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Profit based measures to capture, evaluate and prioritise genetic improvement of water use efficiency and nitrogen use efficiency in sugarcane.

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ABACUSBIO PTY LIMITED

BRIDGING SCIENCE & BUSINESS

PROFIT-BASED MEASURES TO CAPTURE, EVALUATE AND PRIORITISE GENETIC IMPROVEMENT OF WATER USE EFFICIENCY AND NITROGEN USE EFFICIENCY IN SUGARCANE

Report prepared for

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February 2016

DISCLAIMER

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Executive Summary

Sugar Research Australia (SRA) contracted AbacusBio Pty Ltd with IDA Economics Pty Ltd to undertake a systems modelling project to estimate the relative economic value of two potential new performance traits of sugarcane - water use efficiency (WUE) and/or nitrogen use efficiency (NUE) - in different regions and production systems in the Australian industry. The need is for a protocol to guide future investment priorities in multi-trait selection for germplasm development.

There are increasing concerns in sugar production in respect of two key inputs, water and nitrogen. Both environmental and input cost considerations are relevant. The evaluation and selection of cultivars and other approaches to genetic improvement offer potential means to help manage these issues.

SRA investment in genetic improvement of sugarcane comprises two main approaches:

- first, a comprehensive selection and breeding program based on a resource of parental clones, and
- second, through the introduction of new traits (or more extreme variation within those traits) through introgression using other sources of genetic material (cultivars or other sources of sugar germplasm or other sub-species/genera).

Multi-trait selection utilises SRA selection indexes to compare individual clones.

Nitrogen Use Efficiency

The strong positive relationship between yield and the rate of nitrogen application is a powerful disincentive to sugarcane growers to reduce their applications of N. The marginal value (profitability) of increased yield is generally far greater than the cost of additional N, such that additional N represents an insurance policy in the event of a good growing season. However, the reality is that surplus N is becoming an increasing concern due to pollution of waterways and, in particular, damage to the Great Barrier Reef ecosystem. At present there is a requirement for the industry to reduce N in leachate/run-off in sensitive areas but there is the potential for more severe N restrictions to become a key issue in respect of sugarcane growers requiring a 'social licence' to continue to operate. Given the complexities around pricing of N to define the investment value of approaches to reduce N, we have used the current price on N and then assessed the value of savings at an industry level. Within the report we have also considered other approaches.

There are three aspects considered here: the *scale of reduction in nitrogen application that is required*, the *potential value to the industry* from improved NUE (return on investment), and *the credibility of the approach* (including the rate at which a change could be introduced).

The estimated reduction in N applied that is required is about 50 to 65 kg per annum

We have developed an empirical model of nitrogen dynamics in sugarcane, where N applied and yields are expressed as the total over a 3-year cycle from planting (plant, first and second ratoons). This model has been applied to estimate the likely scale of the required reduction in N applications to reduce N losses off-farm. Given this analysis (e.g. Figure 2 and Table 7), we have taken the view that a per hectare reduction of 150 to 200 kg over the three crops will be required to maintain a *licence to operate* in vulnerable areas – this is equivalent about 50 to 65 kg per annum average across the whole crop.

However, applying this general case would reduce yield from about 95% of the maximum to around 80%. Given this premise, we consider the central question as to *how the industry might be able to overcome this potential yield loss* through improved nitrogen use efficiency (NUE). Breeding and management (agronomic practices) are the broad options and a combination will be required. Therefore we have taken the approach of:

a) developing an economic model, and then

b) asking the question, '*what would we have to believe to deliver either or both of these approaches (breeding and management) as viable options from an economic perspective?*', and then

c) considering potential methodologies for implementation of a breeding approach.

If we could make a difference, what would it be worth to the industry in 2036?

The model recognises the critical importance of yield in determining profitability. The impacts were estimated using gross margin analysis (overall profitability) assessing the return on investment as the value of nitrogen cost savings, without any change in yield. A sensitivity analysis of the economic value to a change in the operating environment (the regulatory environment or community pressures to reduce N inputs or limit sugarcane yield in environmentally-sensitive regions) and to input costs is included.

Table S1 presents a summary of the three scenarios where we have looked at the options and asked what would be the direct value to the industry of *savings in N cost only* if growers could save 60 kg N per year (e.g. the baseline through breeding with new varieties first released in 2020 with analysis through to 2036) compared with two other scenarios that combine breeding and management approaches. In other words, is there an economic case for investment in NUE breeding based only on the N savings (regardless of the gains from maintaining a licence to operate)?

Table S1. Summary of potential benefits from improved NUE through approaches that generate an annual average saving of 60 kg N per ha in 2036 (100% adoption, 100% likelihood of R&D success,)

	On-farm (industry) benefits in 2036 (2015 prices, undiscounted values)	Off farm (environmental) benefits
Improved NUE resulting from breeding compared to Baseline/ otherwise case as below		
Baseline (current practices and regulations with new investment in NUE breeding)	N cost savings: estimated at $45 mn in the 2036 year across all growing areas; 54% ($25 mn) is in the Wet Tropics & Burdekin; some expansion in cane production could be expected as profitability has increased but this has not been estimated	Reduced N losses through leaching generates an environmental benefit; the significant off-farm benefit has been noted but not estimated
Scenario 1 (continued improvements in NUE on-farm, plus NUE breeding)	N cost savings from new cultivars are as above, but with ongoing improvement in NUE through improved on-farm practices. If 75% of the 60 kg N per hectare in annual savings arises from management changes, only 25% would be required to come from additional breeding investment. The estimated net benefit of the breeding in 2036 would then be $11.2 mn per annum across all regions, with 54% ($6.2 mn) in the Wet Tropics and Burdekin. But, if breeding can achieve 60kg/ha N saving (i.e. baseline above) and management changes are similar, the total annual N saving (120kg/ha)is then worth about $90 mn in 2036 across all growing areas, with 54% ($49 mn) in the Wet Tropics and Burdekin	Reduced N losses at EOC through leaching generate an environmental benefit
Scenario 2 (Baseline, with additional regulations restricting sugar cane production)	Baseline comparison plus avoided losses: production & profitability of sugarcane is maintained in all regions without additional regulations (whereas it would have been reduced by say 33% in the Wet Tropics and Burdekin without breeding); the estimate of avoided loss in grower profitability (gross margin) is $49 mn in 2036 and the total benefit is $74 mn ($25 mn + $49 mn); the avoided loss in millers' income and the impact on net regional economy were not estimated.	There is no net environmental benefit as regulation is assumed to deliver off-farm benefits (environmental) that are equivalent to those from the breeding program (although there might be a timing issue, depending upon when regulations are applied)

If we could make a difference, how can we assess the value to the industry?

As the next stage we consider the economics in another way that is often regarded as more appropriate when the outcome is considered uncertain. We ask *what would we have to believe to justify the investment in breeding for NUE?* The analysis is presented in Table S2. At a hurdle rate of 20 to 40%

based on the total cost savings to growers in the Wet Tropics and Burdekin, a success factor (adoption x probability of success) of 10 to 30% is required[1].

Table S2. Estimates of the NPV of investment taking the approach of *what would we have to believe to justify an investment in breeding* to meet a required hurdle rate or internal rate of return on the investment

Value proposition	Internal rate of return (based on N at $2 per kg applied)	20%	42%	54%	75%
	Success factor: Adoption level x probability of success	0.4 * 0.25	0.6 * 0.5	1.0 * 0.5	1.0 * 1.0
Success factor: Adoption x probability of success		10%	30%	50%	100%
Estimated gross value to industry (PV, 5% discount rate)		$13	$41	$69	$138
Estimated net value to industry (NPV,5% discount rate less costs of $6 mn)		$7 mn	$35 mn	$63 mn	$132 mn

Is the scale of reduction in N use credible?

Given the responsiveness of sugarcane to N (for the 'general case' as per the empirical model), it is unlikely that there will be an economic argument at the individual farm level to reduce N applications unless growers are convinced of the value of new varieties through N cost savings without yield loss.

Thus the scale of the potential reduction in N is critical and therefore the model has been applied at the variety level using examples of cultivars from a recent SRA-funded trial[2]. We propose that the type of variety that is required is one with good yield at lower applications of N, but which is relatively insensitive to additional N applied during the early, growth response phase.

The underlying hypothesis is that such plants utilise soil N very effectively and, that as a result, the leaching of N will be reduced. As an example, we developed a *varietal variation concept* and modelled three varieties with a range of NUE parameters based on varieties in the SRA-funded University of Queensland research trials, and while investigation of this hypothesis will require further research, initial interpretation of the trials suggests that the scale of change required is credible.

How would NUE be included in a breeding program?

The rationale behind incorporation of a nitrogen utilisation trait within the selection index is to reduce N use in the growing of sugarcane to reduce leaching of N.

There are two approaches to incorporation of NUE within the selection index:

- direct incorporation as another trait (the cost of N is increased in order to reduce the economic weight (EW) for Total Cane Harvested (TCH)), or
- mediation through the impact on yield.

The latter approach recognises the importance of N in driving yield and is preferred as it is much more flexible and the impact of the inclusion of NUE can be defined clearly. It also treats the impact of N in much the same way as disease traits are currently managed within the SRA genetic evaluation system. In essence, this is a form of tandem selection where breeding values are derived using the basic index (being made up of the key drivers of profitability) and then the susceptibility to a particular disease in terms of its impact on yield is incorporated. In this context, the impact of N use is defined through its effect on TCH only in terms of the potential loss of yield.

There are also other potential complementary approaches: one is being used (the introduction of related genetic material such as *Erianthus*) and another is being trialled internationally (genetic modification).

[1] Holding other factors constant, savings of 60 kg N per hectare by 2036 at $2 per kg N (2016 prices and 5% discount rate, Figure 5 and Table 22) in the Burdekin and the Wet Tropics (206,000 ha harvested)

[2] Robinson N *et al* 2009. SaveN Cane: Developing selection tools for N-efficient sugarcane (SRA Project Code 2009/044)

Conclusion in respect of breeding for improved NUE

There is a clear case to investigate the genetic variation in NUE in sugarcane on which any selection and breeding program depends. The model developed for this report provides some leads and proposes an approach. In this respect there may already be considerable variability present within the range of commercial varieties and within the clonal nurseries (including introgressed material).

Water Use Efficiency

There are four aspects in considering WUE namely: *the scale of the issue, assessment of the potential value of a solution, the potential for a breeding solution* and *the rate at which a material change could be introduced*.

Scale: What would complete correction of the current water deficit be worth to the industry?

The basic issue is to estimate the net economic loss or gain in value if water stress could be fully alleviated in cane-growing areas. The potential gains have been estimated previously[3] where water stress factors were based on the principle that plant growth was directly related to water supply and other factors were non-limiting. The same methodology has been applied here and the estimated yield foregone is about 15% (0.65 mn tonne sugar). The financial gain to industry (millers and growers) from alleviating water stress is presented as the gross margin (gross income less variable production costs) for growers and the gross profit for millers (Table S3)[4]. The annual value of correcting this 'water deficit' is estimated at $108 mn.

Table S3. Estimated annual value of gross profit forgone (millers) and gross margin forgone (growers) due to water stress by sub-region (Budget data 2013-14 costs to growers is approximately $23 per tonne for variable costs including N and irrigation as appropriate per tonne sugar)

Region	Estimated yield foregone (14% CCS)		Gross margins (GM) or Gross Profit (GP)/t sugar		Value of yield increase ($mn)	
	Yield %	Tonne sugar	Miller GP	Grower GM	Miller GP	Grower GM
Northern - Herbert	12.7%	0.167 mn	$71	$97	$12.0	$16.4
Burdekin	4.6%	0.053 mn	$65	$108	$3.4	$5.7
Central	23.3%	0.268 mn	$66	$101	$17.8	$26.9
Southern	22.2%	0.164 mn	$67	$92	$11.0	$15.0
Total	**15.3%**	**0.65 mn**			**$44 mn**	**$64 mn**

The yield gap suggests that it is not economic to address the issue using current technologies (farm management in rain-fed systems or irrigation systems) or there is an adoption issue. However, in the absence of variety development targeted at WUE, some improvement in current production systems can be anticipated, including improvements in WUE from the current breeding program. Assuming that new breeding approaches could be developed and applied[5], the NPV of totally alleviating water stress is

[3] Inman-Bamber, N.G. 2007, *Economic impact of water stress on sugar production in Australia*, Proc. Aust. Soc. Sugar Cane Technol., Vol. 29, 2007

[4] Average gross margins/profit have been used given data limitations at the regional level. As a result, the estimated benefits will be an underestimate of the financial benefits but it is a more appropriate measure of the benefits than gross income approach (using ex miller sugar price) which had been used in earlier analysis.

[5] With new varieties first released in 2021 with the first crop being 20% of the total through replacing standard varieties with more efficient varieties for WUE; the first improved varieties that are 10% more efficient are released in 2021, with varieties improving thereafter by 1.5% per year such that varieties released in 2031 would be 28% more efficient

estimated at $180 mn (20 years to 2036, 100% adoption, 5% discount rate) or $177 mn with some allowance for R&D costs.

If we could make a difference, how can we assess the value to the industry?

Two important aspects are the potential for a breeding solution and the rate at which a material change could be introduced. In this respect, it is important to understand the potential provided by other more extreme germplasm (as noted under Proposition #5 in the Report, *Evaluate plants for specific phenotypes or traits*). In the present analysis, we have not assessed directly the rate at which a change could be introduced.

Therefore as there are considerable unknowns, we consider the economics in another way: we ask *what would we have to believe to justify the investment?* That is, we have taken the approach of asking what would be necessary to generate an appropriate rate of return on investment? In this respect, we note that we would have to believe that by including WUE in a breeding program, there would be a substantial economic gain and that inherently superior cultivars that would not have otherwise been identified/selected would be found and that these clones would be commercially viable, and would be made available to producers within a reasonable time-frame and would increase/maintain yield in water-stressed situations.

The economic analysis presented in these terms of *what would we have to believe* is presented in Table S4. At a hurdle rate of 20 to 40% based on the value to growers and millers, a success factor (adoption x probability of R&D success) of 3 to 11% would be required.

Table S4. Estimates of the NPV taking the approach of *what would we have to believe to justify an investment in breeding* to meet a required hurdle rate or internal rate of return on the investment[6]

Value proposition	Internal rate of return (based on N at $2 per kg applied)	20%	40%	87%	141%
	Success factor: Adoption x probability of R&D success	0.15 * 0.2	0.2 * 0.55	0.3 * 1.0	1.0 * 1.0
	Success factor: Adoption x probability of success	3%	11%	30%	100%
	Estimated gross value to industry (PV, 5% discount rate)	$5 mn	$20 mn	$54 mn	$180 mn
	Estimated net value to industry, given R&D costs (NPV,5% discount rate)	$2 mn	$17 mn	$51 mn	$177 mn

Is the scale of the change in WUE credible or what is the potential for a breeding solution?

There is now a substantial literature around defining the components of WUE as a trait in many plant species. There is also evidence from research in sugarcane of genetic variation[7] among clones/varieties (run under fully-irrigated or water stress conditions); however there was very low genotype by environment (GxE)[8] interaction for yield (TCH) or commercial cane sugar (CCS) in respect of re-ranking among the clones between fully-irrigated and water-stressed situations so long as situations of severe water stress (more than 50% reduction in yield compared with full water supply) were avoided. However there was some evidence of scale effects suggesting that some varieties may be less severely affected by water stress than others. Overall, the conclusion is that with selection to date having been operating in a range of environments, clones that are inherently robust (perform well across a range of environments)

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[6] Through replacing standard varieties with more efficient varieties for WUE (first improved varieties are 10% more efficient are released in 2021, with varieties improving thereafter by 1.5% per year).

[7] Basnayake, J, PA Jackson, NG Inman-Bamber & P Lakshmanan 2012. Sugarcane for water-limited environments. Genetic variation in cane yield and sugar content in response to water stress. *Journal of Experimental Botany*, 63, 6023–6033

[8] A genotype by environment interaction (GxE) is an expression of differences in the relative responses of two or more genotypes in different environments (such as different levels of N supply or different amounts of water); such differences may be reflected as changes in rank or relative changes in scale of a particular genotype in relation to another.

are more likely to be selected than those where considerable GxE was evident (i.e. varieties perform differently in different regions/farms because of differences in the growing environment).

In summary, there is evidence of variation but the current breeding approach is likely to be delivering the varieties which are productive across a range of water supply situations (excluding very severe water stress – that is, drought stress). Hence any case for investing must be tempered by the reality that current selection is already delivering well-adapted varieties and that there is little potential for substantial improvement. This notwithstanding, there is a major project underway that will provide considerable data on the components of WUE and provide an indication of the real potential.

Conclusion in respect of breeding for improved WUE

The conclusion is that the continuation of current breeding strategies (but including potential introgression of extremes such as different species) will likely deliver most of the potential gain in WUE. However, there is a case for further pre-breeding research that is targeted at detection of more extreme phenotypes. This work would focus on the development and evaluation of potential traits that may contribute to WUE, with particular emphasis on assessments that can be carried out on a large scale at the very early stages of evaluation in order to improve the chances of detecting clones (including other candidate species) that are more extreme in their phenotype (as compared with those being selected within the current program).

There is also the issue of how to interpret the water stress factors. It could suggest that it is other factors which are limiting the realisation of higher WUE/water stress reduction. It could mean that the previously estimated stress factors relate to varieties of nearly a decade ago and that a rerun of the experiments with current and prospective varieties could be justified.

Background

Sugar Research Australia (SRA) contracted AbacusBio Pty Ltd with IDA Economics Pty Ltd to undertake a systems modelling project to estimate the relative economic value of selected performance traits of sugarcane in different regions and production systems in the Australian industry[9]. The need is for a protocol to guide future investment priorities in multi-trait selection for germplasm development.

There are increasing concerns in sugar production in respect of two key inputs, water and nitrogen. Both environmental and input cost considerations are relevant. Hence the evaluation and selection of cultivars and other approaches to genetic improvement provides a means to help manage these issues.

In this project we have assessed the potential impact/value of including new traits of water use efficiency (WUE) and/or nitrogen use efficiency (NUE) in the genetic improvement program.

SRA investment in genetic improvement of sugarcane comprises two main approaches[10]: first, a comprehensive selection and breeding program based on a resource of parental clones, and second, through the introduction of new traits (or more extreme variation within those traits) through introgression using other sources of genetic material (cultivars or other sources of sugar germplasm or other sub-species/genera). Multi-trait selection utilises specially-developed SRA selection indexes to compare individual clones.

Context and purpose of the Review

Within the Australian sugar industry there are concerns relating to both environmental aspects and to input costs. Breeding, selection and evaluation of cultivars and other approaches to genetic improvement may provide the means to help manage these issues. Other Australian farming industries are facing similar issues to varying degrees and in those industries, plant and animal breeding strategies are used to address such issues. Further, variety development has been a key means of Australian sugarcane growers addressing cane diseases, such as smut.

This project focusses on how to define and evaluate traits for improved water use efficiency (WUE) and/or nitrogen use efficiency (NUE) and considers their potential incorporation into the sugarcane breeding programs. The specific outputs, reflecting the Terms of Reference are as follows.

1. An economic evaluation of the major drivers of NUE and WUE selection indexes for each of the major sugarcane production regions in Australia. This is based on available data, including the performance of current commercial cultivars in target environments and new/optimal cultivars and environments.
2. Identification and valuation of the economic and genetic trade-offs that may arise from the inclusion of either or both of these additional traits to the existing variety selection index including a baseline comparison to measure the incremental net benefit arising from the investment, That is, the benefit from additional breeding compared to first, the baseline (no change in adoption of farm management practices) and second, the otherwise or the counterfactual (changes in practices and other factors such as government regulation).
3. Sensitivity analysis of the economic valuation for the trait indexes to an increase in regulatory or community pressures to reduce nitrogen inputs or block yield potential of sugarcane in

[9] Dr Prakash Lakshmanan of SRA facilitated the review with relevant contacts and information within and outside the sugar industry and provided specific expertise in technical aspects of sugar production. Dr Lakshmanan has not been involved in the preparation of this Report or in the development of the Recommendations

[10] Multi-trait selection utilises SRA selection indexes, and SRA is in the process of reviewing these indexes at present.

environmentally sensitive regions, and to the input costs of fertiliser and power and water for irrigation in relevant regions.

4. Recommendations on trait prioritisation and integration and the relative importance and desirability of the current and future SRA investment in further development of selection indexes for NUE and WUE. This should consider whether the methodologies being developed are cost-effective or whether lower-cost alternatives could be considered that may provide useful outputs without compromising data quality.
5. An assessment of the capacity of the core sugarcane breeding and introgression breeding sectors to integrate new selection indexes for NUE and WUE.
6. An assessment of the cost-effectiveness and likelihood of success of including new selection indexes in the sugarcane core breeding program.

Methodology

The project involved extensive consultation with breeders and researchers in the Australian sugarcane plant breeding programs, economists, other experts and industry associations involved in the sugar industry, along with meetings with growers and productivity groups in each of the main growing regions.

Two workshops were held to outline and discuss the Review's preliminary findings. The Brisbane workshop brought together breeding, technical and SRA interests. The Townsville workshop was primarily grower-focused.

Consultation within the Review

In the consultation phase, there were five aspects considered in detail which taken together, provided the core inputs into the project.

1. The context for considering the place of genetic approaches: understanding what is important to sugar producers (how do they experience issues with water or nitrogen?) and how the industry currently deals with these issues and how it might in the future.
2. The current genetic improvement program and prospects for the future: this includes the current breeding objective, breeding and selection, the genetic evaluation system and the cultivar/variety release program in the context of the potential to incorporate nitrogen and/or water traits (this required an understanding of the importance of other challenges such as disease).
3. The economics of sugar production: the focus is on the economics underpinning the breeding objective and the derivation of economic weights including potential new traits. In this respect, how will sugar producers be expected/required to pay for nitrogen effluent (will this be via a direct penalty or will it be reflected in a cost of providing mitigation)? There are also cost issues with water use and there are other potential constraints – hence what are the possible/probable scenarios of constraints on water and nitrogen use? There are also future sugar prices to consider, albeit given that Australia is a small producer in a world context, although Australia is the second largest export of raw sugar.
4. Developments in sugar cane breeding in other countries, noting that the Australian breeding program draws on genetic material from those programs, including the potential for GM technologies to extend breeding opportunities.

5. Consideration of progress in breeding programs for other species: this is especially in respect of those that are being impacted by changes due to regulatory processes, environmental pressures or adaptation to climate variability.

Broad framework for assessing the value of an investment

Basis

An investment framework approach is the most appropriate way to assess the business case for SRA investment in RD&E to incorporate additional traits in the breeding program. Such an approach enables expected benefits (growers and whole of industry) and costs (R&D and implementation) to be examined having regard to risks and time-frame of the R&D and time-scale of adoption. This includes risks (such as research risks in identifying and measuring the trait), applicability across the industry (all/some regions), adoption levels amongst farmers and crucially the otherwise case (or counterfactual) – how growers can be expected to manage the underlying issues in the absence of varieties incorporating the additional trait.

The value of the investment is expressed in real (inflation-adjusted) net present value terms (discounted cash flow) and internal rate of return, where the value is derived from the following measures:

- investment costs (negative),
- estimated quantified industry benefits from variety improvement over time (including longer-term sustainability) x probability of research success x proportion of industry where benefit is applicable x adoption by growers x probability that the R&D will not become redundant,
- non-quantified industry benefits, *and*
- benefits outside of the industry (including broader community benefits), where the baseline case focusses on no change from current farm management practices, governmental regulation or increases in real prices (of fertilisers, water or pumping costs).

Where the otherwise case considers:

- a continuation of the current breeding program (without an expanded focus on NUE and WUE),
- where growers manage WUE and NUE either through further adoption of relevant strategies to improve efficiency or they develop/utilise new management strategies, or
- growers end up facing additional regulation of their current management practices and/or higher prices for inputs, either way leading to lower farm income.

In this respect, the investment framework approach:

- provides an analytical approach to assessing the value to industry (and generally the community),
- is transparent in both the approach and the use of data,
- enables the implications of other views and data, and sensitivity, to be examined, *and*
- is consistent with the evaluation frameworks used by SRA in other project evaluations.

However in the face of uncertainty about the outcomes of R&D investment, it is often appropriate to supplement this financially-driven analysis, with one that addresses the question of ‘what would I have to believe to justify this investment?’ This can often facilitate a more realistic assessment of the prospects as it reshapes the analysis to consider the likelihood of success and the scale of return required to meet an investor’s hurdle rates.

The approach

Overview

Currently the breeding objective – a whole of industry profit-based objective – includes four traits in the selection index (Total Cane Harvested - TCH, Commercial Cane Sugar - CCS, Fibre content, Appearance grade). The respective economic weights are calculated for the four production regions (Southern, Central, Burdekin and Northern-Herbert). In addition, prospective varieties are screened for disease resistance/vulnerability and the potential impact is then incorporated as the effect of a loss in yield.

The inclusion of one or more additional traits will require an investment in both pre-breeding research and in the breeding program. To date, there has been considerable investment in pre-breeding research and the direct costs of further such research is likely to be significant as additional costs in the breeding phase are more likely to be marginal costs, given the current program (although they may be still significant). Pre-breeding R&D is required to:

- define the profit trait and establish the relationships between changes in the trait and profit
- define the genetic parameters (heritabilities, co-variances, genetic and phenotypic correlations)
- define the selection trait(s) to be recorded and the method of measurement
- derive the economic weight for the trait (analysis and industry discussions)

Breeding program costs include/may include:

- the initial set-up costs and subsequent annual operating costs and any other SRA (and other co-investors) program costs to incorporate the new trait in the selection index
- a larger breeding program (in order to maintain the current level of evaluation within the program)
- the risk that a focus on a new trait that is not driven off sound economic criteria will reduce selection pressure on other traits and actually reduce overall profitability or net economic gain.

The investment analysis

Opportunity cost

The opportunity cost of investing in a new trait for the selection index can be viewed as the:

- opportunities forgone in other SRA projects (breeding and other), albeit noting that the relevant data are not always available, or
- the discount rate used in evaluating rural R&D Corporation projects (a real rate of 5%) which is the approach adopted in this analysis.

Incentives

The major investor in sugar breeding within Australia is SRA, although both CSR and Wilmar have/have had some investment in breeding. The current SRA program has access to, and also exchanges, genetic material with overseas breeding programs and also monitors developments in these programs. Hence access to international variety development to address the NUE and WUE traits is potentially relevant.

Estimation issues

There is considerable uncertainty inherent in the analysis of the opportunity given the status of knowledge in respect of the genetics of NUE and WUE in sugarcane. Therefore in considering the potential of a genetic approach to contribute to a reduction in N losses we have taken the approach of *'what would I have to believe to invest in a genetic approach?'*

Report Overview

Given the context around the options and the potential value of incorporating WUE and NUE in the breeding and evaluation program, the report addresses the following issues.

1. The broad features of the **current approaches to genetic improvement** and evaluation are considered along with the targets for selection and the release of varieties; this includes consideration of approaches to genetic improvement, the value/practicality of a baseline comparison, the case to estimate the net benefit from additional investment in genetic improvement and breeding (including assessment of cultivars across environments).

   This provides the background for estimating the potential value of **nitrogen use efficiency** and **water use efficiency** in the sugar industry and the value proposition for the incorporation of WUE and NUE as new traits within the SRA breeding programs.

2. **Estimating the value of NUE and WUE**: the current breeding objective is underpinned by an economic model; as this model was not made available to the consultants, an alternative was developed and economic values/weights derived for NUE so that it could be considered as a potential new trait for genetic improvement. This approach was not applied to the WUE analysis as it was concluded that, without access to the detailed cost model with costs by region (especially for water), that the generation of economic weights would be fraught with uncertainties. However the WUE model applied operates at a higher industry level, and it recognises the critical importance of yield in determining profitability.

   A sensitivity analysis of the economic value to a change in the environment (regulatory environment or community pressures to reduce nitrogen inputs or limit the yield of sugarcane in environmentally-sensitive regions) and to input costs (fertiliser and power and water for irrigation in relevant regions) is included. The impacts were assessed through a change in the economic weights reflected in an increase in costs) in overall profitability.

   A summary assessment of the **major drivers for incorporation of NUE and WUE** is included for each of the major sugarcane regions in Australia (Southern, Burdekin, Central, Northern-Herbert).

   Assessment of the **potential value of incorporating WUE and NUE** into the SRA breeding program includes the consideration of the potential economic and genetic trade-offs that may arise from the inclusion of either or both of these additional traits in the existing genetic improvement program.

   The **'otherwise case'** is also considered. In other words, what alternative strategies might growers (or the industry in general) adopt to improve WUE and NUE, what other programs might SRA or others develop or promote to improve efficiency in these areas and what other factors might impact on these issues such as regulation?

3. Overview of approaches to genetic improvement and cultivar release with consideration of some **propositions that are relevant to NUE and WUE** in terms of opportunities or options to further develop the breeding, selection, genetic evaluation and variety release programs including:

   a. the specific case for incorporation of NUE and WUE into the breeding program at this time;

   b. an assessment of the capacity of the program (including via introgression) to integrate selection for NUE and WUE (including trait definition);

   c. the potential capacity to reduce the impact of or to mitigate the effect of incorporating NUE and WUE on genetic gain in yield, including assessment of the cost-effectiveness and likelihood of success with the inclusion of new traits (WUE and NUE) in the sugarcane core breeding program;

d. provision of a sound basis to prioritise and detail future research in developing selection indexes for NUE and WUE (including the case for cost-effective methodologies) and the value proposition for future SRA investment in continuation of R&D in this area (pre-breeding research) to assess the scope, value proposition and methods to incorporate NUE and WUE traits in breeding programs.

Overview: Genetic improvement in sugarcane

The broad features of the **current approaches to genetic improvement** and evaluation are considered along with the targets for selection and the release of varieties. This includes consideration of approaches to genetic improvement and the value/practicality of a baseline comparison to measure the net benefit from investment in genetic improvement and breeding (including assessment of cultivars across environments).

This provides the background for estimating the value of **nitrogen use efficiency** and **water use efficiency** in the sugar industry and the value proposition for the incorporation of WUE and NUE as new traits within the SRA breeding programs.

Features

The rationale for this review is to assess the value proposition for incorporating NUE and WUE as new traits within the current variety development system within SRA. In considering the contextual framework, there are three underlying considerations of particular relevance, namely that sugarcane:

- is clonally-propagated - this presents opportunities to ensure outcomes that are more reliable than outcrosses as the influence of genetic variation within a variety is, by definition, limited; this factor helps enable highly-effective and targeted approaches to the introgression of desirable traits;
- exhibits low genetic diversity across the range of commercial varieties; and
- exhibits a very high degree of diversity in terms of genetic structure (numbers of chromosomes, retention of chromosomes in crossing).

Sugarcane is an allopolyploid species that has arisen through the combination of genomes of *Saccharum spontaneum* (with a range in chromosome number from 2n = 40 to 128, but with a basic chromosome number of 8) and *S. officinarum* (with the majority being 2n = 80). Given that the development of allopolyploidism in sugarcane is in the early stages, it can be expected that that the genome will be very fluid – that is, it will be characterised by considerable genomic instability[11]; in fact there is over-whelming evidence that this is the case (highly variable chromosome number).

An increase in ploidy is an increase in the number of sets of chromosomes that arises through mating with a compatible species[12]. Gene expression is altered as a result of such ploidy events, possibly through epigenetic changes and other phenomena such as inter-chromosomal rearrangements. However sugarcane must be considered as a ‘species’ which is in the very early stages of development as an allopolyploid with the most likely level of ploidy across the commercial population in the range of 6 to 14[13].

With this background, it is useful to consider facets that underpin successful quantitatively-based genetic improvement programs in plants and animals; these are dependent on four key factors:

- access to sources of genetic variation (germplasm) as parents;

[11] For example a re-synthesized allopolyploid Brassica, Xiong et al (2011, PNAS 108, 7908-13) found that the plant exhibited considerable aneuploidy, inter-and intra-genomic re-arrangements, chromosome fracture and fusion along with loss of repeat sequences.

[12] Comai L 2005, The advantages and disadvantages of being polyploid. Nature Reviews Genetics, 6, 836-846

[13] Garcia AF et al SNP genotyping allows an in-depth characterisation of the genome of sugarcane and other complex autopolyploids. Scientific Reports. http://www.nature.com/srep/2013/131202/srep03399/full/srep03399.html

- clarity with respect to the selection target (which stems from a soundly-based breeding objective, which is desirably a profit function);
- a set of robust genetic parameters (which are generally derived through a somewhat painstaking effort in data collection and then analysis); and
- a method to define pedigree or genetic relationships within the population under selection (maybe less important in clonally-propagated species).

Current SRA program for variety development

Overview

The breeding objective is the ***maximisation of whole-of-industry profit for sugar production*** with the current program featuring three approaches:

- creating novel genetic variation through crossing selected parents;
- selecting from amongst these crosses and releasing new varieties; and
- continuous improvement/expansion of the parent (nucleus) population through incorporation of elite clones from the selection program and other sources of novel genetic material.

There are four major regions recognised within the Australian sugarcane industry which differ in geography including soil types, climate (heat, water) and challenges from pests and diseases. The regions are Northern-Herbert (Mossman, Tablelands, Musgrave, Innisfall, Tully), Burdekin, Central (Proserpine, Mackay, Sarina) and Southern (Bundaberg, Maryborough, Childers and NSW). SRA operates one crossing and four selection programs in these major regions. The core selection program comprises three stages as below.

