FINAL REPORT 2014/015

Measuring the profitability and environmental implications when growers transition to Best Management Practices

Final report prepared by:	Caleb Connolly, Marguerite Renouf, Mark Poggio and Matthew Thompson
Chief Investigator:	Mark Poggio
Research organisations:	Department of Agriculture and Fisheries; Lifecycles
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lifecycles.

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ABSTRACT

The development of sugarcane Best Management Practices (BMPs) aims to improve the productivity, profitability and sustainability of sugarcane farms. However, there has been limited research that has examined both the economic and environmental implications of BMP adoption on commercial farms in Australia. To alleviate this problem, this project has undertaken a literature review and six case studies on commercial farms in the Wet Tropics analysing the farm profitability and life cycle environmental implications of BMP adoption. After completion, case studies were distributed and extension materials were presented to industry.

Economic, biophysical and farm operational data were collected from the commercial farms to undertake Farm Economic Analysis Tool (FEAT) and Cane Life Cycle Assessment (CaneLCA) tool analyses. Revenues, costs and the environmental impacts of the farming system both before and after BMP adoption were calculated using these tools in order to determine the economic and environmental impacts of the management changes. Results from investment and environmental analyses indicate that BMP implementation in the Wet Tropics can be a win-win for both economic and environmental outcomes. The economic benefit from BMP adoption was found to range between $25 and $220 per hectare per year. The CaneLCA analysis indicated reductions in energy use, greenhouse gas emissions and potential water quality impacts from nutrients and pesticides over the life cycle of sugarcane production.

The adoption of management practices that have been scientifically validated, such as BMPs, mean that adverse impacts on production are unlikely. When adopting any management practice change, however, there is always a risk that production outcomes may not be as expected. Sensitivity analyses identified that the economic and environmental outcomes were sensitive to increases or reductions in cane yield. Such risks can affect the practice adoption decisions of growers and, in the case studies, the approaches taken by growers to mitigate risks differed depending on the individual circumstances of each of the farming businesses. Ongoing communication of the project's findings may encourage growers to consider further BMP adoption, and the methods employed in this project could be applied to develop case studies in other regions.

EXECUTIVE SUMMARY

BMPs have been developed on the basis that they are perceived to be beneficial for production as well as the environment. However, growers are less likely to adopt new management practices in the absence of information regarding their prospects for improved profitability. The objective of the project was to improve current knowledge about outcomes for farm profitability and the environment after adopting Smartcane BMP practices by addressing specific research questions such as “are cane businesses in the Wet Tropics likely to be more profitable from adopting the Smartcane BMPs being analysed?” and “which individual or suites of BMPs present a win-win situation for profitability and environmental outcomes?”

The project objective was met by delivery of planned outputs including, a review of the relevant literature, formation of a project steering group, developing a methodology for evaluating economic and environmental impacts, case study evaluations, a paper submitted to the International Society of Sugarcane Technologists (ISSCT) and a paper submitted to the Australian Society of Sugar Cane Technologists (ASSCT), publication of this final report and various publications and extension activities.

The literature review synthesised knowledge from past research that either separately evaluates the economic and environmental implications of sugarcane growing practices or that brings the economic and environmental aspects together.

A work plan and terms of reference for the project were developed which clarified project details and the roles and responsibilities of personnel participating in the project (Research Team, Project Steering Group, and participating growers). Members of the Terrain NRM Cane Technical Working Group (CTWG) were engaged as a Project Steering Group that included industry representatives from various organisations to provide advice and feedback and assist in selecting appropriate case studies for analysis.

The Research Team collected economic and bio-physical data from selected case study growers and used that data to complete economic and environmental analyses and evaluate the farm profitability and environmental implications of adopting BMPs for farming business. The Farm Economic Assessment Tool was used to calculate operating costs, incomes and gross margins, coupled with an investment analysis to generate indicators of farm profitability. An environmental parameters spreadsheet was compiled to be used in the CaneLCA tool and generate indicators of environmental impacts. The sensitivity of the results to changes in cane yields were also assessed. A suite of practice changes, rather than individual practice changes, were considered in commercial, rather than hypothetical, settings, thus enabling insights from a whole-of-farming system perspective.

Six case studies of different sized commercial farms located between Ingham and Mossman that had adopted various BMPs were developed. Practice changes ranged between farms but included practices associated with soil health, nutrition, weed and pest control and drainage. The cost of implementing the BMPs ranged between $2,200 and $735,000 and depended on the individual circumstances of each farm, types of practice changes and cost of required equipment or earthworks.

Results from the investment and environmental analyses indicated that BMP implementation in the Wet Tropics can be a win-win for both economic and environmental outcomes. The economic benefit from BMP adoption was found to be positive on all farms (indicating that each investment was profitable) but varied among the farms (between $25 and $220 per hectare per year), while the payback period ranged between two and ten years.

Farm profitability was found to be sensitive to cane yield changes, which highlights the need to manage risks. The sensitivity analyses suggest that a drop in cane yield of between 1% and 9% could be experienced in four of the case studies (CS1, CS2, CS4 and CS6) and the grower would still "breakeven" in terms of annual benefit. Increases in cane yield were required in CS3 (14.4%) and CS5 (10.8%) for the grower to breakeven. Yield increases used in the analysis for CS3 and CS5 are detailed further in the body of this report.

The potential sensitivity of farm profitability to cane yield changes highlights the need to manage risks. The case studies provided examples of growers managing risks using various methods when adopting BMPs including the progressive implementation of practice changes over time (step-by-step approach) and co-investment with neighbouring farmers to reduce capital investment costs. Some growers also obtained grants to reduce implementation costs (although such grants were not included in the investment analyses as the aim with a view to isolating the implications of practice changes).

The environmental results indicate that BMP adoption can improve water quality and energy efficiency as well as mitigate greenhouse gas emissions. The case studies indicated that the environmental benefits were not too sensitive to cane yield reductions. For five of the six farms assessed, yields would need to reduce quite considerably (15-40%) for the environmental improvements to be compromised. The sensitivity of environmental results to potential changes in yield was higher in the case of the remaining farm that was already quite eco-efficient before BMP adoption (and the degree of change in environmental impacts after BMP adoption was relatively small for that farm).

The case study results show that BMP adoption in the Wet Tropics can result in improved profitability and environmental improvements. Nevertheless, decision makers need to take into account risks such as potential yield changes. Using a whole-of-farm methodology when evaluating the implications to profitability and the environment as well as interactions between practice changes can help manage specific risk factors. The case studies were extended via the distribution of case study reports to industry and extension networks as well as presentations at a number of workshops in the Wet Tropics. Further communication of the project's findings is planned and may encourage growers to consider further BMP adoption, while extension of the methods employed in this project could be applied to develop case studies in other regions.

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1. BACKGROUND

Over the past several decades the changing farm business environment has provided challenging conditions for sugarcane growers to maintain profitability. Such conditions highlight the need for growers to continually adopt Best Management Practices (BMPs) that improve their profitability and sustainability.

The Smartcane Best Management Practice (BMP) program aims to transition growers towards management practices that improve the productivity, profitability and sustainability of sugarcane farms (Schroeder, Calcino et al., 2008, Collier et al., 2015). The BMPs are intended to maintain and improve soil health and yields and minimise the loss of nitrogen, pesticides, and sediment from farms (Troedson and Garside, 2005, Schroeder et al., 2008, Kroon et al., 2012,Thorburn et al., 2013). The core BMP modules include soil health and nutrient management, weed, pest and disease management and irrigation and drainage management.[1]

However, growers are less likely to adopt new management practices in the absence of information regarding their prospects for improved profitability. Within the adoption literature, the relative advantage of adopting a new practice is heralded as a key motivator of adoption (Rogers, 2003). Relative advantage refers to the perceived net benefit gained after adopting an innovation (relative to the practice it supersedes), and can be influenced by various perceived attributes of adopting a practice, including economic factors such as a practice's impact on costs, production and profitability (Pannell et al., 2006). The larger a practice's relative advantage, the greater the likelihood of adoption.

