The impact of sugarcane growing practices on farm profitability and the environment – a literature review

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Life Cycle Strategies

Queensland Government

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Executive Summary

This literature review forms a component of *SRA Project 2014/015 - Measuring the profitability and environmental implications when growers transition to Best Management Practices (BMP)*. It provides a solid foundation by synthesising past research about the economic and environmental implications of changing to progressive sugarcane management practices. The review identifies gaps in knowledge and provides a better understanding on how this current research can build-on and benefit from past research. Due to the scope of the project work, the literature review focuses on practice change research in the Wet Tropics sugarcane industry.

An examination of available literature identified a progressive shift in practice change research over the last two decades in the sugarcane industry. Earlier research in management practices predominantly focused on practice change that addressed production constraints, for example the Sugarcane Yield Decline Joint Venture. Due to increasing concerns about the health of the Great Barrier Reef from community, government and industry, more recent research has focused on management practices to improve water quality leaving sugarcane farms and the accelerated adoption of Best Management Practices (BMP's). This is particularly the case for sugarcane growing regions adjacent to the Great Barrier Reef.

Despite the growing amount of research, the review of literature revealed a lack of comprehensive case studies integrating economic, environmental and social information. Furthermore, it is often assumed that an increase in production results in greater profitability, however this may not always hold true if business expenses increase or it involves additional capital expenditure. Evaluation of soil health and nutrient management practices forms the bulk of current economic research. Past research studies indicate that excessive nitrogen application rates above best practice will result in increased production costs and lost potential economic return. The review found that aspects of weed, pest and disease management were often integrated due to the inter-related nature of these farming system principals. Consequently, the economic evaluation of weed, pest and disease management practices has typically been undertaken as one component in a whole-of-farm system evaluation. To date, economic research in this area is limited.

In general, research indicates the potential for BMPs to be economically viable but there are circumstances when this is not the case. Many practice changes, such as moving to controlled traffic or a legume fallow, have complex impacts on profitability which are highly case specific.

Environmental life cycle assessment (LCA) is a method for assessing the life cycle environmental impacts of agricultural products, which consider both on-farm and off-farm impacts. Much of the past environmental research in sugarcane has been on 'cradle to grave' applications to bio-energy and bio-fuel products. To date, only a limited number of LCA studies have evaluated the environmental implication of sugarcane growing practices.

Environmental impacts for sugarcane growing vary considerably from one region to the next and within regions. Preliminary work suggests that BMPs can lead to improved environmental outcomes. However, this needs to be explored further based on real, not hypothetical cases.

Methods to evaluate the conflicts and trade-offs between maximising the benefits and minimising the adverse impacts of agriculture include qualitative trade-off analysis, quantitative trade-off analysis and integrated farm models.

A combined evaluation of the economic and environmental implications of management practice change using real (not hypothetical) practice change case studies will be a valuable addition to existing research.

1. Introduction

The Smartcane Best Management Practice (BMP) program aims to transition Queensland sugarcane farmers towards progressive sugarcane growing practices that have both agronomic and environmental benefits. While these practices are inferred to be both profitable and good for the environment, there has been limited research to test this.

A project funded by the Sugar Research Australia (SRA Project 2014/015 – Measuring the profitability and environmental implications when growers transition to Best Management Practices) aims to fill this gap by concurrently evaluating the economic and environmental implications of Smartcane BMP adoption in the context of the Wet Tropics.

This literature review lays some groundwork for the project by synthesising what we currently know from past research about the economic and environmental implications of changing to progressive sugarcane growing practices. It confirms the gaps in knowledge to substantiate the research project, and describes the current state of research, which this project can build-on.

We first provide, in Section 2, a brief overview of the components of the research project – Smartcane BMP practices, and the techniques that will be used to assess them, i.e. farm economic assessment (FEAT tool) and environmental life cycle assessment (CaneLCA). We then review in Section 3 past research that has evaluated the economic and environmental implications of sugarcane growing practices, as well as research that brings these aspects together.

2. Components of the research

2.1 Smartcane BMP program

Smartcane BMP[1] is the industry-led best management practice program developed by CANEGROWERS with funding from the Queensland Government, in response to environmental challenges faced by the cane industry. Launched in December 2013, the program represents a transition away from the previous regulated management of cane growing practices (Reef Regulations, introduced in 2009), towards voluntary best management practice. It defines best practices that sugarcane growers can adopt to gain Smartcane BMP accreditation.

The Smartcane BMP program categorises practices as ‘below industry standard’, ‘at industry standard’ or above industry standard’. Practices that constitute the ‘industry standard’ are not prescribed. Instead the standards describe the desired outcomes, and the specific practices are tailored to regional conditions. These practice definitions are used to recognise and ‘accredit’ the efforts of grower, with the aim of promoting best practices across the industry.

In this project we are specifically interested in cane growing practices being promoted by Smartcane BMP. Therefore we use the BMP management practice categories to be consistent with Smartcane, i.e. soil health and nutrient management; weed, pest and disease management; and drainage management (Appendix 1). The specific management practices considered for analysis are those relevant to the Wet Tropics region.

[1] https://www.smartcane.com.au/home.aspx

Irrigation and drainage management is a component of the Smartcane BMP program. However, as sugarcane production in the Wet Tropics is primarily rain-fed, irrigation management will not be evaluated in the research project. Drainage will be considered as it is influenced by other practice categories, and influences environmental outcomes such as nitrous oxide emissions.

2.2 Farm Economic Assessment Tool (FEAT)

FEAT[2] is an Excel-based tool that models sugarcane farm production from an economic perspective, allowing users to record and analyse revenues and costs associated with their sugarcane production systems. It was developed by the FutureCane project, which was a partnership between the (then) Department of Primary Industries and Fisheries and BSES Ltd (Stewart and Cameron, 2006). FEAT calculates several different economic performance indicators used in agricultural sectors (e.g. gross margin, break-even yields and prices). It will be used to undertake the economic analysis in this research.

2.3 Environmental Life Cycle Assessment tool (CaneLCA)

Environmental life cycle assessment (LCA) has been a commonly-used method for assessing the life cycle environmental impacts of agricultural products, which considers both on-farm and off-farm impacts. It accounts for all resources consumed, wastes generated, and emissions to the environment over the entire life cycle, and generates indicators of environmental impacts (typically greenhouse gas emissions, non-renewable energy use, water quality impacts, human health impacts, biodiversity, etc.). The methodology is well developed (Pennington et al., 2004, Rebitzer et al., 2004), and governed by standards (ISO, 2006).

LCA is one of a number of environmental impact assessment methods. Others are environmental risk mapping (ERM), environmental impact assessment (EIA), multi-agent system (MAS) approaches and linear programming (LP) approaches. LCA is the most appropriate method for our purposes because it is designed to assess production systems (Payraudeau and van der Werf, 2005).