Stage 1 (from year 1): Progeny Assessment Trials (PATs) with c. 25,000 individual seedlings per region representing 250 to 350 families in each region; these are the progeny of clones from the 2,000 plant nucleus (a total of about 900 crosses or families are assessed across the 4 regions); on average there are c. 80 (40 to 200) individuals in four replicated family plots; yields are measured at the family level and clones are selected from within selected families on visual traits at the 1R (first ratoon) stage;

Stage 2 (from year 4): Clonal Assessment Trials (CATs) with c. 2,500 clones (10%) in each region which are planted in single-row (10 m) plots with standards; they are assessed at the P (planting) & 1R stages; from this the top 400 clones are screened for smut in all regions;

Stage 3 (from year 7): Final Assessment Trials (FATs) with c.150 clones (0.6%) selected after screening from within the core and the SmutBuster program; SmutBuster takes resistant clones (desirable recombinants) from susceptible families through a CATs phase and these are included within the FATs stage (2015 is the last year of Smut Buster); in FATs, the 150 clones are planted in 4-row plots (10 m each) at 4 to 8 locations; the two middle rows are harvested in P, 1R and 2R crops.

The best 25 clones (after the P crop) from each selection program then enter the ISE (Interstation Exchange) and are planted in replicates and screened to 1R; they undergo a further round of screening for disease (smut, leaf scald, *Pachymetra* and Fiji disease), and about five clones are selected for further evaluation.

Stage 4 (from about year 9): Further evaluation

Stage 5 (from about year 12): Commercial varieties are released.

The basic proposition underlying the current selection and breeding program appears to be that given that genetic diversity is low, there is a need to ensure that the program maximises the opportunity to generate novel recombinants that may deliver a new source of genetic variation (through favourable genetic combinations); novel sources of germplasm are also incorporated within the nucleus to facilitate this.

Selection

The selection index is a profit function which includes the traits of productivity (TCH or yield - Total Cane Harvested, harvestability and appearance grade[14]), ratooning, disease resistance, and a quality parameter which includes both fibre and sugar (CCS%, Commercial Cane Sugar). The Selection Index is expressed as rEGV[15] (or relative EGV, Economic Genetic or Breeding Value) which combines economic and biological/genetic information to evaluate the economic merit of clones to the whole industry (producer and miller). The EW (Economic Weight) of a trait is defined as the net benefit in dollars per tonne of sugar produced, to the whole industry, resulting from one unit of change in the trait while other traits remain constant. Table 1 below (Wei *et al* 2008) presents the EWs for four traits (albeit that the EWs are being revised at present).

Yield in terms of total sugar harvested (TSH) is the principal driver of profitability. Selection is targeted at the component traits TCH and CCS%. The relative economic weights drive the relative selection pressures on the two traits. In this respect, at a CCS% of 13%, the relative value of a 1 tonne increase in TCH per hectare is 29 to 53% of that achieved by an increase in sugar content[16].

Table 1. Relative Economic Weights for four traits for sugarcane production (Wei et al, 2008)

Trait	Unit	Region			
		North	Burdekin	Central	South
Total Cane Harvested (TCH)	**Tonne per hectare**	0.45	0.73	0.68	0.75
CCS (Commercial Cane Sugar)	**Percentage**	11.76	13.23	9.81	15.88
Fibre content	**Percentage**	–1.67	–2.30	–2.76	–3.08
Appearance grade	**Scale**	5.00	NA	NA	NA
Conversion of TCH to CCS equivalent		3.46	5.62	5.23	5.77
Relative pressure on TCH to that on CCS%		29%	42%	53%	36%
TCH as Proportion of TCH + CCS		23%	30%	35%	27%

The rate of genetic improvement

The current rate of genetic gain has been estimated by Cox & Stringer[17] (using BLUP analysis) and updated by these authors (pers. comm.) for total sugar harvested (TSH); the estimated rate is 238 kg per year for the 20 years from 1996 to 2015. This is made up of an increase in both CCS (commercial cane

[14] Including suckering, side-shooting, and arrowing or flowering

[15] Wei *et al* 2006 Maximising economic benefits to the whole sugarcane industry from the BSES-CSIRO sugarcane improvement program, Proc Aust Soc Sugar Cane Technology 28: 181-186; Wei *et al* 2008 Relative Economic Genetic Value (rEGV) – an improved selection index to replace Net Merit Grade (NMG) in the Australian variety improvement program, Proc Aust Soc Sugar Cane Technology 30: 174-181

[16] For example for the North, a 1 tonne increase in sugar represents 0.13 tonnes sugar which is worth r$0.45, whereas an increase through CCS is worth 0.13*r$11.76 or r$1.53; hence the relative value of TCH is 29% of that of CCS% - r$0.45/ r$1.53.

[17] Cox MC & JK Stringer 2007. Benchmarking genetic gains from new cultivars in Queensland using productivity data. International Soc. Sugar Cane Technologists, 1-7.

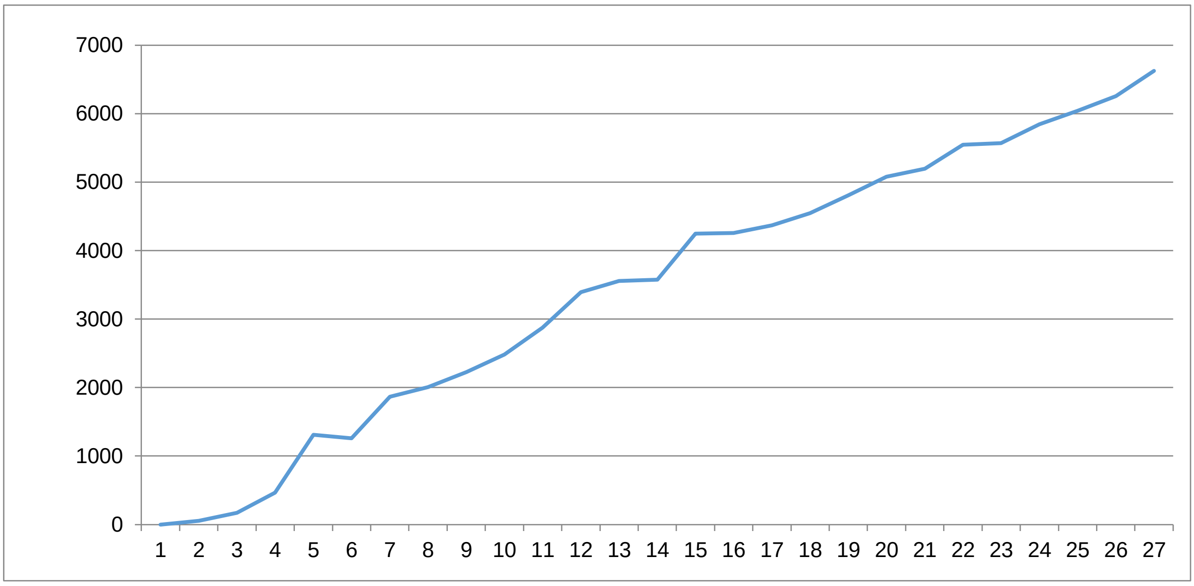
sugar with an annual increase of 0.065% units) and TCH (total cane harvested with an annual increase of 1.28 tonne). The response in TSH is summarised in Table 2 for two 10-year periods.

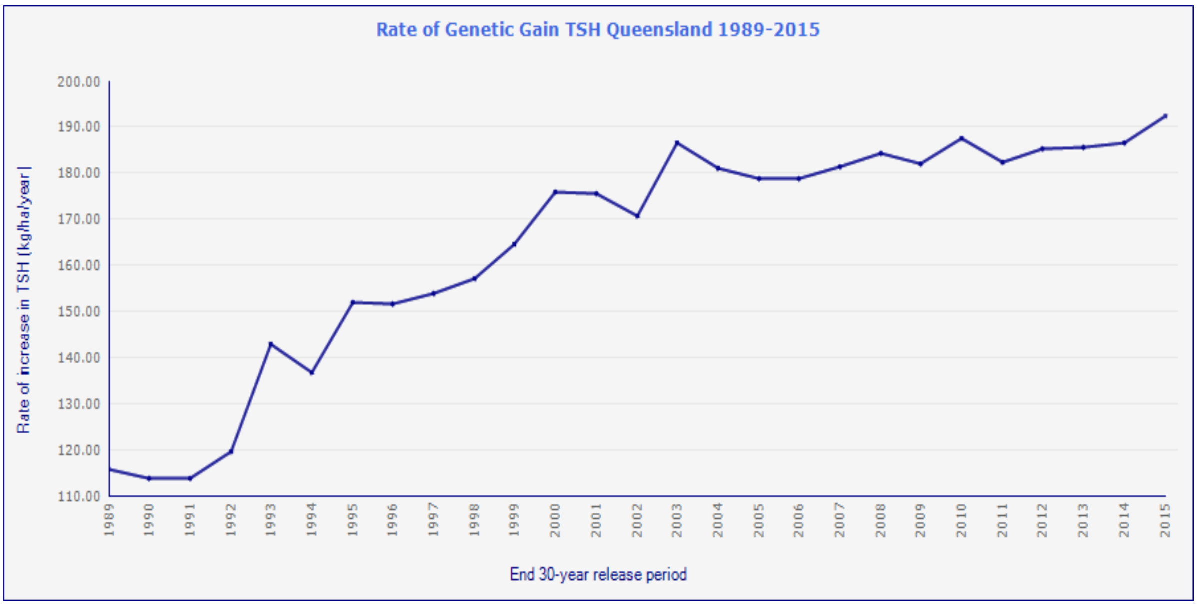
Table 2. Estimation of the rate of genetic gain in TSH over the period from 1996 to 2015

	Estimated initial TSH in kg	TSH after 1 year of genetic gain		Genetic Gain in TSH
1996 - 05	15,240 kg (120.0 tonne at 12.70%)	15,478 kg	Annual gain in TCH of 1.28 tonne & CCS of 0.065%	238 kg per year
2006 -15	18,036 kg (133.9 tonne at 13.47%)	18,260 kg		

Figure 1 presents the cumulative rate of genetic gain from 1989 to 2015. In genetic terms, the results are impressive with a gain in total sugar harvested of about 28% over 20 years based on the 1996 yield.

Figure 1. Upper - Cumulative gain in TSH (total sugar harvested in kg per hectare) for the 27 year period from 1989 (year 1) to 2015 (adapted from M Cox & J Stringer, pers. comm. 2015); Lower - Annual rate of genetic progress for TSH





The response can be dissected according to the equation:

Genetic response (δG) = (i . r . σ_G)

= selection intensity (i) x accuracy of estimates of genetic merit (r) x genetic standard deviation (σ_G), [where σ_G = square root (narrow-sense heritability x phenotypic variance)]; thus $i.r = \delta G / \sigma_G$; given that r is the square root of the narrow-sense heritability, then I = $i.r = \delta G / (\sigma_G.r)$.

Table 3 presents the genetic parameters used in the analysis and summarises the features of the annual genetic response compared with the expectations. The analysis shows that the annualised responses were about 8% of the genetic standard deviation and 11 to 16% of the predicted response from one unit of selection intensity (selection accuracy x genetic standard deviation or narrow sense heritability x phenotypic standard deviation).

Table 3. Genetic parameters (from Wei *et al* 2006[18]) for Total Cane Harvested (TCH) and Commercial Cane Sugar (CCS%) and analysis of the annual response in terms of TCH and CCS%.

	TCH		**CCS%**	
Genetic parameters				
Narrow-sense heritability (h^2)		0.30		0.50
Mean (1996, 2006)	tonne	120, 133.9	%	12.70, 13.47
Annual genetic gain (1996, 2006)	tonne	1.39, 1.18	%	0.077, 0.052
Phenotypic variance		702		1.30
Phenotypic standard deviation	tonne	26.5	%	1.14
Accuracy as the square root of narrow-sense heritability		0.55		0.71
Genetic SD	tonne	14.51	%	0.81
Analysis of the annual response				
Predicted response per unit of selection (Wei *et al* , $r.\sigma_G$)	tonne	7.95	%	0.57
Predicted response as a percentage of the Genetic SD	tonne	55%	%	71%
Actual response	tonnes/year	1.283	% per year	0.0645
Actual response as a percentage of the Genetic SD (i.r)		8.8%		8.0%
Actual response as a percentage of the predicted response per unit of selection		16.1%		11.3%

Table 4 presents the realised selection intensity (i) as:

i = selection response/(genetic standard deviation x accuracy).

To derive these estimates of selection intensity, the selection intensity has been adjusted for the time to generate new varieties. We have used the replacement rate of varieties as the replacement rate within the nucleus; this is about 200 to 250 plants per annum into a nucleus of 2,000 plants; this is equivalent to 8 to 10 years. These estimates are also highly sensitive to the phenotypic variance of the traits.

The theoretical proportion selected is 5 from 72,000 or 0.007%. The actual proportion selected inferred from the calculations above is around 4 to 18% for any one of the three traits. If all traits are independent (nil genetic correlations between them) then the implied overall selection pressure is the product of all three which is 0.03% (10 years) to 0.16% (8 years) or 3 to 16 in 10,000 or so of the plants available. In

[18] Wei X, P Jackson, M Cox & J Stringer 2006. Maximising economic benefits to the whole sugarcane industry from the BSES-CSIRO sugarcane improvement program. *Proc. Aust. Soc. Sugar Cane Technol., 28:*

other words there is some loss of selection pressure over that which is theoretically possible, some of which will be due to further screening for disease resistance.

Table 4. Derivation of realised selection intensity based on the realised rate of genetic gain (Table 3) and the proportion selected as impacted by the generation interval (which takes selection as a 'one-off' event) where the generation interval is 8 or 10 years (it is assumed that 250 clones are replaced in the nucleus per year such that 2000/250 = 8 years, and for 10 years, 200 are replaced so that 2000/200 = 10 years)

Narrow-sense heritability & accuracy	'Generation interval'	TCH		CCS%		Fibre %	
		Selection intensity	Percentage selected	Selection intensity	Percentage selected	Selection intensity	Percentage selected
Heritability of 0.3 (accuracy of 0.55)	1 year	0.161					
	8 years	1.29	10%				
	10 years	1.61	5%				
Heritability of 0.5 (accuracy of 0.71)	1 year			0.113			
	8 years			0.91	18%		
	10 years			1.13	13%		
Heritability of 0.45 (accuracy of 0.67)	1 year					0.113	
	8 years					1.36	9%
	10 years					1.70	4%

Issues in selection and genetic improvement

As noted above there is a moderate to high rate of culling due to disease susceptibility but the inference is that there are aspects of the program that are also muting effective selection. The most likely issues are the poor genetic correlations between the traits used in the early stages of selection and their 'equivalent' commercial traits. However the overall implication is that adding further traits would be expected to compromise the progress in the important yield-driven traits. The application of a profit-based selection index is designed to ensure that the focus remains on the drivers of profitability. However the reliability of an index is critically dependent on the robustness of the economic weights that are incorporated within the index. There are two particular issues:

1. major changes in the relative pressure on different traits with small changes in EWs are not manageable in a practical selection/breeding program,
2. genotype by environment interactions can compromise the value of an index if the environment is highly variable within the same region — which is characteristic of most growing regions; further, growers point to the environmental variation (soils plus climate) within their farms and this is one of the drivers for growing a range of varieties.

Given these issues, the central question in the context of incorporating NUE and/or WUE traits is:

> what is the risk of making poor decisions that compromise profitability?

If either of these issues is a problem, then the breeding approach must be designed to deal with it. In this respect, the preference would be that the selection response is robust in that the chosen traits are not subject to major GxE interactions. That is, the desired plants would be those that perform well across a relatively diverse range of environments.

In the case of nitrogen, this environment would represent a range in N applied and, in the case of water, it would be a range in water supplies. The question then becomes how likely is it that such variation exists within the current germplasm or within the potential range of sugarcane germplasm to render such approaches to genetic improvement feasible. A key aspect is not only utilising what is available for 'todays issues' but also creating options for 'tomorrow's issues' or an intensification of 'today's issues'

Genotype by environment interactions are to be expected for NUE and WUE, although statistical analyses of large numbers of varieties have indicated that GxE is generally not significant. However when individual varieties are compared such GxE is often apparent. For example, recent Australian work[19] where a number of varieties were compared there was essentially no GxE interaction for yield or CCS% due to water supply (in the field, plants that were fully-irrigated were compared with those where yield under water stress was more than 50% of that under fully-irrigated conditions). However in the case of very dry/drought conditions, there was evidence of substantial GxE; in other words the trait under fully-irrigated conditions was not the same as that under drought conditions as reflected in the substantial re-ranking of clones in the two environments. There is also evidence of variation in the pattern of uptake of N and the N requirement, which is also considered further below.

Perspective on the current program in the context of NUE and WUE

The current breeding program and genetic evaluation methodology is sound and reflects best practice in objective genetic improvement based on improving the overall profitability of a business (or businesses within an industry). The rates of genetic gain in the traits are impressive (as evident in Table 2 and Figure 1). However as noted above, the realised selection intensity is lower than expected given the apparent high intensity of screening and selection.

The current approach, following pre-breeding R&D, can be described as comprising four broad phases:

Phase 1: Generate an array of options based on the extraordinary range in terms of the genetic structure of the plant;

Phase 2: Define the performance of families and then select individuals from within these families based on their superior visual phenotype;

Phase 3: Evaluate the selected plants through measurement of individual clone performance, selecting plants with desirable traits and then screening these in situations where they are exposed to a range of biotic (disease) and abiotic (different soil types, different climatic conditions or geographies, water stresses such as water-logging, periods of water deficits including drought) challenges;

Phase 4: Evaluate the candidate varieties as a pre-commercial assessment under more commercially-relevant conditions.

All selection and breeding programs are subject to financial constraints. The program features a high level of investment in the pre-breeding stages. There could be case to consider re-balancing the investment to enable a greater focus on the later evaluation phases but this has not been examined.

[19] Basnayake J, PA Jackson, NG Inman-Bamber & P Lakshmanan 2012. Sugarcane for water-limited environments. Genetic variation in cane yield and sugar content in response to water stress. J Experimental Botany 16. 6023-33

Estimating the value of NUE and WUE

Overview

Sugar cane growers apply significant amounts of artificial nitrogen. Typical rates are in the order of 20 to 150 kg N/ha at planting (20 to 40 kg if following a legume) followed by a further 150 to 200 kg/ha of N at each ratoon; if planting does not follow a legume, then 150 to 200 kg/ha of N is typically applied at planting and at the start of subsequent ratoons. Indicative rates of application and the cost, in the context of expected yield from plant and ratoon crops are shown in Appendix Table 4.1 for two contrasting regions. Sugar cane is grown under natural rainfall, with and without irrigation.

The **'otherwise case'** is also considered. In other words, what alternative strategies might growers (or the industry in general) adopt to improve WUE and NUE or what other programs might SRA or others develop or promote to improve efficiency in these areas? Additionally, what the implications of further regulation or increasing real prices for nitrogen and water?

Approach

The estimation of the potential value of incorporation of nitrogen use efficiency (NUE) and water use efficiency (WUE) into the SRA breeding program includes the identification and valuation of the potential economic and genetic trade-offs that may arise from inclusion of either or both traits in the existing genetic improvement program. However given the current state of knowledge of the traits in genetic terms, we consider that trade-offs can only be assessed at the very general level. Therefore we have taken a pragmatic approach to the assessment and therefore this report focuses on developing a methodological framework.

The framework includes the development of an economic model, the presentation of propositions as to potential approaches including pre-breeding research with a focus on early predictors of (potentially) useful traits, and increased evaluation of potential commercial varieties in a range of environments.

Industry structure

It is necessary to define the structure of the industry in order to assess the potential impact of including WUE and/or NUE in the breeding program. Averaged over the last three years, the industry has harvested 370,000 hectares and crushed 31 million tonnes of cane producing about 4.4 million tonnes of sugar annually. The structure is summarised in Appendix Table 2.6. In order to estimate the area subject to water and nitrogen leaching constraints, a regional structure was applied (Appendix Table 3.4). The summary is in Table 5 below.

Table 5. Regional statistics: Area subject to water or N constraints (Average 2005-10)

Region	Area harvested ('000s hectares)	Estimated area subject to some water constraint	Estimated area subject to N constraint
Southern	63.8	100%	100%
Central irrigated	106.3	100%	100%
Burdekin delta	69.2	100%	100%
Wet Tropics	126.7	0%	100%
Total	366.0		

Traits

We consider NUE and WUE as traits that impact on yield.

The nitrogen model is an empirical one and seeks to define the response parameters to applied N and has been used to generate a sensitivity analysis to the level of N applied (in terms of yield and N uptake). This enables assessment of the impact of the cost of N and of the economic value of an improvement in NUE (expressed as gross margins). The model forms the basis of the assessment of the economics of an increase in yield as a function of N supplied. The model also provides the basic inputs in terms of yield response as a means to assess the cost of further changes in the regulatory environment that might be designed to reduce nitrogen inputs, and in turn, limit the yield of sugarcane in environmentally-sensitive regions. A similar approach has been applied to water use efficiency through estimating the cost of correcting the water deficit in the relevant regions in terms of the impact on overall profitability or gross margins.

Propositions and recommendations

Five propositions are presented to highlight issues around the incorporation of nitrogen and water use efficiency traits within the SRA genetic evaluation and breeding system. As noted previously, the current selection and breeding program is well-structured and is delivering new varieties in the face of very serious challenges, particularly new disease challenges. In this sense, the counter-factual is that without the breeding program, there would not be a practical approach to dealing with disease challenges such that there would most likely not be a sugar industry in many parts of Queensland.

The reality is that whenever a new trait is introduced into a breeding and selection program, the selection pressure on other traits is reduced although, with an economic index, the approach is designed to ensure that overall profitability is enhanced.

Therefore we have summarised five broad value propositions that are candidates for consideration as below. In the following sections we consider the background to each of these propositions for NUE and WUE in more detail.

1. The case or otherwise to incorporate NUE within the breeding program
2. The case or otherwise to incorporate WUE within the breeding program
3. Development of a method to estimate/define the value of genetic modification as an approach to introduce novel traits, especially NUE
4. Definition of the genetic relationships between plants within the nucleus in order to classify or assign plants to sub-populations (primarily genotypic relationships but also phenotypic descriptors) to facilitate early mating and selection decisions
5. Development of methods to assess plants for some specific adapted phenotypes or traits; three candidates are root depth/structure, ratooning (persistence) under commercial conditions, and stomatal conductance.

Proposition #1: The case to incorporate NUE as a trait

Rationale: The case for reducing N run-off and leaching (DIN) in vulnerable areas is clear.

The case: the overall case has been assessed against the characteristics of a successful breeding program[20]. In this respect:

- **NUE** as a trait: NUE is estimated as the yield – TCH or TSH – as a function of N applied; **Uptake Efficiency** (uptake by the plant in terms of N accumulation) can also be defined and is measurable (albeit that at low N inputs net uptake exceeds N supplied);
- industry need and/or environmental considerations: the economic case at the individual farm level to reduce N at current prices of nitrogen is not strong (compared with other traits as the yield response to applied N is very strong) *but* the environmental issues are such that there will be further pressure to reduce N applications which may extend as far as a *licence to operate* in some regions;

[20] Characteristics of a successful breeding program are that: the methodology is quantitatively-based (the trait is measurable); there is a focus on industry needs (profitability plus environmental considerations and users); the specific breeding aspects include access to genetic variation (germplasm) as potential parents, clarity of the selection target (through a soundly-based breeding objective), robust genetic parameters, and a way to define pedigree/ genetic relationships in the population

- specific breeding aspects: these include evidence of genetic variation within the population of parental candidates, and a clear selection target (albeit that there are challenges in terms of the availability of robust genetic parameters).

Objective: The proposed objective is to reduce the need for N by identifying varieties that perform well in lower N situations (good yield at low N) and that are relatively insensitive to additional N applied.

Recommendations

Further underpinning (pre-breeding) research is required but it is important to start now with the evaluation and selection components as in recommendations 1, 2 & 3 below. The recommendations are that:

1. there is investment to improve the characterization of the germplasm resource that includes a phenotypic descriptor of performance under low N conditions (albeit that this may well be selecting for competitive ability within a full-sib family that will be much less relevant in the clonal (real) situation);
2. early selections (Progeny Assessment Trials) seek to identify firstly, plants that perform well under low N, and secondly, that have high Uptake Efficiency of N (given that this involves more focus on looking for extreme phenotypes early, it is important to generate some potentially more extreme material);
3. there is a co-ordinated investment in evaluation of the response to increasing levels of N applied (dose response) for current (and potential new) varieties in vulnerable regions; this will generate better information on current varieties and pre-release information on the suitability of new candidate varieties in low N situations; this will also enable definition of the effect of reducing N (yield & profit) and could lead to variety-specific recommendations for N applications;
4. further underpinning (pre-breeding) research focuses on characterisation of variation within the wider germplasm pool and in developing rapid ways to screen genetic material and plants in the early stages of evaluation.

Proposition #2: The case to incorporate WUE as a trait

Rationale: Water Use Efficiency or more appropriately water productivity (WP)[21] (yield per hectare per unit water supply) is a potential trait for incorporation into breeding programs given that the pressures on water supply are expected to increase for sugarcane growers whether this is due to changing climate or community pressure or the costs of providing water to crops.

The case: this has been assessed against the characteristics of a successful breeding program[22]. In this respect:

- WUE is defined as yield per hectare per mm of water; by definition (as with NUE), it is a complex trait in that many genes are involved in its regulation and the expression is greatly affected by the environment; while the profit trait is WUE, the practical issue to consider is definition of the appropriate recorded traits; there are correlated traits but the case for using any of these at this stage is not clear;

[21] Sadras V, P Grassini & P Steduto 2012. Status of water use efficiency of main crops, SOLAW Background Thematic Report - TR07, FAO

[22] Characteristics of a successful breeding program are that it is quantitatively-based (the trait is measurable), there is a focus on industry needs (profitability + environment & users), the specific breeding aspects include access to genetic variation (germplasm) as parent, clarity of selection target (soundly-based breeding objective), robust genetic parameters, and a way to define pedigree/ genetic relationships in population

- there is an industry need for varieties that can manage a range in the supply of water and still perform very well; performance in any environment is very dependent on WUE and an economic case based on the scale of water deficit and the yield loss and the costs to correct this deficit can be made; however there are considerable unknowns, so that we have taken the approach of *what would we have to believe to invest in incorporating WUE into the breeding program?*
- in research trials there is evidence of genetic variation[23] among clones/varieties; however the reality is that selection to date has been operating in a range of environments and that plants that are inherently robust (perform well across a range of environments) are more likely to be selected than those where considerable GxE was evident;
- ***what would I have to believe?*** that by including WUE in a breeding program, that inherently superior cultivars that would not have otherwise been identified/selected would be found and that these clones would be commercially viable and would increase/maintain yield in water-stressed situations; given this, the approach taken in the Report addresses the issue: *what scale of change would be necessary to justify an investment (in either the breeding program or in other R&D)?*

Objective: There are two parts: to better understand the trait (pre-breeding R&D), and to increase the evaluation of potential varieties in range of environments (but there is not a case at present to incorporate either WUE or WP within the breeding program).

Recommendations

The recommendations are that:

5. there is a co-ordinated investment in evaluation of candidate varieties under a variety of water stress conditions with the objective of providing an assessment of the response of varieties to a changing water supply prior to release (in essence an assay of robustness);
6. there is investment in improving the characterization of the wider germplasm resource (variation within) for water productivity (WP);
7. there is investment in developing and applying rapid ways to screen genetic material (individual plants) in the early stages of evaluation for water productivity (the automated protocols will be appropriate for later stage evaluation when a canopy of a particular clone is to be evaluated);
8. further underpinning (pre-breeding) research focuses on development and evaluation of potential traits that may contribute to WP or WUE (including potential indicator or correlated traits), with particular emphasis on assessments that can be carried out on a large scale in very early stages of evaluation (on individual plants) in order to improve the chances of detecting clones that are more extreme in their phenotype[24].

Proposition #3: Estimate/define value of GM for novel traits

Rationale: The proposition is that a robust method to estimate or define the value of genetic modification as an approach to introduce novel traits is required[25]. There are two basic alternatives – work with a

[23] Basnayake, J, PA Jackson, NG Inman-Bamber & P Lakshmanan 2012. Sugarcane for water-limited environments. Genetic variation in cane yield and sugar content in response to water stress. *Journal of Experimental Botany*, 63, 6023–6033

[24] We note that a current SRA project will provide genetic parameters for water use traits

[25] For example Arcadia Biosciences recently reported that in a greenhouse trial run under low nitrogen conditions, the transgenic sugarcane lines with Arcadia's NUE trait showed substantial increases in biomass and nitrogen uptake compared to conventional

company with an established patent position and well-developed research program in this area (e.g. Arcadia and Syngenta)[26] or seek to develop a unique (and protectable) position. Hence both the selected target and the methodology are important. Practically the development of a unique position in NUE would likely be very difficult. With WUE the issue would be dependent on the actual target. SRA already has projects in this area with major companies in the area, but new gene-editing approaches are likely to create new options[27]. However it will take considerable time for the patent positions to be sorted out, given the recent international activity.

The case: It is a technical option and it provides a much wider range of variation than that which is apparently available within the current germplasm resource.

Objective: A desk-top assessment to develop a robust method to estimate value of genetic modification as an approach to introduce novel traits (technical, commercial, etc).

Recommendation

The recommendation is that:

9. there is investment to develop a robust method to estimate/define the value of genetic modification as an approach to introduce novel traits; the assessment would include the potential to manage a commercially-complex situation (e.g. freedom to operate, patents, partnerships, etc).

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lines, with the leading NUE sugarcane lines showed a 38 to 93 percent increase in biomass over controls (S. J. Snyman, E. Hajari, M. P. Watt, Y. Lu, J. C. Kridl 2015; Improved nitrogen use efficiency in transgenic sugarcane: phenotypic assessment in a pot trial under low nitrogen conditions. Plant Cell Rep (2015) 34:667–669).

[26] Nitrogen-efficient monocot plants, US2013097738 (A1), ARCADIA BIOSCIENCES INC [US]. Methods of increasing nitrogen utilization efficiency in monocot plants through genetic modification to increase the levels of alanine aminotransferase expression and plants produced there from are described. In particular, methods for increasing the biomass and yield of transgenic monocot plants grown under nitrogen limiting conditions compared to non-transgenic plants are described. In this way, monocot plants may be produced that maintain a desired yield while reducing the need for high levels of nitrogen application.

TRANSFORMATION OF SUGAR CANE Syngenta granted US patent 8,742,202 B2 (priority date 2008 or 2009): Methods for the transformation of sugar cane are provided. The methods comprise utilizing sugar cane immature shoots as the source of plant material for transformation. Segments of the immature shoot are excised and transformed by any suitable transformation methodology. In some embodiments, the segments are cultured in embryogenic culture induction medium prior to transformation. Transformation can be per formed via A grobacterium-mediated gene delivery, biolistic transformation, and the like. Transgenic plants are regener ated from plantlets grown under conditions favoring growth of transformed cells while substantially inhibiting growth of non-transformed cells.

Methods for agrobacterium-mediated transformation of sugar cane, CN102958348 (A), SYNGENTA PARTICIPATIONS AG; UNIV QUEENSLAND The present invention provides methods for Agrobacterium-mediated transformation of sugar cane (Saccharum spp.) comprising introducing a nucleotide sequence of interest into a sugar cane callus tissue or cell thereof via Agrobacterium mediated delivery, wherein the sugar cane callus tissue is less than 28 days post-initiation. The invention further provides methods for transforming a sugar cane callus tissue or cell thereof comprising inoculating the sugar cane callus tissue that is less than 28 days post-initiation with an Agrobacterium comprising a nucleotide sequence of interest to produce an Agrobacterium-inoculated sugar cane tissue or cell thereof; and co-cultivating the Agrobacterium and the sugar cane callus tissue to produce a transformed sugar cane callus tissue or cell thereof

The Office of the Gene Technology Regulator (OGTR) of Australia issued a licence to the University of Queensland (UQ) to conduct field trial of GM sugarcane with enhanced sugar content. OGTR allowed the trial to take place from August 2015 to May 2020 in Burdekin, Queensland. The maximum area for the trial is 5ha for field testing with additional 200m^2 for nursery facility and 1,000m^2 for storage and disposal of plant material. The field trial will be conducted to assess the field performance of GM sugarcane and to pinpoint the GM lines exhibiting enhanced sugar content. The project leader of the study is Dr. Luguang Wu, senior research fellow UQ School of Agriculture and Food Sciences

[27] Bortesi L & R Fischer 2015. The CRISPR/Cas9 system for plant genome editing and beyond. Biotechnology Advances 33: 41-52; (doi:10.1016/j.biotechadv.2014.12.006)

Proposition #4: Genetic variation and plant classification

Rationale: The proposition is that there is considerable potential value in the definition of genetic variation and relationships between plants within the nucleus at the molecular (DNA) level in order to classify or assign plants to sub-populations to enable more informed parental selection.