A literature review developed for this project (Collier et al., 2015) identified that knowledge gaps could be addressed by: providing greater certainty about the economic and environmental implications of best management practices though the evaluation of actual rather than hypothetical cases and, by bringing together information about the economic and environmental implications of best management practices in Australian sugarcane growing.

Previous literature has concentrated on examining either the productivity, economic or environmental implications of BMP adoption in isolation rather than addressing all impacts. The majority of past research associated with BMPs has focused, in particular, on the production implications. For example, cane yield impacts have been measured for management practices that improve soil health (reduced tillage, controlled traffic and legume fallows) and nutrient management (optimising N application rates) (Braunack et al., 2003, Garside et al., 2004, Young and Poggio, 2007, Halpin et al., 2008, Schroeder et al., 2009, Schroeder et al., 2010, East et al., 2012, Skocaj et al., 2012). While cane yield is a key determinant of revenue, it does not take into account the investment costs or changes in growing expenses accompanying management practice changes. Given these limitations, the case studies developed in this project examine productivity, economic and environmental implications. In addition, investment costs and changes in growing expenses are factored into the economic evaluation of BMP adoption, which is similar to the approach used by Poggio et al. (2014).[2]

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[1] As in, the three core modules that must be completed by growers to received Smartcane BMP accreditation. https://www.smartcane.com.au/faq2.aspx

[2] This paper assessed changed weed management practices (reduced application rates, precise application and variable rates).

The impact of BMP adoption on the environment (water, air and soil quality) has been evaluated in past research by both computer simulation and actual measurement. For example, research has evaluated the greenhouse gas (nitrous oxide emissions) and water quality effects of changed N management practices (Allen et al., 2010, Thorburn et al., 2010, Wang et al., 2011, Thorburn et al., 2011, Wang et al., 2012, Webster et al., 2012, Biggs et al., 2013, Page et al., 2013, Wang et al., 2014), the soil health effects of changed tillage and trash management practices (Stirling et al., 2010, Page et al., 2013), and the toxicity-related water quality effects of change herbicide management practices (Masters et al., 2013, Davis et al., 2014). Previous research has generally only focused on the direct environmental impacts of management practice changes but there are also indirect impacts on the environment from up-stream supply chains that produce agricultural inputs (fertilisers and pesticides, fuels and energy, transport). Life cycle assessment (LCA) considers both direct and in-direct impacts in order to derive the total environmental impacts. While the LCA method has been used previously to evaluate hypothetical practice changes (Renouf et al., 2013), the project research builds on that work to evaluate actual instances of practice change on commercial sugarcane farms. Consequently, the environmental implications of practice change for whole farming systems are estimated.

The case studies developed in this project evaluate the farm profitability and life cycle environmental implications of BMP adoption on six commercial sugarcane farms located in the Wet Tropics region of North Queensland. The novel approach used for the case studies considers both the economic and environmental implications of BMP adoption and uses actual data from real farms to carry out comprehensive assessments. As a result, the findings provide a holistic “economic-environmental” understanding of the implications of BMP adoption in the Wet Tropics region. The grower case studies also provided opportunities to consider the social dimensions of practice change, the differences between farming systems and the interactions between practice changes.

As discussed further in section 3.2 (outcomes and implications), the outcomes from this project provide valuable resources to help inform practice change decisions that address both the imperative to improve profitability and the desire to maintain the industry’s environmental stewardship commitments.

Key abbreviations and acronyms are detailed in Appendix 1 of this report. Metadata disclosures are detailed in Appendix 2. Whilst the literature review forms a self-contained section to this report (Appendix 3), brief comments are made regarding the literature review throughout this report.

2. PROJECT OBJECTIVES

The objective of the project was to improve current knowledge about outcomes for farm profitability and the environment after adopting Smartcane BMP modules or practices by addressing specific research questions, including:

1. Are cane businesses in the Wet Tropics likely to be more profitable after adopting the Smartcane BMPs being analysed?
2. Of the prioritised Smartcane BMPs, which individual or suites of practices contribute to profitability and environmental performance in the Wet Tropics?
3. What are the variables that influence profitability and environmental performance at the farm level?

4. Which individual or suites of BMPs present a win-win situation for profitability and environmental outcomes?

The project objective was met by delivery of planned outputs (as noted in more detail throughout the body of this report) including the establishment of a Project Steering Group, a review of the relevant literature, case study evaluations, and various extension activities. The research questions are addressed throughout the body of this report and, in particular, in section 6.3 (discussion).

3. OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1. Outputs

3.1.1. Delivery of Outputs

The primary target adoption audience is sugarcane growers in the Wet Tropics region. The ultimate adoption pathway of this research is through dissemination of case study findings to growers, either directly or through intermediaries. Four outputs were detailed in the research agreement (details of delivery are noted below each output).

1) Six case studies involving growers located in the Wet Tropics region, which have switched to priority BMPs. Each case study will include: a financial-economic analysis component using FEAT as well as capital budgeting and risk analyses to evaluate the implications of practice change on farm profitability; and an environmental component using the CaneLCA tool to assess the implications of practice change on environmental factors.

The final case studies were submitted to SRA in September 2017 and the communication of the case studies is detailed in section 4 of this report (industry communication and engagement).[3] Depending on the practice changes made by each grower, case study reports focused on core BMP modules related to improving soil health and nutrient management, weed, pest and disease management, and irrigation and drainage management.[4] The methodology and results of case studies are detailed in sections 5 and 6 of this report.

2) A final written report will be provided that includes a literature review and an overview of project findings and outcomes.

The literature review by Collier et. al. (2015) (hereinafter referred to as the "literature review") was submitted to SRA in November 2015. The literature review is incorporated within this final report (Appendix 3). The communication of literature review findings is detailed further in section 4 (industry communication and engagement).[5]

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[3] Per SRA Portfolio output identification 2016-17 to 2018-19, the set of case studies can be categorised as a Tool/Enabler (SRA Output Category 4: Material, activity or other that indirectly supports/promotes outcomes or further RD&E efforts) related to SRA Outcome is KFA7/Outcome 2 "A skilled advisory sector that drives the adoption of new technology. Case studies were developed during Activities II to IV of the project.

[4] Drainage improvements were reported in two case studies. The other three core BMP modules were addressed in each case study.

[5] The literature review can be categorised as a Tool/Enabler (SRA Output Category 4: Material, activity or other that indirectly supports/promotes outcomes or further RD&E efforts) and the related SRA Outcome is KFA7/Outcome 1 "Research results and new technologies are communicated and transferred in an appropriate

The literature review confirmed that the project could provide greater certainty about the economic and environmental implications of best management practices in Australian sugarcane growing (through the evaluation of actual rather than hypothetical cases) and could bring together information about the economic and environmental implications of BMPs. Previous economic evaluations were outlined relating to sugarcane growing aspects such as nutrient management, fallow management, tillage, compaction and weed, pest and disease management. Past empirical and modelling studies and life cycle assessment studies evaluating environmental implications were also outlined. The literature review did not identify any past sugarcane studies that concurrently evaluated both economic and environmental implications.[6]

3) Presentation materials including fact sheets for extension activities.

Primary extension activities, including presentations at three events in October and November 2017. Presentation materials and industry update emails were also provided to industry throughout the course of this project. Extension activities are detailed further in section 4, Industry Communication and Engagement and publications are detailed in section 8, Publications.[7]

4) Paper submitted to ASSCT for consideration.