Undertaken to its full extent, LCA captures the full life cycle of a product ('cradle to grave') from the extraction of natural resources (coal, oil, natural gas, minerals, metal ores, water, etc.) to produce inputs through to the final use and disposal of a product. However it can also be applied at reduced scopes, to assess partial life cycles up to the farm ('cradle to farm gate'). As this project is specifically interested in the cane growing phase, the review from here focuses on 'cradle to farm gate' applications of LCA.

CaneLCA[3] is a customised LCA tool for sugarcane growing ('cradle to farm gate'). It was designed to make assessment more rapid, and was designed to evaluate and compare the environmental performance of different growing practice (Renouf and Allsopp, 2013). It considers all the on-farm and off-farm activities associated with cane growing, from the production of farming inputs to the delivery of harvested sugarcane to the farm gate (Figure 1). Environmental impact indicators are generated (per tonne of harvested sugarcane) for the environmental aspects known to be most

[2] https://www.daf.qld.gov.au/plants/field-crops-and-pastures/sugar/farm-economic-analysis-tool.

[3] http://eshop.uniquest.com.au/canelca/.

important for sugarcane growing, i.e. water quality, water use, fossil fuel use and greenhouse gas emissions (carbon footprint).

Activities included in the 'cradle to farm gate' life cycle of sugarcane growing

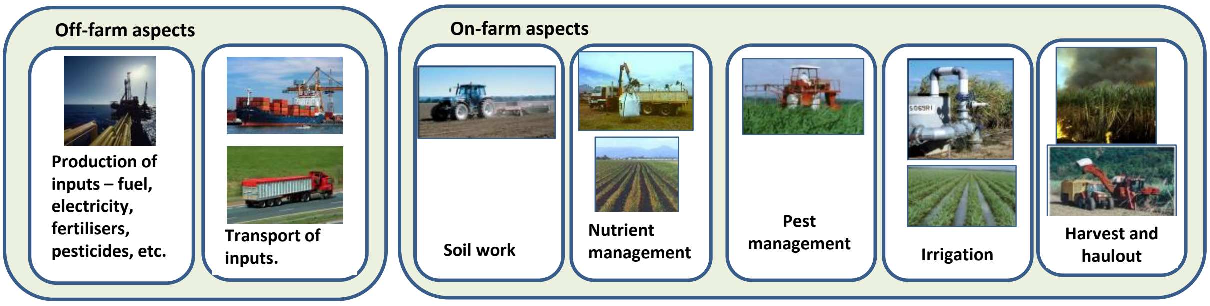


Figure 1: Aspects of the 'cradle to farm gate' life cycle of sugarcane growing included in the scope of the CaneLCA tool

CaneLCA is one of only a few LCA tools customised specifically for agriculture. Carbon foot printing tools are available for agricultural activities (dairy, cotton, grain, vegetables, bananas, wine, livestock) (University of Melbourne, 2012), and one for sugarcane (Rein, 2010). CaneLCA differs from these by assessing a range of environmental impact categories (not just carbon footprint), and giving flexibility for altering production details. Therefore, it is more suited to assessing different cane growing practices against multiple environmental objectives.

3. Past evaluations of the economic and environmental implications of cane growing practices

3.1 Economic evaluations

There is a growing body of research investigating the economic impact of best management practice in the Australian sugarcane industry. A summary of research in the context of the Wet Tropics region is provided in Table 1. Economic evaluation of soil health and nutrient management practices forms the bulk of current research, whilst that related to weed, pest and disease management practice is less common and seldom analysed in isolation of a whole-of-farm system change.

Economic evaluation has typically been undertaken using partial budget analysis. Partial budget analysis measures the effect of management practice change on short term expenses and revenues directly related to the practice. This kind of analysis is useful when measuring the economic effect of minor changes (such as altering the rate of nitrogen application). However it can fail to capture the full impact of management practice change on farm profitability when capital expenditure is required. A growing number of studies have attempted to measure the impact of BMP adoption on whole-of-farm profitability, incorporating capital investments, and calculating parameters such as the net present value, break-even point and annualised equivalent benefit of investments.

Economic evaluation of sugarcane production has been greatly facilitated by the development of the Farm Economic Analysis Tool (FEAT) (see Section 2.2), and a number of the past research activities described here have used FEAT.

This section summarises what we currently know from past research about the economic implications of practice changes being promoted by the SmartCane BMP program, in relation to i) nutrient management ii) fallow management iii) tillage and compaction, and iv) weed, pest and disease management. It focuses on past work specifically related to the Wet Tropics region.

Table 1: Past studies evaluating economic implications of cane growing practices in the Wet Tropics

Cane Growing Aspect		Economic Aspects Influenced	Reference
Soil health and nutrient management	Nitrogen application rate - Optimal N rate	Fertiliser cost, cane yield	*(Skocaj et al., 2012)* *(Schroeder et al., 2009)* *(Schroeder et al., 2010)*
	Fallow management - Legume Fallow	Legume planter. Mulcher. Fuel, oil repairs and maintenance, labour, chemical cost - Spray out cane. Legume crop growing costs. Reduced N in plant cane. Income from legumes. Increased cane yield. Decreased bare fallow management weed control costs.	*(Garside et al., 2004)* *(Young and Poggio, 2007)* *(East et al., 2012)*
	Tillage management - Reduced tillage - Controlled traffic - Zonal tillage	GPS unit and base station. Zonal tillage implements. Implement (spray boom, planter) modifications. Increased field efficiency – reduced fuel, oil, repairs and maintenance. Reduced labour cost. Zonal tillage implements. GPS unit and base station.	*(Braunack et al., 2003)* *(Halpin et al., 2008)* *(East et al., 2012)*
Weed, pest and disease management	Reduced herbicide rate Strategic residual use Use of directed application equipment and appropriate nozzles Rate varies between blocks		(Poggio et al., 2014)

3.1.1 Nutrient Management

The objective of nutrient management is to select the proper nutrient rate, placement, source and timing for profitable and sustainable crop production. Of all in-field nutrient management practices, nutrient rate has the greatest influence on profitability. Nitrogen, phosphorus and potassium are the largest fertiliser expenses in sugarcane production. Past research studies indicate that excessive nitrogen application rates above best practice will result in increased production costs and lost potential economic return. Applying more nutrients than needed by the crop to assure maximum yield is economically inefficient. When assessing the relative profitability of different nutrient application rates, the cost of fertiliser, application rate and impact on yield are key considerations.

Yield influence

The SIX EASY STEPS approach has undergone extensive development and rigorous testing in glasshouse, laboratory, small plot experiments and larger-scale on-farm replicated strip-trials for more than a decade. Consequently, the validity of the SIX EASY STEPS guidelines is well illustrated. Schroeder et al. (2009) conducted replicated strip trials in successive ratoon crops on nine of the major soil types of the Johnstone Catchment. Results indicate that yield of cane and sugar content is not compromised by the SIX EASY STEPS approach. Schroeder et al. (2010) conducted replicated field trials in the Tully district over two successive ratoon crops and also concluded that the SIX EASY STEPS options produced comparable yields to those obtained from the grower application rate. Skocaj et al. (2012) compared SIX EASY STEPS and grower determined nutrient rates in four strip trials on two different soil types in Tully. Results of the study indicate that yields can be maintained using the SIX EASY STEPS guidelines in the Wet Tropics region.