The case: The definition of genetic variation would enable or facilitate a more structured approach to the selection of parents from the nucleus; as a later development, the relationship with phenotypic traits will also be valuable. The following aspects are relevant:

- such genetic analysis is now feasible as a consequence of the advances in DNA technology and in particular, the availability of a 50,000 SNP panel[28] (and there is evidence that this approach to classification will be viable in sugar cane)[29];
- there is also the potential that such genotypic descriptors of sub-populations would correlate with some broad phenotypic features and hence a second component is development of phenotypic descriptors[30]; it is likely that many accessions to the nucleus are well-characterised phenotypically as they are themselves commercial varieties or late-stage accessions from the selection/ evaluation phase so that some preliminary work would be feasible;
- in general, the cost of developing phenotypes is such that high-throughput, automated/semi-automated low-cost recording or screening systems are essential (for some traits this is likely to be especially difficult and hence the definition of the trait that is being targeted is essential); in this respect, the work in the response to smut challenge represents an impressive example;
- there is potential value in methods to define structural genetic variation (for example, cytogenetic approaches complemented by SNP approaches especially incorporating allelic dosage and the presence or 'rare' alleles which may be present in chromosomal segments that are more likely to be shed in the initial crossing)[31].

Objective: Define the genetic variation to enable assignment (classification) of individual plants (including extreme material) to specific sub-populations[32]

Recommendations

The recommendation is that:

10. there is investment to develop a system to classify plants genetically to enable/facilitate a structured approach to parental selection.

[28] Indications are that this SNP panel it has been selected to include only common variants; however given the degree of structural genetic variation within sugarcane it may be that minor alleles are of particular interest as they may reflect retention of chromosomes within a plant and may provide useful information in terms of defining underlying genetic variation and assigning individuals)

[29] Duarte Filho LSC, PP Silva, JM Santos et al 2010, Genetic similarity among genotypes of sugarcane estimated by SSR and coefficient of parentage. Sugar Tech 12(2): 145-149

[30] In parallel there is a case to describe phenotypic variation (e.g. internode length, number of nodes, plant height, stem colour, stem diameter, root depth/structure, stem number/tillering, leaf shape, sugar content, rate of ratoon decline (persistence), etc).

[31] Garcia AF et al SNP genotyping allows an in-depth characterisation of the genome of sugarcane and other complex autopolyploids http://www.nature.com/srep/2013/131202/srep03399/full/srep03399.html

[32] See Wang *et al* 2009, Assignment of individual genotypes to specific forage cultivars of perennial ryegrass based on SSR markers. Crop Science 49: 49-58

Proposition #5: Evaluate plants for specific phenotypes/traits

Rationale: The proposition is that there is a case for considering traits that, based on genetic improvement in other plants species, may be considered as specific target traits in their own right. Three candidates that are particularly relevant to nitrogen and water use efficiency are root depth/structure, and stomatal conductance, and possibly ratooning (or ratoon persistence) under commercial harvesting conditions. Root structure and ratoon persistence are two traits which highlight the value of integrating intensive post-release evaluation into the overall variety evaluation process. The approach would involve comparative evaluation of genotypes that have been selected from among the pool of genotypes based on these characteristics (i.e. comparison of some deep vs shallow-rooted varieties).

The case: *Root depth/structure* – the hypothesis is that selection for increased root depth and/or improved structure can be expected to target a more robust plant through improved access to water and nutrients; the expected outcome would be a plant with reduced phenotypic variance across environments and years. Selection will require an appropriate trait definition and a method of measurement. There is also the possibility that current selection puts more relative pressure on above-ground yield and actually penalises root growth due to a low genetic correlation between the two traits within the selection range.

Ratoon persistence – the rate of yield decline under commercial harvesting is an issue highlighted by growers which is also relevant to a consideration of N application rates and N dynamics (especially given the tendency to use high rates on N); the proposition is that there are one or more component traits that are likely to be major contributors to resistance/resilience to mechanical damage; three possible traits within a genetic evaluation program are recovery from tissue damage, root depth/strength and tillering (this may be superfluous as it seems that it may already been covered within a current project).

Stomatal conductance – the trait may provide an early indicator of yield potential (Basnayake *et al* in preparation[33]) and hence there is a case to assess/develop practical methods to measure the trait in early stages of the selection program.

Objective: Define/assess the potential value of these phenotypes to contribute valuable genetic variation to the development of new varieties (including potential sources of variation from other related species that are candidates for introgression).

Recommendations

The recommendation is that:

11. a project (or related projects) to evaluate genetic variation in root depth/structure and stomatal conductance and the relationships with specific traits such as above/below ground growth (yield), water productivity and NUE, etc are considered for investment (this is not proposed as part of a breeding program as such but rather as tests of hypotheses that may provide phenotypic leads).

[33] Basnayake J, PA Jackson, NG Inman-Bamber, P Lakshmanan in preparation. Variation in stomatal conductance and its genetic correlation with crop productivity.

Nitrogen Use Efficiency

The breeding option

Background

There is good evidence for meaningful genetic variation in nitrogen utilisation[34], whether expressed as internal NUE (iNUE - biomass produced per unit of tissue N) or NUE (biomass per unit N applied). However under the conditions of the primary study by Robinson *et al* (2007) in sugarcane (60 genotypes in a glasshouse trial with two levels of N supplied), the genotype x N interaction[35] was very small, but the genetic variation for biomass production was up to 3-fold higher under low N than under high N supply. The researchers also noted *'however, six of the 10 best performing genotypes produced most biomass and had highest iNUE at low and high N supply suggesting that the underlying cause for high biomass production and high NUE is independent of N supply in these genotypes'.* Whan *et al* (2010) note that there may also be a resource of greater variation in NUE within non-commercial material in which case managed introgression may be an option such as through inter-crossing and detection of appropriate recombinants using marker-trait associations[36].

Definitions

There is some confusion in the literature with respect to definition of NUE traits, and therefore Box 2 presents definitions[37]. As noted by Brauer & Shelp (2010) there is good evidence from breeding programs for variation in both uptake efficiency (UpE) and utilization efficiency (UtE)[38] in several important grain crops.

Box 2: definitions	
Usage index (UI)	= SDM x [(SDM) / (N content of shoot)]
Uptake efficiency (UpE)	= (plant (or shoot) N content) / (N supply)
Nitrogen Use Efficiency (NUE)	
Utilization efficiency (UtE)	= (biomass) / (plant (or shoot) N content)
Internal NUE (iNUE) – Robinson *et al* (2007)	
Agronomic efficiency (AE)	= [(biomass with fertilizer) – (biomass of unfertilized control)] / (N supply)

Empirical model of nitrogen dynamics

The current breeding objective is underpinned by an economic model (which utilises a *relative Economic Genetic Value* or rEGV approach). However as this model was not made available to the consultants, an alternative was developed. The new model recognises the critical importance of yield in determining profitability. A sensitivity analysis of the economic value to a change in the environment (such as the regulatory environment or community pressures to reduce nitrogen inputs or limit the yield of sugarcane

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[34] Robinson, N *et al* (2007) Sugarcane genotypes differ in internal nitrogen use efficiency. Functional Plant Biology 34. 1122-29

[35] A genotype by environment interaction (G*E) is an expression of differences in the relative responses of two or more genotypes in different environments (in this case different levels of N supply); such differences may be reflected as changes in rank or relative changes in scale of a particular genotype in relation to another.

[36] Whan, A *et al* (2010). A quantitative genetics approach to nitrogen use efficiency in sugarcane. Functional Plant Biol 37. 448-54

[37] After Good, AG *et al* (2004). Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? Trends Plant Sci. **9**(12). 597 – 605. doi:10.1016/j.tplants.2004.10.008.

[38] Brauer, EK and Shelp, BJ (2010). Nitrogen use efficiency: re-consideration of the bioengineering approach. Botany. 88: 103-109

in environmentally-sensitive regions) and to input costs is included. The latter impacts were assessed through gross margin analysis to assess the effect on overall profitability. This same approach can be applied to modify the economic weights (reflected in an increase in costs).

Model features

The approach utilises an empirical model of nitrogen dynamics in sugarcane, where N applied and yields are expressed as the total over a 3-year cycle from planting (plant, first and second ratoons); the yield (TCH) response is linear from 200 to 500 kg N applied over the 3 year period (note that this assumes that planting follows a legume). The model also includes a parameter for the loss of N by leaching. The model can be modified in terms of N as required and the full details are in Appendix 2 and Appendix Tables 2.7 and 2.8 with data extracted from a recent trial included as Appendix Tables 2.9 (UQ044).

The model is based on the following inferences derived from a range of literature (including Appendix Table 2.7). While the inputs to the model are approximations and may well be contentious, it is the principle behind the approach that is important. The key facets are as below.

a) TCH responds curvilinearly to N applied (Schroeder *et al* 2010); in the model it is expressed as a $\log_{10}$ function (Table 6) with a response of 0.267 tonnes of TCH per kg N applied in the linear phase (200 to 500 kg N applied over the 3 crops); the dose response provides a potentially powerful way of defining the trait; the parameters derived from this regression are the slope or response function, and the intercept which represents the interpolated yield at zero N applied.

Table 6. Regression relationships (logarithmic) between N accumulation (kg N/hectare, y) and cane yield (TCH tonnes/ha, x) and TCH (tonnes/ha, y) as a function of N applied (kg/ha, x) as a cumulative total over the 3 crops (planting to second ratoon)

	LOG_{10} N ACCUMULATION (y) TCH (x)	LOG_{10} TCH YIELD (y) N APPLIED (x)
Slope	0.00256	0.000362
Intercept	1.62	2.25

b) the total N loss (EOC, end of catchment[39]) is around 5 kg N per crop at a rate of 200 kg N per hectare per annum based on this rate being applied at a Burdekin site (Stewart et al 2003[40]) but the discussion indicated that this may be an underestimate; our empirical model generates values in this range (N losses (N leached at EOC) of 6 to 30 kg N over 3 years at total rates from 390 to 670 kg N applied); to generate an appropriate empirical value for N leached, the function has been derived as a cubic function of N applied [N leached = (N applied (kg/ha))^3/10^7)];

c) N accumulation (kg) per tonne TCH (y) was derived as a function of N applied (x, kg per ha): y = 0.00033N + 0.61

The dose response to N supply can be expanded by using more levels of N such that the maximum yield and other parameters of the N responses are generated. Hence the proposed trait parameters are:

a) **b yield**, the slope or response function in terms of TCH or N accumulation as a function of N supply (through the linear response phase)

b) **y base**, the (interpolated) yield at the base N supply of say 200 kg N per hectare

[39] Brodie JE *et al* 2012 (Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues, priorities and management responses. Marine Pollution Bulletin 65, *81-100)*

[40] http://www.clw.csiro.au/lbi/documents/Estimating%20Nitrate%20Leaching.pdf; Stewart LK, PB Charlesworth, KL Bristow 2003. Estimating nitrate leaching under a sugarcane crop using APSIM-SWIM. Proceedings from: MODSIM 2003 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, July 2003 (note that the paper refers to N loss in two ways as total N loss and as nitrate-n loss)

c) **y 0.8 max**, the N applied at 80% of the maximum yield

d) **y 0.95 max**, the N applied at 95% of the maximum yield

e) **y max**, the maximum yield where there is no further response to N supply

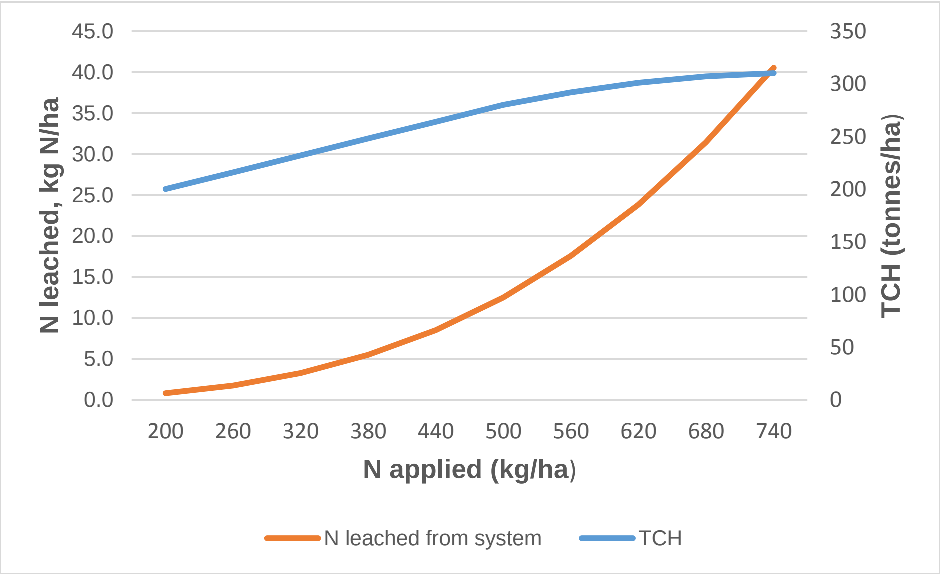
f) **N leached**, the estimate of the N applied at say 6 kg N leached (DIN) per hectare over the 3 crops.

A summary of the indicative trait parameters derived from this model is presented in Table 7 while some of the relationships are presented graphically in Figure 2.

Table 7. Empirical model – the general case: Indicative trait parameters for the response to N applied over three crops (total kg N applied per hectare plant to second ratoon); the **b yield** (response slope through the linear phase) is 0.267 tonnes per hectare per kg N

Proposed trait parameter	N applied (kg/hectare) over 3 crops	TCH parameters over 3 crops			TSH (tonnes /ha) over 3 crops	Nitrogen parameters over 3 crops		
		TCH (tonnes /ha)	Percentage of maximum TCH yield	TCH response (tonnes/ha) per kg N		Accumulation (kg N per hectare)	N uptake	N leached (kg/ha)
Response parameters								
y base	**200 kg N**	200	65%	1.0	26.0	136	68%	0.8
y 0.8 max	**380 kg N at 80% max yield**	248	80%	0.65	32.2	184	48%	5.5
y 0.95 max	**569 kg N at 95% max yield**	295	95%	0.52	38.3	237	42%	18.5
y max	**740 kg N at max yield**	310	100%	0.42	40.3	267	36%	40.5
Nitrogen leaching parameters (based on N limit of 2 kg N leached per year or 6 kg N over 3 years)								
N leached parameter	**392 kg N**	251	81%	0.64	32.7	187	48%	6

Figure 2. Empirical model (general case) outputs over the three crops: Relationships of total yield (TCH, tonne per hectare) and N leached (kg per hectare) to N supplied



However while N loss is related to N rates, it is likely that much of the N is lost due to heavy rain events at times when there is considerable available N in the soil. While the models provide a simple way of explaining the issue and provide a basis for estimating the effect of the level of N applied on leaching losses, they are empirically-based and do not take into account such (stochastic) events. The basic premise is that a reduction in total N loss requires a reduction in N application. Hence the principle is that a reduction in N loss can only be achieved by a reduction in N demand or by an approach that increases plant uptake at the same level of N applied or even better at a lower level of N. Therefore it is important that more robust models are developed and applied to provide more robust assessments. In this respect the APSIM modelling provides a sound basis (e.g. Inman-Bamber 2007[41]).

Financial model

At the next stage, a simple Gross Margin (GM) model was developed (the full details are in Appendix Table 3.2). Table 8 presents the Gross Margin analysis from the empirical model for the overall 'average' crop (general case) over the three seasons.

Table 8. Gross Margin analysis as per the empirical model (general case) over the three crops at variable costs of $16 per tonne of TCH

Base parameters					
N applied (kg per hectare)		200	500	560	740
TCH Yield (tonne per hectare)		200	280	292	310
Percentage of maximum yield		65%	90%	94%	100%
Price per tonne sugar	**N cost per kg of N applied**	**Gross Margin ($/ha) according to TCH yield (tonnes per hectare)**			
		200	**280**	**292**	**310**
$350	**$2**	$2,770	$3,438	$3,508	$3,434
$400		$3,680	$4,712	$4,837	$4,844
$450		$4,590	$5,986	$6,165	$6,255
$350	**$3**	$2,570	$2,938	$2,948	$2,694
$400		$3,480	$4,212	$4,277	$4,104
$450		$4,390	$5,486	$5,605	$5,515
$350	**$4**	$2,370	$2,438	$2,388	$1,954
$400		$3,280	$3,712	$3,717	$3,364
$450		$4,190	$4,986	$5,045	$4,775

In Table 8, the important facets to note are that at high N costs or low sugar prices, there is little or no change in the gross margin above 90% of maximum yield (280 tonne TCH over the three crops). Table 9 presents a sample of the output of this general model in terms of the sensitivity of the GM to the price of sugar and the cost of nitrogen applied. The outputs clearly indicate such sensitivity of the gross margin (in terms of N applied – expressed as GM per kg N) to the sugar price and to the cost of N and the level of N applied.

[41] Inman-Bamber, NG, *Economic impact of water stress on sugar production in Australia*, Proc. Aust. Soc. Sugar Cane Technol., Vol. 29, 2007

Table 9. Sensitivity of the Gross Margin per kg N applied to changes in the cost of N and the price of sugar at variable costs of $16 per tonne TCH (no water costs)

Cost per kg N applied per hectare	Change in GM per hectare per kg of additional N applied								
	Sugar price of $350 per tonne			Sugar price $400 per tonne			Sugar price $450 per tonne		
	200 to 500 kg N	500 to 560 kg N	680 to 740 kg N	200 to 500 kg N	500 to 560 kg N	680 to 740 kg N	200 to 500 kg N	500 to 560 kg N	680 to 740 kg N
Variable costs of $16 per tonne TCH (excluding N with no water costs)									
$2.00	$2.23	$1.17	-$1.21	$3.44	$2.08	-$0.98	$4.65	$2.99	-$0.75
$3.00	$1.23	$0.17	-$2.21	$2.44	$1.08	-$1.98	$3.65	$1.99	-$1.75
$4.00	$0.23	-$0.83	-$3.21	$1.44	$0.08	-$2.98	$2.65	$0.99	-$2.75
$5.00	-$0.77	-$1.83	-$4.21	$0.44	-$0.92	-$3.98	$1.65	-$0.01	-$3.75
$6.00	-$1.77	-$2.83	-$5.21	-$0.56	-$1.92	-$4.98	$0.65	-$1.01	-$4.75

Derivation of economic weights

The methodology for the derivation of economic weights used by SRA (Wei *et al* 2006, 2008) was not available. Therefore the empirical model (Table 7) was used as the basis for the calculation of economic weights. Table 10 presents the gross margins in the response range from 80 to 90% of maximum yield as the basis for derivation of Economic Weights for yield, CCS and fibre content which are in Table 11.

Table 10. Calculation of gross margins in the response range from 80 to 90% of maximum yield as the basis for the derivation of Economic Weights (N at $2 per kg applied, other variable costs of $16 or $22 per tonne TCH and a sugar price of $400 per tonne and 14% CCS) over 3 crops (plant to second ratoon)

	N applied - kg per hectare	Estimated N leached (kg/ha)	Yield (TCH tonne per hectare)	GM per tonne of TCH ($) as function of variable cost per tonne TCH		GM per hectare ($) as function of variable cost per tonne TCH	
				$16	$22	$16	$22
At 80% of maximum yield	380	5.5	248	$4,299	$2,811	$17.34	$11.34
At 90% of maximum yield	496	12.2	279	$4,699	$3,025	$16.84	$10.84
Change between 80 & 90%	116	6.7	31	$400	$214	$12.90	$6.90

Table 11. Derivation of Economic Weights for four regions expressed as Gross Margins (from the data in Table 10 and the rEGV (ex Wei *et al* 2008)) based on estimates for the GM for TCH (at variable costs of $16 per tonne TCH excluding water costs and $2 per kg N) in the range from 80 to 90% of maximum yield

Trait	Unit of genetic change	Source	Weighted	Region			
				North	Burdekin	Central	South
Total cane harvested (TCH)	Tonne per hectare	rEGV		0.45	0.73	0.68	0.75
		Derived for this report[42]		$9.12	$14.79	$13.78	$15.19
CCS (Commercial Cane sugar)	Percentage CCS	rEGV		11.76	13.23	9.81	15.88
		Derived for this report		$238.25	$268.03	$198.74	$321.72
Fibre content	Percentage fibre	rEGV		-1.67	-2.3	-2.76	-3.08
		Derived for this report		-$33.83	-$46.60	-$55.92	-$62.40

[42] The conversions are based on the relative contribution to the total sugar production of 30% from the north. 21% from the Burdekin, 27% from central and 22% from the south

The data in Table 11 have been used to estimate the economic value of the current rate of genetic gain (about $33 per hectare per year excluding fibre - Appendix Table 5.1 based on genetic gain in Table 3).

The required reduction in N leaching losses and the economics of N application

The industry targets for environmentally-sensitive regions are a 50% reduction in N loss by 2017/18[43] and an 80% reduction by 2025.

With sugarcane, the N applied is not usually all taken up by the crop and the difference between the amount of N supplied as fertiliser and that in the harvested cane and trash is the N surplus (Parris 1998[44]). A recent study by Webster et al (2012)[45] measured DIN loss in surface runoff water over 3 years comparing conventional N application (180 kg N/ha/year) with N applied to replace exported N (cane plus trash) from the previous crop (c. 94 kg N/ha/year). DIN losses in surface water averaged about 60% lower in the latter treatment but the 5% lower yield was not significant. The average N surplus was greatly reduced in the replacement fertiliser treatment and N runoff was reduced from about 15 to 10 kg/hectare/year (this is about twice the loss in the empirical model in Table 13) with DIN losses of about 2 kg/hectare/year in the standard treatment but less than 1 kg in the lower N treatment. The major source of N loss in runoff was actually dissolved organic nitrogen (about 10 and 7 kg/hectare/year respectively).

For the present purposes, the current rate of leaching is taken to be in the range of 7 to 10 kg N per hectare per year at an application rate of around 190 kg N per hectare per year (e.g. 19 kg leached at a rate of about 570 kg N applied over the three crops as per Table 7 where yield is about 95% of the maximum). Hence the reduction required is from say 20 to 30 kg over 3 crops to say 6 kg N leached.

Examples of the predicted relationships in the situation where there is a requirement to reduce the rate of N application to reduce N leaching (as a consequence yield is reduced) are given in Table 13. This is the same empirical relationship as presented in Table 8 which has been expanded to include the change from 95 to 90% of maximum yield. The model estimates reductions in N leached (as total N per hectare) of 6.7 kg (in the 90 to 80% of maximum yield range) and 6.3 kg (in the 95 to 90% range).

Table 13. Empirical model: Estimates of reductions in N applied due to N restrictions and the consequent reduction in yield (TCH) over the first three seasons of a crop (plant, first and second ratoons)

	Reduction from 95 to 90% of max yield	Reduction from 90 to 80% of the max yield	Total reduction from 95 to 80% max yield
Reduction in N applied (kg N per hectare)	73	116	189 kg N (from 570)
Reduction in yield (TCH in tonne per hectare)	15.5	31	46 tonne TCH/ha
Reduction in N leached (N in kg per hectare)[46]	6.3 kg N (18.5 to 12.2)	6.7 kg N (12.2 to 5.5)	13 kg N/ha

The economics of N application are illustrated in Table 14 as an extension of Table 13. The sacrifice in gross margin terms at $2 per kg N is estimated at $214 to $400 per hectare over the three crops in the 90 to 80% of maximum yield range and $77 to $214 per hectare in the 95 to 90% range. The impact of a change in the price of N (conceptually as a 'tax' to reduce N use) shows that the price of N would have to more than double ($4.33 to $5.44 in Table 14 without any water costs) per kg of N applied to eliminate the benefit of increasing yield from 80 to 95% of the maximum.

[43] A review of nitrogen use in sugarcane, December 2014 (SRA) but Brodie et al 2012 state that a 50% reduction was due by 2013

[44] Parris, K 1998. Agricultural nutrient balances as agri-environmental indicators: an OECD perspective. *Environmental Pollution* 102, 219–225

[45] Webster AJ, R Bartley, JD Armour, JE Brodie, PJ Thorburn 2012. Reducing dissolved inorganic nitrogen in surface runoff water from sugarcane production systems. Marine Pollution Bulletin 65. 128-135

[46] Based on estimates of 5.5, 12.2 and 18.5 kg N leached over the 3 crops at 80, 90 and 95% of the maximum yield

Table 14. General case: Estimates of reductions in gross margin (GM) per hectare and the 'break-even' price of N where there is no change in GM with a reduction in yield due to N restrictions (as per Table 11)

	$16 per tonne TCH (no water costs)		$22 per tonne TCH (with water costs)	
	Reduction from 95 to 90% max yield	**Reduction from 90 to 80% max yield**	**Reduction from 95 to 90% max yield**	**Reduction from 90 to 80% max yield**
Reduction in GM per hectare ($) at a N cost of $2 per kg applied	$170	$400	$77	$214
'Break-even' price of N ($ per kg N) where change in GM is zero	$4.33	$5.44	$3.05	$3.84

Implications

Hence for the 'general case', given the responsiveness of sugarcane to N, it is unlikely that there will be an economic argument at the individual farm level to reduce N applications unless growers can be convinced of the value of new varieties. The latter must be considered unlikely in the absence of other incentives to change behaviour. Consequently the case for considering NUE in a breeding program must be built on the opportunity foregone should N leaching be restricted by regulation. Therefore this is the basis of the analysis to consider NUE in the later section of this report (*The case to incorporate NUE*).

Given the analysis above (e.g. Figure 2 and Table 7), we take the view that a reduction in N per hectare of 150 to 200 kg over the three crops (570 to 390 kg as per Table 7) will be required to maintain a *licence to operate* in vulnerable areas. According to the general case above, this would necessitate a reduction in yield from about 95% of the maximum to around 80%. Given this premise, we consider the central question as to *how the industry might be able to address this need*. Breeding and management (agronomic practices) are the options and a combination will be required. Therefore we address both in the following sections and have taken the approach of:

a) asking the question, '*what would we have to believe to render either or both of these approaches as viable options from an economic perspective?*', and then by

b) considering some potential methodologies for implementation of a breeding approach.

Defining the trait: NUE

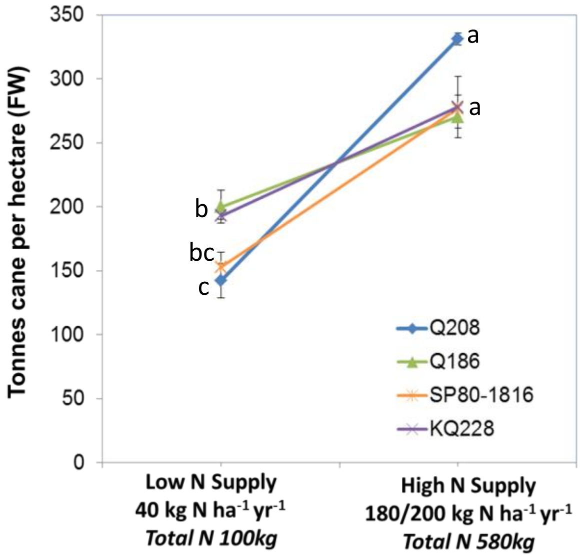
Nitrogen Use Efficiency (NUE) is a complex trait; that is there are several loci that contribute to genetic variation, the expression of the trait is subject to considerable environmental influence (e.g. nitrogen supply, soil type, etc), and there is also evidence of genotype by environment interaction. There are three aspects to consideration of NUE namely: the scale of the issue, the potential for a breeding solution and the rate at which a material change could be introduced.

In terms of the desired impact on N leaching, the required change as above is 50% to 80% reduction in N losses. The pattern of leached N loss is incorporated in the model as a curvilinear function (such as quadratic or cubic). Given that a regulatory option is further restriction on N applied (and leached), it is important to consider the relationship between N applied and N accumulation by sugarcane across environments and these relationships between varieties within environments.

The efficiency of utilisation of exogenous nitrogen inputs (NUE) into the system is defined as the yield per unit of N applied. However the reality is that at low N inputs into the system (20 to 40 kg N per hectare or 100 kg over the 3 crops as per Figure 2), the NUE is very high and the net uptake of N actually exceeds N supply. At such low levels of N, the plants are mining soil N. An example from a recent trial (UQ044) where sugarcane was grown at two levels of N in two environments is in Appendix Table 2.9.

There is now a substantial literature around defining NUE as a trait in many plant species: for example, should it be defined at a low level of N input or a high level or under alternating high/low levels. Hence trait definition is an issue in itself as discussed earlier, with the underlying issue being that sugarcane is highly responsive to N. Figure 3 presents the dose response (albeit with only two N rates) from UQ044[47] trial for four varieties. The range in dose response was from c. 0.12 to 0.40 tonnes TCH per kg N/hectare.

Figure 3 (from UQ044 Report). Cumulative yield (TCH) of representative genotypes Q208, Q186, KQ228 and SP80-1816 at low and high N supply for the three crops (plant to second ratoon) at Burdekin site; letters indicate statistically significant differences (ANOVA Tukey's post hoc $p<0.05$) between genotypes; note that 'total N' refers to the cumulative fertiliser application over the three year crop cycle[48].



Methodology for NUE

The general empirical model as described (Figure 2) can be applied at the variety level. For example, two of the trait parameters from the dose responses for the four varieties at the Burdekin site in Figure 3 (note that the N applications are less than in our model as planting followed a legume fallow) were:

y base, c. 140 to 200 tonnes per hectare at the base N supply of 100 kg N per hectare;

b yield, c. 0.12 to 0.4 tonnes of cane per hectare per kg N applied (assuming that it was linear).

Therefore the model has been extended to provide for consideration of appropriate phenotypes or a set of phenotypes to define NUE. Given the analysis, we propose that the ideotype required is one that:

- has good yield at low applications of N (high y base at say 200 kg N over say 3 crops), but
- is relatively insensitive to additional N applied during the linear response phase (low b value).

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[47] Robinson N *et al* 2009. SaveN Cane: Developing selection tools for N-efficient sugarcane (SRA Project Code 2009/044)

[48] UQ044 Report Table 7. Genotypes with proposed characteristics selected for further evaluation characterisation of NUE traits in controlled conditions and low N input field trials (not that these 4 clones are 4 of 15 proposed for further work)

Clone	**Origin**	**Proposed characteristics**
KQ228	Australian	High TCH, less responsive to applied N
Q186	Australian	High relative yield at low N, less responsive to applied N
Q208	Australian	High TCH at high N, Responsive to N applied
SP80-1816	Brazilian	High TCH at low N input

The underlying hypothesis is that such plants utilise soil N very effectively and, that as a result, the leaching of N will be reduced. While investigation of this hypothesis will require research, if it is shown to be appropriate, then the phenotype of the candidates can be assessed in two stages:

- initial screening/evaluation of plants at only a low level of N application;
- the next stage of screening would take selected clones that would then be evaluated across a range of N application rates to derive the response slope (*b value*) and the *base TCH* functions.

As an example, we developed a *varietal variation concept* and modelled three varieties with a range of NUE parameters based on the responses in Figure 3. Table 15 summarises the NUE parameter for the three putative varieties that represent a range of responses to applied N. Table 16 summarises the data for N leached and TCH yield. Table 17 presents components of TCH and N responses per the model.

The features of the three varieties are: variety 1 exhibits a very high rate of response to applied N (0.40 tonne per kg N in the linear response phase), but a relatively low yield of 160 tonne TCH at the base rate of 200 kg N (*base TCH*) over the three crops. By contrast, variety 3 has a high *base TCH* (256 tonne) and a low response rate of 0.10 tonne per kg N through the linear response phase). Variety 2 is intermediate.

Table 15. Proposed varietal variation concept – marginal NUE within ranges of N applied: the 3 varieties represent a range of responses to applied N with a linear response from 200 to 500 kg N/ha over 3 crops

	Putative Variety 1			**Putative Variety 2**			**Putative Variety 3**		
	Very high marginal N response			**Intermed marginal N response**			**Low marginal N response**		
N applied (kg/ha)	200-500	500-560	560-740	200-500	500-560	560-740	200-500	500-560	560-740
NUE: Marginal TCH response (tonne/kg N/ hectare)	0.400	0.367	0.208	0.233	0.214	0.104	0.100	0.100	0.058

Table 16. Proposed varietal variation concept – N leached and TCH yield as functions of N application

	Putative Variety 1				**Putative Variety 2**				**Putative Variety 3**			
N applied (kg/ha)	200	500	560	740	200	500	560	740	200	500	560	740
N leached (kg N/ha)	1	13	18	41	1	13	18	41	1	13	18	41
TCH Yield (tonne/ha)	160	280	292	330	215	285	292	310	256	286	292	300
% of maximum yield	52%	90%	94%	106%	69%	92%	94%	100%	83%	92%	94%	97%

Table 17. Proposed varietal variation concept – components of the TCH and N responses

Parameters	**Components of response**	**Putative Variety**		
		1	2	3
TCH yield (Tonne per hectare)	b yield (NUE or TCH per kg N applied) in linear phase of 200 to 500 kg N	0.400	0.233	0.100
	Base TCH yield at 200 kg N applied	160	215	256
	Leaching parameter: TCH yield at N loss (N leaching limit) of 2 kg N per year (reduction from 30 kg N to 6 kg N over 3 years)[49]	237	260	275
Nitrogen applied (kg per hectare over the 3 crops)	N (kg/ha) applied at 80% of maximum yield	460	341	40
	N (kg/ha) applied at 95% of maximum yield	703	580	455

Table 18 presents the GM analysis for the *varietal variation concept* at a range of sugar and N prices.

