ESTIMATING ECONOMIC IMPACTS OF CONTROLLED RELEASE FERTILISERS IN SUGARCANE SYSTEMS: AN ECONOMIC RISK CASE STUDY ANALYSIS

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Abstract

AN ECONOMIC RISK framework for assessing economic impacts of adopting controlled release nitrogen fertilisers (CRFs) is presented, taking into account variable climatic and economic conditions. Specifically, economic impacts of switching from urea to various CRF products are assessed by comparing: 1) average economic returns, 2) economic returns in good years, represented by highest returns with a cumulative probability ($CVaR0_{0.95}$), and 3) big losses in bad years, represented by lowest returns with a cumulative probability ($CVaR_{0.05}$) across alternative fertilisers. The risk framework is underpinned by a modelling approach that integrates agricultural production system simulation modelling (APSIM), probability theory, Monte Carlo simulation, financial-risk analysis techniques and threshold analysis. The analysis is carried out in a specific case study in the wet tropics, Queensland for one soil type and sugarcane management system as a first analysis to identify economic issues that may arise with adoption of CRFs. Results show that yield responses to fertiliser inputs are highly variable with variable climate. The potential for profitable adoption of CRFs is largely influenced by the relative cost of CRFs compared with the cost of urea. At equal cost, CRFs would likely realise higher average net returns and higher returns in both good and bad years than conventional fertilisers thereby improving the overall economic viability of agricultural enterprises. If, however, the cost of CRF was at least twice the cost of conventional fertilisers, adoption of CRFs would likely result in reduced average net returns and lower returns in bad years, thereby increasing the downside economic risk. A blend of CRFs and urea performs better than urea and CRFs in good years at N rates between 60 and 150 kg N/ha, indicating that additional yield gains from switching to a blend could offset additional costs, assuming CRFs cost twice as much as urea. At twice the cost of urea, profitable adoption of CRFs is only achievable in a scenario where half as much CRFs as urea are applied to get the same yield. The likelihood of this occurring is low under our specific case study climate, soil and management system scenario, but would likely be higher in high yield climate, soil and management system case study scenarios. Overall, net returns from sugarcane are sensitive to variable sugar prices, yields, and harvesting and fertiliser costs. Changes in a number of factors could make adoption of CRFs more economically and environmentally attractive. These include: 1) consistent growth in the cost of conventional fertilisers, 2) steady technological advances in the performance and efficiency of CRFs, 3) reduction in CRF production costs and future costs for CRFs and 4) increasing demand for CRFs as a possible solution for mitigating N loss to sensitive coastal and marine ecosystems. The next step is to extend this analysis to different regions with different climate, soil types, and management systems to identify combinations of factors under which profitable adoption of CRFs is likely.

Introduction

The rate of inflation in agricultural input costs is typically not matched by a similar rate of growth in commodity prices. This decline in real incomes can be offset by seeking productivity gains, typically through adoption of new technologies including high yielding crop varieties and more efficient fertiliser management strategies.

Controlled release nitrogen fertilisers (CRFs) may present an opportunity to increase profits by enabling reductions in the quantity (and therefore cost) of fertiliser applied, or increasing yields without a corresponding increase in fertiliser costs.

The potential for beneficial adoption of CRFs as an alternative to conventional fertilisers will depend on whether these efficiency gains would result in benefits that outweigh the higher per unit cost of CRFs.

CRFs are currently more expensive than conventional fertilisers. Lammel (2005) estimated that CRFs cost between 1.3 and 1.6 times more than conventional urea. Trenkel (2010) found that CRFs cost between four and six times the cost of conventional fertilisers. Shaviv (2001) and Chen *et al*. (2008) suggested that controlled release fertilisers can cost up to10 times the cost of conventional fertilisers.

The main objective of this economic risk analysis is to assess the impact of adopting CRFs on profitability of the sugarcane enterprise using a case study in the Wet Tropics, Queensland for one soil type and one management system as a first analysis of economic issues that may arise with switching to CRFs.

Specifically, we assess whether or not, to what extent, and under what circumstances would switching from conventional fertilisers to CRFs increase or decrease expected net returns and variability in economic returns. Another objective is to understand important sources of economic risk to profitable adoption of CRFs and to assess the cost effectiveness of using CRFs as a strategy for mitigating economic risk.

A number of economic studies have acknowledged the importance of uncertain yield responses to nitrogen (N) and how this uncertainty can influence the economic impact of various fertiliser management activities (Brennan *et al*., 2007; Monjardinho *et al*., 2013; Oliver and Roberston, 2009; Sadras, 2002; Yu *et al*., 2008).