Reduced nitrogen application rates

Maintenance of yield with lower nutrient inputs leads to an increase in profitability. If nitrogen application rates being used are above the SIX EASY STEPS guidelines then producers can gain economically by reducing rates to those levels. On the other hand, if producers are already applying nitrogen at the SIX EASY STEPS recommended rate, reduction below those rates may impose an economic penalty via yield reductions. In both scenarios the magnitude of the economic benefit/loss is largely a function of revenue (yield and CCS) and cost (fertiliser, harvesting and levies) relative to the recommended application rate. In situations where a reduction in nitrogen application rate results in a substantially lower yield, consideration of other parts of the farming system is required such as weed control and harvesting costs.

N application rates recommended by SIX EASY STEPS are generally lower than usual grower practice. Schroeder et al. (2009) found SIX EASY STEPS rates were on average 32kg N/ha lower and 27kg N/ha lower in the first and second years of a replicated field trial. In a field trial in Tully Skocaj et al. (2012) found N inputs were on average 17.5kg N/ha lower using SIX EASY STEPS compared to usual grower practice. Based on a urea price of $0.578/kg a 1kg reduction in N per hectare (2.17kg reduction in urea) equates to a saving of $1.25/ha. Consequently when grower moves from a self-determined application rate to SIX EASY STEPS guidelines cost savings are between $22/ha to $40/ha. Based on the economic evaluation of a model farm in the Wet Tropics this is equivalent to a 1.2 per cent to 2.1 per cent reduction in total costs (Collier, 2014).

3.1.2 Fallow Management

Successive plough-out replant leads to a build-up of pests and diseases. The introduction of break crops, particularly nitrogen fixing legumes, breaks the disease cycle and provides a source of fixed nitrogen for the next plant cane crop. The economic implications of adopting a legume fallow are multifaceted. Fertiliser and weed control cost savings typically result from a well-grown legume fallow. However the costs of growing a legume fallow is often higher than maintaining a bare or weedy fallow. Plough-out replant results in a larger area of the farm under cane but over time yields are diminished. Legumes may be harvested providing an additional source of income dependent on the yield and price of legumes. Capital investment, and consequently return on investment, is highly dependent on existing machinery available and whether or not contractors are used. All of these aspects contribute either positively or negatively to overall farm profitability and the aim of past economic evaluations has been to quantify the net gain/loss.

Yield influence

Field trials in the Wet Tropics indicate that legume fallows may be adopted without yield penalty and may also increase yield in the subsequent plant cane crop. Garside et al. (2004) undertook field trials in Ingham and Gordonvale to analyse controlled traffic, minimum tillage and legume fallow. Data from the experiments showed that inclusion of a legume fallow into the sugarcane farming system resulted in improved cane yields in the following plant cane crop. Overall yield (t/ha) improvement ranged from 15 to 25 per cent and CCS was not adversely affected. Garside & Bell (2001) undertook field trials in Gordonvale and found that the yields recorded with conventional planting (113 t/ha at 14.5 CCS) where only legume nitrogen was applied, were comparable with those achieved for adjacent plant cane blocks (120 t/ha at 14.2 CCS) where 150 kg/ha N and mill mud were applied.

Reduced N application rates

Legume crops provide a source of fixed nitrogen and reduce the rate of nitrogen fertiliser required in the next plant cane crop. A well-managed legume fallow can produce between 140kg/ha to 300kg/ha of nitrogen depending on the type of legume and growing conditions (Poggio et al., 2007). Extensive evidence exists to show that there is little to no need to apply nitrogen fertiliser to a plant cane crop following a well grown legume fallow (Garside and Bell, 2001), (Garside et al., 1997),(Bell et al., 2003). Given that a plant cane crop yielding 100 t/ha needs around 140kg/ha of nitrogen, fertiliser cost savings can be significant (Poggio et al., 2007). If the legume crop is harvested the amount of nitrogen available to the plant cane crop is reduced. This is because when a legume crop is harvested, 60 per cent to 70 per cent of the nitrogen in the tops is removed with the seed (Bell et al., 1998, Garside et al., 2004). Consequently, harvesting a legume fallow will provide an additional source of income and will also increase the nitrogen fertiliser cost in plant cane relative to an unharvested fallow.

Cost of legume crop

The cost of growing a soybean crop depends on how the crop is managed and where it is grown. Growing costs typically include the cost of seed, pesticides, fuel, oil, repairs and maintenance and labour. If the crop is to be harvested, harvesting costs, transport costs and levies will also be incurred. Growing costs in legumes were estimated by Garside (2004) at between $160/ha to $180/ha. An evaluation of production costs on a model farm in the Wet Tropics estimated growing costs at $204/ha (Collier, 2014). Poggio and Hanks (2007) estimated the cost to be between $180/ha to $270/ha compared to a bare fallow cost of $125/ha. To determine the overall economic impact of a legume fallow legume growing costs are weighed against fertiliser and weed control savings in plant cane as well as any income from harvested legumes. For an unharvested legume fallow in the Herbert, Poggio and Hanks (2007) found that a legume fallow with conventional farming practices provided a similar farm gross margin and operating return to a bare fallow system.

Capital investment

The machinery investment required to adopt a legume fallow will depend on the current machinery owned and if there is a preference to either use contractors or purchase new machinery. Typically a legume planter or contract planting is required. If pre-formed mounds are used a bedformer or contractor to perform this operation may also be required.

3.1.3 Tillage and Compaction

The economic implications of moving from conventional tillage to a reduced tillage or controlled traffic system are complex and case specific. Key considerations concerning the impact on profitability are changes to yield of cane, sugar content and consequently revenue, as well as improved fuel and labour efficiencies impacting operating costs. Capital investment, and consequently return on investment, is highly dependent on existing machinery available, whether or not GPS guidance is utilised and if row spacing is to be reconfigured. Fixed costs may be impacted by consolidation of the tractor fleet and implements.

Yield influence

Field trials conducted in the Wet Tropics, Bundaberg and Mackay indicate that controlled traffic farming may be adopted without yield penalty. Braunack, McGarry and Halpin (2003) conducted a non-replicated field trial in Bundaberg to compare different tillage practices during land preparation for planting. Conventional tillage and a reduced tillage strategy involving cultivating only the old crop row on the same 1.5m row spacing were evaluated. Results indicate that yield of cane and sugar content is not compromised by a reduction in tillage. Braunack and McGarry (2006) conducted replicated field trials in Tully and Ingham. Single rows grown at 1.5m spacing with conventional tillage and dual rows grown at 1.8m spacing with controlled traffic were evaluated. Results indicate that moving to a controlled traffic system had no negative impact on yield of cane or sugar content. Agnew et al. (2011) compared 1.5m row and 1.8m single row spacing treatments in a non-replicated trial in Mackay and also concluded that 1.8m row spacing had no detrimental impact on yield. Garside et al. (2009) evaluated row spacing and planting density effects on yield in large-scale field trials in Gordonvale, Tully, Ingham, Mackay, and Bundaberg. Row configurations ranging from 1.5m single rows to 1.8m dual rows, 2.1-m dual and triple rows, and 2.3-m triple rows were evaluated. Results showed that all row configurations produced similar yield.