[49] Relevant to the 50% reduction in N load at EOC by 2013 (Total N plus DIN, DON, PN); Brodie *et al* 2012 (Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues, priorities and management responses. Marine Pollution Bulletin 65, *81-100)*:

Table 18. Proposed varietal variation concept: Gross margins ($ per hectare) as a function of N applied (total over 3 crops) for three putative varieties at sugar prices of $350 to $450 per tonne, N costs of $2 to $4 per kg N applied and variable costs of $16 per tonne TCH (linear N response from 200 and 500 kg N)

		Gross Margin analysis according to TCH yield (tonnes per hectare) and N applied											
		Putative Variety 1: Very high marginal N response				**Putative Variety 2: Intermediate marginal N response**				**Putative Variety 3: Low marginal N response**			
TCH (tonne/ha)		**160 t**	**280 t**	**292 t**	**330 t**	**215 t**	**285 t**	**292 t**	**310 t**	**256 t**	**286 t**	**292 t**	**300 t**
N applied (kg/ha)		200	500	560	740	200	500	560	740	200	500	560	740
Price per tonne sugar of $350													
Cost per kg N applied	**$2**	$2,136	$3,438	$3,508	$3,751	$3,008	$3,517	$3,508	$3,434	$3,658	$3,533	$3,508	$3,275
	$3	$1,936	$2,938	$2,948	$3,011	$2,808	$3,017	$2,948	$2,694	$3,458	$3,033	$2,948	$2,535
	$4	$1,736	$1,804	$2,388	$2,271	$2,608	$2,517	$2,388	$1,954	$3,258	$2,533	$2,388	$1,795
Price per tonne sugar of $400													
Cost per kg N applied	**$2**	$2,864	$4,712	$4,837	$5,252	$3,986	$4,814	$4,837	$4,844	$4,822	$4,834	$4,837	$4,640
	$3	$2,664	$4,212	$4,277	$4,512	$3,786	$4,314	$4,277	$4,104	$4,622	$4,334	$4,277	$3,900
	$4	$2,464	$3,712	$3,717	$3,772	$3,586	$3,814	$3,717	$3,364	$4,422	$3,834	$3,717	$3,160
Price per tonne sugar of $450													
N cost per kg N applied	**$2**	$3,592	$5,986	$6,165	$6,754	$4,964	$6,111	$6,165	$6,255	$5,987	$6,136	$6,165	$6,005
	$3	$3,392	$5,486	$5,605	$6,014	$4,764	$5,611	$5,605	$5,515	$5,787	$5,636	$5,605	$5,265
	$4	$3,192	$4,986	$5,045	$5,274	$4,564	$5,111	$5,045	$4,775	$5,587	$5,136	$5,045	$4,525

Table 19 expands the analysis and presents the change in yield over the linear response phase (of TCH yield to N applied). This provides a further component of methodology to develop an Economic Weight for N application in terms of its impact on yield. Likewise Table 20 presents the gross margin responses.

Table 19. Proposed varietal variation concept: Changes in yield (TCH, tonne per hectare) over the linear response phase (200 to 500 kg N per hectare over the 3 crops) for the three putative varieties

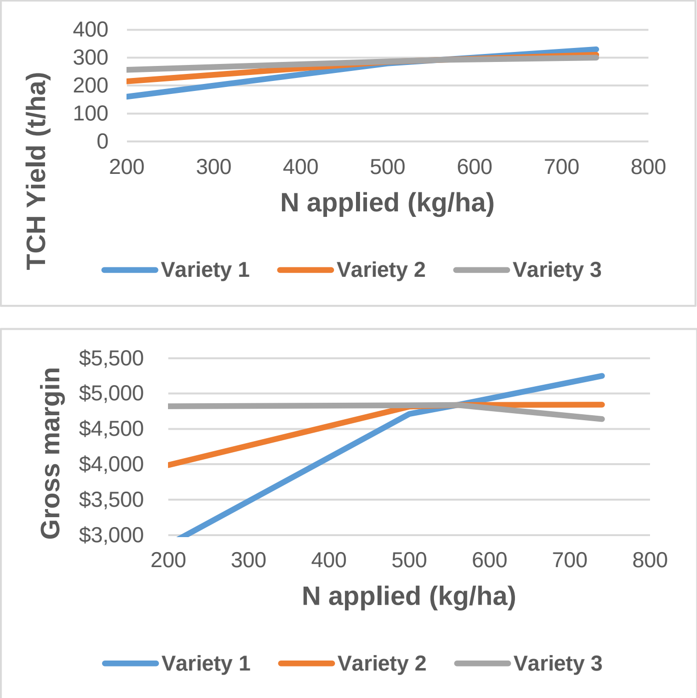
Gross Margins (GM)	**Putative Variety 1: Very high marginal N response**			**Putative Variety 2: Intermediate marginal N response**			**Putative Variety 3: Low marginal N response**		
	200 kg N	500 kg N	From 200 to 500 kg N	200 kg N	500 kg N	From 200 to 500 kg N	200 kg N	500 kg N	From 200 to 500 kg N
TCH (tonne/ha)	160	280		215	285		256	286	
TCH response to N (tonne/ha/kg N)			0.400			0.233			0.100

Table 20. Proposed varietal variation concept: Changes in GM over linear response phase (200 to 500 kg N/ha over the 3 crops (sugar at $400/tonne, N at $2 per kg, variable costs of $16 per tonne TCH)

Gross Margins (GM)	**Putative Variety 1: Very high marginal N response**			**Putative Variety 2: Intermediate marginal N response**			**Putative Variety 3: Low marginal N response**		
	200 kg N	500 kg N	From 200 to 500 kg N	200 kg N	500 kg N	From 200 to 500 kg N	200 kg N	500 kg N	From 200 to 500 kg N
GM per hectare	$2,864	$4,712		$3,986	$4,814		$4,822	$4,834	
GM change/ha			$1,848			$828			$12
GM change per kg N applied			$6.16			$2.76			$0.04

Figure 4 presents some of the model predictions from Tables 15 through 19 graphically.

Figure 4. Proposed varietal variation concept: Relationships between – A) the TCH and N applied or NUE (Tables 15, 16, 17, 19), and B) Gross margins ($ per hectare) as the total over the three crops for the three putative varieties at a sugar price of $400 per tonne at $2 per kg N applied (Tables 18, 20).



Incorporating NUE within the system

The rationale behind incorporation of a nitrogen utilisation trait within the selection index is to reduce N use in the sugarcane system to reduce leaching of N. Hence there are two approaches to incorporation of NUE within the selection index:

- direct incorporation as another trait: the cost of N is increased in order to reduce the economic weight (EW) for TCH;
- mediation through the impact on yield: this recognises the importance of N in driving yield.

The second is preferred as it is a much more flexible approach and the impact of the inclusion of NUE can be defined clearly. It also treats the impact of N in much the same way as disease traits are currently managed within the SRA genetic evaluation system. In essence this is a form of tandem selection where breeding values are derived using the basic index (being made up of the key drivers of profitability) and then the susceptibility to a particular disease in terms of its impact on yield is incorporated. In this context, the impact of N use is defined through its effect on TCH only in terms of the potential loss of yield. The Economic Weight can be defined as a slope function which is:

Change in Gross Margin ($ per kg N applied) = 20.4*NUE - 2.0,

where NUE is the relationship between yield (TCH tonne per hectare, y) and N (kg N applied per hectare, x) in the range from 0.40 to 0.10[50].

[50] $6.16 /kg N applied at NUE of 0.400, $3.44 at 0.267, $2.76 at 0.233 & $0.04 at 0.100 derived from GM analyses in Tables 9 & 18.

Other approaches to improving the genetics of NUE

The current program involves the generation of large numbers of individuals which are then evaluated in a range of environments. There are two complementary approaches: one is being used (the introduction of related genetic material) and another is being trialled internationally (genetic modification).

In terms of N utilisation, it is important to recognise that *S. spontaneum* and *S. officinarum* discriminate against soil nitrate and prefer ammonium ions (nitrate at 40 to 50% of ammonium uptake). Given that nitrate is the predominant form of soil nitrogen, the ability to take up nitrate is very important. In contrast to the situation with *Saccharum*, *Erianthus*, a related species, took up nitrate at about 80% of the rate for ammonium ions. Thus *Erianthus* which is being incorporated in crosses at the PAT stage may provide one way in which to enhance NUE.

Genetic modification offers a potential alternative or complementary approach to selection and breeding and there is some evidence of success in early evaluations in South Africa[51].

Economic benefits

Background

The potential benefits of incorporating a NUE trait in the selection index are evaluated in terms of their potential to maintain or improve industry profits (at the current industry size) through:

- cost savings to growers (lower N fertiliser costs), and/or
- avoided costs (e.g. avoiding losses in income and profit due to restrictions on input use or other activities which lead to reduced cane yield or area grown).

In addition there are potential off-farm benefits, specifically lower N application leading to lower EOC N load (Total N and DIN, DON, Particulate N losses) off farm and associated environmental benefits.

Baseline

The baseline case is a continuation of current farming practices but with the breeding impact incorporated. The important facets are:

- the NUE trait can be readily incorporated in the selection index for the respective regions;
- selection on the NUE trait delivers an N saving with no change in TSH (or a small increase); and
- no changes in farm practices (management, prices or regulation) and area planted is unchanged.

Otherwise scenarios

The potential gains from breeding are then compared against the otherwise case – where farm practices are expected to change in response to a number of factors including N prices, further adoption of NUE technologies, new technologies, additional regulations (which might for example limit the level or timing of N application or indeed growing of sugar cane in some areas) or industry responses to the these additional regulations.

The baseline represents the use of breeding only (that is new varieties). Given both the uncertainty as to whether additional regulation concerning N use might eventuate, two otherwise case scenarios have been developed, both of which are necessarily simplifications:

- Scenario 1: Continuing development and adoption of on-farm practices that improve NUE, with no additional regulation — the N saving required from new varieties through breeding is thus reduced;

[51] Snyman, SJ, E Hajari, MP Watt, Y Lu, JC Kridl 2015. Improved nitrogen use efficiency in transgenic sugarcane: phenotypic assessment in a pot trial under low nitrogen conditions. Plant Cell Rep (2015) 34:667–669.

- Scenario 2: Baseline plus additional regulation, where regulation results in a significant reduction in cane production as N use is restricted and/or sugarcane is not permitted in some regions; Scenario 2 would arise if Scenario 1 did not occur (i.e. if further improvement in N management failed).

Farm level budgeting using industry average and best practice indicates that N use ranges from around 140 to 200 kg N per hectare per year (Appendix Table 2.4). Financial analyses of the otherwise scenarios are presented in Appendix 2. Suffice to say that any strategy will require both breeding and management approaches but the practicality of both approaches in terms of accessible genetic variation for exploitation through breeding and the cost-effectiveness of alternative forms of N (slow release) or other management interventions are speculative at this point, although fertigation does also provide some potential[52].

As outlined with the *proposed varietal variation concept*, we have made the case that inclusion of NUE in the sugar cane breeding system is worthy of serious investigation and there are reasonable grounds to consider that selection and breeding for NUE could reduce N requirement and N use. However, estimating the potential gains is speculative as there is little R&D in Australia or elsewhere to guide the assessment. Against this background, the analysis used illustrative estimates of potential gains. Further, it is assumed that in selecting for NUE there is no trade-off in performance for other traits (such as CCS).

In addition to benefits to growers, improved NUE (if it increased TCH across the industry) could benefit millers. A higher volume, other things being equal, should lower average milling costs with benefits to millers and growers. The financial value of off-farm environmental benefits has not been estimated but one way where it has been accounted for is via the increase in the cost of N applied (Table 22 above).

The baseline case is a continuation of current farming practices (noting that these differ between regions) with the breeding impact incorporated. However in the main, growers apply N (along with other elements) to the plant and ratoon crops. The level of N applied differs between and within farms depending upon growers' assessments of N requirements (preferably following the Six Easy Steps) which reflect N status and crop yield expectations. Typically, N and other nutrients are 'applied' as a 'combined application' (as fertilizer, or mill mud or other nutrient sources, including prior legume crops) on plant crops and at the ratoon stages; some growers apply split applications of N or apply N more evenly (e. g. with fertigation).

This analysis points to significant cost savings that could be realised by growers if more N-efficient varieties can be grown, given no trade-off with other traits (yield, sugar content, etc). In addition there are the off-farm environmental benefits through reduced N leaching. Given that TSH and other factors remain unchanged, growers would be expected to select improved NUE varieties as there is a N cost saving and no downside on TSH. A key issue for realisation of off-farm environmental benefits is adoption by growers which will be driven primarily by on-farm cost savings (in the absence of regulation).

Estimated expected benefits from breeding

The benefits have been estimated on the basis that, in the short term, some existing varieties will be identified as being more nitrogen-efficient and that these will be planted in the most "vulnerable" areas (Wet Tropics and Burdekin) but also in other areas enabling an annual reduction of N applied per hectare, without impacting TSH yield. The savings to growers are modelled on the following basis (Box 3).

Box 3: Model of savings

- Cost savings potentially apply to all regions
- Plant crop plus 4 ratoons (each 20% harvested area) with N savings in the plant and ratoon crops
- Gain from first improved NUE varieties: N saving of 20 kg per hectare (the first harvest will be in 2021)

[52] Thorburn P, j Biggs, K Bristow, H Horan & N Huth, Benefits of sub-surface application of nitrogen and water to drip irrigated sugarcane (http://www.netafim.com.au/article/benefits-of-sub-surface-application-of-nitrogen-and-water-to-drip-irrigated?49718)

- Gain from subsequent improved NUE varieties: Each new variety offers N saving of 4 kg per hectare over the previous variety (e.g. saving from new varieties planted in 2021 and first harvested in 2022 is 24 kg N per hectare)
- New varieties: Released annually and used in plant crop for that year
- Eventual gain achieved: N saving of 60 kg per hectare per year (2031 is the year of the first harvest of this variety)
- Probability of successful release of new improved NUE varieties: 50%
- Adoption: 30%, 60% or 100% of the plant crop is planted to the new varieties
- Price of N of $2 or $4/kg (real 2016 prices)

Estimated expected benefits under Scenarios 1 and 2

Under Scenario 1 it is postulated that a range of other (non-variety) developments will lead to improved NUE across the Wet Tropics and Burdekin and that these other developments will achieve benefits equivalent to those realised by breeding as per the Baseline.

Under Scenario 2, gains from the additional investment in plant breeding include the benefits in the baseline case plus the avoided income losses which would occur under additional regulation (with these losses beginning around 2023).

Estimated potential annual benefits in 2036

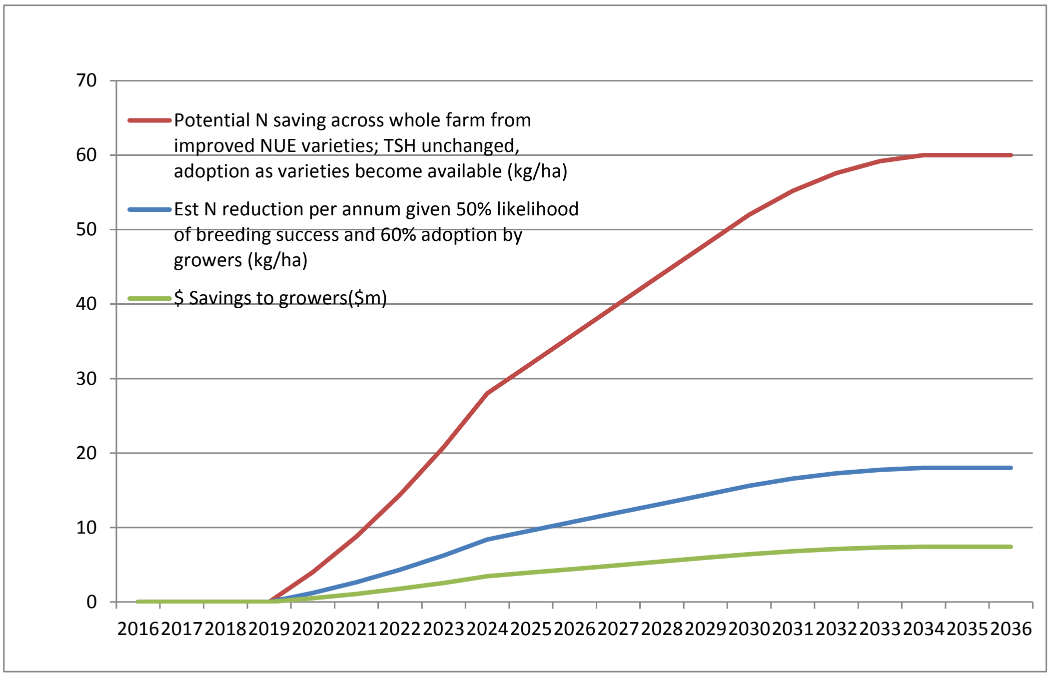
Indications of the benefits are shown in Table 21 as the Baseline.

Table 21. Summary of potential benefits from improved NUE through approaches that generate an annual saving of 60 kg N per ha in 2036 (100% adoption, 100% likelihood of success,)

	On-farm (industry) benefits (2015 prices, undiscounted)	**Off farm (environmental) benefits**
Improved NUE resulting from breeding compared to Baseline/ otherwise case as below		
Baseline (current practices and regulations with new investment in breeding)	N cost savings: estimated at $45 mn per year in 2036 across all growing areas; 54% ($25 mn) in the Wet Tropics & Burdekin; some expansion in cane production could be expected as profitability has increased but this has not been estimated	Reduced N losses through leaching generates an environmental benefit; the significant off-farm benefit has been noted but not estimated
Scenario 1 (continued improvements in NUE on-farm, with breeding)	N cost saving from new cultivars as above, but with ongoing improvement in NUE through improved on-farm practices. If 75% of the 60 kg N per hectare in annual savings arises from management changes, only 25% would be required to come from additional breeding investment. The estimated net benefit of the breeding in 2036 would then be $11.2 mn per annum across all regions, with 54% ($6.2 mn) in the Wet Tropics and Burdekin. But if breeding can achieve 60kg/ha N saving (i.e. baseline above) and management changes are similar, the total annual N saving is then worth $90 mn in 2036 across all growing areas, with 54% ($49 mn) in the Wet Tropics and Burdekin	Reduced N losses at EOC through leaching generate an environmental benefit
Scenario 2 (Baseline, with additional regulations restricting sugar cane production)	Baseline comparison plus avoided losses: production & profitability of sugarcane is maintained in all regions (whereas it would have been reduced by say 33% in the Wet Tropics); the estimated avoided loss in grower profitability (gross margin) is $49 mn in 2036 and the total benefit is $74 mn ($25 mn + $49 mn); the avoided loss in millers' income and the impact on net regional economy were not estimated.	There is no net environmental benefit as regulation is assumed to deliver off-farm benefits (environmental) that are equivalent to those from the breeding program (although there might be a timing issue, depending upon when regulations are applied)

The time profile of annual benefits (N savings and value of N savings) against the Baseline is shown in Figure 5.

Figure 5. Estimated industry benefits in the vulnerable regions: Impact of replacing standard varieties with highly N efficient varieties (equivalent to combination of Varieties 2 & 3, Table 17) with no change in Total Sugar Harvested (the vulnerable regions are the Wet Tropics and Burdekin Delta, areas which represent 54% of the total sugar harvested in Australia).



Net Present Value of benefits

With 100% adoption of improved NUE varieties (holding the other factors constant) the total cost savings (60kg N per hectare by 2036 at $2 and $4/kg N, 2016 prices) in the Wet Tropics and Burdekin (206,000 ha harvested) (Figure 5 and Table 22) have been estimated as $69 mn in NPV terms over 20 years to 2036 (5% discount rate, $2 per kg N applied).

- With estimated additional R&D (breeding costs) of $0.50 mn per annum each year (NPV $6 mn), the NPV is estimated at $63 mn (IRR 54%).
- At an N cost of $4 per kg, the NPV of the net cost savings increases to $132 mn.

Under the Baseline of 60% adoption, the benefits are proportionately less (NPV $35 mn and an IRR of 42%). Under Scenario 1:

- If on-farm management changes also achieve an N saving of 60kg/ha by 2036 across 60% of production, the benefits from the N saving are about double the Baseline ($70m and 80%)
- If however total N savings from all sources (farm management and breeding) are 60 kg N/ha, and breeding is responsible for 25% of the saving, the estimated benefits from breeding are $16 mn (NPV) or an IRR of 14%.

Table 22. Investment returns: Net Present Value (NPV) of replacing standard varieties with highly N-efficient varieties (equivalent to combination of Varieties 2 & 3, Table 17) with no change in Total Sugar Harvested in the vulnerable regions (Wet Tropics, Burdekin Delta representing 54% of the total sugar harvested)

	$2 per kg N applied		**$4 per kg N applied**	
	60% adoption	**100% adoption**	**60% adoption**	**100% adoption**
NPV of savings to growers ($ mn) at discount rate of 5%	$41	$69	$83	$138
NPV of savings to growers less R&D costs ($ mn) at discount rate of 5%	$35	$63	$76	$132
Internal Rate of Return (IRR)	42%	54%	59%	74%

Under Scenario 2, the gains from additional plant breeding are the benefits against the baseline plus the avoided losses which would occur under additional regulation (with these losses beginning around 2023). The estimated investment returns are substantial, primarily driven by the avoided losses in the Wet Tropics and Burdekin (Appendix Table 2.8).

- The NPV of the net benefits is around $343mn
- The IRR is estimated at around 94%

This analysis points to the significant cost savings that could be realised by growers if more N-efficient varieties could be developed and released, given no trade-off with cane yield, sugar content or other factors. In addition, there are the broader off-farm environmental benefits through reduced N losses to waterways. The annual reduction in N use by 2036 would be 3,700 tonne N per annum[53] and in the 20 years to 2036, the total reduction in N use would be 42,000 tonnes.

Table 23. Summary of the estimates of the value of investment in breeding taking the approach of *what would I have to believe to justify an investment in breeding* in terms of meeting a required hurdle rate or internal rate of return on the investment

Estimating the economic value of gains due to breeding: the base model (Nitrogen at $2 per kg applied)					
Value proposition	Internal rate of return	20%	42%	54%	75%
	Success factor: Adoption x probability of success	0.4 * 0.25	0.6 * 0.5	1.0 * 0.5	1.0 * 1.0
	Adoption x probability of success	10%	30%	50%	100%
	Estimated gross value to industry	$13	$41	$69	$138
	Estimated net value to industry	$7 mn	$35 mn	$63 mn	$132 mn

53 205,000 ha at 60kg/ha at 60% adoption at 50% R&D likelihood of success = 3,700 tonnes

Water Use Efficiency

Analysis

Scale of the issue

The first aspect is estimation of the net economic loss or gain value if water stress could be alleviated in cane-growing areas and the potential gains have been estimated by Australian researchers[54] (2007). The methodology is summarised in Appendix 3 (data in Appendix Table 3.11). The main features are: water stress factors were based on the logic that plant growth was directly related to water supply (e.g. if roots can supply 80% of the daily water demand, then biomass will accumulate at 80% of potential for the day and the stress factor will be 0.8); other factors were assumed to be non-limiting.

Therefore in the present analyses, the same methodology has been applied as these original water stress factors are likely as appropriate today as in 2007. While there will have been some changes due to on-farm management changes (trash retention, controlled traffic farming and other precision techniques) and perhaps varieties, the estimates are sufficiently robust for the present analysis. The results are summarised in Table 23 (see also Appendix Table 3.11). The estimated increase in yield is about 15% (0.65 m tonne sugar) which, at $400 per tonne sugar, would increase gross income (or reduce gross income forgone) by about $260 mn per annum (compared with $230 mn in the original 2007 analysis with sugar at $350 per tonne, Inman-Bamber 2007).

Table 23. Estimated yield losses (tonne sugar and value) due to water stress by sub-region (water stress factors are from Inman-Bamber 2007)

Region	Total production: 2005 - 2014		Water stress factor	Yield foregone	Estimated yield loss	
	Percentage of crop by area	Sugar (m tonne)			Tonne sugar	Value at $400/t
Northern & Herbert	30%	1.31	0.887	12.7%	0.167 mn	$67 mn
Burdekin	26%	1.14	0.956	4.6%	0.053 mn	$21 mn
Central	27%	1.15	0.811	23.3%	0.268 mn	$107 mn
Southern	17%	0.74	0.818	22.2%	0.164 mn	$65 mn
Weighted mean or total		**4.34**	**0.869**	**15.3%**	**0.65 mn**	**$261 mn[55]**

The usual approach in investment analysis of industry benefits due to alleviating a problem (water stress in this case) is to estimate the benefits or financial gain in terms of profits foregone rather than gross income foregone. The financial gain to industry (millers and growers) from alleviating water stress can be measured as the additional gross margin (gross income minus the variable costs of production), although strictly spreaking the additional marginal costs of production should be used, and these are likely to be less than the average variable costs of production[56]. For present purposes, the average gross margin (growers) and gross profit (millers) has been used (Table 24 and Appendix Table 3.12). This approach will lead to the financial gains being underestimated but, given the limited data available at the regional

[54] Inman-Bamber, N.G., *Economic impact of water stress on sugar production in Australia*, Proc. Aust. Soc. Sugar Cane Technol., Vol. 29, 2007

[55] Of the total, 35.3% ($92 mn) of the revenue accrues to millers (with 48% gross profit), and the remaining 64.7% ($169 mn) accrues to growers (38% gross margin).

[56] The average gross margin for growers has all variable costs deducted; the marginal gross margin for a yield increase would have only the additional harvesting and additional other input costs needed to achieve a yield increase, for example additional fertiliser

level, using average gross margins was reasonable in the circumstances and certainly preferable to the gross income approach (using an ex mill sugar price) adopted in earlier analyses.

The data in Table 24 help define the scale. At 14% CCS, 0.65 mn tonne of sugar is equivalent to 4.65 mn tonne total cane harvested at a cost of $153 mn per annum ($261 mn less $108 mn, Table 24). Hence the value realised from completely correcting the water deficit in terms of gross profit accruing to the millers is estimated at $44 mn with a gross margin to the growers of $64 mn.

Table 24. Estimated profit foregone (millers) and gross margin forgone (growers) due to water stress by sub-region (Appendix Tables 3.11 & 3.12)

	Gross Profit (GP) or Gross margins (GM): Budget data 2013-14 ($/t sugar)		**Value of yield increase (based on Budget data 2013-14)**			
	Miller GP	**Grower GM**	**Miller Gross income**	**Miller GP**	**Grower Gross income**	**Grower GM**
Northern - Herbert	$71	$97	$25.0	$12.0	$42.4	$16.3
Burdekin	$65	$108	$7.1	$3.4	$13.9	$5.7
Central	$66	$101	$37.0	$17.8	$70.1	$27.0
Southern	$67	$92	$22.9	$11.0	$42.4	$15.0
Total			**$92 mn**	**$44 mn**	**$169 mn**	**$64 mn**

Given the above estimates of the value of the yield increases, the NPV is estimated at $180 mn (20 years to 2036, 5% discount rate); this is realised through being able to select varieties to *fully* overcome the water stress yield gap with new varieties first harvested in 2021 (with 4 ratoons with the first crop being 20% of the total crop); i.e. 100% R&D success and 100% adoption; note that this excludes any pre-breeding R&D costs, and any additional costs of the breeding program and pre-release evaluation.

There is also the potential for savings in irrigation costs (water purchase plus pumping); in this case, if improved varieties could reduce total costs by 2.5% (25% reduction in irrigation costs), this would generate an additional $6m in NPV terms. The value of a 2.5% saving (small in relation to the yield effect) is included within the NPV of $180 mn. If the savings in irrigation costs were doubled to 50%, then the NPV would increase to $186 mn.

Potential solutions

The fact that there is a substantial yield gap due to the water deficits suggests that it is not economic to address this using current technologies (irrigation systems, irrigation management, farm management in rain-fed systems) or alternatively there is an adoption issue. However in the absence of new WUE variety development, some improvement in current production systems can be anticipated. This includes improvements in WUE within the scope of the current breeding program. These improvements taken together, might, say, reduce the yield gap by 50% (as per Table 26). This implies that further R&D, outside of relatively small modifications to the existing SRA pre-breeding R&D and breeding investments, would be required to deliver a 50% reduction in the theoretical yield gap.

The breeding option

Background

The potential benefits of incorporating a WUE trait in the selection index have been evaluated in terms of the potential to maintain or improve whole of industry profits/margins (growers and millers), at current industry size or with expansion through:

- cost savings to growers (lower water costs, purchase and pumping) where irrigation costs are significant in all regions except the Wet Tropics, and/or
- productivity gains to growers (improved TCH from improved WUE) which, at the whole of industry level could lead to cost savings to millers given total an increase in TCH volume, and/or
- avoided costs (e.g. avoiding income and profit losses due to restrictions on input use or other activities which lead to reduced cane yield or area grown).

In the first instance, the potential gains in each of these areas have been estimated against a baseline on the basis that:

- a WUE trait can be readily incorporated in the selection index for the respective regions,
- selection on the WUE trait delivers a water cost saving but there is no change in TCH compared with other varieties released at the same time, and
- farm practices (driven by either management, prices or regulation) and the area planted remains the same as today.

The potential gains are then assessed against the otherwise case – where farm practices are expected to change in response to water costs and/or additional regulations (which might limit the level or timing of water application or restrict growing of sugar cane in some areas) with further adoption of technologies to improve the efficiency of water use.

Defining the trait

Water Use Efficiency (NUE) is a complex trait; that is, there are several loci that contribute to genetic variation, the expression of the trait is subject to considerable environmental influence as yield is critically dependent on water availability and there is also considerable genotype by environment interaction (e.g. interaction with N supply). The definition of WUE is important to the discussion and the term water productivity (WP)[57] (yield per hectare per unit of water supply) is more appropriate.

The potential value of incorporating WUE in the breeding program

There are three aspects in respect of considering WUE namely: *the scale of the issue* (as above), *the potential for a breeding solution* and *the rate at which a material change could be introduced*. However there are considerable unknowns, so that we ask: *what would we have to believe to invest in incorporating WUE into the breeding program?* In response, we note that would have to believe that by including WUE in a breeding program, there would be a substantial economic gain and that inherently superior cultivars that would not have otherwise been identified/selected would be found and that these clones would be commercially viable, and would be made available to producers within a reasonable time-frame and would increase/maintain yield in water-stressed situations.

In respect of a breeding program, there are other costs (modelled as): pre-breeding R&D (8 years at $125K per year), additional costs of breeding program ($200K per year from year 4 to 13) and pre-release evaluation of potential varieties ($100K per year from year 4). When these are accounted for, the NPV declines from $180 mn to around $177 mn.

Therefore the conclusion is that based on this analysis, there is a case to address the issue of water productivity. That is, significant benefits would accrue to the industry should varieties be available that could manage a range in the supply of water and still perform very well. In this respect, change in profit expressed as an economic weight is the preferred method for inclusion of WUE in selection but this would

[57] Sadras V, P Grassini & P Steduto 2012. Status of water use efficiency of main crops, SOLAW Background Thematic Report - TR07, FAO

require access to the data behind the SRA economic models, the request for which was declined. However in its absence we used margins or profit as indices of value. Performance in any environment is very dependent on WUE and an economic case based on current costs or higher water costs in the future and/or increasing problems with water supply (less reliable rain, irrigation costs) can be made. It now comes down to detail in respect of the other two aspects to be considered.

What is the potential for a breeding solution?

This is the second aspect to be considered. There is now a substantial literature around defining the components of WUE as a trait in many plant species. There is also evidence from research trials of sugarcane of genetic variation [58] among clones/varieties (run under fully-irrigated or water stress conditions) but there was very low GxE interaction for yield (TCH) or commercial cane sugar (CCS), when a large number of clones were included in the analyses. However this is in-part a scale issue, and when individual clones are compared, there is evidence (as with NUE) of re-ranking among the clones.

The conclusion is that selection to date has been operating in a range of environments and that plants that are inherently robust (perform well across a range of environments) are more likely to be selected than those where considerable GxE was evident. In summary there is evidence of variation but the current breeding approach is likely to be delivering varieties which are productive across a range of water supply situations (perhaps excluding very severe water stress – that is, drought stress). Hence any case for investing must be tempered by the potential that current selection is likely to be delivering well-adapted varieties and that there may be limited potential for substantial improvement. In this respect, there is an issue with respect to the selection pressure that can be brought to bear in the early stages of selection where several clones are grown together. In such situations, there is evidence of considerable competition between genotypes – this competition will favour genotypes that can capture limited resources (such as water or nitrogen) compared with neighbouring plants. However if new rapid methods are to detect variation in WUE at these stages of selection, then methods must be adaptable to individual plants. These considerations notwithstanding, there is a major project underway that will provide considerable data on the components of WUE (including genetic parameters) and provide an indication of the real potential in phenotypic and genetic term[59, 60].

It is then necessary to estimate the scale of improvement that would be required to justify inclusion of WUE, but two other factors need to be considered also.

- It is improbable that new varieties will totally overcome the water stress gap, especially in the near to medium term. For the purposes of the analysis a 10% gain in WUE (and $ benefit from reduced water stress) in the first of the new varieties (harvested in 2021) has been used, with an improvement in WUE of 1.5% per annum thereafter.
- Rates of adoption will be influenced by a range of factors (including grower expectations of improved WUE leading directly to higher TCH, with no additional management or other costs). For

[58] Basnayake,J, PA Jackson, NG Inman-Bamber & P Lakshmanan 2012 Sugarcane for water-limited environments. Genetic variation in cane yield and sugar content in response to water stress. *Journal of Experimental Botany*, 63, 6023–6033

[59] In this respect, it is important to note that the nature of the early selection phases in the SRA sugarcane breeding program means that there is intense competition between genotypes; this is very different to the real-world situation where the competition is between plants of the same genotype. The importance of this difference is unknown but some researchers have made the case that it is likely to be very important due to the negative genetic correlation between conductance and transpiration efficiency, and potentially water use efficiency.