Further, international studies provide contrasting conclusions on the economic impact of switching from conventional fertilisers to CRFs (Arrobas *et al*., 2011; Farmaha and Sims 2013; Khakbazan *et al*., 2013).

We considered multiple sources of uncertainty, including the response of yields to changes in N application rates and variable sugar prices and fertiliser costs to answer the question: under what economic conditions would adoption of CRFs in sugarcane production systems be profitable?

In what follows, we:

1) Describe the implementation data and methods for a Tully region case study in the wet tropics;

2) Provide results of the economic impact assessment of adopting CRFs, including expected changes in yield, net returns and variability in returns; and

3) Discuss relevance of our study and implication of our results.

Our assessment framework is underpinned by a modelling approach that integrates agricultural production system simulation modelling (APSIM), probability theory, Monte Carlo simulation, and financial-risk analysis techniques.

We utilise a finance technique based on the concept of conditional value at risk ($CVaR$) to estimate the weighted average of expected economic returns in good years when yield is high and N loss low ($CVaR_{0.95}$), represented by highest returns with a cumulative probability of five percent and in bad years when yield is low and N loss high, represented by lowest returns with a cumulative probability of five percent ($CVaR_{0.05}$), following Kandulu *et al*. (2012).

Methods

In this section, we describe:

1) The conceptual model for estimating net annual returns under various N fertiliser products at various application rates,

2) The yield simulation model for estimating yield responses under various N fertilisers products at various N application rates,

3) Calculations used to estimate net returns, including data values used and their sources; and

4) How variability was quantified to take economic risk and uncertainty into account.

The conceptual economic model for estimating net economic returns

The conceptual economic model for estimating annual net returns, NR_i, to sugarcane under various N application rates, i, was based on a gross margin analysis of typical variable farm input and operations in sugarcane production in the Wet Tropics region. Net returns were calculated as the difference between farm revenues and the sum of fertiliser costs and harvesting costs, following Di Bella *et al.* (2014).

These costs were identified as the relevant variable farm input and operations costs that would vary with different N fertiliser products at various N application rates. Revenues were calculated using simulated yield responses under various fertiliser products at various application rates and sugar price. Figure 1 illustrates the conceptual model, key revenue and cost components and variables used to estimate net returns under the three different N application strategies.

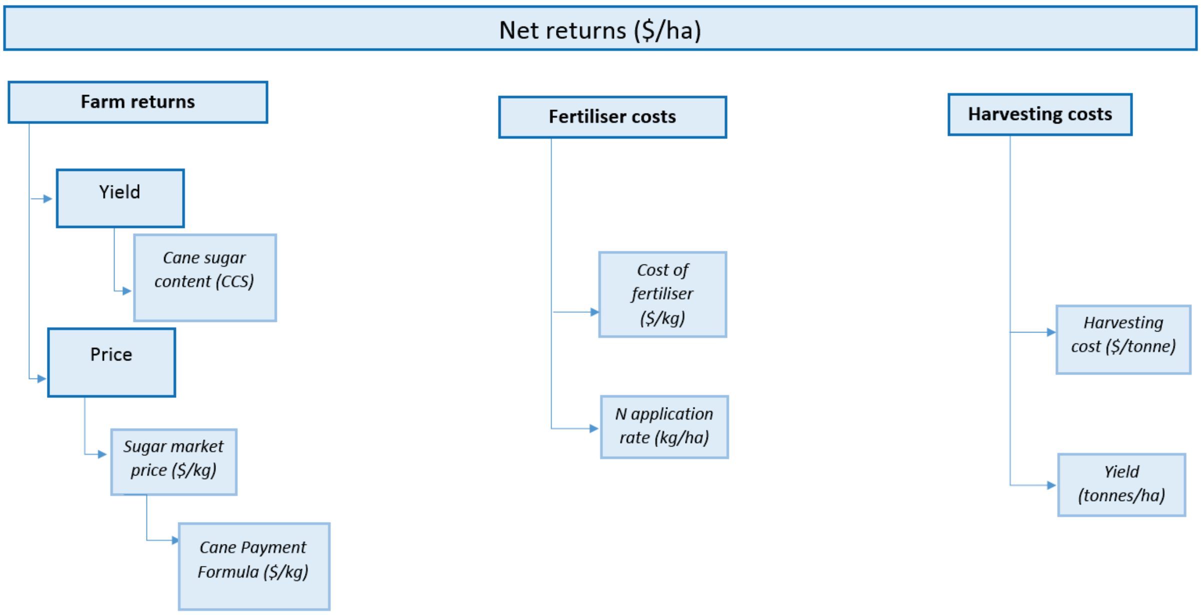

Fig. 1—Organisational structure used to estimate net revenues and costs under various N fertiliser products at various application rates.