Operating costs

Zonal tillage, with or without increasing row spacing, will result in a reduction in fuel consumption and labour by increasing field efficiency, decreasing tractor load and increasing speed of the operation (East et al., 2012). Halpin et al. (2008) compared fuel consumption and labour under a 1.6m row conventional tillage system and a 1.8m row controlled traffic system. Results indicate that tractor hours were reduced by 39 per cent and fuel consumption was reduced by 58 per cent under the controlled traffic system. Likewise, Braunack et al. (2003) found that moving from conventional tillage to a reduced tillage strategy on the same 1.5 m row spacing reduced labour by 27 per cent and fuel consumption by 25 per cent. Large cost savings in fuel, repairs, maintenance and tractor hours are less significant when the overall change to total costs is considered. For example, an evaluation of production costs on a model farm in the Wet Tropics found machinery costs (fuel, oil, repairs and maintenance) accounted for 3 per cent of total costs (Collier, 2014). In this scenario, a 58 per cent reduction in fuel costs would equate to a 1.74 per cent reduction in total costs.

Capital investment

With vast reductions in cultivation there is the opportunity to reduce the tractor fleet requirement. High capitalisation comes with a high fixed cost and consequently a smaller number of less powerful tractors will lower fixed costs. Fixed costs to consider are depreciation, storage costs, finance costs and insurance.

Some reduction in tillage may be achieved with no new capital investment by using current implements and reducing the number of passes. For zonal tillage, existing implements may be modified by removing tynes/blades in the wheel tracks and/or by widening the implements. East found the cost of implement modification to be $29,500 and $41,500 for a 50 hectare and 150 hectare farm, respectively (East et al., 2012). Alternatively new zonal implements may be purchased and old implements made redundant. Depending on the value of machinery purchased, sold or salvaged capital investment may be high or cost neutral (Halpin et al., 2008). Zonal tillage can be adopted without GPS however the practical implementation of controlled traffic without guidance has proved difficult and investment in auto-steer technology is often considered pivotal in implementing zonal tillage practices (Halpin et al., 2008). Purchase of a GPS unit and base station is around $40,000 (East, Simpson and Simpson 2012). Capital investment in GPS may be reduced when the cost of a cabin-mounted rover unit is shared between growers (Halpin et al., 2008).

Moving to a controlled traffic system with wider row spacing is a transitional process. Each year only a proportion of the farm is under fallow and therefore row spacing can only be reconfigured on these sections. This means that variable cost savings are not realised over the entire farm immediately and therefore return on investment may be low. For example, East, Simpson and Simpson (2012) investigated the economics of controlled traffic farming by a grower in Mackay and found that savings in variable costs were only just sufficient to make the investment in zonal implements and GPS worthwhile over 12 years.

3.1.4 Weed, pest and disease management

Many aspects of weed, pest and disease management are inter-related. For example, most diseases of sugarcane are not managed by crop protection products alone, or at all, and rely on a combination of hygiene practices, variety selection and fallow management. Weed management also utilises a combination of practices. Herbicides are used in conjunction with cultural practices such as trash blanketing, strategic tillage, and farm hygiene. Consequently, the economic evaluation of weed, pest and disease management practices has typically been undertaken as one component in a whole-of-farm system evaluation.

Poggio, et al. (2014) used economic and agronomic modelling to quantify the economic impacts of weed management practices in the Burdekin, Tully and Mackay regions. The report indicated that progressing from current to reduced herbicide rates and targeted application is generally expected to be profitable and provide the highest return on investment across all farm sizes and cane districts. The magnitude of the return on investment has a positive relationship with farm size, primarily because the investment is spread across a greater productive area on larger farms. The results were found to be critically dependent on regional-specific variables including biophysical characteristics and enterprise structure, especially in relation to farm size and location.

3.2 Environmental evaluations

Given the focus of the Australian sugar industry on water quality issues, the environmental implications of sugarcane growing in Australia have mostly been considered in relation to meeting water quality objectives for protecting the Great Barrier Reef (Thorburn et al., 2013). There has also been consideration of nitrous oxide (N_2O) emissions in relation to greenhouse gas (GHG) emissions (Thorburn et al., 2010). The wider environmental implications of growing sugarcane, such as resource efficiency over its life cycle have been considered less. . Intuitively, one might expect that improved resource efficiency (fuel, machinery, fertilisers, pesticides etc.) associated with progressive practices, and that drive the previously discussed observed economic benefits, would also result in reductions in such impact. However, this has not been fully researched to date.

This review summarises past research that has evaluated i) the direct environmental impacts using empirical measurement or modelling, and ii) the life cycle environmental impacts of cane growing practices using LCA. The second of these is more relevant to this project because we have elected to consider the life cycle environmental implications of cane growing practices using the CaneLCA tool (see section 2.3). However we discuss past empirical measurement and modelling research, as the project can draw on it to improve the predictive capacity of the CaneLCA analysis.

3.2.1 Direct environmental impacts using empirical measurement or modelling

There is a relatively large body of literature that has used empirical measurement or modelling to evaluate the environmental implications of different practices (Table 2). These have either measured or simulated (using agronomic models) how different practices influence direct losses of contaminants from the farm to the environment[4], or environmental values such as soil health and soil carbon.

More than half of such past studies (16 out of 27) have evaluated and compared practices related to nutrients management (of both nitrogen and phosphorus). Most of these (14) are related to nitrogen management and consider nitrogen losses to air and water, especially in Australia and Brazil. In the US, the interest seems to be on phosphorous and sediment losses to water. There has also been interest (in Australia) in how practices influence pesticide losses to water. The other categories of study are those related to soil health and soil carbon through alternative cultivation and harvest residue management practices.

Most measurement studies have evaluated and compared the influence of individual practice changes. However the use of agricultural simulation modelling has enabled practice change to be evaluated in a whole of system context, as it enables the interactions between different aspects of cane growing to be considered. For example, Thorburn et al (2011) considered the interrelationship between nitrogen application and irrigation management in relation to N losses to water. Biggs et al. (2013) evaluated the whole farming system, considering how a suite of practice changes (combining reduced tillage, controlled traffic, legume break crop, and educed N application) influence N losses.

[4] Nitrous oxide (N_2O) and ammonia (NH_3) to air; losses of nitrogen, phosphorus, pesticides and sediment to water (in runoff and leaching); and losses and sequestration of carbon dioxide (CO_2) leading to changes in soil organic carbon.