An abstract for the Australian Society of Sugar Cane Technologists (ASSCT) paper has been accepted for presentation at the 40th annual ASSCT conference in Mackay in April 2018 (Poggio et al., 2018), and will subsequently be distributed by email, as noted in section 4 (Industry Communication and Engagement). Given the ASSCT is “a forum for scientists, engineers, chemists, institutions, farmers, companies and individuals interested in [sugarcane] technology” the presentation of the paper will provide an opportunity to extend research findings of the project to a wider audience.[8] The paper is listed in section 8, (publications). A plenary paper was also presented (by Bernard Schroeder) at the International Society of Sugar Cane Technologists conference in Thailand, December, 2016 (Poggio et al., 2016). A detailed description of the environmental evaluation method used in the project (CaneLCA) has been published in a scientific journal (Renouf et al., 2018).

3.1.2. Further development

The research model and processes used in this project in the Wet Tropics can also be used to extend similar research to other sugarcane-growing regions. Further case studies in other regions will determine if BMP adoption also provides positive outcomes in regions where the nature of the BMP

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and timely manner across the industry value chain, supporting increased uptake of best-practice and innovative technology.” It was developed during Activity I of the project.

[6] The literature review did identify studies of sugarcane bio-products that consider the environment and economic aspects of different bio-production scenarios. However, these relate to alternatives for the processing of sugarcane rather than the growing of sugarcane. There has also been joint consideration of the trade-off between economic and environmental outcomes for progressive practices for other agricultural commodities.

[7] The communication and extension of case studies can be categorised as Communication/capacity building SRA Output Category 5: Engagement activity or information that promotes communication, adoption and/or industry capacity building) and the related SRA Outcomes are the aforementioned KFA7/Outcome 1 and KFA7/Outcome 2. The ASSCT paper can be considered under the same SRA Output Category and SRA Outcomes. Extension activities occurred throughout the project and workshops and submission of the ASSCT paper took place during Activity V of the project

[8] Details of ASSCT are available from the ASSCT website. https://www.assct.com.au/about-assct/what-is-assct

changes are different to those in the Wet Tropics. This process will require further data collection and analysis in the respective regions.[9]

Other matters that could benefit from further research include:

- The implications of BMP adoption relating to soil health characteristics and longer term production implications. For example, the interaction between fallow management and subsequent sugarcane production levels and the implications of BMP adoption on crop cycle length;
- Analysing if there have been cane yield changes after BMP adoption by comparing the before and after cane yields for farms that have adopted BMP with comparable yield data for the productivity zones where BMP has not been implemented;[10] and
- The use of different business structures, such as co-operatives and collaborative farms, by sugarcane growers in the wet tropics (particularly in circumstances where the cost of implementation for BMP adoption is relatively large and the farm size is relatively small).
- Greater certainty in the future quantification of water quality implications of BMP would be aided by generating region-specific emissions factors (for nitrogen species, phosphorus and pesticides) and by collating data about the nitrogen and phosphorus contents of mill mud generated from sugar mills.

Opportunities also exist for further extension of the case study findings. Because each farming business is unique, consideration of growers' individual circumstances is necessary prior to BMP adoption. Growers may be assisted by discussions with local extension staff (and one on-to-one support) as well as consideration of agronomic research and by collecting and monitoring farm data. The case study reports provide growers and extension staff with a useful starting point to discuss the economic and environmental implications of BMP adoption.

3.2. Outcomes and implications

This project will provide economic, social and environmental benefits that will encourage, and ultimately enhance, adoption of BMPs.

Regarding economic outcomes, given that the results indicate a positive annual benefit for all case study farms, ranging between $25 and $220 per hectare per year, it is expected that costs of the project could be recouped if further adoption of BMPs occurs.[11] The project outputs provide resources that will enable growers to consider how resources such as capital and labour can be used efficiently and effectively.

Regarding environmental outcomes, the case study evaluations found that adoption of BMP in the Wet Tropics can reduce the potential for water quality impacts. There can also be added benefits of

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[9] Methods developed in our project may be incorporated in SRA project 2017/005 "Measuring soil health, setting benchmarks and driving practice change in the sugar industry."

[10] Essentially, accounting for seasonal fluctuations in yield by comparing farm yields to productivity zone yields.

[11] Subject to factors such as variations between farm characteristics, practice implementation and variations in local biophysical factors. As in, costs can be expected to be recouped if BMP practices are implemented by growers in a way suited to their individual circumstances that is within growers' individual investment capacities and results in positive annual benefits across a sufficient area of land.

reduced fossil fuel use and greenhouse gas emissions over the life cycle of sugarcane production. If wider adoption of BMP in the Wet Tropics region occurs, then reductions in eutrophication potential (from nutrient losses), and reductions in eco-toxicity potential (from pesticide losses) could be expected.[12]

Regarding social outcomes, by highlighting the sensitivity of economic and environmental benefits to production changes in each case study, and reporting the insights of case study participants, the project enables growers to consider how they might manage risks and adopt management practices that optimise the profitability and environmental performance of their individual farming system. For case study participants, and growers who choose to adopt BMPs, further changes may become more manageable as growers build on existing knowledge and relationships with advisors and improve ways of evaluating potential changes to their businesses. Project findings also demonstrate the environmental improvements that have been delivered by growers in the Wet Tropics, which may build understanding and relationships between growers and the wider community.

Findings from this project have promoted discussion and provided a mechanism for researchers and extension personnel to demonstrate the profitability and environmental implications and incorporate these matters in their recommendations.

The project has demonstrated the application of the CaneLCA eco-efficiency calculator tool in commercial settings, thus validating the applicability of the prior investment made under SRDC project UQ045 “Development of a streamlined life cycle assessment (LCA) tool for assessing the environmental benefits of progressive cane growing” (Renouf and Allsopp, 2013).

The dissemination of information in stages has promoted BMP adoption in a timely manner. The Project Team will continue to work with Department of Agriculture and Fisheries (DAF) extension officers and other industry extension officers for broader engagement and communication of the results of case studies.

As noted in section 3.1.2 (further development), the knowledge and processes developed from this project can be utilised in future projects and case studies in other regions.

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[12] Subject to factors such as variations between farm characteristics, practice implementation and variations in local biophysical factors.

4. INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1. Industry engagement during course of project

Industry engagement during the course of the project included the following activities:

1) A project presentation was delivered during the SRA and Department of Environment and Heritage Protection Nitrogen Use Efficiency Workshop in Brisbane in 2015.
2) The pilot case study was presented to the Project Steering Group at the Wet Tropics Sugar Industry Partnership (WTSIP) meeting (Innisfail) in October 2016. Mark Savina from the pilot farming business, SALMEC, assisted the Research Team to present key case study findings.[13]
3) An overview of project and key outputs was presented at the SRA and Department of Environment and Heritage Protection Nitrogen Use Efficiency Workshop in Brisbane in 2016.
4) An overview of the project and pilot case study was included in the SRA Performance Report 2015/16.[14]
5) A plenary paper was presented (by Bernard Schroeder) at the International Society of Sugar Cane Technologists conference in Thailand, December, 2016 (Poggio et al., 2016), presenting the overarching need for joint consideration of economic and environmental consideration in best management practice, which underpins this project.
6) Findings and insights from case studies 1, 2, 3 and 4 were presented at the Australian Agricultural and Resource Economics Society (AARES) annual conference in Brisbane during February, 2017.
7) Results of case studies 2, 3 and 4 were included in the SRA Performance Report 2016/17.[15]
8) Findings and insights from case studies 2, 3 and 4, and the background to case studies 5 and 6 were presented to the Project Steering Group at the Wet Tropics Sugar Industry Partnership (WTSIP) meeting in August, 2017.
9) Inclusion of case studies within the introductory packs for the Project Uplift Farming Systems Initiative.
10) Findings from all six case studies were presented at three events within the Wet Tropics (local extension officers and the Project Steering Group assisted the Research Team in arranging the opportunities to present the case study findings):
    a. Innisfail WTSIP extension team meeting on 11 October 2017 (Innisfail);
    b. SRA Soil health Masterclasses on 1 November 2017 (Mulgrave) and on 2 November 2017 (Tully). At the SRA Soil Health Masterclass workshops, growers (Mark Savina from SALMEC, and Adrian Darveniza) co-presented with the Research Team (see section 5.1 for further details).
11) The six case study reports were published online at the Queensland Government publications website throughout the course of the project.[16]
12) An e-mail distribution list was established with over 35 key representatives within the Australian sugarcane industry. To date, the Research Team has provided 5 industry update

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[13] Details of how the project would be undertaken were also presented at a WTSIP meeting in June 2015.