The conceptual model we developed for estimating net returns has three distinct components: 1) a farm revenues component consisting of yield and price; 2) a fertiliser cost model dependent on N application rate and the market price for urea, the most common N fertiliser used in the case study region, and for various CRF products; and 3) a harvesting cost estimator constituting per hectare cost charges by contractors in the Wet Tropics region, and dependent on expected yield per hectare.

Modelling crop yields

Agricultural Production Simulator for sugarcane (APSIM-Sugarcane) was used to simulate annual sugarcane yields under six N rates between 30 kg N/ha and 180 kg N/ha in increments of

30 kg N/ha over a period of 108 years between 1902 and 2010 (Thorburn *et al*., 2011; Verburg *et al.*, these proceedings). Specifically, the sugarcane growth simulation model simulated sugarcane yields considering ground cover, soil-water balance, nitrogen uptake, taking into account N losses and N_2O emissions and how they vary with climate, and the amount of N available to the plant to use. Soil N and water conditions were re-set after every harvest to avoid carry-over effects that could differ between the fertiliser products.

Year to year differences in yield responses to N were modeled for a scenario involving one local soil type for 12-month ratoon crops under early planting (May 1). For full technical details on APSIM-sugarcane and other applications of this model, readers are referred to Thorburn *et al.* (2011) and Verburg *et al.* (these proceedings).

Estimating net economic returns

A description of calculations of key components of our model for estimating net returns, including farm revenues, fertiliser costs, harvesting costs is provided in this section using mathematical equations. Parameter definitions, values, units and sources are summarised in Table 1.

Net returns under various N application rates, *i*, were calculated as:

$$NR_i = (Y_i \times CPF) - (C_N \times N_i) - (C_H \times Y_i) \qquad [1]$$

where *CPF* is the cane payment formula used by Queensland sugar industry to allocate net income from sugar sales between farmers and millers calculated as:

$$CPF_i = \left(P_S \times 0.009 \times (CCS_i - 4)\right) + 0.662 \qquad [2]$$

Yi is APSIM simulated yield in tonnes of cane per hectare.

Quantifying variability

We quantified climate induced variability in yield responses to various N fertiliser products at various N rates by fitting probability density functions to frequency distributions of simulated annual yields over 108 years using @RISK software.

Variability in economic factors including price of sugar, and N cost was also quantified by fitting probability density functions to time-series data on global sugar and urea prices over a period of 20 years from 1995 to 2015 using data from the World Bank data.
(http://www.indexmundi.com/commodities/?commodity=sugar&months=360&currency=aud).

We calculated 1 000 probable net return values from random values sampled from input parameter value ranges and generated frequency distributions for NR_i.

Further, we applied the financial concept of conditional value at risk (*CVaR*) to calculate the average expected return of the highest net returns in good years, $CVaR_{0.95}$ and lowest expected returns in bad years, $CVaR_{0.05}$.

Table 1—Notation descriptions and values for NR_i calculations (see Equations (1) and (2)).

Notation	Description	Unit	Value (range)	Source(s)
C_U	Cost of urea fertiliser	$/tonne	103–570	Data from the World Bank (http://www.indexmundi.com/commodities/?commodity=sugar&months=360&currency=aud)
C_H	Harvesting cost paid to contractors	$/tonne	6–7.5	(Mallawaarachchi and Quiggin, 2001; Di Bella *et al.*, 2014)
P_S	Market price of sugar	($/tonne)	213–498	Data from the World Bank (http://www.indexmundi.com/commodities/?commodity=sugar&months=360&currency=aud)
CCS	Commercial Cane Sugar, a measure of recoverable sugar in the cane.	Percentage	10–15	(FAO, 2015)

Net returns for four different N fertiliser products were estimated including urea and three different CRF products:

1) A product of CRF with a linear N release pattern;

2) A blend of urea and a product of CRF with a linear N release pattern in equal proportions; and

3) CRF with a sigmoidal N release pattern that synchronised better with crop N uptake.

We refer the reader to Verburg *et al* (these proceedings) for a detailed description of the CRF products considered in this analysis.

Economic returns were calculated under two urea:CRF cost ratios, including a scenario that assumed a 1:1 cost ratio and another scenario that assumed a 1:2 cost-ratio.

We assessed the relative contribution of each uncertain parameter in equations (1) and (2) to variability in estimates of net returns using Monte Carlo simulation to calculate 1 000 random values of net returns. The sensitivity of net return estimates to variability in each uncertain parameter was analysed by measuring the effect of varying each parameter while holding all other parameters at their median values, following Kandulu and Connor (2016).