Table 2: Past empirical and modelling studies evaluating environmental implications of cane growing practices

Cane growing aspect		Environmental aspect influenced	Region	Reference
Soil health and nutrient management	Nitrogen application rates	Nitrous oxide (N_2O) emissions	Australia	*(Thorburn et al., 2010)*
		N losses (water quality) from N runoff	Australia – regions in GBR catchment	*(Webster et al., 2012)*
	Split N application	Nitrous oxide (N_2O) emissions	Australia	*(Allen et al., 2010)*
	Legume break crop	N inputs / losses Nitrous oxide (N_2O) emissions	Australia	*(Park et al., 2010, Wang et al., 2012)*
	Nitrification inhibitors, Controlled release fertilizers	Nitrous oxide (N_2O) emissions	Brazil	*(Soares et al., 2015)*
			Australia	*(Wang et al., 2014, Wang et al., 2012)*
	Biochar application	Nitrous oxide (N_2O) emissions	Australia – Tweed Valley	*(Quirk et al., 2012)*
	Dunder (vinasse) application	Nitrous oxide (N_2O) emissions Ammonia volatilisation	Brazil	*(Paredes et al., 2014)*
	Dunder (vinasse) application Trash management (green cane harvest)	N inputs	Brazil	*(de Resende et al., 2006)*
	Nitrogen application rates (including consideration of water management)	N losses (water quality) from runoff and leaching	Australia	*(Thorburn et al., 2011)*
	Irrigation management	P losses (water quality)	USA - Florida	*(Rice et al., 2002, Daroub et al., 2011, Lang et al., 2010)*
	Trash management - green cane harvest	Nitrous oxide (N2O) emissions	Australia	*(Wang et al., 2011)*
		Soil organic carbon	Brazil	*(La Scala et al., 2012, La Scala et al., 2006, De Figueiredo and La Scala, 2011, Pinheiro et al., 2010)*
		Soil erosion	USA - Florida	*(Kornecki and Fouss, 2011)*
	Tillage management - Reduced tillage - Controlled traffic Trash management - green cane harvest	Soil health	Australia	*(Stirling et al., 2010)*
	Tillage management - Reduced tillage Trash management - green cane harvest	Soili organic carbon	Australia	*(Page et al., 2013)*
Pesticide management	Tillage management - Row spacing,	Pesticide loss (water quality)	Australia – Mackay /	*(Masters et al., 2013)*

Cane growing aspect		Environmental aspect influenced	Region	Reference
	- Dual rows - Controlled traffic		Whitsundays	
	Alternative pesticides	Pesticide toxicity (water quality)	Australia	*(Davis et al., 2014)*
Whole of system	Tillage management - Reduced tillage - Controlled traffic Nitrogen application - Legume break crop, - Reduced N application	N loss (water quality)	Australia	*(Biggs et al., 2013)*

3.2.2 Life-cycle environmental impacts

Environmental life cycle assessment (LCA) has been applied to sugarcane products since the early 2000s in many countries, including Australia. See Renouf et al. (2010) for a full review. The recognition of sugarcane as an efficient source of renewable bio-energy and bio-fuels (Miller et al., 2007, Renouf et al., 2008) has meant that much of the past LCA research has been on 'cradle to grave' applications to bio-energy and bio-fuel products. However we are interested here in the sugarcane growing phase, and so the review from here focuses on 'cradle to farm gate' applications.

Past Australian LCA studies have found that an important route for reducing the environmental footprint of sugarcane products is to reduce the environmental impacts of cane growing (Renouf et al., 2014), since this phase dominates life cycle impacts of sugarcane products (Renouf et al., 2011). The environmental hot-spots for sugarcane growing are well understood[5], and environmental impacts are also known to vary considerably from one region to the next and within regions (Renouf et al., 2010). Within regions, the variation is suspected to be due to differences in practices. However the influence of practices on environmental performance is not well understood, and is a focus of this research. The review of literature identified only a few LCA studies (4) that have evaluated the environmental implication of sugarcane growing practices (Table 3).

All of the past studies have addressed or included practices and strategies for improved nitrogen (N) management. For example, van der Laan et al (2015) used LCA, along with agronomic modelling, to quantify the environmental benefits per unit of cane of combined improvements in irrigation and N application in South Africa. They found that decreasing N leaching through improved irrigation scheduling, reduced the rate of fertilizer N applied, leading to reductions in life-cycle non-renewable energy consumption and greenhouse gas emissions (GHG) by 20 per cent and 25 per cent. The energy savings come from reduced urea production, and GHG savings some from a combination of reduced urea production and reduced N_2O emissions. Fukushima and Chen (2009) similarly assessed combined changes in irrigation and N application, but also cultivation in Taiwan. However contrary to Laan et al., they concluded that increased fertilisation and irrigation led to increased yield which had the effect of reducing the life-cycle GHG impacts per unit of cane.

In the first comprehensive LCA study of different practices, Renouf et al (2013) used the streamlined LCA tool (CaneLCA) to assess the environmental implications of a whole of farming system change

[5] Known environmental hotspots for sugarcane growing are nitrous oxide emissions from the denitrification of applied nitrogen, loss of nutrients (nitrogen and phosphorous) and pesticide active ingredients to water, fertiliser production, energy use for irrigation, on-farm fuel use in tractors and harvesters, and cane burning emissions.

from conventional to best-management practices (BMP). It was based on hypothetical description of practice in the Wet Tropics, Burdekin and Mackay regions of Australia. It was predicted that most BMPs would result in environmental benefits and no down-sides across all impact categories (energy, GHG, water quality, water use). However, some practice change may have inadvertent downsides. The current project will build on this prior work by using the CaneLCA tool to examine in more detail the environmental impacts of BMP, but for actual rather than hypothetical case studies.

Table 3: Past 'cradle to farm gate' LCA studies evaluating environmental implications of cane growing practices

Cane growing aspect		Environmental aspect influenced	Region	Reference
Soil health and nutrient management	Nitrogen application (including consideration of water management)	Energy input GHG emissions Water quality Water use	South Africa	*(van der Laan et al., 2015)*
	Increased inputs to promote yield: Nitrogen application Tillage management (including consideration of water management)	GHG emissions	Taiwan	*(Fukushima and Chen, 2009)*
Whole of system	Legume break crop Reduced tillage Reduced N application rates Trash retention (green can harvesting) Alternative herbicides	Energy input GHG emissions Water quality Water use	Australia	*(Renouf et al., 2013, Renouf et al., 2014)*

3.3 Combined evaluation of economic and environmental considerations

The literature review did not identify any past sugarcane studies that concurrently evaluated both economic and environmental implications. Three studies of sugarcane bio-products consider the environment and economic aspects of different bio-production scenarios (Cavalett et al., 2012, Fazio and Barbanti, 2014, Su and Tso, 2011). However these relate to alternatives for the processing of sugarcane rather than the growing of sugarcane.

While there have been no combined evaluations for sugarcane, there has been for agriculture more generally. Since the late 1990s there has been a growing field of research that evaluates the conflicts and trade-offs between the maximising the benefits of agriculture (food production, farm income) and the minimising the adverse impacts of agriculture (environmental and social). Some of this has been directed toward agricultural policies at the national scale or landscape scale (Pretty et al., 2000, ten Berge et al., 2000, Wolf et al., 2015, Andreoli and Tellarini, 2000). However we are interested in its application to decision making in relation to production systems and practice at the farm scale, for which there is a growing number of examples (Lu et al., 2003, Rasul and Thapa, 2004, Eltun et al., 2002), (ten Berge et al., 2000, Meyer-Aurich, 2005, Rotz et al., 2005).