[14] Included at page 19 of that report. Accessible from the SRA website. https://sugarresearch.com.au/sra-information/publications/

[15] Included at page 24 of that report. Accessible from the SRA website. https://sugarresearch.com.au/sra-information/publications/

[16] Reports are listed in section 8 of this report, and are accessible from the Queensland Government publications website. https://publications.qld.gov.au/dataset/best-management-practices-for-sugarcane

e-mails to inform of the projects progress and to distribute publications. A further e-mail will be provided to the distribution list attaching this final report.

13) Case studies 5 and 6, and a project summary factsheet, will be distributed and presented during two SRA industry update meetings in March, 2018.
14) A conference paper summarising the economic and environmental results from the six case studies has been accepted for oral presentation and publication at the Australian Society of Sugar Cane Technologists (ASSCT) conference in April 2018 (Poggio et al., 2018).
15) A detailed description of the environmental evaluation method used in the project (CaneLCA) has been published in a scientific journal (Renouf et al., 2018).

It is also noted that some presentation attendees have subsequently downloaded and registered the Farm Economic Analysis Tool (FEAT) used in this research.

Links to online publications are provided in section 8 of this report (Publications).

4.2. Industry communication messages

Key industry and communication messages likely to be relevant as a result of the project findings include:

- **Win-Win**: BMP implementation in the Wet Tropics can be a win-win for both economic and environmental outcomes and can add value to farming businesses who transition towards BMP.

- **Step by step**: Various approaches can be taken, depending on individual circumstances, with a view to helping ensure positive economic benefits. For example, costs of implementation can be shared with other growers (and combined applications made for grant funding) or practice changes can be progressively implemented over a period of time (to minimise initial costs of implementation and evaluate the impact of changes);

- **Find what works for you**: As the degree of economic and environmental benefits of transitioning to BMP can be sensitive to increases or reductions in cane yield, unique farming business circumstances are important for growers and advisors to consider. As a practice change can affect the implementation of other practices, the more information that can be taken into account regarding a grower’s existing farming system (and the potential impact of BMP changes on economic, environmental, social and agronomic factors) the better.

- **Make a start and seek expert advice**: Further changes may become more manageable as growers build on existing knowledge and relationships with advisors and improve ways of evaluating potential changes to their businesses.

- **Productivity zone comparisons**: Monitoring and comparing productivity zone yield data (if available) may assist growers in isolating and evaluating the production outcomes of BMP changes.

- **Assess your business**: The FEAT and CaneLCA tools have proven to be beneficial in evaluating a combination of practice changes in real, commercial settings. Growers can benefit from registering and using FEAT to consider their individual circumstances.

Section 6 (results and discussion) considers the case study results in more detail. Benefits of the project are also detailed further in Section 3 (outputs, outcomes and implications).

Each farming business is unique in its circumstances and therefore the parameters and assumptions used in each case study reflect the situations of individual case study participant’s only. Consideration of individual circumstances must be made before applying the case studies to another situation.

5. METHODOLOGY

5.1. Project components

This section outlines the methodology of various components of the project, including:[17]

1) Literature review;
2) Selection and recruitment of case study participants;
3) Case study evaluations; and
4) Extension and communication of findings to industry.

The literature review (Appendix 3) synthesised knowledge from past research that either separately evaluates the economic and environmental implications of sugarcane growing practices or that brings the economic and environmental aspects together. The literature was categorised by various sugarcane growing aspects such as "soil health and nutrient management" and by economic and environmental aspects. The Research Team[18] conducted searches of various sources including, for example:

- Databases such as Web of Science and the DAF database; and
- Past papers from ASSCT and ISSCT as well as the SRA, DAF and Google Scholar websites.

A work plan and terms of reference for the project were developed which clarified project details and the roles and responsibilities of personnel participating in the project (Research Team, Project Steering Group, and participating growers). The terms of reference document was utilised to obtain consent from growers participating in the project.

Members of the Terrain NRM Cane Technical Working Group (CTWG) were engaged as a Project Steering Group. Members of the CTWG included industry representatives from various organisations including, for example, Herbert Cane Productivity Services Ltd (HCPSL), Tully Cane Productivity Services Ltd (TCPSL), Tully Sugar Limited, Mossman Agricultural Services, and Canegrowers as well as DAF and the SRA Professional Extension and Communications Unit. As the project progressed, a sub-group was formed to provide more immediate feedback on issues that arose over the course of the project. The Project Steering Group provided technical advice and feedback on publications and assisted in extending case study findings to industry.

The Project Steering Group also assisted in the selection of appropriate case studies for analysis and, insofar as practical, case studies were selected according to the following criteria:

1. Growers who are willing participants in the project;
2. Growers who have made a recent transition to core BMP practices;
3. Growers with detailed and accurate knowledge of their past and current farming system.

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[17] For completeness, it is noted that the project's specified "activities" included selection of case studies (this activity included the literature review), pilot case study, first set of case studies, second set of case studies and extension and communication of findings to industry.

[18] Including Mark Poggio, Principal Agricultural Economist at DAF, Marguerite Renouf, Senior Scientist at Lifecycles and, other agricultural economists at DAF over the course of the project.

4. Farms representing a cross-section of Wet Tropics sub-regions and in high priority areas for water quality.
5. Opportunity for alignment with existing trials funded by SRA.

The Research Team collected economic and bio-physical data from the selected case study growers by meeting with growers on farm for initial data collection, and obtaining further information through discussions with relevant extension officers or subsequent contact with growers. Growers provided data from before and after BMP changes were made in relation to production (for example, cane rotations, yields, commercial cane sugar (CCS) and in some instances production data was obtained via mills, local productivity service organisations or SRA), production inputs (for example, agrochemical usage), machinery and implement data (for example, field efficiency, repairs and maintenance, width of pass), farm operations, fixed cost information and capital expenses required for the farming system change. Information in relation to local labour and contracting rates were obtained from growers and extension officers or by the Research Team contacting local contractors directly. Prices in relation to pesticides, herbicides, fertilisers and legumes were typically obtained by the Research Team directly contacting local suppliers.

The Research Team used the data collected to complete economic and environmental analyses and evaluate the farm profitability and environmental implications of adopting BMPs for farming business. The Farm Economic Assessment Tool (FEAT) was used to calculate operating costs, income and gross margins, coupled with an investment analysis to generate indicators of farm profitability.[19] An environmental parameters spreadsheet was compiled to be used in the CaneLCA tool and generate indicators of environmental impacts.[20]

Investment and environmental analyses allowed evaluation of the profitability of the whole farming system and the life cycle environmental impacts of cane production after BMP adoption. The sensitivity of the results to changes in cane yields were also assessed. A suite of practice changes, rather than individual practice changes, were considered in commercial, rather than hypothetical, settings, thus enabling insights from a whole-of-farming system perspective.

The results of the economic and environmental evaluations of each case study were documented in a series of six case study reports. Matters detailed in the case study reports included:

- Key findings;
- About the farm;
- What changes were made?
- What does this mean for business?