Results

This section is structured such that results of climate-induced variability in yield responses to various N fertilisers at various application rates are presented first. Next, we present results on estimated net economic returns for four fertiliser products including conventional urea, a blend of urea and CRF with a linear N release pattern in equal proportions, CRF with a linear N release pattern and CRF with a sigmoidal N release pattern that synchronised better with crop N uptake.

Finally we provide results of a sensitivity analysis quantifying the importance of various sources of economic risk and variability are provided.

Yield variability

Overall, yields increased with increasing N rates (Figure 2). Yields plateau at rates above 150 kg N/ha. In addition, yields were highly variable under different N fertiliser products and at various N rates and assumed a normal distribution approximation (Figure 3).

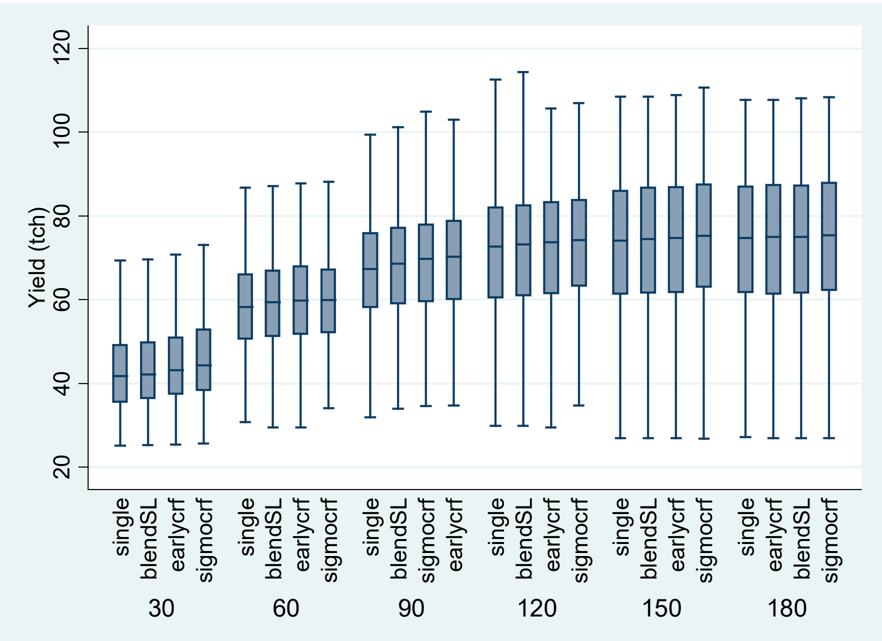

Fig. 2—Variability in simulated cane yields in tonnes of cane per hectare (tch) for various N fertiliser products at various rates of application. Box plots show 25th, 50th and 75th percentiles and the ends of whiskers show most extreme values calculated as Q_3+1.5(Q_3–Q_1) and Q_1–1.5*(Q_3–Q_1) where Q_1 is the 25th percentile and Q_3 is the 75th percentile.

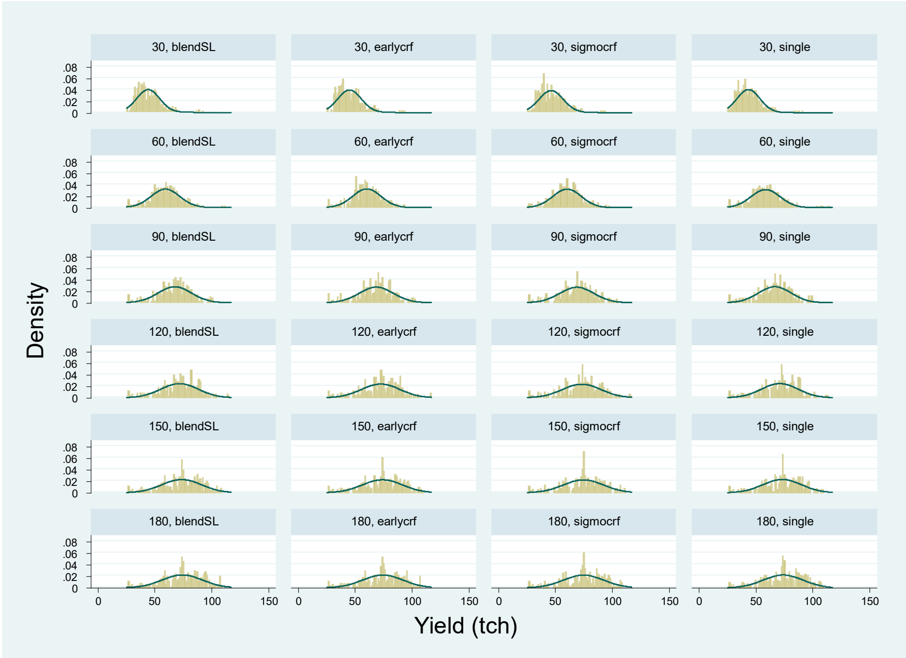

Fig. 3—Frequency distribution of simulated cane yields under various N fertiliser products at various rates of application.