The methods that have been used to report and interpret economic and environmental considerations alongside each other are summarised here. They have been listed in terms of their complexity, i.e. from least to most complex.

Qualitative trade-off analysis separately evaluates environmental and economic criteria, and then brings them together in a qualitative appraisal of where there are trade-offs between environmental and economic objectives. See an example in Figure 2.

- A range of different cropping systems for a model farm in Norway (the Apelsvoll experiment) were ranked from most to least favourable options for environmental impacts alongside economic considerations, to identify the options that give environmental benefits with least economic downsides or vice versa (Eltun et al., 2002)

- Trade-offs between profitability and environmental stewardship were assessed for six US grain cropping systems incorporating alternative tillage intensities, cover crops, herbicide and nutrient applications (Lu et al., 2003). It involved not only profitability and environmental analysis, but also risk analysis, and described the trade-offs for risk-adverse and risk-neutral farmers.

- Conventional and organic cropping systems in Bangladesh were compared across 12 sustainability indicators (including environmental, profitability as well as land productivity indicators) (Rasul and Thapa, 2004).

- The environmental and economic performance of five Charolais beef production systems in France were compared in relation to farm income versus energy inputs and greenhouse gas emissions (Veysset et al., 2010) .

Quantitative trade-off analysis separately evaluates environmental and economic criteria, and then brings them together as quantitative indicators of trade-offs. See an example in Figure 3.

- The trade-offs between financial and environmental outcomes in the production of second generation biofuel feedstocks from cereal straw in the UK were assessed by evaluating farm gross margins (with a linear programming optimisation model), and life cycle energy inputs and greenhouse gas (GHG) emissions (with LCA) (Glithero et al., 2012). These results were brought together to quantify the trade-offs. This was presented as the degree to which one desired outcome is foregone when the other criteria are maximised (i.e. gross margins, energy output and GHG mitigation). For example, income foregone per unit of environmental benefits, or vice versa.

Generation of a **single sustainability index** integrates multiple economic and environmental indicator values. See an example in Figure 4.

- This approach was used to evaluate the relative sustainability of arable crops in northern Italy, by integrating 15 different indicators of agro-ecological and economic performance (Castoldi and Bechini, 2010).

Integrated farm models simulate the physical and biological processes on farms to quantify both environmental parameters and economic parameters within the one tool. These have been generically described as bio-economic farm models (BEFM) (Janssen and van Ittersum, 2007), but include a number of different approaches (multi-criteria analysis, linear programming etc.). See an example in Figure 5.

- Multi-criteria analysis was used to assess the environmental, economic and social conflicts and trade-off for different soil erosion control measures in soybean production in Argentina (Cisneros et al., 2011). The results showed a strong conflict between environmental and economic interests.

- An integrated farming system model was used to evaluate the environmental and profitability performance of nitrogen management scenarios on grassland grazing systems for livestock in Germany and the Netherlands (Rotz et al., 2005). It simulated physical and biological processes to estimate bio-physical parameter, and used this information to also predict production costs, income, and farm net return and profit.

- Multi-goal linear programming has been used to inform a better balance between economic goals, rural employment and environmental protection in the Netherlands, using three case studies of dairy, flower and arable farming (ten Berge et al., 2000).

- A method of combining an agronomic simulation model and a mathematical multi-objective programming model was used to analyse the effects of farm management practices and water application efficiency on farmer's revenue and nitrate leaching in Italy (Semaan et al., 2007). It found trade-offs between the levels of nitrate leaching and net farmer's revenue, which was influenced by nitrogen tax policies and water pricing.

- Multi-criteria modelling and optimisation was used to analyse the interactions of the economic and ecological consideration on a case study integrated farm section of a research station in Bavaria, Germany (Meyer-Aurich, 2005). It used a model called MODAM, which simulates agricultural land use at farm level, calculates the economic returns and environmental impacts, and runs farm optimizations with a linear programming tool. The environmental objectives integrated into the model were soil erosion, nitrogen balance, greenhouse gas emissions and energy input. It quantified trade-offs and generated abatement cost curves. Linear programing for optimising scenarios against multiple objectives in the context of sustainable agriculture is described in (Payraudeau and van der Werf, 2005).

This project will review these various approaches to the joint presentation of economic and environmental consideration to decide if they are appropriate for extension of information to personnel in the Australian sugarcane industry, or devise an alternative approach.

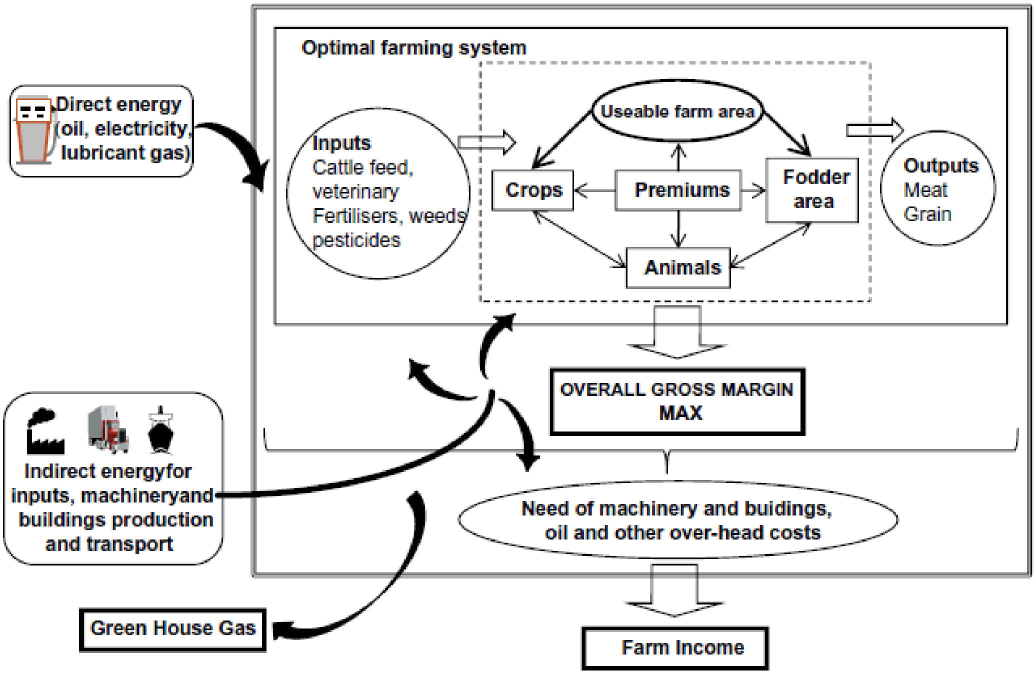


Figure 2: Examples of a qualitative trade-off analysis (taken from Veysset et al. (2010))

		Gross margin maximised	Net energy maximised	GHG emissions minimised
Crop Mix[a]	Winter wheat (SR, 75% N)	133.33	200	0
	Winter wheat (NSR, 50% N)	0	0	200
	Winter barley (ASR, SR)	133.33	0	0
	Winter field beans	0	200	200
	Winter oilseed rape	133.33	0	0
Finance	Overall farm costs	263,284	197,567	179,446
	Overall farm revenue	549,066	466,238	421,519
	Gross margin	285,782	268,671	242,072
Energy	In	9367	5752	5090
	Out	35,115	31,952	26,033
	Net	25,727	26,200	20,942
GHG emissions		1,772,947	933,841	761,354

[a] SR – straw removed, 75% N where 75% of the recommended nitrogen fertiliser has been applied, NSR – no straw is removed, 50% N where 50% of the recommended nitrogen fertiliser has been applied, ASR – crop is grown after a cereal crop where the straw was removed.