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[19] FEAT is a Microsoft 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. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/sugar/farm-economic-analysis-tool

[20] CaneLCA is a Microsoft Excel® based tool that calculates 'eco-efficiency' indicators for sugarcane growing based on the life cycle assessment (LCA) method. It streamlines the complex LCA process to make it more accessible to researchers, agricultural advisors, policy makers and farmers. https://eshop.uniquest.com.au/canelca/

- How much did it cost to make the changes?
- Was the investment profitable?
- What does this mean for the environment?
- What about risk?
- What's the bottom line?

Case study reports and extension material were completed to promote project outcomes and case study findings. For extension activities where the Research Team presented alongside growers, such as the presentations to the SRA masterclasses in March 2018, the Research Team met with growers on farm before the event to prepare the grower for the topics that would be covered and to obtain photos of machinery, equipment or sugarcane paddocks that related to the transition to BMP. The photos were then incorporated into the presentations, allowing growers to discuss their experiences that related to the photos and their transition towards adopting BMPs.

The Research Team asked the growers questions to allow the presentation to progress in a conversational story-telling fashion and also presented economic and environmental case study findings. In an effort to communicate one aspect of the environmental findings in easy-to-understand terms, "cars off the road each year" was reported as an equivalent measure of the change in greenhouse gas emissions.

Project findings have been communicated to the wider industry audience through i) periodic project updates sent by email to the Project Steering Group and other industry professionals (5 Industry Update emails), ii) presentations to the Project Steering Group at Cane Technical Working Group (CTWG) meetings, and iii) presentations to industry workshops. A paper and oral presentation is planned for the conference of the Australian Society of Sugarcane Technologists (ASSCT) in Mackay in April 2018. Further details are provided in Section 4.1.and publications are listed in section 8.

5.2. Case study locations and practice changes

The six case study farms (CS1 – CS6) selected range in size from 90 ha to 830 ha and are located across the Wet Tropics sub-regions, with farms located near Ingham, Tully, Innisfail, Cairns and Mossman (Fig.1).

Figure 1 Locations of case study farms

Fig.1 map adapted from Data by Region, 2011-16 Catalogue No. 1410.0. ABS data used with permission from the Australian Bureau of Statistics. <www.abs.gov.au> Licensed under Creative Commons Attribution 2.5 Australia (CC BY 2.5 AU) <www.creativecommons.org/licenses/by/2.5/au>. The map adaptations, including markers indicating approximate locations of case study farms, are not attributed to the ABS.

Each of the case study farms has progressively implemented various practice changes that are relevant to core BMP modules. As noted in section 1 (background), the core BMP modules relate to improving soil health and nutrient management, weed, pest and disease management, irrigation and drainage management.[21] Case study 3 also involved cessation of post-harvest burning of harvest residues, which occurred only for the plant cane. This was not a full transition from burnt to green cane harvesting.

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[21] In the case study reports, practice changes relating to soil health and to nutrient management have been reported separately. Drainage improvements were considered in two case studies. Only practice changes relating to the core Smartcane BMP modules are reported.

Table 1 Weed, pest and disease management: Key herbicide practices before and after BMP changes

	Before BMP changes	**After BMP changes**
CS 1	Diuron and hexazinone in plant and ratoon cane No insecticide	Banded spraying in plant cane (30 per cent of time) No Diuron in plant and reduced Diuron in ratoon cane Reduced 2,4-D in plant and ratoon cane Insecticide - Talstar
CS 2	Diuron, hexazinone and atrazine in plant cane	No diuron in plant cane No atrazine in plant cane
CS 3	Irvin legs	Dual herbicide sprayer – reduced herbicide application (Diuron, paraquat and 2,4-D).
CS 4	Diuron and Hexazinone in plant cane	No diuron in plant cane Variable rate controller
CS 5	Spraying rows and inter-rows with the same chemicals.	Band spraying chemicals using shields Spraying with hi-rise tractor Some changes to herbicide active ingredients (e.g. replaced imazapic with metolachlor)
CS 6	Standard spraying/calibration	Variable rate spray controller Reduced use of some chemicals in plant cane and ratoons.

Table 2 Soil health: Key practices before and after BMP changes

	Before BMP changes	**After BMP changes**
CS 1	Heavy tillage 1.52m row spacing Legume fallow (50% of fallow area)	Reduced tillage (zonal ripping and tillage) 1.8m single row spacing GPS guidance Increased legume fallow with preformed mounds (100% of fallow area)
CS 2	Heavy tillage (discing, ripping and rotary hoe) 1.52m row spacing Cow pea fallow	Reduced tillage (zonal ripping, no rotary hoe) 1.68m row spacing GPS guidance Soy fallow crop using direct drill
CS 3	Plough-out/replant 1.52m row spacing	Bare fallow 1.8m row spacing
CS 4	Bare fallow 1.6m row spacing	Cowpea fallow 1.8m row spacing Reduced tillage
CS 5	Bare fallow Heavy tillage 1.52m row spacing	Planting a legume crop (Cowpeas) Reduced tillage and planting into preformed beds 1.62m row spacing GPS guidance
CS 6	1.58m row spacing Conventional planting Heavy tillage / machinery operations (discing, ripping, strategic rotary hoe 20% of blocks, grubbing, marking out)	1.8m row spacing GPS guidance for machinery operations Bed forming and conventional planting Reduced tillage/machinery operations (reduced discing, zonal ripping, strategic rotary hoe 10% of blocks, bed forming)

Table 3 Nutrient management: Key practices before and after BMP changes

	Before BMP changes	After BMP changes
CS 1	Grower determined nutrient rate	Following the SIX-EASY-STEPS guidelines to determine the required nutrients and soil ameliorants
CS 2	No mill mud Grower determined nutrient rate	Mill mud applied to plant and ratoon Following the SIX-EASY-STEPS guidelines to determine the required nutrients and soil ameliorants
CS 3	No mill mud Grower determined nutrient rate	Banded mill mud application in ratoons Following the SIX-EASY-STEPS guidelines to determine the required nutrients and soil ameliorants
CS 4	Broadcast mill mud application Grower determined nutrient rate	Banded mill mud application in ratoons Following the SIX-EASY-STEPS guidelines to determine the required nutrients and soil ameliorants
CS 5	Grower determined nutrient rate	Following the SIX-EASY-STEPS guidelines to determine the required nutrients and soil ameliorants
CS 6	Applying same fertiliser rate across all blocks Applying same lime rate in all (fallow) blocks Grower determined nutrient rate	Varying fertiliser rate between blocks Varying lime rate between (fallow) blocks Following the SIX-EASY-STEPS guidelines to determine the required nutrients and soil ameliorants

Table 4 Drainage management: Key practices before and after BMP transition

	Before BMP changes	After BMP changes
CS 5	Minimal drainage work	Laser levelling to improve drainage
CS 6	Drainage issues (waterlogging, machinery ruts and bogging)	Improved drainage (by laser levelling, undertaking earthworks, installing underground pipes and spoon drains)

5.3. Investment analysis method

Investment analyses were used to evaluate the profitability of each farming business before and after BMP adoption. As noted in section 5.1 (project components), data was collected in relation to farm operations, investments and growing costs. Revenues were calculated using production data from the relevant mill (generally a five-year average) and a five-year average (2010-15) net sugar price of $430 per tonne (Queensland Sugar Limited, 2015).

The Farm Economic Analysis Tool (FEAT) (Stewart and Cameron 2006) was used to calculate the farm gross margin before and after BMP adoption. Gross margins were calculated by subtracting the variable costs for growing and harvesting the crop from the revenue received from the crop. Gross margins before and after BMP adoption were compared and the difference in annual cash flows calculated, which was then aggregated over the life of the investment. A discount rate of 7% was used to take into account the time value of money.