Net economic returns

N rates at which peak net return are realised are lowest in bad years ($CVaR_{0.05}$), higher under average conditions (*NR*) and highest in good years ($CVaR_{0.95}$), indicating that higher rates of N will be of most benefit when under favorable climate conditions, high sugar prices, and low N costs. In bad years, high fertiliser costs are less likely to be offset by returns under low yield due to unfavorable climate and low sugar prices (Figures 4 and 5).

Overall, CRFs realised higher average net economic returns than urea assuming the same cost at N rates between 30 and 180 kg N/ha (Figure 4*a*).

Yield gains from increasing N rates from 30 to 90 kg N/ha more than offset additional N cost resulting in increasing net economic returns (Figure 4*a*). Diminishing additional net returns can be observed between 90 and 120 kg N/ha. Decreasing net returns indicate higher additional N costs than additional net returns from yield gains at N rates higher than 120 kg N/ha. Decreasing additional net returns occur at 120 kg N/ha for CRF fertilisers and at 150 kg N/ha for urea indicating that CRFs have a lower economically optimum N rate than urea.

Overall, CRFs realise higher net economic returns than urea in good years, representing five percentile of the highest attainable returns under favorable climate and economic conditions assumed at the same cost as urea (Figure 4*b*). This indicates that switching from urea to CRFs has the potential to increase net returns in good years at N rates between 30and 180 kg N/ha.

CRFs also perform better in bad years, representing five percentile of the lowest attainable returns under unfavorable climate and economic conditions assumed at the same cost as urea at N rates between 30 and 180 kg N/ha (Figure 4*c*). This indicates that CRFs could reduce the downside risk of incurring big losses in bad years. Further, in bad years, urea realises its optimal net return value at 60 kg N/ha, a net return value realised at 30 kg N/ha under the CRF with a sigmoidal release pattern, *sigmoCRF* (Figure 4*c*).

This indicates that CRFs may present an opportunity to increase profits by enabling reductions in the quantity (and therefore cost) of fertiliser applied, or maintaining yield levels at lower N application rates in bad years.

Overall, urea realised higher net economic returns than CRFs assuming 1:2 cost-ratio (Figure 5*a*).