[60] *X. Zhang et al. (2011) attributed greater WUE to improved varieties and higher soil fertility, leading to higher final total dry matter (DM)—seen in increases of 30% DM for wheat and 6% DM for maize—and increased harvest index (HI), especially in maize; from* Crop yields and global food security: will yield increase continue to feed the world? Fischer, R. A., Byerlee, D., & Edmeades, G. O. (2014). Crop yields and global food security: will yield increase continue to feed the world? Canberra: Australian Centre for International Agricultural Research. Retrieved from http://aciar.gov.au/publication/mn158 (See also Appendix 3).

simplicity, the potential benefits have been estimated with a 30%, 60% and 100% flat rate of adoption (of production) (i.e. not increasing over time).

The rate at which a material change could be introduced

This is the third aspect to be considered. However it is important to understand the potential provided by other more extreme germplasm (as noted in Proposition #5, Evaluate plants for specific phenotypes or traits). In this analysis, we have not assessed directly the rate at which a change could be introduced because of the uncertainty surrounding the assumptions that would be required. Rather we have taken the approach that the investment by definition is risky and therefore it is more appropriate to take the approach of asking *what would be necessary to generate an appropriate rate of return on investment*?

Therefore Table 25 provides estimates of the Net Present Value (NPV) and the Internal Rate of Return (IRR) due to gains from breeding at a range of adoption rates. To achieve an IRR of around 40% will require both a yield improvement through selection for WUE of initially around 10% with the first harvests in 2021 (and increasing by 1.5% per annum) plus an adoption rate of around 21%. The 40% IRR is based on the equivalent due to the introduction of more N-efficient varieties (Table 22 - at a cost of $2 per kg N and an adoption rate of 60% without accounting for any other issues such as a ‘licence to operate’).

Therefore in terms of comparative returns the consideration comes down to one of belief in the scale and pace of improvement possible. In the future, these could be informed by the research which is currently underway along with access to the economic models that underpin the estimation of economic weights (which were not made available for this report). However the information is not available at present.

Table 25. Investment returns due to gains from breeding (assuming that there are no WUE improvements from improved on-farm or other practices): NPV and IRR due to replacement of standard varieties with more efficient varieties for WUE (the first improved varieties that are 10% more efficient are harvested in 2021, with varieties improving by 1.5% per year thereafter at 30%, 60% and 100% adoption overall).

	30% adoption	**60% adoption**	**100% adoption**
NPV of gains to growers ($ mn) at discount rate of 5%	$54 mn	$108 mn	$180 mn
NPV of savings to growers less R&D costs ($ mn) at discount rate of 5%	$51 mn	$105 mn	$177 mn
Internal Rate of Return (IRR)	87%	116%	141%

The otherwise case

Background

The specific options for the otherwise case may be somewhat limited. In practice selection to date has been operating in a range of physical environments and those plants that are inherently robust (perform well across a range of environments) are more likely to be selected than those where considerable GxE was evident. In other words, there is an argument that selection for high WUE is a contributor in the selection process. However the otherwise case may include alternative breeding approaches such as genetic modification (see Proposition #3).

The otherwise opportunity

As outlined above, new cane varieties that are more efficient in terms of WUE or WP represent one option to help overcome the yield opportunity arisng from water stress. Others that may be open to a range of investors include: growers - improved on-farm irrigation management practices, pumping systems, mulch cover; commercial investors - water and irrigation infrastructure, irrigation efficiency;

governments - infrastructure; and more generally - the industry through RD&E to address the yield potential. However, addressing the issue with 'more water' may not work in the sense that it may create on-farm productivity issues (for example, off-farm environmental impacts). Therefore the issue has been considered through an otherwise case scenario, where the Net Present Values (NPV) have been estimated for the scenario where WUE improvements from improved on farm or other practices enable 50% of the variety improvement gains to be otherwise realised (assumed at no additional costs to growers/industry); the remaining 50% is derived from breeding. This is summarised in Table 26.

Table 26. Investment returns for Otherwise case - WUE improvements from improved on-farm or other practices achieve 50% of variety improvement gains: NPV and IRR of replacing standard varieties with more efficient varieties for WUE (the first improved varieties that are 10% more efficient are harvested in 2021, with varieties improving by 1.5% per year thereafter at 30%, 60% and 100% adoption overall).

	30% adoption	**60% adoption**	**100% adoption**
NPV of gains to growers ($ mn) at discount rate of 5%	$27 mn	$54 mn	$90 mn
NPV of savings to growers less R&D costs ($ mn) at discount rate of 5%	$24 mn	$51 mn	$87 mn
Internal Rate of Return (IRR)	61%	87%	108%

Conclusion

To achieve an IRR of over 40% will require a yield improvement through selection for WUE of initially around 10% (and increasing by 1.5% per annum), with 50% of the WUE gain attributable to breeding plus an adoption rate of improved varieties of over 50%.

The conclusion is that the continuation of current breeding strategies (but including potential introgression of extremes such as different species) will likely deliver gain in WUE. It is important to note that increased yield is itself expected to increase WUE at the whole crop level[61].

However there is a case for further pre-breeding research that is targeted at detection of more extreme phenotypes. This work would focus on the development and evaluation of potential traits that may contribute to WUE, with particular emphasis on assessments that can be carried out on a large scale at the very early stages of evaluation in order to improve the chances of detecting clones (including other candidate species) that are more extreme in their phenotype (as compared with those being selected within the current program).

There is also the issue of how to interpret the water stress factors. It could suggest that it is other factors which are limiting the realisation of higher WUE/water stress reduction. It could mean that the previously estimated stress factors relate to varieties of nearly a decade ago and that a rerun of the experiments with current and prospective varieties could be justified.

[61] Crop yields and global food security: will yield increase continue to feed the world? Fischer, R. A., Byerlee, D., & Edmeades, G. O. (2014). Crop yields and global food security: will yield increase continue to feed the world? Canberra: Australian Centre for International Agricultural Research. Retrieved from http://aciar.gov.au/publication/mn158

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PROFIT-BASED MEASURES TO CAPTURE, EVALUATE AND PRIORITISE GENETIC IMPROVEMENT OF WATER USE EFFICIENCY AND NITROGEN USE EFFICIENCY IN SUGARCANE: APPENDICES ONLY

Report prepared for

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Contents

Appendices

Appendix 1: Broad framework for assessing the value of an R&D investment

Introduction

An investment framework approach is the most appropriate way by which to assess the business case for SRA investing in RD&E to incorporate additional traits in the breeding program.

An investment framework enables the expected benefits (to the growers and the whole of industry) and costs (of the R&D and its implementation) to be examined having regard to the risks and time frame of the R&D. This includes risks (such as research risks in identifying and measuring the trait concerned), applicability across the industry (all or some regions), adoption levels amongst farmers and crucially the otherwise case – how growers can be expected to manage the underlying issues in the absence of varieties incorporating the additional trait.

The value of the investment is expressed in real (inflation-adjusted) net present value terms (discounted cash flow), internal rate of return or other investment return metrics, where the value is derived from the following measures:

- investment costs (negative)
- estimated quantified industry benefits from the variety improvement over time (including longer term sustainability) x probability of the research success x proportion of the industry where the benefit is applicable x adoption by growers x probability that the R&D will not become redundant (compared to otherwise)
- non-quantified industry benefits
- benefits outside of the industry (including broader community benefits)

In this respect, the investment framework approach:

- provides an analytical approach to assessing the value to industry (and more generally the community)
- is transparent in both the approach and the use of data
- enables the implications of other views and data, and sensitivity more generally, to be examined
- is consistent with the evaluation frameworks used by SRA in other project evaluations.

The approach

Overview

Currently the breeding objective – a whole of industry profit-based objective – includes four traits in the selection index. The respective economic weights are calculated for the four production regions. In addition prospective varieties are screened for disease resistance/vulnerability.

The inclusion of an additional trait (or possibly more than one trait) will require an investment in both pre-breeding research and in the breeding program. The pre-breeding costs are likely to be the most significant as the additional costs in the breeding phase are more likely to be marginal costs, given the existing breeding program (although they may be still significant).

Pre-breeding R&D is required to:

- define the profit trait and establish the relationships between changes in the trait and profit
- define the genetic parameters (heritabilities, co-variances, genetic and phenotypic correlations)

- define the selection trait(s) and the method of measurement
- derive the economic weight for the trait (analysis and industry discussions)

Breeding program costs include:

- consideration of a larger breeding program (in order to maintain the current level of evaluation for the existing varieties)
- the risk that a focus on a new trait that is not driven off purely economic criteria for that trait that consequently reduces the selection pressure on the other traits and actually reduces overall or net economic gain
- the initial set-up costs and subsequent annual operating costs

Other SRA program costs to incorporate the new trait in the selection index.

These costs need to be estimated for SRA and other co-funders, over time.

Assessment of potential benefits from an additional trait

The potential benefits of incorporating an additional trait in the selection index are evaluated in terms of their potential to improve industry profits (at current industry size or with expansion) through:

- productivity gains to growers (such as higher yield for a given level of input use), and/or
- cost savings to growers and to the wider industry (such as lower input costs), and/or
- avoided costs (e.g. avoiding profit losses due to restrictions on input use or other activities).

The potential gains in each of these areas need to be estimated on the basis that the trait can be readily incorporated in the selection index, given the regional differences in growing environments, farming practices and other issues including potential off-site impacts (such as water quality and the consequent effects on local water supplies, wetlands, or the Reef). However, in this respect, economic weights differ between regions and variety recommendations are already quite specific to particular regions and even sub-regions.

In estimating the gains, consideration is given to the otherwise case. Specifically, will the estimated gain (when the new varieties are released) change over time? Will/would growers develop or adopt other strategies to managing the issue in question (such as nitrogen use) one way or another. New product options or management approaches could become available (including outputs from other SRA projects) or be adopted by more growers or by adopting growers producing a greater proportion of the crop - alternatively the reverse could apply.

Also, assessing the potential benefits within a compared to otherwise framework enables issues such as future industry sustainability to be addressed explicitly. For example, in the absence of varietal improvement the industry may contract, or contract to more marginal production areas, or its expansion (for example into new areas in Northern Australia) maybe more limited.

Likelihood of R&D success

A range of factors will determine the likelihood of success including the ‘inherent riskiness of the R&D (is it applied or basic/novel R&D?), the capability of the researchers involved (local and international), and/or the level of investment (for example, a higher level of investment may enable additional research capability to be employed and the time frame reduced).

Estimating the probability of success will involve a degree of judgement.

Time-frame to variety release

Variety development by SRA and its predecessors typically takes about 12 years from when the original parent crosses are made to release of a new variety. In the case of new trait development the breeding time is unlikely to be much different but there is the pre-breeding R&D and the associated time frame.

However any change in the methodology may impact the development time-frame, albeit a reduction in the time from first selection to release will generate benefits through a more rapid return.

Adoption by growers

A range of factors influence adoption by growers, chief amongst them is the expected change in net profit, with all costs (and risks) considered. Typically there are limited additional cash costs to growers in adopting a new variety. The main additional cash cost is new seed/billets, although for growers always purchasing new (tissue culture) plants, there would not be an additional cost. However varieties with greater ratoon persistence would reduce establishment costs as this would reduce the fallow area (currently the generally-accepted figure is that about 16% of area is fallow). Other costs of a new variety are the potential lower than expected yield/CCS in initial years as growers learn how best to manage the new variety in their particular circumstances (aided by inter-regional evaluation information). These issues may well be more important where a new variety incorporates new trait(s) which require significant management changes (such as nutrient supply) and emphasises the relevance of guidelines with regard to soil type and water requirements.

New varieties are more applicable (often intentionally) to particular regions and site-specific situations (the SRA variety tool helps growers assess varieties). However, historically, adoption across the relevant regions/situations takes time. Also, growers typically grow a selection of varieties in order to manage harvesting times, production risks and their farm management schedules.

Adoption across the industry is measured as the proportion of production/area (as against number of growers) and is estimated over time.

Adoption may also be relevant to the otherwise case. For example, if an increasing proportion of the cane area is being managed under BMP regimes this needs to be allowed for in the time profile of the otherwise case (above).

Redundancy

There are two broad reasons why incorporating a new trait in the selection index might become redundant or at least require a continuing investment to maintain its relevance, namely obsolescence and a change in the level of relevance.

An example of obsolescence might be where traditional breeding is challenged by the incorporation of genetic modification (GM) technology. However, GM may not change the selection index or relative economic weights, but rather it is more likely (if used) to reduce the length of the breeding time-frame (once the regulatory hurdles are overcome) by reducing the complexity of decision-making (by providing a major shift in one target trait) in the selection of individual clones. GM technology is challenging traditional breeding in a number of plant species. Given the recent advances[1] it is evident that there is potential for GM technology in sugarcane breeding and offers potential opportunities (e.g SRA projects with partners).

New varieties of sugarcane are developed to address changes in the market/growing environment (and especially disease resistance). An issue with any new trait is the extent to which the selection index becomes less relevant unless there is a continuing investment in pre-breeding and breeding R&D.

Other benefits

There are a number of potential other benefits which are generally considered but are usually unquantifiable in the current context which include:

- co-incidental benefits to the sugar industry of including the new trait that have not been included above such as a wider array of options which reduce risk;
- inter-industry: these might include the research learnings which have application to other Australian plant breeding investments;

[1] Arcadia

- community-wide: these are particularly relevant in respect of off-farm environmental benefits, such as reduced nutrient flow into streams and subsequently the Reef; although they are not quantified, they need to be identified;
- international: there may well be benefits to overseas sugarcane or other plant breeding programs.

Opportunity cost

The opportunity cost of investing in a new trait for the section index can be viewed as

- the opportunities forgone in other SRA breeding or other SRA projects; while conceptually appropriate the relevant data are not always available
- the standard discount rate used in evaluating rural R&D corporation projects (real 5%, although some RDCs use 7%)
- the rate of return that growers and millers might earn instead of the levy.

For present purposes a real 5% discount rate has been used. The usual investment metrics are applied (Net Present Value (NPV), Internal Rate of Return (IRR) and the Benefits/Cost (B/C) ratio).

Appendix 2: Investment analysis of NUE

Assessment of potential benefits from an additional trait

The potential benefits of incorporating a NUE trait in the selection index are evaluated in terms of their potential to maintain or improve industry profits (at current industry size) through:

- cost savings to growers (lower N fertiliser costs), and/or
- productivity gains to growers (improved TCH from improved NUE) which, at whole of industry level could lead to cost savings to millers given total TCH volume increase, and/or
- avoided costs (e.g. avoiding income and profit losses due to restrictions on input use or other activities which lead to reduced cane yield or area grown).

In addition there are potential off farm benefits, specifically lower N application on farm leading to lower DIN losses off farm and associated environmental benefits. Spill-over benefits from a sugar cane NUE breeding program could include application of NUE assessment techniques to other crops also.

In the first instance potential gains in each of these areas are estimated against a baseline of current practices with the following features:

- the NUE trait can be readily incorporated in the selection index for the respective regions;
- selection on the NUE trait delivers an N saving;
- farm practices (driven by management, prices or regulation) are unchanged; and
- the sugar regions of most focus are the Wet Tropics and Burdekin.

The potential gains are then estimated against the otherwise case – where farm practices are expected to change in response to a number of factors including N prices, further adoption of NUE technologies, new technologies, additional regulations (which might for example limit the level or timing of N application or indeed growing of sugar cane in some areas) or industry responses to the these additional regulations.

Given both the uncertainty as to whether additional regulation concerning N use might eventuate, two otherwise case scenarios have been developed, both of which are necessarily a simplification:

- Scenario 1: Continuing development and adoption of on-farm practices which in effect improve NUE, with no additional regulation;
- Scenario 2: Baseline (since there are no ongoing improvements as postulated under Scenario 1) plus additional regulation, where that regulation results in a significant reduction in cane production as nitrogen use is restricted and/or sugarcane growing is no longer permitted in some regions.

The scope of the benefits from breeding relative to the otherwise cases is shown in **Appendix Table 2.1**.

Appendix Table 2.1: Broad scope of benefits from improved NUE **other than** through breeding

	On-farm (industry) benefits	**Off farm (environmental) benefits**
Improved NUE resulting from strategies other than through breeding – that is, the otherwise case of:		
Baseline (current practices and regulations)	N fertiliser cost savings;	Reduced DIN leaching (with environmental benefit)
Scenario 1 (continued on-farm improvements in NUE)	N fertiliser cost savings; but smaller than the baseline as NUE continues to improve in any case	Reduced DIN leaching (with environmental benefit)
Scenario 2 (Baseline, with additional regulation restricting sugar cane production)	Scenario 1 plus further ‘avoided losses’ - sugarcane profitability is maintained in all regions (whereas it would have been reduced due to hypothesised restrictions on N use and resulting lower TCH)	No net environmental benefit as hypothesised regulation assumed to deliver equivalent off farm environmental benefits to the breeding program (although there might be a timing issue, depending upon when regulations are applied)

Current practice

Farm level budgeting using industry average and best practice shows N use ranges from around 140kg/ha to 200kg/ha per year (**Appendix Table 2.2**).

Appendix Table 2.2: N use - Current industry practice (based on $2/kg N cost)

		Wet Tropics	Burdekin Delta	Central irrigated	South irrigated
		Location			
		Wet tropics	Burdekin	Proserpine	Bundaberg
Farm					
Area	ha	62.5	180	125	62.5
Cane harvested	tonne	5050	21564	10875	5750
Sugar	tonne per hectare	10.3	17.4	12.2	12.6
Nitrogen: Crop life cycle (plant plus 4 ratoons)					
N/ha	kg/ha	700	990	790	690
$ N/ha at N of $2 per kg	$/ha	$1,400	$1,980	$1,580	$1,380
Fertiliser application (allocating total spread cost to N)	$/ha	$66	$65	$77	$66
Total N costs	$/ha	$1,466	$2,045	$1,657	$1,446
Nitrogen: Average across plant and ratoon per annum					
N/ha	kg/ha	140	198	158	138
$ N/ha	$/ha	$280	$396	$316	$276
N/t cane harvested	kg/t cane harvested	1.7	1.7	1.8	1.5
N/t sugar produced	kg/t sugar produced	13.6	11.4	13.0	11.0
Total N costs	$/ha	$293	$409	$331	$289

Source: Derived from average farm budget data (Canegrowers) with N at $2/kg

Benefits relative to the baseline of no change in overall industry NUE

The baseline case focusses on the Wet Tropics and Burdekin as these are the areas where NUE attracts most attention. The Baseline is a continuation of current farming practices, noting that these differ between regions and within them. However, in the main growers apply N (along with other elements) to the plant crop and to the ratoon crop. The level of N applied will differ between and within farms depending upon growers assessments of N requirements (typically following the 6 Easy Steps to N use) which reflect N status and crop yield expectations. Typically, fertilizer is applied at one application, although some growers apply split applications of N.

Including NUE in sugar cane breeding has the potential to reduce N use and/or increase TCH. However, estimating these potential gains is somewhat speculative as there is little R&D in Australia, or elsewhere to help guide such an assessment. Against this background, the investment analysis has used an illustrative, probably conservative, estimate of the potential eventual N saving of 60kg per ha (by about 2030 — a 38% saving against the current industry average rate of N use), with no change in TCH.

The probable trade-off between N use and TCH should be an early research task to help clarify the worth of further investment. Again as a simplification, the gains from the N saving have been applied equally across all regions. However, given regional differences in N applications and NUE, the potential N cost savings and TCH increases differ between regions. Further, it is assumed that in selecting for NUE there is no trade-off in performance of other traits (such as CCS).

The implications of this eventual N saving for the average farm in each region and at the industry level are presented in **Appendix Table 2.3**.

Given the respective areas of sugarcane, and leaving to one side adoption rates over time of new varieties, the potential industry-level benefit from achieving improved NUE through breeding, given the simplified approach outlined above, is estimated at around $7mn per annum. For the Wet Tropics and Burdekin it is $4mn per annum. The effect of using the 10 year average area of cane harvested is marginal compared to using the 2014 data.

Appendix Table 2.3: Annual cost savings with an illustrative 60 kg/ha saving in N

			Region				Industry
			Wet Tropics	**Burdekin Delta**	**Central irrigated**	**South irrigated**	**Average or Total**
Farm							
Area cane harvested per farm		ha	62.5	180.0	125.0	62.5	103
N use/ha		kg/ha	140	198	158	138	156
Industry							
Area (Average 2005-2010)		ha	126,683	69,176	106,325	63,753	365,936
Area (2014)		ha	134,690	71,163	105,213	60,366	371,432
Estimated N use (2014 area)		tonne	18,857	14,090	16,624	8,331	57,901
Savings							
N savings at 60 kg/ha in 2036		38%					
N Savings per farm		kg	3,750	10,800	7,500	3,750	7,791
N savings industry		tonne	8,081	4,270	6,313	3,622	22,286
At an N cost at $2/kg N applied	N cost savings per farm	$	$7,500	$21,600	$15,000	$7,500	$15,600
	N cost savings industry	$ mn	$16.2	$8.5	$12.6	$7.2	$44.6

In addition to benefits to growers, if the improved NUE resulted in increased TCH across the industry, it could benefit millers. A higher volume, other things being equal, should lower average milling costs per tonne with consequent financial benefits to millers and growers.

There are also potential environmental benefits off farm. The extent of these benefits (through reduced DIN) will depend upon the nature of the NUE gain. For example, it may enable reductions in N application and reduced DIN or enable higher TCH production from the same level of N and perhaps unchanged levels of DIN. The financial value of these off farm environmental benefits has not been estimated.

Benefits relative to the otherwise case: Scenario 1

The otherwise case (i.e. compared to the baseline or the situation in 2014) requires analysis of a range of factors which will influence future N use and NUE in the sugarcane industry. To the extent that N saving can be achieved (in part) by a range of other factors, the demands from an NUE breeding program are reduced. Alternatively, if an NUE breeding program can deliver the level of N savings outlined in the Baseline, the Scenario 1 gains are then the same as the Baseline. The nature and extent of these other factors impacting upon N use are considered below.

Additional adoption of on-farm NUE strategies. A number of factors are reported to have contributed to improvements in fertiliser NUE in recent years including:

- growers adopting Six Easy Steps N guidelines, rather than using generalised industry N guidelines;
- increased attention to using the optimal form, application method, rate, placement and time of application of nitrogen fertiliser according to the block and to soil type;

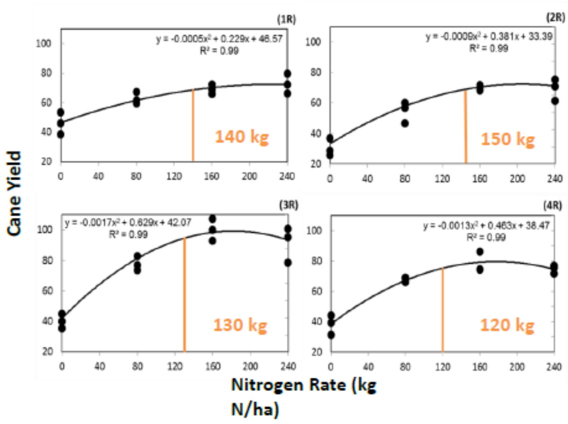
- increased use of soil and leaf testing to better predict soil and crop nutrient requirements;
- increased capacity to apply different rates of nitrogen to different blocks;
- improved awareness of nitrogen inputs from other sources;
- more focus on balanced nutrition using a wider range of nutrients leading to higher yields;
- increased awareness of the different ways in which nitrogen can be lost; and
- a perception by growers that many years of green harvesting and trash retention has led to an increase in soil organic matter levels, which results in greater amounts of nitrogen being recycled. [2]

N response and N costs. Growers have a financial (cash cost) incentive to manage N use. Nitrogen costs money and is a cash cost that growers can influence (through application rates, N source, including legume crops prior to planting). The price of N influences N usage — higher prices translate into lower usage, other things being equal. However, the following apply:

- N is a small cost in total variable growing costs (8% to 13%, depending upon the region);
- The financial return from using N, and applying high rates, is significant;
- The price of N has fallen in real terms (i.e. adjusted for inflation);
- N usage dropped in 2007 in response to the sharp increase in the urea price, but increased again once prices fell; apart from this dramatic price rise, the demand for N by cane growers appears to be relatively price inelastic; near term, real price increases are unlikely given energy costs.[3]

Nonetheless, growers have a financial incentive to apply N at a rate (early in the growing season) that will deliver maximum production under favourable weather conditions, even though the expected (average) yield will invariably be lower (given seasonal variability) – thus there is a degree of 'surplus application'[4].

Appendix Figure 2.1: Response to N use in sugarcane: Wet tropics - an example, noting variation between regions (rainfall, temperature, soils), and farming systems[5]



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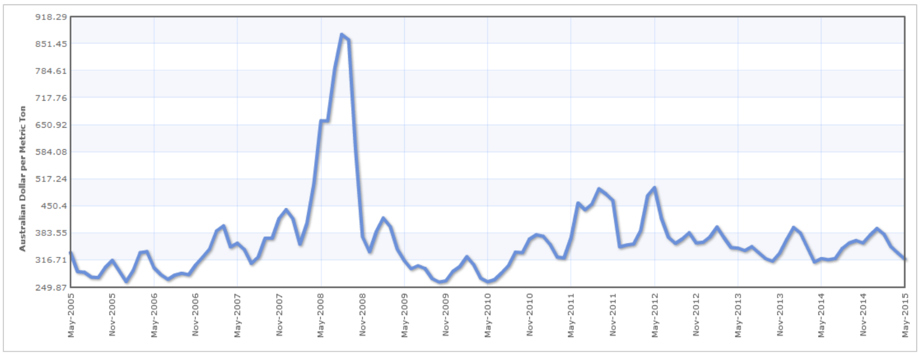
[2] Wood AW, BL Schroeder BL & R Dwyer 2010. Opportunities for improving the efficiency of use of nitrogen fertiliser in the Australian sugarcane industry. Proc Aust Soc Sugar Cane Technol 32: 221-233

[3] In the near term urea prices are likely to remain 'stable' given the forecast continuing faster growth in supply relative to demand (Fertilizer outlook 2014-18, International Fertilizer Industry Association, Annual Conference, Sydney 2014). Further, rises in world urea prices derived from rising energy prices (natural gas in particular) would be offset to some extent by an appreciation of the $A given the significance of energy exports in Australia's balance of trade.

[4] Schroeder BL, AW Wood, M Sefton et al 2010. District yield potential: An appropriate basis for nitrogen guidelines for sugarcane production. Proc Aust Soc Sugar Cane Technol 32: 193-209.

[5] Notes: Yield response to applied N (0, 80, 160 and 240 kg N/ha) at the T1 trial site (2006 to 2009) for the first, second, third and fourth ratoon crops. The orange vertical line indicates the calculated N rate producing 95% of the maximum yield in each year (Skocaj et al., 2013b). Source: SRA, Review of Nitrogen Use Efficiency in Sugarcane, December 2014, pg.76

Appendix Figure 2.2: World urea price May 2005 to May 2015 **(**Source: Derived from World Bank data[6])

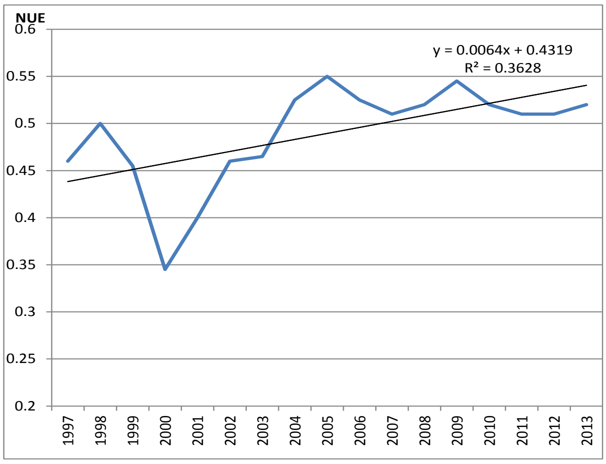


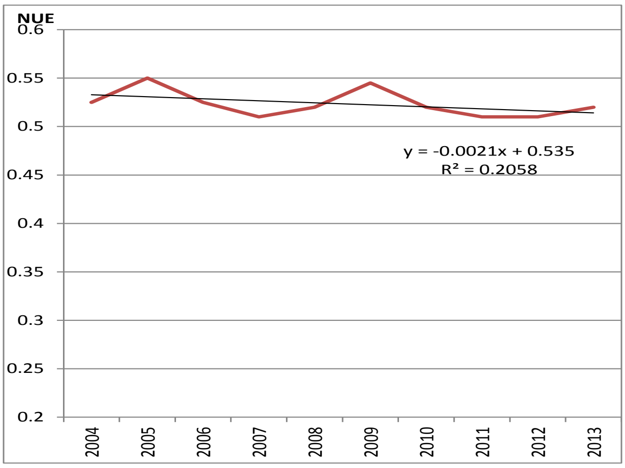
Description: Urea, (Black Sea), bulk, spot, f.o.b. Black Sea (primarily Yuzhnyy) beginning July 1991; for 1985-91 (June) f.o.b. Eastern

Overall NUE (cane harvested/N applied) has trended up since 1997, suggesting an improvement in NUE. However, the measure used is applied N and takes no account, in particular, of N supplied from legume crops prior to the planting year and thus may overestimate the improvement in NUE if the use of legume crops has been increasing.

However, analysis of the data in the post 2003 period suggests a decline in NUE (**Appendix Figure 2.3**)

Appendix Figure 2.3: NUE and average N application rates 1997 to 2013 (Source: AbacusBio and IDA Economics analysis based on SRA December 2014)[7]



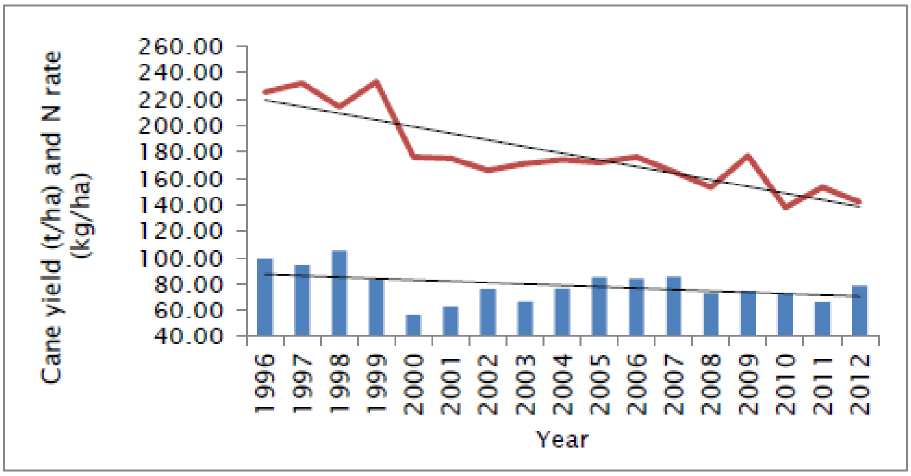


[6] Source: http://www.indexmundi.com/commodities/?commodity=urea&months=120&currency=aud

[7] Notes: Fertiliser N use efficiency (tonnes cane/kg N) for sugarcane production in eastern Australia 1997-2013. N use derived from fertiliser sales by commercial suppliers, Incitec Pivott in particular (www.incitecpivotfertilisers.com.au/News/Latest%20News/Achieving%20more%20from%20applied%20nitrogen%20in%20cane)

Also, cane yields have declined at a faster rate than N application rates (as per Appendix Figure 2.4 suggesting a decline in NUE). Declining productivity can be due to a range of factors (besides N application rates) including climatic, soil health, plant diseases, genetic and crop management factors as well as structural change in the industry (within and between regions). As the SRA *Review of Nitrogen Use Efficiency in Sugarcane* noted " assessing whether there is a causal relationship between lower yields and declining fertiliser use would require a substantial new research effort" (pg. 12).

