenue generates a total of 13,698 ACCUs from emissions abatement. For the life of the project the revenue amounts to $13,699 for each farmer achieving a project total of $136,981 at the baseline ACCU price of $10/t.

The costs to register and establish the 10-farm ERF project in this analysis would total $58,000. Audit costs are the largest cost line item in the project at $160,000. This results in a total project transaction cost of $218,000. Cost estimates from auditors and ERF projects proponents surveyed produced a similar range of results (Department of Agriculture 2013; Australian Carbon Traders 2014; Australian Farm Institute 2014; Endeavour Environmental 2014; Energetics 2014; GHD Australia 2014; Pangolin Associates 2014). The cost estimate used in Table 6 is a reflection of the complexity of establishing an historical baseline, sourcing documentation and verifying technical issues associated with emissions abatement. Each individual landholder is required to comply with method standards every second year of the project, incurring significant project costs, although auditing costs were anticipated to decline as the project progressed. In this initial analysis, the project costs are greater than project revenue creating a negative return using the baseline price of carbon $10/t/$CO_2$e and an emissions abatement per hectare of 477kg/ha per cotton crop.

If an individual land holder was only participating in the ERF to receive financial gain in the form of selling the ACCUs earned by the project, in the above ERF scenario the farm would lose $8,102 over the life of the project, which is equivalent to a 7 year project loss of $81,019. When considering the overall gross margin of the project this loss needs to be balanced with any co benefits gained by undertaking the project, including the reduction in fertiliser cost.

Those commercially operating existing ERF projects by comparison generate significantly more ACCUs, which provides more capacity to cover project costs. By definition, the Clean Energy Regulator considers a project with an annual abatement under 50,000 ACCUs a ‘small’ project (CER 2014). A number of registered projects participating in ERF methods for avoided emissions show much larger project scale in terms of total ACCUs issued; landfill (494,876), avoided deforestation (273,522), savannah burning (65,507), the destruction of methane from piggeries (19,345) (Climate Friendly 2015). This hypothetical cotton-N ERF project in this study generated a total of 13,698 ACCUs which is positioned well below all other active ERF projects. A much larger area under cotton would need to be aggregated in a project to provide commercial scale and any net benefits to growers. Any third party aggregation costs have not been factored into this study. Under the current auditing requirements of the Clean Energy Regulator, participating farmers need to comply with an individual audit potentially resulting in linear increase in project costs. To balance the project revenue and costs and generate project profit, extensive, large scale individual farms are needed to offset potential audit costs as indicated by those viable projects currently participating in the ERF.

A break-even analysis determined the point at which total revenues equal total costs. The analysis was conducted on the ERF project scenario for the area grown to cotton, an ACCU of carbon and emissions abatement levels. If all other variables were kept constant and the area of cotton grown within the project area increased to 11,426ha (from 7180ha) the project would break even. If these hectares were grown by fewer than 10 farms, then transaction costs would be reduced and the project would become profitable. With all other variables kept constant, a carbon price of $15.92 would result in the project breaking even. The final variable tested was emission abatement, if the abatement could be increased to 759.1kg/ha (from 477kg/ha) the ERF project would break even.

**Table 6. An estimate of revenue and costs associated with a hypothetical emissions abatement project under the Carbon Farming Initiative in the Lower Namoi Valley NSW**

| | | Per Landholder | 7 Year Project Total |
|---|---|---|---|
| Income | | | |
| 10 farms aggregated in to 7,180ha p.a (477kg CO2e avoided/ha 4 crops x $10/t CO2e) | | $13,699[1,2] | $136,981 |
| Cost Area | | | |
| General (administration, fees, setting up, structural cost areas) | Start up, initial accreditation and ERF Registration | $300[3] | $3,000 |
| | Initial Legal Advice | $2,500[3,4] | $25,000 |
| Reporting/auditing | Initial Verification @ $1500 day est. 2 days | $3,000[5] | $30,000 |
| Per Landholder range:$12,000-$40,000 | Statement preparation to accompany offset report (every 2nd year) | $16,000[4,5,6,7,8,9] | $160,000 |
| Total Cost | | $21,800 | $218,000 |
| Project Margin | | -$8,102 | -$81,019 |

[1.] Roth Rural (2014); [2.] John and Swoboda (2014); [3.] Australian Farm Institute (2014); [4.] Australian Carbon Traders (2014); [5.] Department of Agriculture (2013); [6.] Energetics (2014); [7]. Pangolin Associates (2014); [8]. Endeavour Environmental (2014); 9.GHD Australia (2014).