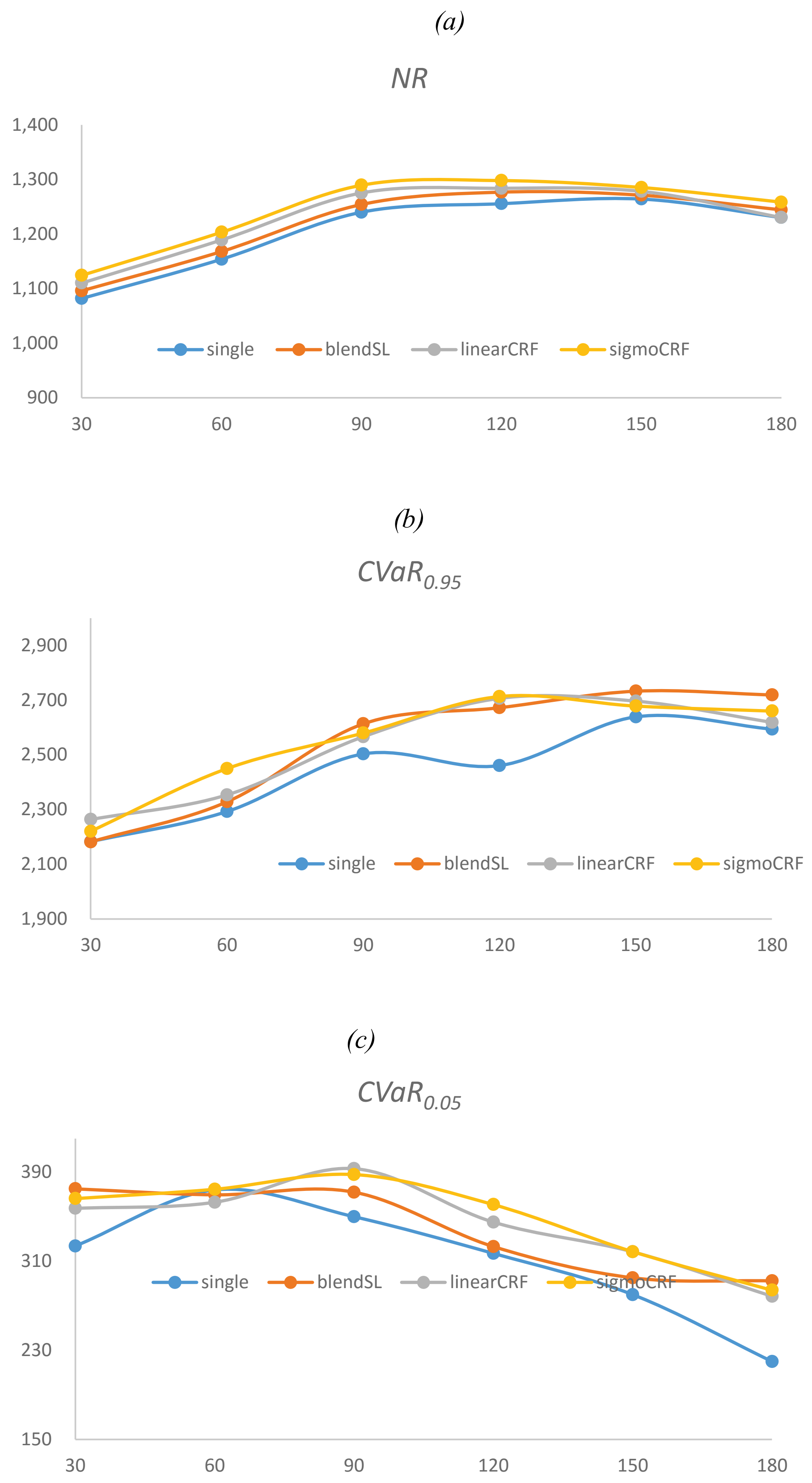

Fig. 4—Net average economic returns (*a*), $CVAR_{0.95}$ (*b*) and $CVAR_{0.05}$ (*c*) assuming the same cost for urea and CRFs under different N fertiliser products at various N rates.