Appendix Figure 2.4: Sugarcane yields (histogram) and N rates (red line) for eastern Australia (Source: SRA December 2014)



Opportunities from future R&D. As to the future there are additional drivers which will impact upon NUE. Some of these factors are recognised, while others will require additional R&D. The SRA review of *Nitrogen Use Efficiency in Sugarcane* identified the following topics for future R&D (including variety screening for NUE):

- Matching N supply to crop N demand by appropriate legume break crop stubble management, split fertiliser applications and/or appropriate enhanced efficiency fertilisers;
- Proximal sensing using various techniques to assess the adequacy of N inputs;
- Mechanisms / formulations to address temporal and spatial variability in the landscape, soil or crop growth/yields;
- Developing SIX EASY STEPS guidelines for Precision Agriculture by targeting in-field variability;
- Screening varieties for crop NUE;
- Development of mitigation strategies for denitrification, and a possible decision support component within "SafeGauge for Nutrients" to assess risk of denitrification;
- Development of N management strategies for older ratoons within the crop cycle;
- Development of N management strategies for time-of-harvest (earlier- versus later-cut ratoons, etc)
- Development of a decision support tool within NutriCalc and SafeGauge for Nutrients to provide advice on efficacy of enhanced efficiency fertilisers for profitability and environmental outcomes; further assessment of the bioavailability of N (and P) from mill by-products and/or value added products during a cropping cycle.[8]

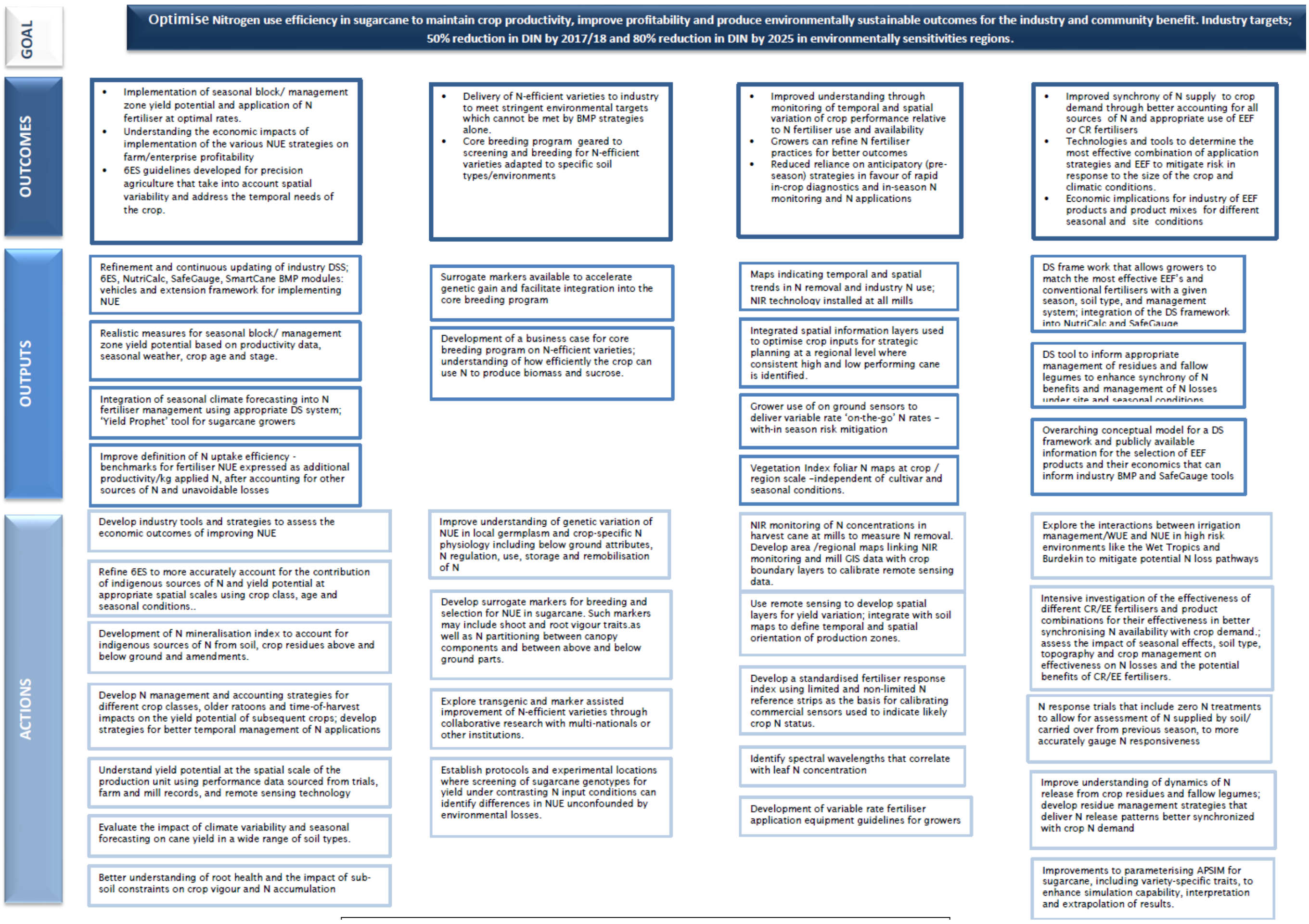
The potential for better seasonal weather forecasts to help grower decisions re early season N application rates in the light of forecast seasonal conditions is another that could be added to this list.

[8] SRA Review of nitrogen Use efficiency in Sugarcane, December 2014, pgs 76-77.

Policy changes. The implementation of controls by the Queensland Government regulating the amount of nitrogen and phosphorus (P) fertiliser that can be applied to sugarcane crops in north Queensland (REFERENCE) are aimed at protecting the Reef from excess nutrients derived from agricultural activities.

Industry strategies. The recent SRA sponsored *Review of NUE in sugarcane* outlines a path forward for the industry, businesses within it, and government agencies to progress further improvements in NUE (***Appendix Figure 2.5***). The pathway includes a significant component, and associated financial investment, in genetics and breeding aimed at both near term and longer term improvements in NUE.

Appendix Figure 2.5: Optimising NUE: Pathways



Conclusion. Analysis of the underlying drivers of improved on-farm NUE suggests that NUE is likely to improve. Although grower response to increased N prices (even if they eventuate) is very unlikely to improve NUE to any great degree, further adoption of NUE strategies coupled with further R&D in that area will help improve NUE.

Industry is united in recognising that NUE needs to be addressed if additional controls on N use and cane growing are to be avoided, hence the strong support for the pathways outlined in the *Review of NUE in sugarcane,* although these have yet to be formally adopted and implemented. The lead time before the impacts are observable also has to be recognised. Nonetheless, the pathways proposed (taken together) aim to reduce DIN by 80% by 2025 in environmentally-sensitive regions. Further, the possibility or prospect of additional regulation aimed at improving NUE will encourage growers individually, supported by industry level organisations and government agencies, to further improve NUE.

That said, the recent trends in NUE, as measured by cane produced/N applied suggest at least a levelling levelling off. If the (non-plant breeding) pathways outlined in the SRA Review can achieve the objective of a significant reduction in DIN (in essence the otherwise case) the contribution which plant breeding can play will be diminished. The plant breeding component is one of four broad strategies that are proposed and is essentially independent and additive to the others. It could be said that 'about 25%' of the reduced DIN goal will be achieved by the plant breeding investment, as there is insufficient analysis in the Review to make a robust quantitative assessment of the relative contributions, costs or timeframe.

A 25% contribution from plant breeding suggests that 75% of the prospective gain from improved NUE and resulting lower DIN will be achieved *without* the plant breeding investment. That estimate has been applied as the basis of the Otherwise Case: Scenario 1. On this basis the cost saving/TCH benefits to growers from the postulated breeding program, given the other factors likely to impact on NUE in the future, is estimated at around $1mn per annum (25% of $4mn).

Benefits relative to the otherwise case: Scenario 2

The main distinguishing feature of Scenario 2 is that there are *assumed* significant N use controls and more specifically land use controls including limiting or precluding areas where sugarcane can be grown.

The implication of such controls is that cane production volumes would decline, given much reduced N applications and a smaller area under cane. Such changes would have significant implications for the growers that are impacted (lower net incomes) and the relevant mills (reduced throughput against unchanged fixed costs and consequently lower net returns, including possibly closure of some mills). These impacts would flow through to regional level economies. It is speculative to identify regions that might be impacted and the extent to which they may be affected in terms of lost production if more stringent land use controls were implemented. However, to provide some guidance on these issues the impact of a 33% reduction in cane production in the Wet Tropics has been examined.

Given the area involved and typical income and net returns, the gain to growers from the postulated sugarcane breeding program is estimated in total at around $49mn per annum as below:

- N cost savings as against the Baseline (since the other developments are per Scenario 1 are not expected to eventuate, hence the imposition of regulation), ie $4mn per annum);
- plus the avoided income loss from not seeing the Wet Tropics sugarcane area fall by 33%, (avoiding a fall in gross income of an estimated $115m/year leading to a $45m/year fall in growers' gross margin (both on the 2014 area) (**Appendix Table 2.4**).

Appendix Table 2.4: Estimated farm income loss: Wet tropics - Landuse controls (Source: AbacusBio and IDA Economics analysis)

Area harvested			
Mill	2014 area	10 year av area	
Mossman	13,981	7,972	
Tableland	3,682	6,807	
Mulgrave	11,555	12,877	
South Johnstone	21,925	12,065	
Bundaberg Sugar North	0	11,194	
Tully	27,747	24,028	
Herbert River Mills	55,800	53,027	
Total	134,690	126,683	
(Source SRA Mill Report)			
Financials ($/ha harvested, pa)	2013-14		
Income	$2,592		
Total variable costs	$1,590		
Gross margin	$1,001		
Fixed expenses	$911		
Farm operating profit	$91		
(Source Canegrowers)			
Analysis			
Proportion of sugarcane area excluded from production		33%	
Lost Gross income ($m, pa)	$115	$108	
Lost Gross Margin ($m, pa)	$45	$42	

Sugarcane breeding (taking as a given that relevant varieties can be successfully developed and adopted coupled with further adoption of improved farm management practices outlined above should be able to meet the expectations of reduced DIN, thus averting these regulated production controls. Thus the benefit of the breeding program (given the above factors) is avoiding the loss in farm operating income, assuming that there are no other farming (or land use activities) which could replace the lost sugarcane income (without DIN or other offsite impacts).

As well as avoiding the loss in farm income there are potential losses in mill income and net regional economic effects (reduced farm purchases and expenditure arising from lower farm income). These impacts are more difficult to estimate without detailed mill and regional economic data. To the extent that production might also be regulated in other production regions, growers' avoided income loss in these regions would also need to be included.

Potential benefits: Summary

The summary of estimated benefits from improved NUE through sugar cane breeding is presented in **Appendix Table 2.5**, given a 60 kg per N hectare per annum saving by 2036, 100% adoption and 100% likelihood of R&D success).

Appendix Table 2.5: Summary of potential benefits: Improved NUE from plant breeding - the otherwise case(s) building on Appendix Table 2.1 (60 kg per N hectare per annum saving by 2036, 100% adoption and 100% likelihood of R&D success).

	On-farm (industry) benefits	Off farm (environmental) benefits
Improved NUE resulting from breeding compared to otherwise case of:		
Baseline (current practices and regulations)	N cost savings. Est $44.6m per annum (across all of growing areas; $24.7m per annum in the Wet Tropics and Burdekin); some expansion in cane production (as profitability increased) (not estimated)	Reduced DIN leaching (with environmental benefit). Significant off farm benefit noted but not estimated.
Scenario 1 (continued on-farm improvements in NUE)	N cost saving, but ongoing improvement in NUE through improved on-farm practices (in place & proposed) means that 75% of the N savings required (as per the strategy) are realised without any further investment in breeding; hence N savings from plant breeding are 25% of total NUE gain (against baseline measurement). Breeding need only deliver 15kg N/ha saving. The estimated benefit from 15kg /ha saving is $11.2mn per annum across all regions, with 54% ($6.2 mn) in Wet Tropics and Burdekin	Reduced DIN (with significant environmental benefit) but smaller than baseline as NUE improving through other strategies
Scenario 2 (Baseline, with additional regulation restricting sugar cane production)	Baseline comparison plus 'avoided losses' - sugarcane production and profitability maintained in all regions (whereas it would have been reduced by an estimated 33% in the Wet Tropics). Estimated avoided loss in grower profitability (gross margin) of $49mn per annum. Total benefit $70mn ($24.7mn + $45mn). Avoided income loss to millers and net regional economy impacts not estimated.	No net environmental benefit as regulation assumed to deliver equivalent off farm environmental benefits to the breeding program (although there might be a timing issue, depending upon when regulations are applied)

Research investment

The scope and level of the plant breeding R&D and subsequent breeding investment likely to be needed to address the NUE issue has not been articulated to the consultants. However, recognising the challenges in the issue, the experience in this area of research in other crop industries (within Australia and overseas) it is probable that a significant investment will be required and that the investment would have to be funded primarily by SRA. This is particularly in pre-breeding.

However, a key issue is how the investment question is approached. Specifically, at one level the existing breeding program could be expanded to incorporate selection for NUE. This might entail additional SRA funds of say $0.5m above the existing plant breeding investment. In addition to SRA funds, co-investment from growers (in kind to support field trials) would be required. There is also the question of co-investment outside of the sugar industry, including government agencies responsible for environmental issue.

A possible scenario is:

- R&D funding for 3 years to identify relevant traits, assess parent cultivars, access international material - an indicative estimate of $2m per annum.
- Additional funding to the current breeding program to enable screening for NUE - an additional $0.5m per annum (following completion of the above R&D, although there is a case to implement some immediate screening).

Likelihood of R&D success

A range of factors will determine the likelihood of success in being able to select for NUE in future sugar cane varieties. These include the 'inherent riskiness of the R&D' (is it applied or basic/novel R&D?), the capability of the researchers involved (local and international), and/or the level of investment (for example, a higher level of investment may enable additional research capability to be employed and the time frame reduced).

NUE related R&D to date offer mixed views. Anecdotal and local level industry studies point to the capacity to select for NUE (comments at industry workshop, Townsville). However, others in the current breeding program have raised doubts. Dr Mike Cox, Manager, Plant Breeding SRA, commented that:

"We believe that NUE is more of a concept than a trait. We have seen no evidence of a trait that could be used in a breeding program (i.e. is measurable, variable and sufficiently heritable).

NUE research has mostly been done with highly selected clones (i.e. selected under optimal or industry standard N fertiliser environments). While the UQ044 results do seem to indicate different responses to N (low and high N), most of the evidence shows that GxN variance components are either not significant (statistically) or not important (i.e. very small in relation to G).

We suspect that we are more likely to find extremes in seedling populations [although it may be difficult to use (measure) any NUE related traits in this stage], so a targeted breeding sub-program should lead to development of specific genotypes. These could be:

- *varieties that have high rEGV (TCH, CCS etc) under low N environments; this would be relatively easy to do;*
- *Varieties that have high rEGV and take up maximum amounts of applied (+ soil mineral?) N; this would be extremely expensive (leaf N and soil N determinations on each clone) and possibly not practical*[9]

With respect to genetic modification technologies, there is a view that GM technologies are high cost and there are significant market access uncertainties for GM sugar.

A conservative 50% probability of research/breeding success has been used in the analysis.

Time-frame to variety release

Variety development by SRA and its predecessors typically takes about 12 years from when the original parent crosses are made to release of a new variety. In the case of new trait development the breeding time is unlikely to be much different but there is the pre-breeding R&D and the associated time frame, as outlined above. However any change in the methodology may impact the development time-frame. A reduction in the time from first selection to release will increase the benefits as growers have earlier access to improved varieties.

One means of improving access to new varieties is to focus on NUE in the existing variety trials (at the same time as pre-breeding R&D). This would potentially enable much earlier access to improved NUE varieties. It is estimated that a potential gain of 20kg/ha can be identified from the trial varieties and that

[9] Email Dr Cox to Peter Fennessy, 14 July, 2015

this gain would be available to growers for the 2020 plant crop. Thereafter, an annual gain from continued selection pressure for NUE is estimated to deliver a further 4kg/ha per annum.

Applicability across the industry

The inter- and intra-regional (and within farm) differences in climate, soils and management options mean that a range of varieties are required by the industry. This will mean that NUE traits/selection will need to be developed or applied across a range of varieties. In doing so it is probable that not all regions/sub regions will have access to varieties with improved NUE at the same time. Further, the priority is variety selection for the Wet Tropics and Burdekin (a harvest area of 196,000 ha); this analysis has focussed on those regions.

Adoption by growers

A range of factors influence adoption by growers, chief amongst them is the expected change in net profit, with all costs (and risks) considered.

New varieties are more applicable (often intentionally) to particular regions and site-specific situations (the SRA variety tool helps growers assess varieties). However, historically, adoption across the relevant regions/situations takes time. Also, growers typically grow a selection of varieties in order to manage harvesting times, production risks and their farm management schedules.

Estimates of the rate and level of adoption can be made using historical data/observations for comparable technological changes. In the case of a new trait in varieties there may be specific considerations as well as general considerations such as managing risks associated with seasonal impacts and harvesting schedules. Overall growers are reported to be quick to adopt varieties where there are demonstrable financial gains.

The latter issue is important. There is a view amongst some growers (expressed during industry discussions) that off-site impacts from DIN are not an issue, either because there is little DIN going off site or even if there is, there is minimal adverse impact (on the Reef). Hence these growers are likely to only adopt NUE varieties if there is enough (i.e. on farm financial benefit) in adopting the NUE varieties.

Typically there are limited additional cash costs to growers in adopting a new variety. The main additional cash cost is new seed/billets, although for growers always purchasing new (tissue culture) plants, there would not be an additional cost. However varieties with greater ratoon persistence would reduce establishment costs as this would reduce the fallow area (currently the generally-accepted figure is that about 16% of area is fallow).

Other costs of a new variety are the potential lower than expected yield/CCS in initial years as growers learn how best to manage the new variety in their particular circumstances (aided by inter-regional evaluation information). These issues may well be more important where a new variety incorporates new trait(s) which require significant management changes (such as nutrient supply) and emphasises the relevance of guidelines with regard to soil type and water requirements (and thus the trial period before full release to industry).

The rate of adoption is also ‘limited’ to the plant crop – which comprises about 20% of the harvested area (plant plus 4 year ratoon) — although there is a significant range in ratoon lengths between growers and between varieties.

Adoption across the industry is measured as the proportion of production/area (rather than the number of growers) and is estimated over time. Adoption may also be relevant to the otherwise case. For example, if an increasing proportion of the cane area is being managed under BMP regimes this needs to be allowed for in the time profile of the otherwise case (above). Significantly, the support to growers to help in assessing new varieties is well established, in particular, local productivity groups.

Given the importance of the NUE issue, the demonstrated promotion and support for NUE strategies, the probable commercial gains from adopting varieties with improved NUE (assuming limited trade-offs with other attributes) and the capacity to switch to new varieties (albeit with management learning issues) suggests a relatively high adoption rate and fast rate of adoption.

To simplify the analysis three broad scenarios of adoption have been used: 30%, 60% and 100%. That is, 30/60/100% of the plant crop in 2020 is planted to the new improved NUE varieties. Further, the level of adoption is held constant through time (which may be too conservative, but it simplifies the analysis of benefits).

Redundancy

There are two broad reasons as to why incorporating a new trait in the selection index might become redundant or at least require a continuing investment to maintain its relevance, namely obsolescence and a change in the level of relevance.

An example of obsolescence might be where traditional breeding is challenged by the incorporation of genetic modification (GM) technology. However, GM may not change the selection index or relative economic weights, but rather it is more likely (if used) to reduce the length of the breeding time-frame (once the regulatory hurdles are overcome) by reducing the complexity of decision-making (by providing a major shift in one target trait) in the selection of individual clones. GM technology is challenging traditional breeding in a number of plant species. Given the recent advances[10], it is evident that there is potential for GM technology in sugarcane breeding and GM offers potential opportunities (SRA project with DuPont[11]). Further, there are also market considerations which at present appear to limit the feasibility of using GM strategies. Overall the GM solution will not be a near term option for the industry.

An issue with any new trait is the extent to which incorporating it in the selection index becomes less relevant because the problem goes away (unlikely and the contrary is more likely) or is superseded by other technologies (for example on farm BMPs or N product development limiting off farm DIN issues).

Neither issue is likely in the case of NUE. Accordingly, a continuation of NUE related breeding investment has been incorporated in the analysis ($0.5m per annum, 2016 real prices).

Other benefits

There are a number of potential other benefits which are generally considered but are usually unquantifiable. In the current context these include:

- co-incidental benefits to the sugar industry of including the new trait that have not been included above such as a wider array of options which reduce risk;
- inter-industry: these might include the research learnings which have application to other Australian plant breeding investments;
- community-wide: these are particularly relevant in respect of off-farm environmental benefits, such as reduced nutrient flow into streams and subsequently the Reef; although they are not quantified, they need to be recognised;
- international: there may well be benefits to overseas sugarcane or other plant breeding programs.

Investment analysis

Against the Baseline

The benefits from developing/selecting improved NUE varieties have been modelled for the Wet Tropics and Burdekin. The key parameters and their estimated values are presented below in Appendix Box 1. The time profile of N savings and the value of N savings are shown in **Appendix Figure 2.6** and **Appendix Figure 2.**.

[10] Arcadia reference

[11] Check with PL

Appendix Box 1: Summary of parameter values: Modelling the investment value of improved NUE

Cost savings potentially apply Wet Tropics and Burdekin (area 205,853 ha (area harvested 2014)

Plant crop plus 4 ratoons (each 20% harvested area) with N savings in the plant and ratoon crops

Gain from first improved NUE varieties: N saving of an initial 20kg per hectare (the first harvest will be in 2021)

Gain from subsequent improved NUE varieties: Each new variety offers N saving of 4kg per hectare over the previous variety (e.g. saving from new varieties planted in 2021 and first harvested in 2022 is 24 kg N per hectare)

New varieties: Released annually and used in plant crop for that year

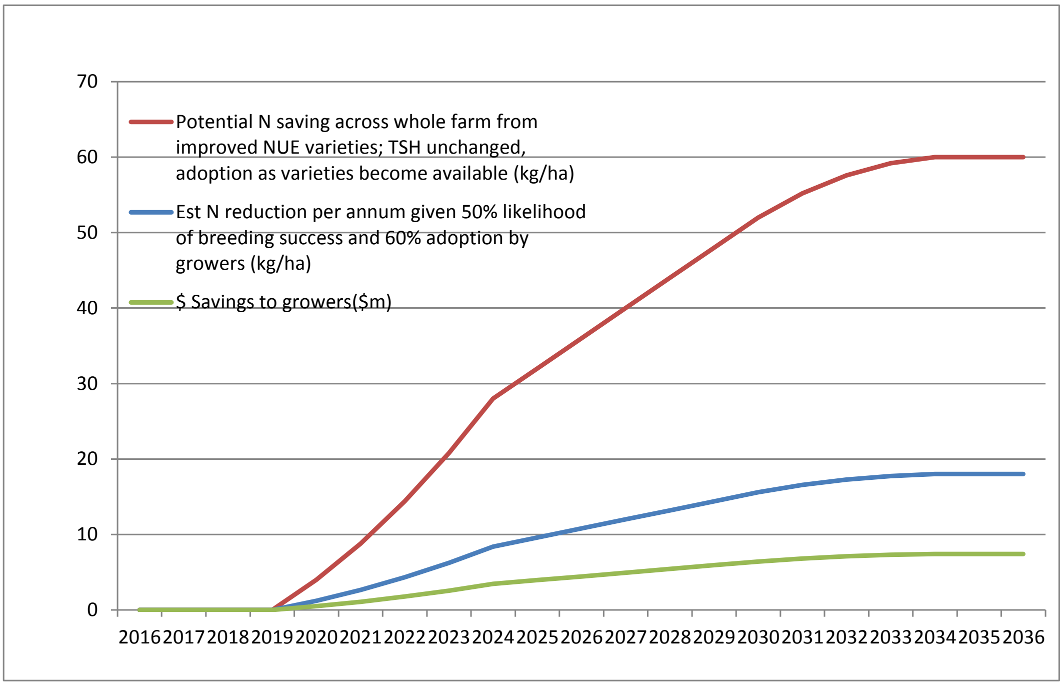
Eventual gain achieved: N saving of 60 kg per hectare per year (2031 is the year of the of the first harvest of this variety)

Probability of successful release of new improved NUE varieties: 50%

Adoption: 30%/60%/100% of the plant crop is planted to the new varieties

Price of N $2/$4/kg (real 2016 prices)

Appendix Figure 2.6: Time profile of benefits from improved NUE varieties: Wet Tropics and Burdekin



Appendix Figure 2.7: Investment in sugarcane variety development for NUE: Investment returns: Wet Tropics and Burdekin region: Compared to Baseline

Real 2016 prices			2016	2017	2018	2019	2020	2021	2030	2031	2032	2033	2034	2035	2036
Additional R&D and breeding investment	$m		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
R&D Success probability	50%														
Adoption profile	Start	Growth													
Potential N saving across whole farm from improved NUE varieties; TSH unchanged, adoption as varieties become available (kg/ha)			0.0	0.0	0.0	0.0	4.0	8.8	52.0	55.2	57.6	59.2	60.0	60.0	60.0
Adoption by growers	60%		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Est N reduction per annum given 50% likelihood of breeding success and 60% adoption by growers (kg/ha)			0	0	0	0	1	3	16	17	17	18	18	18	18
$ Savings to growers($m)	205853	$2.00	0.00	0.00	0.00	0.00	0.49	1.09	6.42	6.82	7.11	7.31	7.41	7.41	7.41
NPV of savings	5%	$40.8													
Net benefits	$m		-0.5	-0.5	-0.5	-0.5	0.0	0.6	5.9	6.3	6.6	6.8	6.9	6.9	6.9
Discount factor	5.0%	0	1	0.95	0.90	0.86	0.81	0.77	0.49	0.46	0.44	0.42	0.40	0.38	0.36
Discounted costs and benefits															
NPV: Benefits	$m	$41.5	0.00	0.00	0.00	0.00	0.40	0.84	3.13	3.16	3.13	3.06	2.94	2.80	2.66
NPV: Costs	$m	$6.6	0.50	0.48	0.45	0.43	0.41	0.39	0.24	0.23	0.22	0.21	0.20	0.19	0.18
NPV: Net benefits	$m	$34.9	-0.50	-0.48	-0.45	-0.43	0.00	0.45	2.89	2.93	2.91	2.85	2.75	2.61	2.48
Benefit cost ratio		6.3													
Internal rate of return	%	42%					3								

Source: AbacusBio and IDA Economics analysis

The investment returns using the above shows that an investment in NUE in sugarcane breeding (given Scenario 2 in the otherwise case – probable restriction of sugarcane production areas) would be profitable

Even at the low rate of adoption of 30% (and an N cost of $2/kg, real 2016) the investment in the R&D is estimated to return $14mn in present value terms, allowing for the additional R&D costs. This represents an IRR of 27%.

At the higher adoption rate of 60% – which is quite plausible — the investment return is about double an NPV of $35mn — and an IRR of 42%. If the price of N were to rise to $4/kg (real 2016) the estimated return is 59% (at 60% adoption) (Appendix Table 2.6A).

Appendix Table 2.6A: Investment return: Improved NUE from plant breeding

30% adoption	$2 kg N applied	$4 kg N applied
NPV savings to growers	$21	$41
NPV savings to growers less R&D costs	$14	$35
B/C ratio	3	6
IRR	27%	42%
60% adoption	**$2 kg N applied**	**$4 kg N applied**
NPV savings to growers	$41	$83
NPV savings to growers less R&D costs	$35	$76
B/C ratio	6	13
IRR	42%	59%
100% adoption	**$2 kg N applied**	**$4 kg N applied**
NPV savings to growers	$69	$138
NPV savings to growers less R&D costs	$63	$132
B/C ratio	10	21
IRR	54%	74%

Investment return Scenario 1

Under Scenario 1 it is postulated that a range of other (non-variety) developments will lead to improved NUE across Wet Tropics and Burdekin and that these other developments will achieve the bulk (estimated at 75%) of the quantified benefits when measured against the Baseline.

Thus with 60% adoption of improved NUE varieties (and holding the other factors constant) the investment returns from additional breeding under Scenario 1 (with N at $2/kg) are estimated at $4mn (NPV) or an IRR of 14% (Appendix Table 2.6B).

Appendix Table 2.6B: Investment returns Scenario 1

60% adoption	$2 kg N applied	$4 kg N applied
NPV savings to growers	$10	$21
NPV savings to growers less R&D costs	$4	$14
B/C ratio	2	3
IRR	14%	27%

Investment return Scenario 2

Under Scenario 2, the gains from additional plant breeding are the benefits against the baseline plus the avoided losses which would occur under additional regulation (with these losses beginning around 2023). The estimated investment returns are substantial primarily driven by the avoided losses in the Wet Tropics and Burdekin (Appendix Table 2.6C).

- The NPV of the net benefits is around $343mn
- The IRR is estimated at around 94%

Appendix Table 2.6C: Investment returns Scenario 2

60% adoption	$2 kg N applied	$4 kg N applied
NPV savings to growers	$350	$378
NPV savings to growers less R&D costs	$343	$371
B/C ratio	53	57
IRR	94%	97%

The Scenario 2 analysis is subject to several caveats/observations.

- Scenario 2 of the otherwise case is that, in the absence of much improved management of N by the sugarcane industry (specifically in the Wet Tropics and Burdekin), it is hypothesised that restrictions would be implemented on where and how cane is grown (It is postulated that a third of the Wet Tropics plus Burdekin area would no longer grow cane). In that situation there would be considerable loss of net income to sugarcane growers. If the investment in NUE varieties can deliver appropriate new varieties (and thus negate any additional regulation) that income loss would be avoided.
- An explicit valuation of off-farm environmental benefits has not been necessary under Scenario 2. It is hypothesised that the industry either develops mechanisms to address the off-site DIN issue or (as a certainty) restrictions are placed on the industry to achieve that end. Either way the DIN issue is 'addressed'.
- Almost all (91%) of the estimated benefits from the investment derive from the avoided loss in growers' incomes. N fertiliser cost savings deliver 9%.
- The timeframe to 2036 is somewhat arbitrary. Equally, a longer time period does not significantly improve the return since benefits past 2036 are discounted by about 70% at the 5% discount rate.
- Some benefits have not been quantified: specifically, the implications for millers in a whole of industry approach. Under Scenario 2, successful NUE variety development would also avoid lost miller net incomes. However, without detailed budget analysis quantifying that loss has not been possible but it would be significant as the hypothesised cane area loss would lead to mill closures.
- Flow-on regional economic benefits deriving from the continuation of cane growing have not been estimated. Again these would be significant given the potential loss in cane area if restrictions on growing areas were to be introduced.

Nitrogen in the breeding program

Model development

The model is based on the following inferences derived from a range of literature:

Appendix Table 2.7. Empirical model of nitrogen dynamics in sugarcane where N applied and yields are expressed as the total over the 3-year cycle from planting (combined planting, first and second ratoons).

Parameters: NUE is *Nitrogen Use Efficiency* as kg N accumulated per hectare/N applied; N leached is expressed as kg per hectare and as per hectare/N applied; the yield (TCH) response is linear from 120 to 420 kg N applied over 3 years; sugar content is calculated as 13% CCS.

N applied (kg per hectare)	TCH parameters			Sugar	Nitrogen parameters				
	TCH (tonnes /ha)	Percentage of maximum TCH yield	Marginal TCH tonnes response per kg N	TSH (tonnes /ha)	Kg N per tonne TCH	Accumulation (kg N per hectare)	NUE	N leached (kg/ha) Total	N leached (kg/ha) % of N applied
200	200	65%		28.0	0.680	136	**68%**	0.80	**0.40%**
260	216	70%	**0.267**	30.2	0.700	151	**58%**	1.76	**0.68%**
320	232	75%	**0.267**	32.5	0.720	167.0	**52%**	3.28	**1.02%**
380	248	80%	**0.267**	34.7	0.740	183.5	**48%**	5.5	**1.44%**
440	264	85%	**0.267**	37.0	0.760	201	**46%**	8.5	**1.94%**
500	280	90%	**0.267**	39.2	0.780	218	**44%**	12.5	**2.50%**
560	292	94%	**0.200**	40.9	0.800	234	**42%**	17.6	**3.14%**
620	301	97%	**0.150**	42.1	0.820	247	**40%**	23.8	**3.84%**
680	307	99%	**0.100**	43.0	0.840	258	**38%**	31.4	**4.62%**
740	310	100%	**0.050**	43.4	0.860	267	**36%**	40.5	**5.48%**

Appendix Table 2.8. Financial analysis as a Gross Margin model: Responses as a function of N applied

2.8A Financial analysis as a Gross Margin model: Responses as a function of N applied at $400 per tonne sugar, with input costs of $16 per tonne excluding water and N with N at $2 per kg.

N supplied (kg/hectare)	% of max yield	Value of sugar ($400 per tonne)	Other costs ($16.00 per tonne)	N cost ($2.00 per kg applied)	Gross Margin (GM) per hectare	Marginal change in the GM per hectare as a function of N applied: Per 60kg increase in N applied	Per kg N applied
200	65%	$7,280	$3,200	$400	$3,680		
260	70%	$7,862	$3,456	$520	$3,886	$206	$3.44
320	75%	$8,445	$3,712	$640	$4,093	$206	$3.44
380	80%	$9,027	$3,968	$760	$4,299	$206	$3.44
440	85%	$9,610	$4,224	$880	$4,506	$206	$3.44
500	90%	$10,192	$4,480	$1,000	$4,712	$206	$3.44
560	94%	$10,629	$4,672	$1,120	$4,837	$125	$2.08
620	97%	$10,956	$4,816	$1,240	$4,900	$64	$1.06
680	99%	$11,175	$4,912	$1,360	$4,903	$2	$0.04
740	100%	$11,284	$4,960	$1,480	$4,844	-$59	-$0.98

2.8B Summary of financial analysis: Responses in Gross Margin per hectare as a function of N applied over the first three crops (planting to second ratoon) at a sugar price of $400/tonne with input costs of $16 per tonne excluding water and N (with N at $2 per kg).