## Sensitivity Analysis

A sensitivity test helps to assess the effect of variability in key variables in the analysis on the robustness of the results (Sinden and Thampapillai 1995). In this instance the variables considered for sensitivity testing included the price of N, the ACCU price, the price of cotton lint, the sequestration rate and the discount rate.

The cost of N has a history of fluctuations, for example in 2008 the urea price was 80% higher than two years previously (ABARES 2013). Sensitivity testing found that a 100% increase in the N price (to $2.90/kg) reduced the optimal N input (where marginal cost equals marginal returns) from 200kg of N to 180kg of N per hectare and resulted in a greater spread between the optimal and common practice scenarios. At the N price of $2.90/kg, the emissions and the costs of the application of the optimal rate (180kg) are also reduced due to the reduction in applied fertiliser. The 100% increase in N price results in a net benefit of 6.03% ($316/ha) by applying the optimal rate instead of the industry standard rate, compared to 2.3% ($126/ha) benefit at the base N price of $1.45/kg.

With both a 25% and 50% increase in the N price ($1.813/kg and $2.175/kg respectively) the optimal rate of N remained at 200kg. This indicates that the price of N would have to increase significantly to affect the optimal application rate of N. When a 50% reduction in the price of N was considered, the optimal rate increased from 200kg/ha to 220kg/ha of N. Increases in the optimal rate of fertilisation (in respect to the price of N) are restricted by the N response curve. With the maximum yield achieved at a rate of 240kg/N, the optimal rate will remain one increment below (in this case 220kg/N), unless N was free, then the optimal rate would be the rate to achieve maximum yield.

The 2014-15 budget review (John and Swoboda 2014) noted the price for avoided $CO_2e$ emissions was from $5 to $18 in various State-based energy saving schemes. A range of ACCU prices were analysed in this study from $5/t carbon dioxide to $30/t. As the ACCU price increases, the net difference between the optimum application and the industry application also increases proportionally (see **Error! Reference source not found.**). For example, a 300% increase in an ACCU results in a 00% increase in both the per hectare social costs of each scenario and the difference between the optimal industry management social costs and those of the industry standard. However, due to the relatively small amounts of money involved, the 300% increase only slightly increases the performance of the optimal rate over standard industry practice from 1.3% to 2.1% of total costs.

**Table 7. Sensitivity test: price of carbon dioxide**

| | | Cost of Net Emissions per ha | | |
|---|---|---|---|---|
| | $/t $CO_2e$ | Optimum | Industry | Difference |
| Low Carbon Price (50%) | 5 | $2.12 | $4.50 | -2.39 |
| BASE | 10 | $4.24 | $9.01 | -4.77 |
| High Carbon Price (150%) | 15 | $6.35 | $13.51 | -7.16 |
| Very High Carbon Price (300%) | 30 | $12.71 | $27.03 | -14.32 |

**Table 8. Sensitivity test: soil carbon sequestration rate**

| | | Cost of Net Emissions per ha | | | |
|---|---|---|---|---|---|
| | kg $CO_2e$/ha | **Optimum** | **Δ base** | **Industry** | **Δ base** |
| **Zero Sequestration Rate** | 0 | $ 9.74 | 230% | $ 14.51 | 161% |
| **Low Sequestration Rate (50% base)** | 275 | $ 6.99 | 165% | $ 11.76 | 131% |
| **BASE** | 550 | $ 4.24 | 100% | $ 9.01 | 100% |
| **High Sequestration Rate (125% base)** | 687.5 | $ 2.86 | 68% | $ 7.63 | 85% |
| **Very High Sequestration Rate (150% base)** | 825 | $ 1.49 | 35% | $ 6.26 | 69% |

Enterprise gross margins for cotton production have been shown to be more sensitive to the price of cotton than the price of N (Powell and Scott 2011). Within this analysis it was found that with a low cotton price of $1.49/kg ($337/bale), (75% of the base price of $450/bale), the optimum application rate remained at 200kg/ha of N. Using a high cotton price of $2.475/kg ($526.5/bale, 25% higher than the base price) resulted in the optimal application rate of N increasing from 200kg/ha to 220kg/ha. Due to the use of a diminishing yield response curve, no matter how high the cotton price, there is no benefit to applying more than 220kg of N.