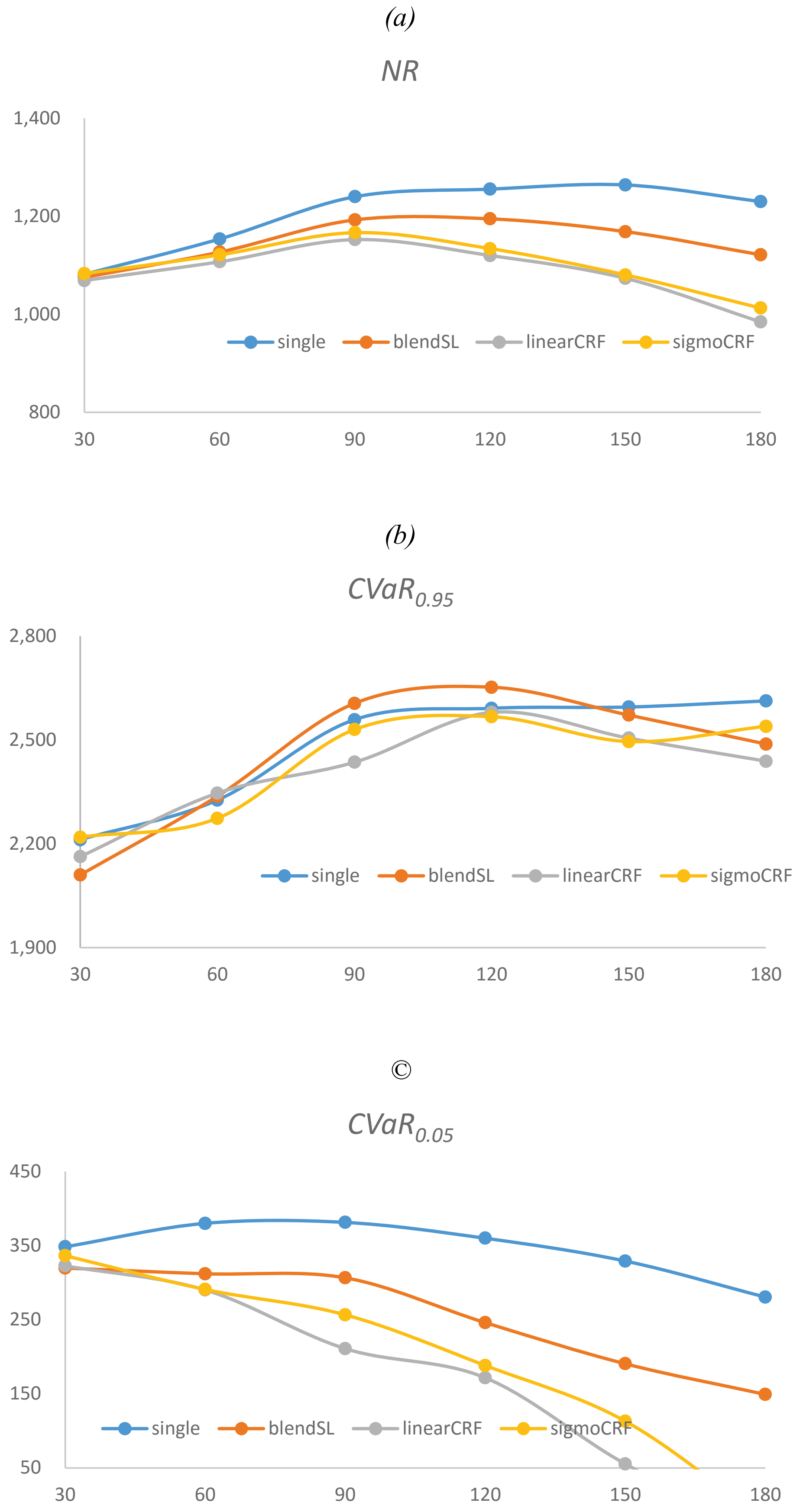

Fig. 5—Net average economic returns (*a*), $CVAR_{0.95}$ (*b*) and $CVAR_{0.05}$ (*c*) assuming a 1:2 cost-ratio for urea and CRFs under different fertiliser products at various N rates.

Under a scenario where CRFs cost twice as much as urea, urea outperforms CRFs in terms of average net returns and expected returns in both good and bad years. Decreasing average net returns to additional N occur at 90 kg N/ha for CRFs, at 120 kg N/ha for a blend of CRF and urea and at 150 kg N/ha for urea, indicating that higher additional N costs more than offset additional net returns from yield gains at lower N rates for CRFs than for urea, largely due to a large difference in cost between CRFs and urea, with CRFs assumed at twice the cost of urea (Figure 5*a*).

Overall, urea realises higher net economic returns than CRFs in good years representing five percentile of the highest attainable returns under favorable climate and economic conditions assumed at the same cost as urea (Figure 5*b*).

This indicates that additional yield gains are not high enough to offset additional N costs of switching from urea to CRFs even in good years. A blend of CRFs and urea performs better than urea and CRFs in good years at N rates between 60 and 150 kg N/ha, indicating that additional yield gains from switching to a blend could offset additional costs assuming CRFs cost twice as much as urea.

Urea performs better than CRFs in bad years at N rates between 30 and 180 kg N/ha (Figure 5*c*). This indicates that the high cost of CRFs make them the least profitable choice of N fertiliser in bad years and could increase the downside risk of incurring big losses in bad years.

Comparing Figures 4 and 5, it can be shown that, assuming CRFs at twice the cost of urea, only in a scenario where applying half as much CRFs as urea and getting the same yield would make it worthwhile to switch from urea to CRFs. Under our specific case study climate, soil and management system scenario the likelihood of this occurring is low at 3 in 100 years (Verburg et al, In this issue).

Sensitivity analysis results

Net return estimates were highly sensitive to variability in sugar prices, yield response to N, estimates of cane sugar content and harvesting and fertiliser costs, as illustrated using estimates of net returns under 90 kg N/ha with environmental costs (Figure 6).

Uncertain sugar prices contributed most significantly to variability in net returns with estimates of net returns ranging between \$483 and \$2 416/ha. Climate-induced variability in yield responses to N contributed substantially to variability in estimates of net returns with net return estimates attributable to varying yields varying between \$593 and \$2 005/ha.