Each investment analysis provided a set of financial performance indicators for the BMP investments, including the Annualised Equivalent Benefit (referred to throughout this report as “annual benefit”), Internal Rate of Return, Discounted Payback Period, Investment Capacity and Operating Return.[22]

Annual benefit is calculated by taking into account the initial investment and the discounted annual change in gross margin aggregated over the life of the investment, which is then transformed into an annualised value. Discounted payback period indicates the number of years it will take to recover the initial capital investment. Internal rate of return represents the amount of money returned to the farming business each year as a percentage of the initial investment.

Investment capacity refers to the maximum amount of money that can be spent before an investment becomes unprofitable, taking into account the cost of implementation and its net present value over the life of the investment. Holding other variables constant, the investment capacity is the cost of implementation at which the net present value would equal zero. The life of machinery and equipment was based on estimates provided by growers but conservatively assumed to be no more than 10 years. Operating return is also calculated by subtracting variable costs and fixed costs from gross revenue.

5.4. Environmental analysis method

The environmental implications of BMP adoption were estimated using the CaneLCA tool[23] (Version 1.03). CaneLCA is an environmental life cycle assessment (LCA) tool customised for sugarcane growing (Renouf, Allsopp et al. 2013), which streamlines the complex LCA process to make it more accessible to researchers, agricultural advisors, policy makers and farmers.

CaneLCA generates environmental impact indicators, which represent the amounts of resources consumed and the amounts of pollutants emitted per tonne of harvested sugarcane. The indicators are estimates of potential impacts and not actual measured impact. They are calculated over the life

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[22] For further explanations in relation to key economic indicators of profit and performance, please see Smith (2014) pp.13-17.

[23] The CaneLCA tool is available from the UniQuest website. https://eshop.uniquest.com.au/canelca

cycle of sugarcane production, including not only those associated with on-farm operations, but also the off-farm production of cane growing inputs (for example, fertilisers, pesticides, fuel, electricity, et cetera), and harvest and haul out of cane up to the transport siding.

The environmental impact indicators account for the most relevant environmental implications of the practice changes, except for effects on soil quality (for example, erosion, compaction, soil organic carbon). The environmental impact indicators include:

- Losses of nutrients to water contributing to water quality impacts (aquatic eutrophication potential), represented as kilograms of phosphate equivalents per tonne of harvested cane (kg $PO_{4\text{-}eq}$/t cane). The nitrifying substances accounted for were nitrogen (N), phosphorus (P) and sugar (COD) over the life cycle of sugarcane production;
- Losses of pesticides active ingredients (AI) to water (kg AI/t cane), and the associated water quality impacts (freshwater eco-toxicity potential). Eco-toxicity potential is estimated using assumed toxicity factors relative to a reference substance (ref) to generate comparative toxicity units for ecosystems per tonne of harvested cane (kg CTUe/t cane). Just direct losses from the farm are considered, not those from off-farm production processes.
- Fossil fuel use, represents the resource depletion of fossil fuels over the life cycle of sugarcane production. It is expressed as kg of oil equivalent per tonne of harvested cane (kg $oil_{\text{-}eq}$/t cane);
- Greenhouse gas (GHG) emissions, represented as kilograms of carbon dioxide equivalents per tonne of harvested cane (kg $CO_{2\text{-}eq}$/t cane) over the life cycle of sugarcane production;

Further details of the methods used in CaneLCA can be found in Renouf et al. (2018). The CaneLCA analysis utilised data collected for the FEAT analysis and additional data regarding, for example, the delivery of agrochemicals and the distances travelled by general farm vehicles. Environmental impact indicators were generated for each of the case study farms before and after BMP adoption. Comparing the before and after results allowed the changes in environmental impacts to be estimated.

As part of deriving indicators of water quality impacts, assumptions are made in the CaneLCA method about the rates of nutrients and pesticide emissions to the environment (emission factors). For nitrogen, emission factors were mostly based on National Greenhouse Gas Inventory accounting methods (Commonwealth of Australia, 2016). 2% of applied N (from fertilisers and from mill mud) was assumed to be directly emitted to air as nitrous oxide (N_2O), and indirect losses of N_2O were also accounted for. A lower N_2O emission factor was assumed for N supplied by cane trash and legume residues (1%), and no N_2O was assumed to be emitted from N fixed by legumes. A further 20% of N applied was assumed to be emitted to water via runoff and leaching, both also based on National Greenhouse Gas Inventory accounting methods (Commonwealth of Australia, 2016).

Volatilisation of ammonia-N was also accounted for, but only when surface-applied. Volatilisation emission factors specific to Australia cane production were used, based on Chapman et al. (1995). For phosphorus (P), 13% of applied P was assumed to be lost via runoff (based on an industry P budget of Bloesch et al. (1997). For pesticides around 10% were assumed to be potentially lost via the various pathways to water, which is a conservative estimate in the absence of typical loss factors. The uncertainty of these estimates is recognised. However, the analysis was focused on evaluating the scale of changes in potential environmental impacts rather than the absolute scale of the impacts. Further details about the assumed emission factors can be found in Renouf et al. (2018).

Emissions to air from cane burning were also accounted for including nitrous oxide (N_2O), nitrogen oxides (NOx), carbon monoxide (CO) and methane (CH_4), but changes only occurred to a very limited extent in case study 3 (post-harvest burning of trash from only the plant cane crop occurred in the before case, but burning ceased in the after case). N_2O, NOx contribute to eutrophication potential and N_2O also contributes to greenhouse gas emissions.

The Cane LCA method uses 'embodied impact' factors for the inputs to cane growing such as fertilisers, pesticides, fuels, energy and transport. These factors quantify the environmental impacts of manufacturing and transporting these inputs (from 'cradle to grave'), and were derived from the from the Australian Life Cycle Inventory (AusLCI) Unit Processes database.[24] For mill mud, which is a waste product from sugar milling, the impacts of its production and transport are assigned to the sugar milling process rather than cane growing and, therefore, are not accounted for. Further detail about the embodied impact factors can be found in Renouf et al. (2018).

The CaneLCA method performs an attributional LCA, which means that the existing attributes of the agricultural system are assessed. This means that direct land use changes that would have occurred in the original establishment of the sugarcane fields are not considered. It also means that when used to compare different sugarcane growing practices, any indirect land use changes that may occur in other production systems are not considered.

5.5. Sensitivity analyses

After considering the review of the literature on agronomic research trials regarding the implications of BMP adoption for production by Collier et al. (2015), yields were generally assumed to be maintained for the purpose of investment analyses. There was an exception for two case studies, due to the characteristics of the practice changes, and yield improvements were based on the grower's historical production data or previous agronomic research. As it was necessary to make assumptions about yield implications, and because yield is a critical variable for both profitability and environmental impacts, sensitivity analyses were conducted to test the influence of potential yield changes.

To conduct the sensitivity analyses on the impact of potential changes in yield on annual benefit, the investment analysis was repeated in incremental decreases and increases in cane yields.[25] One limitation of the economic sensitivity analyses is that changes in price were not considered. As noted in section 5.3 (investment analysis method) the investment analyses was based on a five-year average net sugar price. A review of practice changes by the Research Team in the early stages of the project indicated that cost savings were likely to be the key driver for economic benefits, which in turn are not impacted by price. It is noted that sensitivity analyses in relation to price could be incorporated into future analyses, especially where production implications are measured.

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[24] The database is accessible at the AusLCI website. http://auslci.com.au

[25] For example, a 5% increment was used in the economic sensitivity analyses.

The sensitivity of the environmental implications to potential changes in cane yield was also assessed. This was done by repeating the CaneLCA analysis for incremental decreases and increases in cane yields. All other variable remained the same. This generated a graph that shows how each of the environmental impacts varies depending on cane yield. From this it was possible to identify the yield change threshold at which there would be no environmental improvements from BMP adoption.