Figure 3: Examples of quantitative trade-off analysis (taken from Glithero et al. (2012))

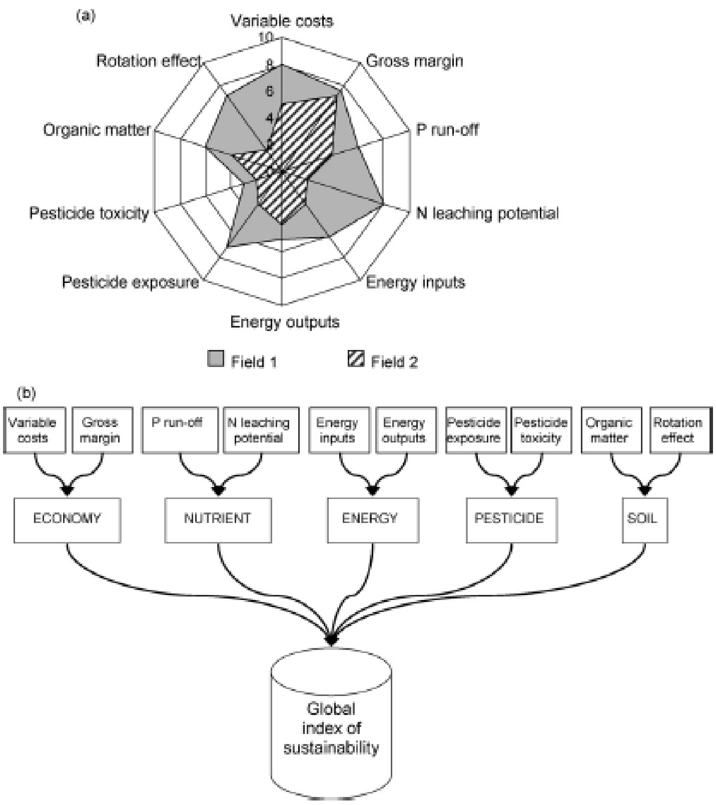
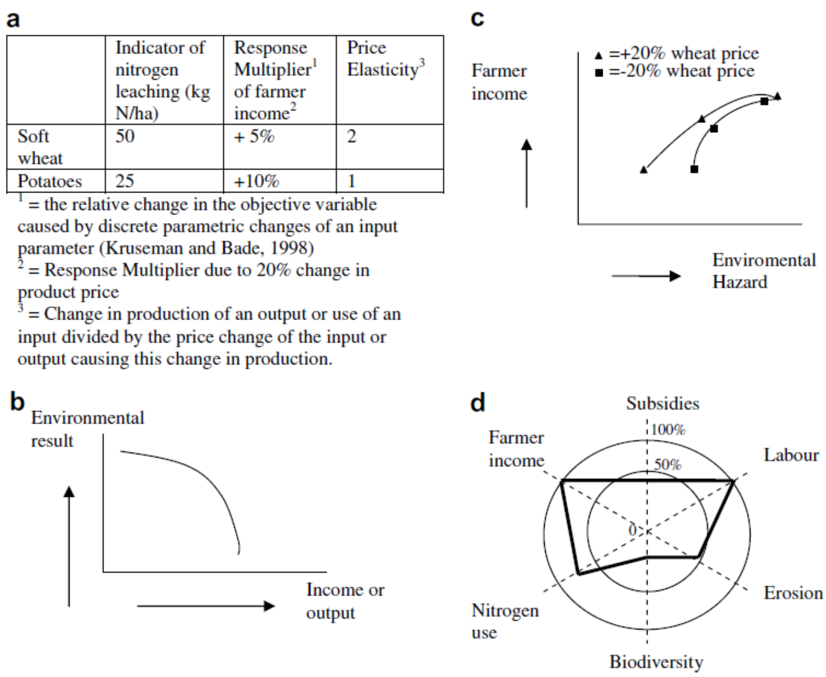


Figure 4: Examples of an integrated sustainability assessment combining agro-ecological and economic indicators (taken from Castoldi and Becchini (2010)).



	Indicator of nitrogen leaching (kg N/ha)	Response Multiplier[1] of farmer income[2]	Price Elasticity[3]
Soft wheat	50	+ 5%	2
Potatoes	25	+10%	1

[1] = the relative change in the objective variable caused by discrete parametric changes of an input parameter (Kruseman and Bade, 1998)
[2] = Response Multiplier due to 20% change in product price
[3] = Change in production of an output or use of an input divided by the price change of the input or output causing this change in production.

Figure 4: Examples of results from integrated farm models (taken from Janssen and van Ittersum (2007): a) indicators, response multipliers and elasticities, b) trade-off curves, c) frontier analysis, and d) spider diagram based on indicators.

4. Conclusions

In the past (up until about 2005), practice change research for Australian sugarcane was driven by the need for increased cane productivity in response to yield declines now known to have been due to declining soil health. Research programs such as the Yield Decline Joint Venture (Troedson and Garside, 2005) successfully identified practice changes that address this, such as reducing soil compaction through controlled traffic, trash blanketing and crop optimising nutrition.

Over the last decade (2005-2015), an emphasis on water quality protection in the Great Barrier Reef has shifted research attention to practices that reduce the losses of nutrients (particularly nitrogen), sediment and pesticides to waterways (Drewry et al., 2008). There is now an extensive body of research related to nitrogen (N) use efficiency (SRA, 2014) and pesticide management practices. The culmination has been definitions of preferred practices that mitigate pollutant losses (nutrient, sediment, and pesticides), such as reduced N application rates, application methods that reduce the propensity for N loss, reduced tillage, supplementation with legume-derived N, better accounting for N application, and switching non-residual herbicides. These practices are now being promoted through the industry's Smartcane Best Management Practices (BMP) Program.