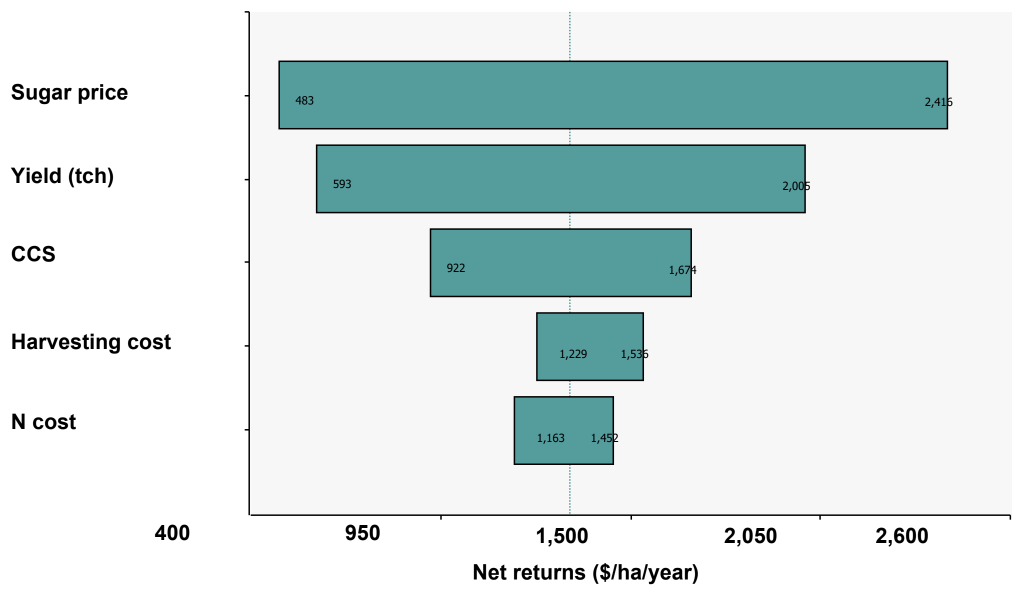

Fig. 6—A tornado chart showing results on measures of sensitivity of net return estimates to variability in each sensitive uncertain parameter holding all other uncertain parameters at their median values for 90 kg N/ha.

Discussion

Use of controlled nitrogen release fertilisers has been considered as a possible long term solution for improving economic and environmental outcomes. However, studies provide contrasting conclusions on the economics of switching to controlled release fertilisers (Arrobas *et al*., 2011; Farmaha and Sims, 2013; Khakbazan *et al*., 2013; Di Bella *et al*., 2014).

Our findings are consistent with key observations from our review of literature on use of CRFs including that:

1) CRFs do not provide a consistent economic advantage over conventional fertilisers across all crop types, locations, and climate conditions,

2) The difference in the cost of CRFs and conventional fertilisers is an important determinant of profitable adoption of CRFs,

3) Economic benefits of CRFs vary with variable climatic conditions, and

4) The market cane price may be important in determining profitable adoption of CRFs,

5) It may be more profitable to apply CRFs in combination with conventional fertilisers under certain conditions, and

6) CRFs may present an opportunity to increase profits by enabling reductions in the quantity (and therefore cost) of fertiliser applied, or maintaining yield levels at lower N application rates.

A number of contextual factors emphasise the relevance of our study. The Australian government is currently developing water quality targets and policies for managing the amount of N discharged to the Great Barrier Reef to restore the health of ecosystems in the reef.

Our assessment is relevant and provides results that can be useful for informing policy decisions, but would require augmentation of environmental and social impact assessments. Omitting environmental impacts underestimates the overall benefit of CRFs, which typically have a higher N utilisation rates and lower N losses than urea.

This study was carried out for one region, soil type and management system as a first analysis of economic issues that may arise from switching to CRFs. The next step is to extend this analysis to different regions with different climate, soil types, and management systems to identify combinations of climate, soil-types and management systems under which profitable adoption of CRFs is likely.

Climates, soils and management systems with higher yield potential could be more suitable for profitable CRF adoption, in particular under high cost differences between CRFs and urea. Further, net returns are highly variable from year to year and thus better prediction and forecasting of which years beneficial adoption is likely would reduce the economic risk of adoption of CRFs.

Conclusions

The potential for profitable adoption of CRFs is largely influenced by the relative cost of CRFs compared with the cost of conventional fertilisers. Yield responses to fertiliser inputs are highly variable with variable climate.

At equal cost, CRFs would likely realise higher average net returns and higher returns in both good and bad years than conventional fertilisers thereby improving the overall economic viability of agricultural enterprises.

At twice the cost of conventional fertilisers or more, adoption of CRFs applied at the same rate of N as conventional urea would likely result in reduced average net returns and lower returns in both good and bad years, thereby threating the economic viability of agricultural enterprises.

CRFs may present an opportunity to increase profits by enabling reductions in the quantity (and therefore cost) of fertiliser applied, or maintaining yield levels at lower N application rates.

At twice the cost of urea, profitable adoption of CRFs is only achievable in a scenario where half as much CRFs as urea are applied to get the same yield.

The likelihood of this occurring is low under our specific case study climate, soil and management system scenario, but would likely be higher in high yield climate, soil and management system case study scenarios. Further, applying CRFs in combination with urea could realise higher net returns than urea in good years under certain conditions.

Overall, net returns from sugarcane are sensitive to variable sugar prices, yields, and harvesting and fertiliser costs. Consistent growth in the cost of conventional fertilisers, steady technological advances in the performance and efficiency of CRFs, reduction in CRF production costs and future costs for CRFs and increasing demand for CRFs as a possible solution for mitigating N loss to sensitive coastal and marine ecosystems could make adoption of CRFs more economically and environmentally attractive.

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