Cost of N per kg applied per hectare	Marginal response in GM per hectare as a function of the additional N applied		
	Linear Phase (200 to 500 kg N)	Margin 500 to 560 kg N	Margin 680 to 740 kg N
$2.00	$1032	$125	-$59
$3.00	$732	$65	-$119
$4.00	$432	$5	-$179
$5.00	$132	-$55	-$239
$6.00	-$168	-$115	-$299

2.8C Sensitivity of the Gross Margin per hectare to changes in the price of N and the price of sugar

Cost of N per kg applied per hectare	Marginal response in GM per hectare as a function of the additional N applied								
	Sugar price of $350 per tonne			Sugar price $400 per tonne			Sugar price $450 per tonne		
	200 to 500 kg N	500 to 560 kg N	680 to 740 kg N	200 to 500 kg N	500 to 560 kg N	680 to 740 kg N	200 to 500 kg N	500 to 560 kg N	680 to 740 kg N
Variable costs of $16 per tonne TCH (excluding N with no water costs)									
$2.00	$2.23	$1.17	-$1.21	$3.44	$2.08	-$0.98	$4.65	$2.99	-$0.75
$3.00	$1.23	$0.17	-$2.21	$2.44	$1.08	-$1.98	$3.65	$1.99	-$1.75
$4.00	$0.23	-$0.83	-$3.21	$1.44	$0.08	-$2.98	$2.65	$0.99	-$2.75
$5.00	-$0.77	-$1.83	-$4.21	$0.44	-$0.92	-$3.98	$1.65	-$0.01	-$3.75
$6.00	-$1.77	-$2.83	-$5.21	-$0.56	-$1.92	-$4.98	$0.65	-$1.01	-$4.75
Variable costs of $22 per tonne TCH (excluding N with $6 per tonne water costs)									
$2.00	$0.63	-$0.03	-$1.51	$1.84	$0.88	-$1.28	$3.05	$1.79	-$1.05
$3.00	-$0.37	-$1.03	-$2.51	$0.84	-$0.12	-$2.28	$2.05	$0.79	-$2.05
$4.00	-$1.37	-$2.03	-$3.51	-$0.16	-$1.12	-$3.28	$1.05	-$0.21	-$3.05
$5.00	-$2.37	-$3.03	-$4.51	-$1.16	-$2.12	-$4.28	$0.05	-$1.21	-$4.05
$6.00	-$3.37	-$4.03	-$5.51	-$2.16	-$3.12	-$5.28	-$0.95	-$2.21	-$5.05

Appendix Table 2.9A (UQ044 Report). Linear regression relationships between TCH (y = total cane harvested tonnes per hectare) over plant to second ratoon crops as a function of N applied (x = kg N applied per hectare))

Trait	Area	N per ha (low, high)	Slope	Intercept	Yield at low N	Yield at high N
Yield as TCH (tonnes per hectare)	Mackay	120 kg N, 480 kg N	0.186	226	248	315
	Burdekin	100 kg N, 580 kg N	0.235	119	142	255

Appendix Table 2.9B (UQ044). Mean, genetic variance and broad-sense heritability (H^2) of traits for 64 genotypes with low (20-40 ^{kg}) and recommended N (160-200 kg N ha^{-1} yr^{-1}) for plant, 1R and 2R crops

Parameter	Site	N supply	Crop	Mean	Variance	Genetic variance	Heritability H^2	CV
TCH (Mk, Mackay & Bu, Burdekin)	Mk	Low	P	109	284	204	0.68	0.21
	Mk	Low	1R	89	235	85	0.52	0.2
	Mk	Low	2R	50	90	50	0.62	0.26
	Mk	Rec	P	123	344	108	0.49	0.18
	Mk	Rec	1R	114	183	130	0.68	0.16
	Mk	Rec	2R	78	109	92	0.72	0.2
	Bu	Low	P	54	201	179	0.73	0.38
	Bu	Low	1R	53	115	55	0.6	0.24
	Bu	Low	2R	35	126	16	0.27	0.35
	Bu	Rec	P	87	221	171	0.7	0.22
	Bu	Rec	1R	99	253	143	0.63	0.2
	Bu	Rec	2R	69	344	126	0.52	0.32
CCS	Mk	Low	P	12.8	0.6	1.6	0.88	0.12
	Mk	Low	1R	13	0.3	1.5	0.93	0.11
	Mk	Low	2R	14.3	0.4	0.96	0.87	0.08
	Mk	Rec	P	12.5	1.2	2	0.84	0.14
	Mk	Rec	1R	12.7	0.7	1.6	0.87	0.12
	Mk	Rec	2R	14	0.3	1.1	0.92	0.08
	Bu	Low	P	13.7	0.5	1.6	0.9	0.11
	Bu	Low	1R	MV	MV	MV	MV	MV
	Bu	Low	2R	13.2	1.6	1.9	0.78	0.14
	Bu	Rec	P	13.4	1.0	2.6	0.9	0.1
	Bu	Rec	1R	MV	MV	MV	MV	MV
	Bu	Rec	2R	12.8	1.1	3	0.89	0.16
N accumulation (kg N ha^{-1})	Mk	Low	P	93	607	159	0.44	0.3
	Mk	Low	1R	65	284	35	0.26	0.35
	Mk	Low	2R	31	91	17	0.36	0.32
	Mk	Rec	P	136	1013	211	0.38	0.26
	Mk	Rec	1R	96	369	138	0.53	0.24
	Mk	Rec	2R	54	156	33	0.39	0.26
	Bu	Low	P	21	64	38	0.64	0.48
	Bu	Low	1R	25	54	19	0.51	0.35
	Bu	Low	2R	MV	MV	MV	MV	MV
	Bu	Rec	P	48	236	68	0.47	0.36
	Bu	Rec	1R	59	246	175	0.68	0.12
	Bu	Rec	2R	MV	MV	MV	MV	MV

Appendix 3. Investment analysis: WUE

Assessment of potential benefits from an selecting for additional traits

The potential benefits of incorporating a WUE trait in the selection index are evaluated in terms of the potential to maintain or improve whole of industry profits(growers and millers), at current industry size or with expansion through:

- cost savings to growers (lower water costs, purchase and pumping), and/or
- productivity gains to growers (improved TCH from improved WUE) which, at whole of industry level could lead to cost savings to millers given total TCH volume increase, and/or
- avoided costs (e.g. avoiding income and profit losses due to restrictions on input use or other activities which lead to reduced cane yield or area grown).

Spillover benefits from a sugar cane WUE breeding R&D program could include application of WUE assessment techniques to other Australian crops as well as sugarcane and other crops overseas.

In the first instance the potential gains in each of these areas are estimated against a baseline, that is:

- a WUE trait can be readily incorporated in the selection index for the respective regions,
- selection on the WUE trait delivers both a water cost saving and a TCH increase, and
- farm practices (driven by either management, prices or regulation) and the area planted remains the same as today.

The potential gains are then estimated against the otherwise case – where farm practices are expected to change in response to water prices; further adoption of WUE technologies; new technologies; additional regulations (which might for example limit the level or timing of water application or indeed growing of sugar cane in some areas) or industry responses to the these additional regulations.

Investment framework

In this analysis, following conventional practice, the value of the investment is expressed in real (inflation-adjusted) net present value terms (discounted cash flow), internal rate of return or other investment return metrics, where the value is derived from the following measures:

- investment costs (negative)
- estimated industry benefits from the variety improvement over time (including longer term sustainability) x probability of R&D success x proportion of industry where the benefit is applicable x adoption by growers x probability that R&D will not become redundant (compared to otherwise)
- non-quantified industry benefits
- benefits outside of the industry (including broader community benefits)

Previous analysis

Inman-Bamber examined the potential economic gains if water stress could be alleviated in sugar cane growing areas.[12]

- Water stress factors were calculated, based on regional level laboratory and field research. These factors were based on the logic that if roots can supply only 80% of the daily water demand, for example, then biomass will accumulate at 80% of potential for that day with a stress factor of 0.8.

[12] Inman-Bamber, N.G., *Economic impact of water stress on sugar production in Australia*, Proc. Aust. Soc. Sugar Cane Technol., Vol. 29, 2007

- Average stress factors were obtained for model settings that best described historical yields which were assumed to be limited by water stress in proportion to the water stress factor. Other factors were assumed to be non-limiting.
- Potential yields unconstrained by water stress were then estimated by dividing historical yields by the stress factor to obtain an estimated yield increase above historical yields, sub region by sub region (**Appendix Table 3.6**).
- Using sub regional data production data and the sugar price at the time (2007, $350/t sugar price) the potential increase in sugar gross income to millers and growers was calculated for each region and in aggregate for the industry. The estimated increase in yield (average 15.3% or 0.5 to 0.55m t sugar) was calculated to lead to an increase in gross income (or reduction in gross income forgone) due to water stress of $230m per annum.

Appendix Table 3.6: Estimated yield losses due to water stress: Inman-Bamber 2007 (sub regions have been aggregated into regions for the purposes of the present analysis)

Sub-Region/Mill	Regional contribution (% of Aust. Sugar production)	Water stress Factor: Sub-region	Potential yield increase: By Sub-region	Region	Water stress factor: Region	Potential yield increase: By region
Tablelands	1	0.850	17.6%	Northern	0.897	10.3%
Innisfail-Tully	18	0.900	11.1%	Northern		
Herbert	11	0.871	14.8%	Herbert	0.871	12.9%
Burdekin	21	0.956	4.6%	Burdekin	0.956	4.4%
Proserpine	5	0.725	37.9%	Central	0.811	18.9%
Mackay	18	0.832	20.2%	Central		
Sarina	4	0.825	21.2%	Central		
Bundaberg-Isis	11	0.768	30.2%	Southern	0.818	18.2%
Maryborough	2	0.767	30.4%	Southern		
Moreton/RockyP	3	0.900	11.1%	Southern		
NSW	5	0.900	11.1%	Southern		
Ord	1	0.950	5.3%	Ord	0.950	5.0%
Production weighted mean		0.867	15.3%		0.867	15.3%

Estimated benefits from alleviating water stress 2015

Yield increases

The stress factors estimated by Inman-Bamber are likely as appropriate today as in 2007. While there will have been some changes due to on-farm management changes (such as trash retention, controlled traffic farming and other precision techniques) and perhaps varieties, they are sufficiently robust for the purposes of the present analysis. Applying the Inman-Bamber stress factors to production levels over the last decade yields much the same potential industry level yield increase – around 0.55m t sugar. The increase at sub region and regional level is detailed in Appendix Table 3.2.

Appendix Table 3.7: Estimated yield losses due to water stress - 2005-2014 production data: Gross income (Source: AbacusBio and IDA analysis)

	Sugar production	Estimated yield increase: No moisture stress		Value of yield increase (growers plus millers) Historical sugar	Region	Gross income: Budget data 2013-14		Value of yield increase: Budget data 2013-14	
	Average 2005-2014			Av sugar price 2005-14 $/t		Miller gross income	Grower gross income	Miller gross income	Grower gross income
				$385	Sugar price $/t	$400			
	Sugar mt	%	Sugar mt	$m		$/t sugar	$/t sugar	$m	$m
Northern	0.753	11.4%	0.086	$33.1	Wet Tropics	$148	$252	$12.8	$21.7
Herbert	0.557	14.8%	0.082	$31.7	Wet Tropics	$148	$252	$12.2	$20.7
Burdekin	1.142	4.6%	0.053	$20.2	Burdekin Delta	$135	$265	$7.1	$13.9
Central	1.150	23.3%	0.268	$103.0	Central irrigated	$138	$262	$37.0	$70.1
Southern	0.735	22.2%	0.163	$62.8	South irrigated	$140	$260	$22.9	$42.4
Ord	0.000	5.3%	0.000		Ord				
Total	4.335	15.3%	0.652	$251				$92.0	$168.8
Total									$261
Gross margin = Gross income minus variable costs									
Grower budget data (income and gross margins) sourced from CaneGrowers									
Miller gross income = Sugar price less sugar price paid to growers									

Appendix Table 3.11 also shows the estimated value of the yield loss, apportioned to millers and growers. The total gross income loss is $261m (at sugar price of $400/t) which is $30mn higher than that from Inman-Bamber ($230m per annum at a sugar price $350/t) (in *nominal terms* – not adjusted for inflation).

However, the usual approach in investment analysis of industry benefits due to alleviating a problem (water stress in this case) is to estimate the benefits or financial gain in terms of profits forgone rather than gross income. The financial gain to millers and growers (the industry) from alleviating water stress can be measured as the aditional gross margin (gross income minus the variable costs of production), although strictly spreaking the additonal marginal costs of production should be used, and these are likely to less than the average variable costs of production. For present purposes the gross margin (growers) and gros profit (millers) have been used given access to data issues. The estimated gross margins are presented in Appendix Table 3.12. It is estimated that the potential whole of industry gross margin/profit gain would be around $108m per annum.

Appendix Table 3.8: Estimated yield losses due to water stress: 2005-2014 production data: Gross margins (Source: AbacusBio and IDA analysis)

	Sugar production	**Estimated yield increase: No moisture stress**		**Region**	**Gross margins: Budget data 2013-14**		**Value of yield increase: Budget data 2013-14**	
	Average 2005-2014				Miller gross profit 48%	Grower GM	Miller GP	Grower GM
	Sugar mt	%	Sugar mt		$/t sugar	$/t sugar	$m	$m
Northern	0.753	11%	0.086	Wet Tropics	$71	$97	$6.1	$8.4
Herbert	0.557	15%	0.082	Wet Tropics	$71	$97	$5.9	$8.0
Burdekin	1.142	5%	0.053	Burdekin Delta	$65	$108	$3.4	$5.7
Central	1.150	23%	0.268	Central irrigated	$66	$101	$17.8	$26.9
Southern	0.735	22%	0.163	South irrigated	$67	$92	$11.0	$15.0
Ord		5%		Ord				
Total	**4.335**		**0.652**				**$44**	**$64**
Gross margin = Gross income minus variable costs; Grower budget data (income and gross margins) from CaneGrowers Miller gross income = Sugar price less sugar price paid to growers; Miller gross profit based on Mackay Sugar *Annual Report 2014* (Gross profit as % of sugar returns (sugar produced * sugar price)). Weighted Av 2010-2014 of 48%								

Further, the stress factor calculations are based on other factors not limiting the yield increase. In practice other factors may well be limiting, hence the calculated stress factors should be viewed as an upper limit.

Cost savings

Another factor to consider are potential cost savings from more WUE varieties. There are two particular aspects:

- the potential for reductions in irrigation water demand and/or the costs or irrigating (water purchase and pumping costs) through development and adoption of more WUE varieties; in some regions increased pumping costs (deriving from recent and potentially future higher electricity charges) are particularly relevant;
- potential capital cost savings in irrigation expansion within existing regions or in new regions, including the development of Northern Australia; however in the latter case, sugar is identified as a potential broadacre crop, apart from existing production areas and associated supply[13]; in the absence of relevant infrastructure costs associated with possible development potential capital and operating cost savings have not been estimated.

In terms of existing production regions, irrigation costs are significant in all regions except the Wet Tropics. The value of cost savings, using a 2.5% total cost saving (incluidng access charges, usage charges and pumping costs) are detailed on a regional basis, in Appendix Table 3.4.

Appendix Table 3.9: Irrigation costs: Sugarcane growing 2013-14 (Source: CaneGrowers data; AbacusBio and IDA analysis)

Irrigation costs	**Wet Tropics**	**Burdekin Delta**	**Central irrigated**	**South irrigated**	
Water use (ML/ha)	0	16	3	3	
	$/ha harvested				
Water (Part B)	0	0	95	152	
Electricity for pumping	0	537	151	279	
Diesel for pumping	0	0	0	0	
Labour for irrigation	0	0	0	0	
Repairs and Maintenance	0	71	26	26	
Total (excl Part A)	0	608	272	458	
Part A	0	120	107	134	
Total (incl Part A)	0	799	406	618	
Part A is the scheme operator's (SunWater) fixed cost portion passed on to growers and is payable for the allocated MLs whether the water is used or not; Part B is the scheme operators variable cost per ML to operate the scheme and passed on to the grower only for the MLs used					
Production: Area harvested	**Wet Tropics**	**Burdekin Delta**	**Central irrigated**	**South irrigated**	**Total**
Area (Average 2005-2010), ha harvested (SRA Mill Report)	126,683	69,176	106,325	63,753	365,936
Cost saving of 2.5% (Total irrigation costs reduce by 25%)	$0.0	$1.4	$1.1	$1.0	$3.4

[13] Australian Government, Our North, Our Future - White Paper on Developing Northern Australia, 2015.,

Research investment

A 2014 SRA proposal, Water use-efficient and drought tolerant sugarcane: trait validation and high-throughput field screening, was costed as the

> *"cost of implementing this technology is project costs + $3 million (based on the cost of equipment and associated facilities and other operational costs at 5 production regions)"*

The proposal outlined that the applicant would provide $332,000 (over 3 years) as in kind and FTE equivalent researchers.

Other project costs were not cited in the proposal overview, but have been estimated at $100,000 over 3 years. In additional, there would be additional costs to the SRA breeding program.

Since the 2014 proposal technology developments mean very small drones that carry equipment with multiple sensing capabilities can be used. The cost is about $200K for the hardware and software for a single unit. Applied across five regions for clone selection, the total cost of implementation for the kind of technology for improving breeding/selection system would be about $1 mn (compared with the previous cost of $3 mn).

Estimated additional R&D costs are set out in Appendix Table 3.10.

Appendix Table 3.10: Estimated additional Pre-breeding R&D and Breeding R&D $ mn

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2033	2034	2035	2036
Pre breeding R&D	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125					
Breeding program					0.2	0.2	0.2	0.2	0.2				
Pre release					0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	0.125	0.125	0.125	0.125	0.425	0.425	0.425	0.425	0.3	0.1	0.1	0.1	0.1

Likelihood of R&D success

A range of factors will determine the likelihood of success in being able to select for WUE in future sugar cane varieties. These include the 'inherent riskiness of the R&D' (is it applied or basic/novel R&D?), the capability of the researchers involved (local and international), and/or the level of investment (for example, a higher level of investment may enable additional research capability to be employed and the time frame reduced).

The reviewers of the CSIRO proposed project commented that the project was 'high risk'

> *"CSIRO technologies (the proposed phenomics technologies) are newly developed; not proven (and new systems may be developed. So the prospect of redundancy is high)"*

The other approach to incorporating project risk is through estimating the likely or feasible yield gain required to achieve the required rate of return.

The latter approach has been adopted. The first improved varieties that are 10% more efficient are harvested in 2021, with varieties improving by 1.5% per year thereafter.

Time-frame to variety release

Variety development by SRA and its predecessors typically takes about 12 years from when the original parent crosses are made to release of a new variety. In the case of new trait development the breeding time is unlikely to be much different but there is the pre-breeding R&D and the associated time frame, as outlined above. However, any change in the methodology may impact the development time-frame, albeit a reduction in the time from first selection to release will generate benefits through a more rapid return.

Given the breeding program already in place (and hence material to select from in trials in available) it is reasonable to conclude that some gain can be made in the next 5 years or so. As noted above a 10% gain in WUE for crops harvested in 2021 has been used.

Applicability across the industry

The inter- and intra- regional (and within farm) differences in climate, soils and management options mean that a range of varieties are required by the industry. As noted above the 'water stress factors' differ between regions – higher in the rainfed areas and lower in irrigation areas (as irrigation water has been available, albeit at a cost). This will mean that WUE traits/selection will need to be developed/applied across a range of varieties.

Given the recognised differences in regional stress factors, which are already incorporated in the measurement of potential yield increases, no further adjustment to address applicability across the industry is required.

Adoption by growers

A range of factors influence adoption by growers, chief amongst them is the expected change in net profit, with all costs (and risks) considered.

New varieties are more applicable (often intentionally) to particular regions and site-specific situations (the SRA variety tool helps growers assess varieties). However, historically, adoption across the relevant regions/situations takes time. Also, growers typically grow a selection of varieties in order to manage harvesting times, production risks and their farm management schedules.

Estimates of the rate and level of adoption can be made using historical data/observations for comparable technological changes. In the case of a new trait in varieties there may be specific considerations as well as general considerations such as managing risks associated with seasonal impacts and harvesting schedules. Overall growers are reported to be quick to adopt varieties where there are demonstrable financial gains.

Typically there are limited additional cash costs to growers in adopting a new variety. The main additional cash cost is new seed/billets, although for growers always purchasing new (tissue culture) plants, there would not be an additional cost. However, varieties with greater ratoon persistence would reduce establishment costs as this would reduce the fallow area (currently the generally-accepted figure is that about 16% of area is fallow).

Other costs of a new variety are the potential lower than expected yield/CCS in initial years as growers learn how best to manage the new variety in their particular circumstances (aided by inter-regional evaluation information). These issues may well be more important where a new variety incorporates new trait(s) which require significant management changes (including irrigation management) and emphasises the relevance of guidelines with regard to soil type and water requirements (and thus the trialing period before full release to industry).

Adoption across the industry is measured as the proportion of production/area (as against number of growers) and is estimated over time. Adoption may also be relevant to the otherwise case. For example, if an increasing proportion of the cane area is being managed under BMP regimes this needs to be allowed for in the time profile of the otherwise case (above).

Significantly, the support to growers to help in assessing new varieties is well established, especially through local productivity groups.

Given the importance of the WUE issue, the demonstrated promotion and support for WUE strategies, the probable commercial gains from adopting varieties with improved WUE (assuming limited trade-offs with other attributes) and the capacity to switch to new varieties (albeit with management learning issues) suggests a relatively high adoption rate and fast rate of adoption. An adoption rate of 30% (initial year of new variety release) with sensitive scenarios of 60% and 100% have been used.

Redundancy

There are two broad reasons as to why incorporating a new trait in the selection index might become redundant or at least require a continuing investment to maintain its relevance, namely obsolescence and a change in the level of relevance.

An example of obsolescence might be where traditional breeding is challenged by the incorporation of genetic modification (GM) technology. However, GM may not change the selection index or relative economic weights, but rather it is more likely (if used) to reduce the length of the breeding time-frame (once the regulatory hurdles are overcome) by reducing the complexity of decision-making (by providing a major shift in one target trait) in the selection of individual clones. GM technology is challenging traditional breeding in a number of plant species. Given the recent advances (Arcadia), it is evident that there is potential for GM technology in sugarcane breeding and GM offers potential opportunities (SRA project with DuPont). Further, there are also market considerations which at present appear to limit the feasibility of using GM strategies. Overall the GM solution will not be a near term option for the industry.

An issue with any new trait is the extent to which incorporating it in the selection index becomes less relevant because the problem goes away (unlikely and the contrary is more likely in the case of water) or is superseded by other technologies (for example on farm BMPs). In this respect, the review panel for the CSIRO proposal noted a ‘high risk of redundancy’ from potentially new systems.

> *“CSIRO technologies (the proposed phenomics technologies) are newly developed; not proven (and new systems may be developed. So the prospect of redundancy is high)”*

Certainly new systems maybe developed to assist with trait identification and to that end there is a redundancy risk with the technology proposed in the CSIRO application. Conceptually this risk should be reflected in the ‘otherwise case’ - that alternative technologies (presumably at lower cost or funded by others apart from SRA) could address the water issue. However, it is difficult to be specific about such options in the abstract and it could be argued that there is perhaps the same likelihood that other technologies will not be developed. The more relevant risk (addressed above under research success) is that the technology might not deliver the hoped for outputs.

To maintain the relevance of specific traits, given changing challenges facing varieties (such as declining disease resistance or new disease threats), a continual investment in plant breeding is required. Accordingly, a continuation of WUE related breeding investment (additional investment on top of the main breeding program) has been incorporated in the analysis (as noted above).

Other benefits and costs

There are a number of potential other benefits which are generally considered but are usually unquantifiable. In the current context these include:

- co-incidental benefits to the sugar industry of including the new trait that have not been included above, such as a wider array of options which reduce risk;
- addressing water stress may give to other management challenges;
- development of the screening technology may have application for other traits in sugar cane – possibly advancing selection (earlier identification of desirable performance) or improving selection accuracy;
- inter-industry: these might include the research learnings which have application to other Australian plant breeding investments;
- community-wide: these are particularly relevant in respect of off-farm environmental benefits, such as reduced water flow into streams and subsequently the Reef; although they are not quantified, they need to be recognised;
- international: there may well be benefits to overseas sugarcane or other plant breeding programs.

Summary

For present purposes the analysis is based on the following.

- The yield gap which new WUE variety development might be able to address is based on the water stress factors published by Inman-Bamber 2007.
- The value of the potential alleviation of the theoretical 'total water stress' is based on gross margins, not gross income.
- The yield gap suggests that it is not economic to address it using current technologies (irrigation systems, irrigation management, farm management in rainfed systems) or alternatively there is an adoption issue.
- Cost savings for irrigators are estimated at 2.5% of current operating costs (using an average $5.50 per tonne sugar cost of irrigation across all regions except the Wet Tropics), although there are limited data to support this 2.5% estimate.
- It is improbable that new varieties will totally overcome the water stress gap, especially in the near to medium term. For the purposes of the analysis a 10% gain in WUE (and $ benefit from reduced water stress) in the first of the new varieties (harvested in 2021) has been used, with an improvement in WUE of 1.5% per annum thereafter.
- Rates of adoption will be influenced by a range of factors (including grower expectations of improved WUE leading directly to higher TCH, with no additional management or other costs). For simplicity the potential benefits have been estimated with a 30%, 60% and 100% flat rate of adoption (of production) (i.e. not increasing over time)
- Some improvement in current production systems can be anticipated (otherwise case with a 50% improvement in WUE from other factors).
- The economic payoff from variety development is then set up in terms of the economic return if the remaining theoretical yield gap were overcome given the likelihood of R&D and breeding success.
- Capital and operational cost savings if industry expansion (in existing or new regions) were to occur have not been estimated.
- Improved WUE may adversely impact on on-farm productivity but none have been identified.
- No off–farm impacts from improved varietal WUE on farm, but if less water were to be used on farm there may be off-farm environmental benefits.
- Increases in yield are expected to increase WUE[14].

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[14] Crop yields and global food security: will yield increase continue to feed the world? Fischer, R. A., Byerlee, D., & Edmeades, G. O.. (2014). Crop yields and global food security: will yield increase continue to feed the world? Canberra: Australian Centre for International Agricultural Research. Retrieved from http://aciar.gov.au/publication/mn158; the following is from this publication:

X. Zhang et al. (2011) attributed greater WUE to improved varieties and higher soil fertility, leading to higher final total dry matter (DM)—seen in increases of 30% DM for wheat and 6% DM for maize—and increased harvest index (HI), especially in maize; The following quotation is from this document. *(see Section 2.6 for definitions of DM and HI). Weather-driven potential evapotranspiration (ET_p; see also Section 2.6) did not change and crop growth duration did not increase for either crop, meaning that increases in crop ET per day were somehow linked to greater crop growth rate. With maize, the smaller ET increase was partly caused by retention of the wheat crop residue, which reduced soil evaporation under maize by 30–40 mm when direct seeding of maize was introduced in 1991. The general improvement in WUE over time, as mentioned above, is easily explained. As discussed in Section 2.6, ET of irrigated field crops is driven more by weather and crop growth duration, and is only weakly dependent on crop leaf area index (LAI). ET is the sum of crop transpiration plus soil evaporation, such that when LAI is low ET is insensitive to LAI because under relatively frequent irrigation (or frequent rains) evaporation from the wet soil surface will largely compensate for lower transpiration from fewer crop leaves. Agronomic management and breeding advances, which can increase early growth rate (but not overall crop growth duration), will increase crop transpiration at the expense of soil evaporation, and thereby increase total DM per unit ET. If HI simultaneously increases (as has often been the case with variety improvement), WUE will further benefit.*

Investment analysis

Appendix Table 3.11: Investment returns ($ mn): NPV of replacing standard varieties with more efficient varieties for WUE (first improved varieties are 10% more efficient are harvested in 2021, with varieties improving by 1.5% per year thereafter at 30%, 60% and 100% adoption).

	30% adoption	60% adoption	100% adoption
NPV of gains to growers ($ mn) at discount rate of 5%	$54	$108	$180
NPV of savings to growers less R&D costs ($ mn) at discount rate of 5%	$51	$105	$177
Internal Rate of Return (IRR)	87%	116%	141%

Appendix Table 3.12: Investment returns: NPV of replacing standard varieties with more efficient varieties for WUE (first improved varieties are 10% more efficient are harvested in 2021, with varieties improving by 1.5% per year thereafter at 30%, adoption).

Real 2015 prices			2016	2017	2018	2019	2020	2021	2022	2023	2024	2029	2030	2035	2036
Additional R&D and breeding	$m		0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.1
Benefit															
TCH increase (start, Per annum inc	10%	1.5%					10%	11.50%	13.00%	14.50%	16.00%	23.50%	25.00%	32.50%	34.00%
Cost saving: Existing prodn. areas	$m						0.1	0.2	0.3	0.4	0.6	0.8	0.9	1.1	1.2
Cost saving: New prodn. areas	$m														
TCH increase							2.16	4.968	8.424	12.528	17.28	25.38	27	35.1	36.72
Other within industry benefits	$m														
Environmental benefits	$m														
Otherwise case benefit															
R&D Success probability	100%														
Adoption profile		Growth													
Applicability across industry	100%		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Additional implementation costs															
Adoption across industry	30%		30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
Benefits	$m						0.67	1.54	2.61	3.88	5.35	7.86	8.36	10.87	11.37
Net benefits	$m		-0.1	-0.1	-0.1	-0.1	0.2	1.1	2.2	3.5	5.0	7.6	8.3	10.8	11.3
Discount factor	5.0%		1	0.95	0.90	0.86	0.81	0.77	0.74	0.70	0.66	0.51	0.49	0.38	0.36
Discounted costs and benefits															
NPV: Benefits	$m	$54					0.54	1.19	1.92	2.71	3.55	4.03	4.08	4.10	4.08
NPV: Costs	$m	$3	0.13	0.12	0.11	0.11	0.35	0.33	0.31	0.30	0.20	0.15	0.05	0.04	0.04
NPV: Net benefits	$m	$51	-0.13	-0.12	-0.11	-0.11	0.20	0.86	1.60	2.41	3.35	3.88	4.03	4.06	4.04
Benefit cost ratio		17.6													
Internal rate of return	%	87%													

Appendix Table 3.13: Investment returns - Otherwise case: WUE improvements from improved on farm or other practices achieve 50% of variety improvement gains: The NPV of replacing standard varieties with more efficient varieties for WUE (the first improved varieties are 10% more efficient and are harvested in 2021, with varieties improving by 1.5% per year thereafter at 30%, 60% and 100% adoption).

	30% adoption	60% adoption	100% adoption
NPV of gains to growers ($ mn) at discount rate of 5%	$27	$54	$90
NPV of savings to growers less R&D costs ($ mn) at discount rate of 5%	$24	$51	$87
Internal Rate of Return (IRR)	61%	87%	108%

To achieve an IRR of over 40% will require a yield improvement through selection for WUE of initially around 10% (and increasing by 1.5% per annum), 50% of the WUE gain attributable to breeding plus an adoption rate of improved varieties of over 50%.

Sugarcane farm budgets 2013-14: By region ((Source: CaneGrowers)

Farm Summary	Wet Tropics	Burdekin Delta	Central irrigated	South irrigated	
Tonnes Harvested	5,050	21,564	10,875	5,750	t cane
Price ($/t)	400	400	400	400	/t sugar
Cane price	$32.08	$38.38	$36.66	$35.53	/t cane
Farm gate price	$23.08	$29.60	$28.30	$26.96	/t cane
Total farming area (ha)	75	203	150	75	ha
Harvested area (ha)	63	180	125	63	ha
Farm average CCS (relative)	12.75	14.50	14.00	13.69	units
Tonnes sugar per hectare	10.3	17.4	12.2	12.6	t sugar/ha
Yield (t/ha)	81	120	87	92	t cane/ha

Farm Profit and Loss by operation	Wet Tropics	Burdekin Delta	Central irrigated	South irrigated		Wet Tropics	Burdeki n Delta	Central irrigate	South irrigate
	$/ha harvested					$/tonne cane			
Income	2,592	4,598	3,189	3,269		32.08	38.38	36.66	35.53
Harvesting & levies	727	1,051	727	788		9.00	8.78	8.36	8.57
Land Preparation	48	39	76	26		0.59	0.32	0.87	0.28
Planting	144	186	146	144		1.79	1.56	1.68	1.57
Fertilising	436	553	435	396		5.39	4.61	5.00	4.30
Weed Control	166	135	133	139		2.05	1.13	1.53	1.51
Disease and Pest Control	69	24	67	28		0.86	0.20	0.77	0.30
Irrigation	0	728	380	592		0.00	6.08	4.37	6.43
Total variable costs	1,590	2,716	1,965	2,112		19.68	22.68	22.59	22.96
Gross margin	1,001	1,881	1,224	1,156		12.39	15.70	14.07	12.57
Fixed Expenses	320	178	276	349		3.96	1.49	3.17	3.80
Other	0	0	0	0		0.00	0.00	0.00	0.00
Depreciation	267	155	147	278		3.31	1.29	1.69	3.03
Wages	323	479	348	368		4.00	4.00	4.00	4.00
Total costs	2,501	3,529	2,736	3,108		30.95	29.46	31.45	33.78
Farm operating profit	91	1,069	454	161		1.12	8.92	5.21	1.75
Fixed costs	911	812	771	996	0	11.27	6.78	8.86	10.82
Land prep & planting	262	249	289	198	0	3.24	2.08	3.32	2.15

Farm Profit and Loss by cost item		Wet Tropics	Burdekin Delta	Central irrigated	South irrigated		Wet Tropics	Burdekin Delta	Central irrigate	South irrigate
		$/ha harvested					$/tonne cane			
Income		2,592	4,598	3,189	3,269		32.08	38.38	36.66	35.53
Harvesting & levies		727	1,051	727	788		9.00	8.78	8.36	8.57
Fuel and oil		66	61	89	54		0.82	0.51	1.03	0.59
R&M Mechanical		71	37	66	61		0.88	0.31	0.76	0.66
R&M Irrigation		0	71	26	26		0.00	0.59	0.30	0.29
Planting		144	186	146	144		1.79	1.56	1.68	1.57
Fertiliser		422	540	420	382		5.23	4.50	4.83	4.16
Chemicals		207	130	174	138		2.56	1.08	2.00	1.51
Electricity		0	537	151	279		0.00	4.49	1.74	3.04
Water		0	120	202	286		0.00	1.00	2.33	3.11
Total variable costs		1,638	2,733	2,003	2,160		20.28	22.81	23.02	23.48
Gross margin		953	1,865	1,187	1,108		11.80	15.56	13.64	12.05
Accountancy and Legal		42	14	42	42		0.51	0.12	0.48	0.45
Postage and phone		43	15	27	43		0.53	0.13	0.31	0.47
Electricity - non irrrigation		23	8	15	23		0.29	0.07	0.17	0.25
Insurance		42	31	40	42		0.51	0.26	0.46	0.45
Rates, rents, taxes		56	70	38	85		0.70	0.59	0.44	0.93
Registration		10	4	16	10		0.13	0.03	0.18	0.11
R&M buildings etc		32	11	48	32		0.40	0.09	0.55	0.35
Headland maintenance		24	8	12	24		0.30	0.07	0.14	0.26
Other		0	0	0	0		0.00	0.00	0.00	0.00
Total farm fixed costs		272	161	238	301		3.37	1.35	2.74	3.28
Farm operating profit		681	1,703	949	807		8.43	14.22	10.90	8.77
Wages		323	479	348	368		4.00	4.00	4.00	4.00
Depreciation#		267	155	147	278		3.31	1.29	1.69	3.03
Finance costs		0	0	0	0		0.00	0.00	0.00	0.00
Total fixed costs		590	634	495	646		7.31	5.29	5.69	7.03
Total costs		2,501	3,529	2,736	3,108		30.95	29.46	31.45	33.78
Farm profit		91	1,069	454	161		1.12	8.92	5.21	1.75

Appendix 4. N - The otherwise case

Appendix Table 4.1. N fertiliser application: Burdekin BRIA and Mackay (Source: FEAT Regional example[15]): the important points to note are the differences in yield and gross margins from planting to third ratoon.