There has been a significant range of potential soil carbon sequestration rates identified in cotton industry research. Within this analysis the cost of net emissions for one hectare of cotton was $4.24 using a carbon sequestration rate of 550kg/$CO_2e$/ha. At a zero soil carbon sequestration rate the net emissions rises to 974kg or $9.74/ha, more than double the cost of the base rate. At a sequestration rate of 825kg/$CO_2$e/ha (the upper range of industry research and 150% of base rate), the cost of net emissions is reduced to $1.49/ha, less than half the cost of the base sequestration rate (Table 8).

The base discount rate used in the analysis is 7%, as per NSW Treasury guidelines (New South Wales Treasury 2007), sensitivity testing is conducted at 4 and 10%. Whilst the difference in NPV ranges from $310,094 to $252,471 respectively, this difference remains 2.3% of the total NPV between the optimum and common industry practice application rate.

It should be noted that the analysis is highly sensitive to the N response curve and a shift in the curve or change in shape of the curve would likely alter the results far more significantly than a change in any one of the variables tested in the sensitivity analysis. A shift or a change in the shape of the curve will occur with spatial or seasonal variability, soil types and variances in field agronomic history or when using results from other sources of N research.

## Conclusion

The analysis suggests the impact of placing a value on nitrous oxide emissions in cotton will not be significant within the individual enterprise budget.

The study does not assume that the N response curve from one location is representative for all cotton growing seasons or regions. Rather, two alternative N management strategies are considered per hectare and at a farm scale using a site specific N response curve. Starting soil nitrate levels, mineralisation and in-crop rainfall are highly variable both between seasons and cotton growing regions and the analysis does not account for the variation in resulting N response curves.

The common industry practice of applying additional N fertiliser (and assuming a linear relationship between N and yield) in this analysis has resulted in a practically unchanged yield (<0.1%) yield compared to what would have been achieved using the optimal rate of N but a 2.2% lower ($121/ha) net benefit (as per yield response curve). For a cotton area of 718ha, over a seven year period this results in a NPV of $278,861. Whilst a small per hectare cost can add up over the total crop, in the long term a potential yield reduction would cost the grower even more. The results illustrate the importance of understanding the N requirements for an individual crop and having confidence in calculating the optimal rate of N and applying that optimal rate.

The sensitivity analysis provides insight into which variables have the greatest effect on the results. As the price of N increases, the optimal N input (where marginal cost equals marginal returns) of N decreases from 200kg to 180kg, resulting in a greater spread between the two management scenarios. Due to the relatively low net emissions per hectare, a change in the price of carbon or the sequestration rate has a minimal effect on the change in total costs. In line with expectations, results also indicated as the price of cotton increased, so did the optimal N input (to a maximum of 220kg of N). The analysis shows that an increasing cost of N has a more pronounced effect on profitability than the ACCU price or soil carbon sequestration rates. However, these changes in costs are minor relative to the change in income from a potential yield increase (or decrease) if a different yield response curve was used.

An investigation of the viability for an avoided emissions project under a potential ERF method found significant economies of scale are required to offset high transaction and audit costs. A potential aggregation of ten farms in the lower Namoi resulted in a negative project return at the baseline ACCU price of $10 over the seven year project life. Competing projects in other industries which enjoy larger economies of scale and with the ability to mitigate higher volumes of $CO_2$e are more likely to be successful at auction with a lower ACCU price. Additionally, the complexity surrounding measuring historical and future improvements in N management in cotton at a farm scale continues to create challenges for participation in the ERF cotton N method.

In terms of the results providing value to growers in the cotton industry, despite some broad assumptions in the analysis, applying N at optimal levels over a large area through repeated crop cycles can offer savings when compared to an application above maximum yield requirements. Moreover, as illustrated by Table 2, the rate of return of the last unit of N diminishes rapidly as we approach optimal levels of product (as shown as a percentage in the right hand column). Coupled with an increasing emissions factor at higher N rates, farmers applying N fertiliser at optimal levels can reduce the carbon footprint of their cotton and achieve economic benefits at a crop enterprise level irrespective of ERF participation. Industry continues to review extension on optimal nitrogen management strategies to increase grower confidence in decision support systems and regional trial results.

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***Authors' Certification***

We, John Welsh, Janine Powell and Fiona Scott, the author(s) of this paper have undertaken the necessary steps for ethical clearance, where necessary, to conduct the research projects that produced the results presented in this paper.

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