In parallel with this has been research that investigates the economic implications of industry transition to these more environmentally-sensitive practices (for example, van Griken et al., (2010) and Poggio et al., (2014)). However it has been common for studies to not be comprehensive in terms of considering all aspects influencing long-term profitability. Also they have tended to consider particular practices changes in isolation of the whole farming system, and to be based mostly on hypothetical assumptions. It is often assumed that increased in production results in greater profitability. However this is not always the case, particularly when a practice change increases operating expenses or involves additional capital expenditure. More recent economic evaluations (since 2010) have recognised the importance of considering the farming system as a whole, to give a more holistic picture. Such research indicates the potential for progressive practices to be economically viable, but there are circumstances when this is not the case. What should be further explored are the variables that influence farm profitability and economic viability, through evaluation of real (not hypothetical) practice change case studies.

The environmental implications of practice change have been considered in relation to meeting water quality objectives for the Great Barrier Reef and GHG emissions (nitrous oxide) in relation to climate change. However, the wider resource efficiency implications over the life cycle of cane growing have been explored less. So it is not well known whether practices changes for addressing one environmental objective (say water quality) inadvertently compromise other environmental objective (say energy conservation and GHG mitigation). Environmental life cycle assessment (LCA) has been used to test this for progressive practices based on hypothetical scenarios (Renouf et al., 2013b, Renouf et al., 2014). This preliminary work suggests that many of the progressive practices can lead to improved environmental outcomes across all impact categories. However this needs to be explored further based on real, not hypothetical cases.

The literature review identified that while there has been joint consideration of the trade-off between economic and environmental outcomes for progressive practices in agriculture generally, there has not been work done specifically on sugarcane.

In summary, the gaps in knowledge that this research aims to address are:

- develop a framework to evaluate the economic and environmental implications of practice change in a holistic manner;
- provide greater certainty about the economic and environmental implications of best management practices in Australian sugarcane growing though the evaluation of actual rather than hypothetical cases;
- bring together of information about the economic and environmental implications of best management practices in Australian sugarcane growing.

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Appendix 1

SmartCane BMP Industry Standard Management Practices[6]

Soil Health and Nutrient Management
Managing compaction
Row spacing and most machinery wheel spacings are matched, initial row establishment formed GPS guidance. Where possible machinery operations are delayed to avoid operating in wet field conditions.
Trash management
Green cane trash blanket (GCTB) is retained on suitable soils. In cold environments trash is raked from the stool and maintained in the interspace or cane is burnt prior to harvest. Where a water logging risk exists, cane is burnt prior to harvest.
Fallow management
Soil cover is maintained throughout the wet season either through the use of a trash blanket and sprayed out cane or through the growth of a fallow crop like legumes. No living cane is present during the fallow period to break pest and disease cycles.
Preparing land for planting
Plant cane is established after a fallow using zonal or minimum tillage. Tillage methods minimise soil structural damage and compaction.
Tillage management in-crop
Tillage in plant cane is kept to the minimum necessary to establish row profiles and irrigation furrows and to apply fertiliser and pesticides. For GCTB – no tillage in ratoons other than fertiliser and pesticide applications is used.
Managing salinity and sodicity
The presence / risk of salinity and sodicity is determined and monitored through the use of soil tests and on-farm management practices including application of soil ameliorants.
Soil Sampling
Soil sampling that meet industry and legislative requirements are collected from blocks to be planted and sent for analysis. Records kept refining future nutritional programs.
Calculating optimum nutrient rate
Regulatory minimum (for growers in Wet Tropics, Burdekin, Mackay-Whitsundays): The regulated method is used to develop nutrient program for N & P. For N, district yield potential is used with adjustments made according to the N mineralisation index of soils which is based on OC%. Other sources of N including from irrigation water, mill mud and legumes are voluntary deductions. OR Six Easy Steps Nutrient Management program is used
Placement
On steep slopes only (i.e. Innisfail on Red Ferrisol soils), fertiliser is applied banded on the surface. Apply when crop root system has developed. Mill by-products are applied on the row, not in the interspace. Granular fertilisers are applied subsurface in the drill (i.e. stool split or side banded). Mill by-products are applied on the row, not in the interspace. Surface-banded applied fertiliser products are incorporated by overhead irrigation as soon as possible or within 7 days. Liquid fertiliser products are applied subsurface, or on the surface only under pressure.
Timing
Apply fertiliser six to eight weeks after harvesting or when cane is approximately 600mm high on early- to mid-season cut cane where practical. And if late cut cane, apply when practical taking weather into consideration. Never apply fertiliser when runoff from storms is expected before the nutrient can penetrate to the root zone.
Calibration
Application equipment is calibrated prior to the season and at each product and batch change.
Record keeping
Records are kept of soil tests, application rates, products, placement, calibration of equipment and person

[6] *Source: https://www.smartcane.com.au/home.aspx*

applying. Records are used to review and modify future nutrient management.
Weed, Pest and Disease Management
Canegrub Management
Canegrub control decisions are based on monitoring plant damage and/or on risk assessment based on soil texture, proximity to known adult feeding sites and topography. Grub species has been identified.
Rat Management
Both in-crop and harbourage areas are managed to avoid build-up of rats
Other Pests
Presence of or potential presence of pests is known and managements practices are carried out as required.
Weed Management
Weed management plan is developed and implemented in line with the SRA weed plan template and key considerations.
Disease Management
Farm planning and operations take account of the mechanisms of disease spread and deliberate and considered strategies are implemented to avoid introduction of diseases and/or spread of diseases on farm. Known diseased blocks are actively managed to reduce or eliminate disease.
Product Selection
All products used are approved (registered or permitted) for intended purpose and timing of application Products are selected in accordance with integrated management plans (weeds/pests/diseases).
Chemical Storage And Mixing And User accreditation
All people who apply chemicals have the appropriate competencies and training or are supervised by someone with the appropriate competencies and training. Chemicals are stored in appropriate storage premises that meet the requirements of workplace health and safety. Chemicals are mixed at locations on farm that meet label requirements and legal requirements under Reef protection legislation. Chemical drums are disposed of through drumMuster. Unwanted chemicals are disposed of through Chemclear or other approved disposal systems
Chemical Application and Record Keeping
Products are applied according to the label or permit directions and legislative requirements under the Chemical Usage (Agricultural and Veterinary) Control Act 1999. Records of chemical management inputs are kept for each field Nozzles are selected based on label requirements for product and target. Application equipment is calibrated at the start of each season and at change of product or change of water rate. Herbicides are applied at the ideal weed and crop growth stages A chemical management plan that identifies sensitive areas, buffer zones, problem pest areas and is reviewed annually, is included as part of an IWM or IPM plan. Timing of chemical applications minimises loss of chemicals in runoff and residual chemicals are applied prior to the commencement of the wet season.
Drainage Management
Surface Drainage System Design
A whole of farm (or area) drainage plan has been developed – water is removed from the farm within 72 hours (or as quickly as possible given local conditions) while minimising erosion and downstream flooding.
Subsurface Drainage System Design
A drainage system that removes excess water from the root zone has been implemented. Acid sulphate soils should be considered Saline drainage water is disposed of appropriately
Erosion Management
Grass is maintained on headlands and drains Cover is maintained on fallow ground