Burdekin BRIA				
Parameters	**Plant spring**	**1st Ratoon**	**2nd Ratoon**	**3rd Ratoon**
Hectares	30	30	30	30
Yield (tonnes per hectare)	129	115	107	98
CCS % (Average 2004-2013)	14.87	14.92	14.76	14.64
Cane price $/tonne (Average 2008-2012)	$42.94	$43.14	$42.50	$42.03
Gross Margin $/ha (Average 2004-2013 cane prices and July 2013 input prices)	$2,782	$3,135	$2,780	$2,417
N Fertiliser use (Application (additional) budgeted at $8.78/ha plus labour)	Urea (46%N)	Fertiliser (Barratta - Impact Fertilisers blend of 32.2% N; 2.7% P; 8.1% K and 2.6% S)		
Total fertiliser application (kg/ha)	100	618	618	618
Price per tonne (July 2013)	$578	$700	$700	$700
Cost per hectare	$58	$433	$433	$433
N applied (kg/ha)	46	199	199	199

Mackay					
Parameters	**Plant spring**	**1st Ratoon**	**2nd Ratoon**	**3rd Ratoon**	**4th Ratoon**
Hectares	25	25	25	25	25
Yield (tonnes per hectare)	95	93	82	78	71
PRS relative (2004-2012 excl 2006,2010, 2011)	14.08	13.99	13.89	13.88	13.83
Cane price $/tonne (Average 2004-2013)	$40.36	$40.12	$39.84	$39.82	$39.68
Gross Margin $/ha (Av 2004-2013 cane prices and July 2013 input prices)	$1,072	$2,199	$1,825	$1,700	$1,472
N Fertiliser use (Application (additional) budgeted at $8.78/ha plus labour)	DAP (18% N; 20.2% P; 1.5% S)	CK160s (Incitec blend) (25.5% N; 2.4% P; 15.5% K and 2.8% S)			
Total fertiliser application (kg/ha)	185	640	640	640	640
Price per tonne (July 2013)	$815	$633	$633	$633	$633
Cost per hectare	$151	$405	$405	$405	$405
N applied (kg/ha)	33	163	163	163	163

[15] Source: Farm Economic Analysis Tool (FEAT) v3.0 Regional Scenario Example files

Box 1. Obligations under the Reef legislation

In late 2009, the Queensland Parliament passed the *Great Barrier Reef Protection Amendment Act 2009* that targets improved water quality in streams flowing into the Great Barrier Reef lagoon. This has significant implications for cane growing in the three priority catchments – Mackay-Whitsunday, Burdekin Dry Tropics and Wet Tropics (areas from Sarina north). Cane farming in these catchments is deemed to be an Environmentally Relevant Activity (ERA). This means that growers in those catchments must:

1. Not use or prepare a registered ERA product (agricultural chemical) for carrying out an agricultural ERA other than in a way that complies with the prescribed ERA conditions for the product;

2. Not apply nitrogen or phosphorous in excess of the optimum amount based on soil testing and a calculation using the Government approved method;

3. Keep all records relating to agricultural chemicals, fertilisers and soil ameliorants for at least 5 years and produce these records when requested by Government. There are fines for not producing or keeping these records.

In addition, if a Cane Production Area (CPA) for sugarcane is 70 hectares and above in the Wet Tropics, the grower must develop an Environmental Risk Management Plan (ERMP). ERMPs must be accredited by the Department of Environment and Resource Management (DERM) and the grower must comply with the management plan. The grower must provide an annual report about the implementation of the ERMP. There are substantial fines for non-compliance.

Box 2. What is the SIX EASY STEPS program?

The SIX EASY STEPS program is an integrated nutrient management tool that enables the adoption of best practice nutrient management on-farm. It consists of

1. Knowing and understanding your soils.
2. Understanding and managing nutrient process and losses.
3. Regular soil testing.
4. Adopting soil-specific nutrient management guidelines.
5. Checking on the adequacy of nutrient inputs (e.g. leaf analyses).
6. Keeping good records to modify nutrient inputs when and where necessary

The overall objective of the program is to provide guidelines on how to implement balanced nutrition on-farm with the ultimate aim of optimising productivity and profitability, without adversely influencing soil fertility or causing off-farm effects. It is also aimed at giving growers the required skills to develop nutrient management plans for their farms.

For example, while SIX EASY STEPS represents current best practice, it will be modified to include use of slow release fertilisers[16] and other practices as they are developed. Also some growers are now adopting N replacement approaches.

Appendix Table 4.2. N Management strategies used in the Australian sugar growing industry

Traditional	Maximising productivity and linking N application rates to sugar price	Averaged industry regional production functions	Chapman (1994), Schroeder *et al.*(1998)
Grower developed	Minimising risk of yield losses	In excess of 'traditional' rate or personal preferences	Johnson (1995), Wegener (1990)
SIX EASY STEPS	Sustaining sugarcane production; profitability in combination with environmental responsibility	District yield potentials and soil specific N mineralisation index	Schroeder *et al.*(2005), Wood *et al.*(2003)
N Replacement	Minimising N application rates. Focus on the environment and N-use efficiency	N input based on yield and N off-take of previous crop	Thorburn *et al.*(2007, 2008)

Given the current realities for N use in the sugar industry, Schroeder et al (2009) concluded that:

> *In terms of the current circumstances (escalating input costs, moderately low sugar prices, decreasing cane supply and environmental pressures), it is important to ensure that on-farm strategies enable growers to remain profitable and sustainable. This can only be achieved if they select management options that allow maintenance of yields (cane and sugar) in combination with inputs that are cost*

[16] Role of controlled release nitrogen in improving N-efficiency (ICL & HCPSL, 2015)

effective and are environmentally responsible. Our assessment shows that these objectives are possible when the SIX EASY STEPS approach is used. Alternative approaches, that are either wasteful of nutrient inputs (and are therefore environmentally unacceptable) or that lead to productivity losses (and are therefore likely to affect industry viability) should not be seriously considered as appropriate N inputs strategies for sugarcane production.

Other technologies are being investigated. For example, the slow release fertilisers research project 2014/011 aims to provide an understanding of how, when and where controlled release fertilisers work best, and what characteristics and specifications the controlled release fertiliser products need to have to provide reliable benefits in the face of crop-soil system interactions and seasonal climate variability.

The dilemma facing growers and the wider sugar industry is well-captured in two recent reports[17] [18]. The Smith et al (2014) Report on the impact of sugarcane management practices on the Great Barrier Reef refers to a study which investigated the cost-effectiveness of adopting nutrient management activities that improve water quality by reducing losses of Dissolved Inorganic Nitrogen (DIN) from sugarcane farms (van Grieken et al). While the financial-economic component identified various changes to nutrient management practices that reduce DIN losses from the farm and are likely to be profitable, it highlighted variation in economic modelling outcomes between regions due to bio-physical characteristics and enterprise structure. The overall Report by Smith et al concludes:

'*There is a currently a gamut of scientific research being undertaken to quantify the environmental impacts of sediment, nutrients and pesticide concentrations on the GBR ecosystem. While the efficient adoption of BMPs that improve water quality is considered a key mechanism in improving the overall health of the GBR ecosystem, there has been limited economic work carried out linking the adoption of BMPs to environmental and social issues in the GBR catchment. Whilst abundant literature exists on sugarcane management practices to minimise environmental risk, often that literature fails to address the economic impacts of these changes. Furthermore, few studies provide an economic assessment of BMP adoption that takes into account the unique biophysical and socio-economic characteristics of each NRM region. Adoption of new practices by landholders (whether they be to improve environmental outcomes or productivity) results from a complex decision-making process where relative advantage, especially in economic terms, is a key motivator. Growers will be unlikely to readily adopt unproven practices if the changes are perceived as a high risk to farm profitability*'.

Given the cost pressures on the industry, it is to be expected that the N price will influence usage. The world price of urea (principal N source for sugarcane in Australia) has fluctuated by around 15% year to year in the last decade (except for 2008 when the price increased 3-fold, Appendix Figure 2.2). The price of energy is the main driver of urea price but in real terms (adjusted for inflation) the world price (as urea) has fallen substantially over the last 20 years. The world price of DAP (diammonium phosphate) moves in a similar fashion to urea. Nonetheless, the price of N at Australian ports and the price spread on farm has risen.

However, overall the N price has a very limited impact on grower's decisions to use N, although a major driver of the N management strategies adopted by growers was the 2008 hike in urea prices and the expectation that a carbon tax would be introduced, which in turn would increase the costs of urea. However the use of the DYP approach to generate the recommended levels of N means that it is virtually inevitable that N will be applied in excess.

Given the total quantities applied over the last several years there are indications of increasing efficiency (Appendix Figure 2.3). There were no clear trends in fertiliser NUE in the period from 1997 to 2003 due to adverse seasonal conditions and fluctuating crop yields, but in 2004, NUE exceeded 0.5 tonne cane/kg

[17] Smith, M., Poggio, M. J., Thompson, M. & Collier, A. (2014). *The Economics of Pesticide Management Practices on Sugarcane Farms: Final Synthesis Report*. Department of Agriculture, Fisheries and Forestry (DAFF), Queensland

[18] Van Grieken, M., Poggio, M., Smith, M., Taylor, B., Thorburn, P., Biggs, J., Whitten, S., Faure, C., and Boullier, A. (in press) *Cost-effectiveness of management activities for water quality improvement in sugarcane farming*. Report to the Reef Rescue Water Quality Research & Development Program. Reef and Rainforest Research Centre Limited, Cairns

nitrogen for the first time and has remained above this level since. The highest levels recorded were 0.56 in 2005, due a high yielding crop with a favourable growing season, and 0.55 in 2009 with lower crop yields, but with lower fertiliser application rates.

The prospect of future regulation (in respect of the Reef and greenhouse gas abatement) has continued to encourage the development of farm management strategies to further improve NUE (such as alternative slow release forms of N). The Australian sugar industry has intensified efforts to improve NUE (Wood et al. 2010[19]), and governments have enacted regulations that require growers to adopt practices that reduce the risk of off-site losses of sediment and chemicals (Thorburn & Wilkinson 2013). These regulations stipulate that the target for N is a 50% reduction from 2009 to 2013. Research has recognised that:

- managing crops to attain their potential yield results in nutrient surpluses and therefore there is a decision to be made as to the minimum surplus required; as noted earlier, the target rate for fertilizer application was 20% above the average yield (across all regions); to maintain yields the N surplus needs to be about 50kg N/ha thus building in an inevitable surplus and potential for adverse offsite impacts (Figure X below is an example of work that shows that there was no yield response beyond about 110 kgN/ha);
- it is essential to manage for nutrients derived from organic sources;
- at low nutrient surpluses tactics to increase efficiency should assist (e.g. splitting applications and using slow N release fertilisers);
- irrigation efficiency should help reduce losses (Thorburn, Wilkinson and Silburn, 2013)[20]

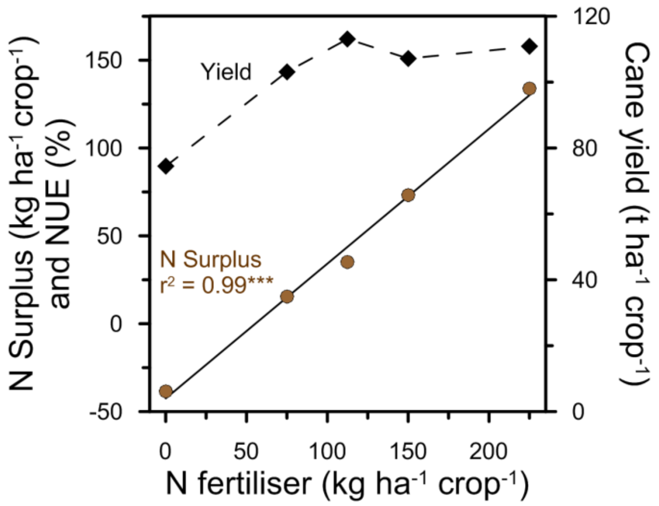

Fig X. Sugarcane N response (Bundaberg site from Thorburn *et al* 2003, 2013, cited by Thorburn, Wilkinson & Silburn 2013)

Why has NUE improved?

A number of factors are reported to have contributed to improvements in fertiliser NUE[21] [22] that have been evident over the last 15 or so years including:

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[19] Wood AW, BL Schroeder BL & R Dwyer 2010. Opportunities for improving the efficiency of use of nitrogen fertiliser in the Australian sugarcane industry. Proc Aust Soc Sugar Cane Technol 32: 221-233

[20] Thorburn, P; S. Wilkinson & M. Silburn 2013. Management practice overview from Reef Plan Scientific Consensus Statement: Sediments, nutrients and pesticides; http://reefcatchments.com.au/files/2013/02/Thorburn-SCSU-Ch-5.pdf; see also Catchments to Reef continuum: Minimising impacts of agriculture on the Great Barrier Reef, Agriculture, Ecosystems & Environment, Volume 180, Pages 1-210 (1 November 2013) http://www.sciencedirect.com/science/journal/01678809/180

[21] Wood AW, BL Schroeder BL & R Dwyer 2010. Opportunities for improving the efficiency of use of nitrogen fertiliser in the Australian sugarcane industry. Proc Aust Soc Sugar Cane Technol 32: 221-233

- growers adopting the Six Easy Steps nitrogen guidelines, rather than using generalised industry nitrogen guidelines;
- increased attention to using the optimal form, application method, rate, placement and time of application of nitrogen fertiliser according to the block and to soil type;
- increased use of soil and leaf testing to better predict soil and crop nutrient requirements;
- increased capacity to apply different rates of nitrogen to different blocks;
- improved awareness of nitrogen inputs from other sources;
- a trend towards a focus on balanced nutrition that uses a wider range of nutrients leading to higher yields;
- increased awareness of the different ways in which nitrogen can be lost;
- increase in the cost of nitrogen relative to sugar revenues;
- a perception by growers that many years of green harvesting and trash retention has led to an increase in soil organic matter levels, which results in greater amounts of nitrogen being recycled.

However the major issue is the need to make decisions with respect to N use early in the growing season given the reluctance of growers (for very good economic and practical reasons) to avoid split dressings. The difficulty of predicting weather conditions means that the ability to formulate N input strategies prior to a particular growing season is itself difficult. In turn this means that the most appropriate option for growers is to apply fertilizer with the aim of producing the best crop and to assume that the season will be characterised by favourable weather conditions (essentially rainfall)[23].

Achievements in terms of NUE and implications

The recent water quality data reveal that only a 10% reduction in N load has been achieved in the 2009 to 2013 time frame, although 50% of growers have adopted improved crop management practices (State of Queensland 2014).

There have been significant advances in the management strategies and tactics which can improve NUE, which have been focussed primarily on reducing the surplus N applied to crops. The ongoing work with controlled release fertilisers is an important aspect for the future. Clearly there is potential for further improvement, particularly at an industry level which will involve more widespread adoption of known strategies. However, the economics alone in terms of the price of N are not likely to justify any investment in improving NUE (as is highlighted in the empirical model below and in Appendix Table 3E).
Further, it appears that some off site impacts are inevitable. Projections have indicated that industry wide adoption of current best management practices would reduce dissolved inorganic N only by 10 to 15%, and ‘best case’ scenarios based on improved management are expected to achieve a 60% reduction in dissolved inorganic N exported (Thorburn & Wilkinson 2013). It is important to note that the limit of these reductions may also apply even with more efficient varieties since the optimal fertiliser strategy is still based on potential yield and average yield will always be less than the potential. This highlights the genetics of the mechanism for improved NUE which is considered in the next section on the breeding approach. The scale of the issue is important to consider. In one sense, it can be argued that the DIN loss is a function of the surplus N applied to the crop. A recent study by Webster et al (2012)[24] measured DIN loss in surface runoff water over 3 years in an experiment that compared the conventional fertiliser N application (180 kg N/ha/year) with N applied to replace exported N (cane plus trash) from the previous

[22]www.incitecpivotfertilisers.com.au/News/Latest%20News/Achieving%20more%20from%20applied%20nitrogen%20in%20cane

[23] Schroeder BL, AW Wood, M Sefton et al 2010. District yield potential: An appropriate basis for nitrogen guidelines for sugarcane production. *Proc Aust Soc Sugar Cane Technol* 32: 193-209.

[24] Webster AJ, Bartley R, Armour JD, Brodie JE, Thorburn PJ 2012. Reducing dissolved inorganic nitrogen in surface runoff water from sugarcane production systems. *Marine Pollution Bulletin* 65. 128-135

crop (c. 94 kg N/ha/year). DIN losses in surface water averaged about 60% lower in the latter treatment but the 5% lower yield was not significant. The average N surplus was greatly reduced in the replacement fertiliser treatment. The results are summarised in Appendix Table 4.2.

Appendix Table 4.2. Example of N dynamics under two systems with agronomic data for the three crops (Table 3 from Webster et al 2012[25])

Crop	Yield (t/ha)		N exported in crop (kg/ha)		Kg N/tonne harvested		Trash N (kg/ha)		N surplus (kg/ha)	
	N_{farm}	N_{repl}	N_{farm}	N_{farm}	N_{farm}	N_{repl}	N_{farm}	N_{repl}	N_{farm}	N_{repl}
2004	76	71	50	45	0.66	0.63	30	26	136	57
2005	77	75	43	46	0.56	0.61	20	27	136	40
2006	55	51	37	35	0.67	0.69	36	31	138	61

[25] Webster AJ et al 2012. Reducing dissolved inorganic nitrogen in surface runoff water from sugarcane production systems, Marine Pollution Bulletin 65: 128-135

Appendix 5. Further background

Extract from *A review of nitrogen use efficiency in sugarcane*[26] (December 2014), Sugar Research Australia (confidential Report to SRA and the Department of the Environment reproduced with permission)

Review structure

The review consists of an introductory chapter, six independently written chapters addressing different aspects of crop production and N fertilizer management at both crop and farming systems scales, and a concluding chapter providing an overarching synthesis of key issues and an identification of future research priorities. Briefly, the content of each chapter is outlined below.

Chapter 1 – a background to the issues surrounding N management in the sugar industry and an analysis of trends in N fertilizer use over the period 1996-2012 crop seasons (A Wood and M Bell).

Chapter 2 – a chapter detailing the evolution of decision support frameworks and the SIX EASY STEPS program that currently support N management in the sugar industry, including presentation of experimental results from which the current N fertilizer rate recommendations are derived (B Schroeder *et al*.). The chapter describes the circumstances that have prompted the need for an N management system aimed at sustainability – profitable sugarcane production in combination with environmental responsibility and the processes of validating and determining the economic impacts for growers. The SIX EASY STEPS program forms the basis of current industry best management practice. The program sets district-specific nutrient guidelines and a well-developed delivery mechanism that can be further fine-tuned to deliver enhancements.

Chapter 3 – a broad overview of published and unpublished information relating to the source of N accumulated in cane crops, crop demand for N at different critical growth stages, the fate of N inputs (fertilizers, legumes and amendments) in the soil-crop continuum and a re-examination of frameworks for quantifying efficiency of N use. The current industry approach of calculating N fertilizer requirements based on an aspirational district yield potential, without reference to site specific management factors or seasonal forecasts, is a significant constraint to making improvements in N use efficiency (NUE). Similarly, adoption of improved terminology and experimental protocols to quantify fertilizer NUE by taking into account background soil N supply and crop recovery of applied N would allow a much clearer focus on fertilizer N management improvement (M Bell *et al*.).

Chapter 4 – an exploration of opportunities to improve NUE through exploitation of genetic variation in the efficiency with which N is captured by the crop and utilized to produce both biomass and harvestable yield. This chapter explores advances and approaches used in other crop species and contrasts that with the limited data available for sugarcane and potential future opportunities for improvement (N Robinson *et al*.).

Chapter 5 – this chapter explores the potential use of remote and proximal sensing as a means of accurately determining crop N status and facilitating in-season management responses, as well as a means of retrospective analysis of crop and genotypic performance in response to spatial and seasonal variables. It overviews a variety of sensor types and platforms, looks at application in other industries and identifies potential applications in the sugar industry. On the basis of this synthesis, some strategies for the possible application of proximal sensing to measuring foliar nitrogen concentration in sugarcane are proposed. Additionally, remote sensing offers a number of 'value adding' benefits for improving the monitoring of seasonal and spatial variation in crop yield over time (A Robson *et al*.).

Chapter 6 – a broader scale exploration of crop N use at a cropping systems scale, applying the latest simulation capability to explore spatial and temporal variability in crop productivity, NUE and environmental losses due to various pathways (atmospheric as well as into receiving waters) in response to different N sources and management strategies. This chapter also demonstrates the value of this

[26] A Review of Nitrogen Use Efficiency in Sugarcane SRA 2014

simulation capability to explore the potential benefits of different management interventions on NUE and environmental losses at local and regional scales (P Thorburn *et al*.).

Chapter 7 Part I – provides an overview of the development and relative effectiveness of different products and methodologies collectively described as Enhanced Efficiency Fertilizers (EEFs), and assesses their potential role for improving NUE in the sugar industry. Most of these products endeavour to better synchronise the supply of plant-available nitrogen with demand by the crop, either by slowing the release or inhibiting the formation of forms of nitrogen vulnerable to losses. The results from limited trials in Australia suggest that EEFs may have agronomic and environmental benefits in at least some situations. The effectiveness of products is affected by a complex set of interacting soil, crop, climate and management factors. Season and site variability contribute to inconsistent performance suggesting that more in depth investigations are warranted. The economic and management implications of using different approaches are discussed (K Verburg *et al*.)

Chapter 7 Part II – this chapter provides a commercial context to the use of EEFs in the Australian sugar industry, covering issues such as the available products, pricing relative to traditional fertilizer N sources and current industry experiences with their use (J Kraak *et al*.).

Chapter 8 – this is an overview chapter that collectively considers data and issues covered in the specialist chapters, undertakes further analysis where appropriate and develops unifying themes upon which future advances in NUE could be based. This chapter also identifies major knowledge gaps under key themes and identifies research methodology or approaches that should be followed in some instances (M Bell and P Moody).

Review Findings (relevant to this Review)

Improved crop genetics delivering improved recovery and use of applied N

The industry currently does not have a good understanding of how efficiently existing genotypes can recover and use N to produce biomass and sucrose. If these benchmarks can be developed for existing genotypes, the opportunity then exists to develop methodologies to routinely benchmark material emerging fromthe breeding program for attributes contributing to improved NUE. While a longer term objective, such genetic approaches to improving NUE are being widely adopted in other industries.

Goal

Optimise Nitrogen use efficiency in sugarcane to maintain crop productivity, improve profitability and produce environmentally sustainable outcomes for the industry and community benefit. Industry targets; 50% reduction in DIN by 2017/18 and 80% reduction in DIN by 2025 in environmentally sensitivities regions

Outcomes

Delivery of N-efficient varieties to industry to meet stringent environmental targets which cannot be met by BMP strategies alone

Core breeding program geared to screening and breeding for N-efficient varieties adapted to specific soil types/environments

Outputs

Surrogate markers available to accelerate genetic gain and facilitate integration into the core breeding program

Development of a business case for core breeding program on N-efficient varieties; understanding of how efficiently the crop can use N to produce biomass and sucrose

Actions

Improve understanding of genetic variation of NUE in local germplasm and crop-specific N physiology including below ground attributes, N regulation, use, storage and remobilisation of N

Develop surrogate markers for breeding and selection for NUE in sugarcane. Such markers may include shoot and root vigour traits.as well as N partitioning between canopy components and between above and below ground parts

Explore transgenic and marker assisted improvement of N-efficient varieties through collaborative research with multi-nationals or other institutions

Establish protocols and experimental locations where screening of sugarcane genotypes for yield under contrasting N input conditions can identify differences in NUE unconfounded by environmental losses

Introduction and trends in nitrogen fertiliser use (from Chapter 1 by MJ Bell, A Wood and P Moody)

The Australian sugarcane industry is predominantly situated in coastal catchments adjacent to the Great Barrier Reef (GBR), and while occupying only ~1.3% of the total GBR catchment areas, is deemed to be responsible for contributing an estimated 6%, 18% and 18% of the average annual anthropogenic loads of Total Suspended Solids (TSS), Particulate Phosphorus (PP) and Particulate Nitrogen (PN) delivered to the GBR lagoon (Australian Government 2014). It is also deemed to contribute an estimated 56% of the Dissolved Inorganic Nitrogen (DIN). The discharge of Nitrogen

(N) is of particular concern as it stimulates outbreaks of the Crown of Thorn Starfish, a major predator of GBR corals (De'arth *et al*. 2012). At the same time, these losses of N represent an inefficient or wasted investment by sugarcane growers in costly fertilizers, as well as a potential lowering of crop productivity, so improvements to N use efficiency in the sugarcane industry represent an opportunity to achieve a rare win-win situation for both the environment and industry productivity and profitability

The Australian and Queensland governments established the Reef Water Quality Protection Plan in 2003 to halt and reverse the decline in the quality of water entering the GBR lagoon. Investments by government and industry/growers in recent years to improve agricultural management practices have resulted in significant practice change and predictions of a 6-15% reduction in key pollutants (State of Queensland 2013b). However scenario analyses conducted for the 3rd Reef Plan Report Card (State of Queensland 2013C) suggest that even wholescale adoption of current A (Aspirational or cutting edge) class nutrient management practices may not achieve the Reef Plan 2009 water quality targets for DIN reduction, and that other options to improve NUE and/or reduce N inputs need to be investigated.

Improving the management of N used in sugarcane production to mitigate the impacts of run off of dissolved inorganic nitrogen (DIN) and poor water quality on the Great Barrier Reef is a complex issue. There are differing views and expectations on the impact of N on the reef, fertiliser rates used by growers, programs to determine N requirements of sugarcane, N loss pathways, the drivers and influence of DIN on COTS initiation sites, the targets needed to meet water quality and how best to achieve those targets. At the CANEGROWERS Nitrogen Forum held in Townsville in February 2014, research from the Wet Tropics based on catchment, paddock and stream monitoring between 1986- 2009 notionally identified the need for DIN losses to the environment to be reduced by approximately 10 kg of DIN per hectare of cane in order to have a significant effect on water quality and to meet Reef Plan targets of a 50% reduction in DIN. This comment provided common ground; growers, researchers and extension officers alike responded positively to this approach as it provided an aspirational target that is achievable, supported by research and able to be met with a suite of strategies and not just a reduction in rate of N fertiliser. However it was also clear that there were significant gaps and uncertainties around the identification, development and implementation of any such strategies, and that there was a clear need for a joint industry-government funded research program to improve NUE in sugarcane. These developments prompted the Australian Government Reef Program to commission and fund this review of N use in the Australian sugar industry.

Evolving nature of nitrogen management in the Australian sugar industry (from Chapter by BL Schroeder, B Salter, PW Moody, DM Skocaj and PJ Thorburn)

Baseline N application rates for each district (page 27)

District yield potential is used to determine the baseline N application rate for replant and ratoon cane using a multiplier of 1.4 kg N per tonne of cane up to a cane yield of 100 tonnes and 1.0 kg N per tonne of cane thereafter, as previously suggested by Keating *et al*. (1997). This multiplier was developed as a 'rule of thumb' measure of N requirement based on simulated first ratoon crop yields from a well-drained soil at Ingham over 100 years (1895-1994). The baseline N application rate for districts with a DYP of 120 t cane/ha is therefore (100 x 1.4) + (20 x 1.0) = 160 kg N/ha. This increases to 170 kg N/ha for areas with a DYP of 130 t cane/ha, and 190 kg N/ha to 220 kg N/ha for DYPs of 150 and 180 t cane/ha respectively (Schroeder *et al*., 2010a).

Target fertiliser N-use efficiency (page 32)

The concept of improving NUE is not new to the Australian sugar industry. The information provided thus far in this chapter has illustrated the concepts and developments that have all aimed at improving NUE in various ways. It is widely accepted that from an agronomic viewpoint, nutrient use efficiency should be viewed in terms of yield per unit of nutrient applied. This is also termed Partial Factor Productivity (Dobermann, 2007). It can be considered as the product of recovery and utilisation (Wood and Kingston, 1999) as shown in Equation 1 below:

Yield/unit nutrient applied = (unit nutrient taken up/unit nutrient applied) x (yield/unit nutrient taken up)

i.e. YIELD EFFICIENCY = RECOVERY x UTILISATION *Equation 1*

Yield efficiency should be the objective of any commercial cropping system. Increases in nutrient use efficiency should be viewed as either achieving:

- The same yield with less fertiliser, Greater yield with less fertiliser, or Greater yield with the same amount of fertiliser (Wood and Kingston, 1999).

Based on the above, two terms exist for reporting on NUE, are:

- Fertiliser N-use efficiency factor (t cane/kg N) = yield (t cane/ha) / N applied (kg N/ha), and corresponds to the term "Partial Factor Productivity" mentioned above.
- N fertiliser utilisation index (kg N/t cane produced) = N applied (kg N/ha) / yield (t cane/ha). This is the reciprocal of "Partial Factor Productivity".

In this equation, no account is taken of yield at nil applied N, as is the case in some other agricultural industries. Bell *et al* (this review) refer to this index as the "Apparent Agronomic Efficiency of Fertiliser N".

Fertiliser guidelines such as the SIX EASY STEPS program aim to improve NUE by ensuring that N fertiliser utilisation is as low as possible, or the fertiliser N recovery is as high as possible. The proviso is that productivity and profitability are not negatively affected. As these 'efficiency' terms are reciprocals of each other, both the rate of N applied and the cane yield influence these calculated values.

The values shown in Table 2.8 (recommended application rates and DYP) were used to determine the target N fertiliser utilisation index (N application rate / DYP) and fertiliser N-use efficiency (district potential yield / N application rate) values that apply to replant / ratoon cane and plant cane in each of the districts (Table 2.9). The target N fertiliser utilisation index value ranges from 1.33 kg N/t cane (for replant / ratoon cane grown on soils with very low soil organic C in districts with a yield potential of 120 t cane/ha) to 0.61 kg N/t cane (for plant cane grown on soils with 1.6% organic C in the higher yield potential (180 t cane/ha) areas of the Burdekin region. Target fertiliser N-use efficiencies therefore range from 0.75 t cane/kg N to 1.64 t cane/kg N respectively. These values reflect the N contribution from soil organic matter and are therefore always higher than normally indicated by the so-called Apparent Agronomic Efficiency of Fertiliser N.

With account taken of other sources of N (legume fallow crops, residual mineral N remaining after horticultural crops that are grown in rotation with sugarcane, and irrigation water), lower N fertiliser utilisation with corresponding higher apparent fertilisation N-use efficiencies (Table2.9). Where sources of N supply enough N to meet the N requirement for sugarcane production, the N fertiliser utilisation index will be zero.

The SIX EASY STEPS program recognises that if a sub-district or farm consistently produces higher yields than the DYP, the baseline application rate should be adjusted upward by 1 kg applied N per tonne of cane above the DYP. For example if the overall yield on a farm in the Bundaberg/Isis district, calculated over a ten year period, is 130 t cane/ha, then the baseline N application should be set at 170 kg N/ha. The N application rates based on soil organic carbon would then be 10 kg N/ha greater than those shown in Table 2.4 and be in line with the values shown for the Mackay / Proserpine district. Conversely, if a sub-district or farm consistently produces lower yields than the DYP, the baseline N application rate should be decreased using the same approach. Obviously if these adjustments are made, the two target N-use efficiency factors will be influenced.

Appendix Table 5.1. Estimates of the overall annual value of the current rate of genetic gain per hectare in Gross Margin terms and in the four regions (assuming that the yield effect is the same across all regions)

Trait	Annual rate of genetic change	Value of annual genetic gain in Gross Margin terms (GM in $ per hectare)				
		Weighted GM	GM by regions			
			North	Burdekin	Central	South
TCH	1.283 tonne per hectare	$16.55	$11.70	$18.97	$17.68	$19.49
CCS	0.0645%	$16.27	$15.37	$17.29	$12.82	$20.75
Fibre						
Total		**$32.82**	**$27.06**	**$36.26**	**$30.49**	**$40.25**