Another uncertain variable that influenced the environmental analysis was the amount of nitrogen (N) and phosphorus (P) present in mill mud. For two of the case studies (CS3 and CS4), changes in the use of mill mud were considered in the economic and environmental evaluations. As it was not possible to obtain accurate estimates of the N and P contents of the applied mill mud, it was necessary to use assumed values from literature (Hogarth and Allsopp, 2000, Table 12). As a number of the environmental impact indicators are influenced by N and P application rates (eutrophication potential and greenhouse gas emissions), it was considered important to understand how this uncertainty may influence the results. Therefore sensitivity of the environmental implications to variance in mill mud N and P contents was assessed by repeating the CaneLCA analysis for incremental increases in N and P content. From this it was possible to identify the N and P content at which there would be no improvements in eutrophication potential and greenhouse gas emissions from BMP adoption.

6. RESULTS AND DISCUSSION

6.1. Economic implications of BMP adoption

A detailed analysis of yield changes after BMP adoption was difficult to quantify because of data constraints and, where analysed, it generally showed no difference. However, in case study 5 yield improvements were explored in greater detail because of the available data and scope of the practice changes involved. In this case study, the grower noted yield improvements after progressively implementing BMP changes. For example, the grower identified drainage issues so he laser levelled the farm and soon after observed yield improvements.[26]

Fig.2 compares the average cane yield on the grower's home farm[27] to the productivity zone average and shows the progressive improvement in yield since making the farming system changes that began in 2009. Whilst it is difficult to attribute all of the yield increases to BMP adoption, over the period 2012 to 2016 the grower's cane yields on the home farm have on average been 18 tonnes of cane per hectare (tch) above the productivity zone, which is a 27% improvement.

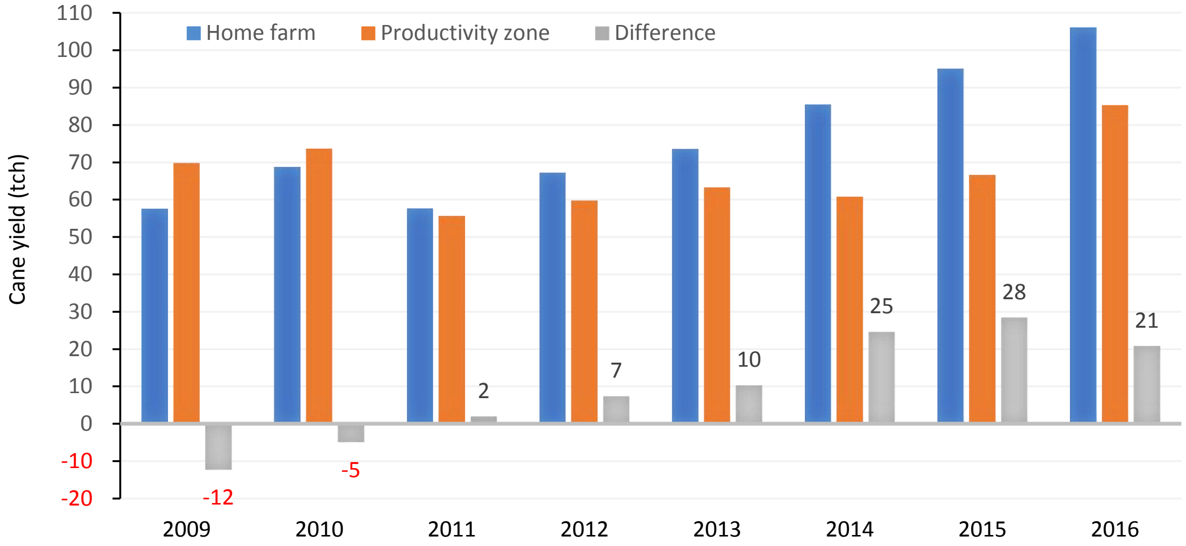

Figure 2 Comparison of cane yield on home farm to the productivity zone in case study 5

Past research has tended to focus on the productivity aspects of BMP adoption, however, other factors such as costs and prices are vital to determine the impact to overall profitability. Case study farm size and results of investment analyses are summarised Table 5. The annual benefit after making the BMP changes ranges from $25/ha/yr to $220/ha/yr (whilst the internal rate of return ranged between 12% and 66% and these results were above the 7% discount rate applied). These results suggest that the BMP changes added value to each farming business investigated.

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[26] It is not suggested that there will be yield increases for each farm that adopts BMPs, as each farming business is unique in its circumstances and implementation of practice changes. When adopting any management practice change there is always a risk that things may not go as planned (e.g. yield loss, financial risk). However, the adoption of management practices that have been scientifically validated, such as BMPs, mean that adverse impacts on production are unlikely.

[27] The grower purchased his home farm in 2009 and another farm in 2013.

Table 5 Case study farm size, investment analyses results and break-even yield change[28]

	CS1	**CS2**	**CS3**	**CS4**	**CS 5**	**CS 6**
Farm Size	830 ha	167 ha	240 ha	150 ha	90 ha	760 ha
Cost of implementation	$338,700	$28,300	$2,200	$100,475	$151,500	$735,016
Investment capacity	$999,320	$134,654	$99,868	$125,749	$287,770	$1,041,142
Annualised equivalent benefit (AEB) /ha/yr	$101	$100	$58	$25	$220	$57
Discounted payback period	5 years	2 years	6 years	8 years	6 years	10 years
Internal rate of return	29%	66%	33%	12%	20%	14%
Change in operating return /yr	$124,500	$16,542	$38,400	$11,305	$37,834	$81,244
Break-even yield change	-7.2%	-7.3%	14.4%	-0.9%	10.8%	-2.0%

Table 5 presents a summary of the investment results from each of the six case studies. It is important to note that the Annualised Equivalent Benefit (AEB) refers to the change in profitability from before BMP adoption to after adoption, not the total profitability of the farm. As highlighted in section 5.2 (case study locations and practice changes), there are considerable differences between the case study farms. For example, they are in different locations and had different management practices both before and after BMP adoption. In addition, the case study farms are different sizes, have different soil types and other biophysical characteristics, are influenced by the environment differently and the farm managers have different management styles and risk profiles. Given these considerable differences, it is very difficult to make valid comparisons between the case studies. Furthermore, each farm made a variety of management practice changes, which makes it difficult to isolate the effect of individual practice changes given the complex interactions between practice changes particularly in terms of yield. Nevertheless, some common effects can be identified with regards to changes in operating costs. This is discussed further in section 6.3 (discussion).

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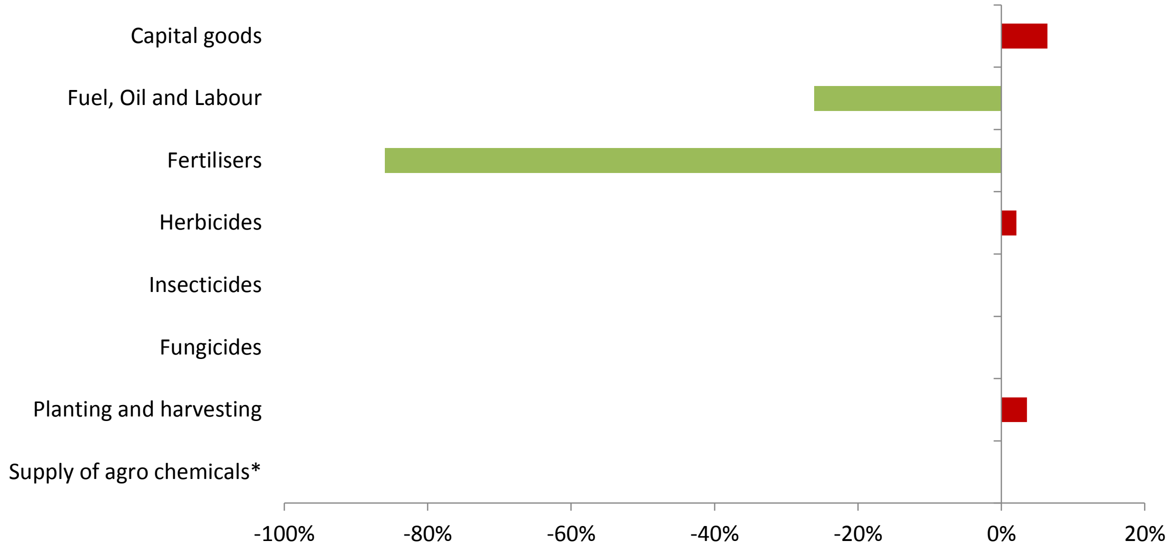
[28] Further explanations of the parameters in this table are provided in section 5.3 (investment analysis method). Previous versions of the CS1 and CS2 reports have been updated in line with an improved CaneLCA methodology and the revised results are reported in this table.

The changes in costs due to BMP adoption vary depending on a range of factors including the nature of the BMP changes and the particular parameters of each case study (such as farm size, machinery and equipment). It should also be noted that yields and costs can influence the annual benefit and payback period of an investment.

An example of operating cost changes from BMP adoption is shown in Fig.3, from CS2.



*Cost to supply agro-chemicals is embodied in fertilisers /herbicide /insecticide /fungicide cost.

Figure 3 Contribution to change in farm operating costs (%) in CS2

In the CS2 example, through adoption of the SIX-EASY-STEPS nutrient program, the grower reduced money spent on fertilizer ($95/ha per year less). In a number of the case studies, (including CS2), farms that switched to reduced tillage spent less money on fuel, oil and labour as well as repairs and maintenance on machinery. Reductions in money spent on fuel, oil and labour were also due to wider row spacing, which reduces tractor hours through the reduction of the total number of rows and therefore distance travelled.

In all case studies except for CS3, cost savings were partially offset by increases in costs in the 'capital goods' category, referring to the cost of repairs, maintenance and, in particular, depreciation of machinery and equipment (in CS5 and CS6 cost increases relating to laser levelling or drainage improvements were also noted separately).

It is noted that the grower in CS3 implemented changes in a way that minimised the cost of implementation. In particular, the grower modified existing equipment to make the transition, converting his Irvin spray boom to a dual herbicide sprayer, and also reduced the money spent on fertilisers by over 60% (refer to the case study report for further details). Given the nature of the practice changes including a transition from a plough out-replant cycle to a cycle incorporating a fallow, the grower's payback period is 6years.

Fig. 4 shows the costs of implementation of BMP changes (also referred to as "Investment Cost") and the corresponding investment capacity of growers, displayed in order of farm size (from smallest to largest, left to right). The investment analyses indicate that the costs of implementation of each farming business did not exceed their respective investment capacities (indicating the investments were profitable). Growers could have invested between $175/ha to $1,544/ha more than the actual amounts invested before the cost savings, or in some cases revenue increases, would be insufficient to provide the required (7 per cent) return on investment. For example, in CS2, the grower could have invested more than four times his cost of implementation.

In CS4, the grower shared the total investment cost with a neighbor and, as a result, the cost of implementation (being the grower's half share in the investment) was less than the investment capacity of the CS4 grower (indicating the investment was profitable). For larger farms, costs of implementation are spread over a larger area, reducing the per hectare change in costs. For example, in CS1 the total cost of implementation was larger than in CS4 ($338,700 > $100,475), however, the dollar per hectare cost was relatively smaller ($408 < $698) as costs were spread across a larger farm area.

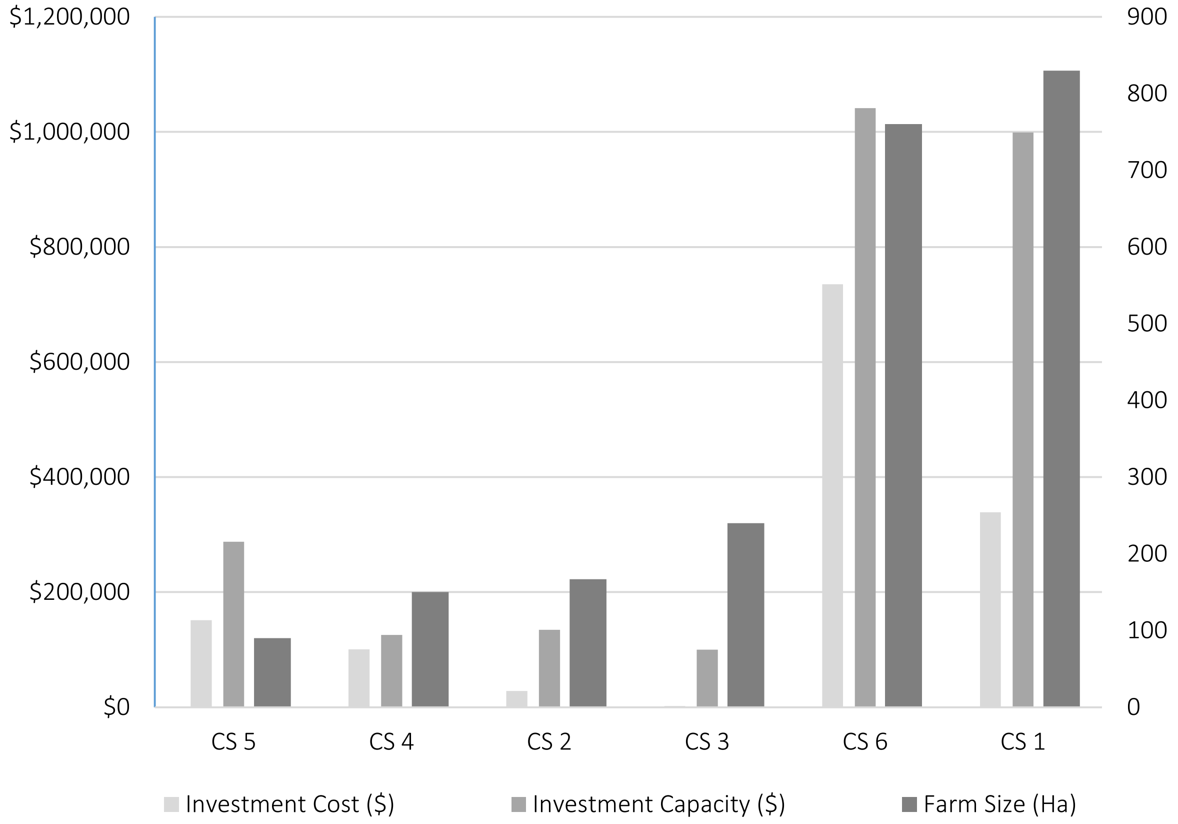


Figure 4 Investment cost and investment capacity in order of farm size

To understand the risk and uncertainty of practice changes in each case study, the sensitivity of the economic results to changes in cane yields were considered using a sensitivity analysis, as detailed in section 5.5. Table 5 shows the percentage change in cane yield (t/ha), required for each investment to breakeven in terms of annual benefit. The sensitivity analyses suggest that a drop in cane yield of between 1% and 9% could be experienced in four of the case studies (CS1, CS2, CS4 and CS6) and the grower would still "breakeven" in terms of annual benefit.

For case studies 3 and 5, cane yields were assumed to increase as a result of BMP adoption, based on the grower's historical production data or previous agronomic research. The yield improvements considered were above the break-even yield changes noted in Table 5, and corresponded with a positive annual benefit.

The grower in CS3 transitioned from a plough out-replant cycle to a cycle incorporating a fallow. Agronomic research by Garside and Bell (2011) indicates that cane yield per hectare can increase considerably in response to a fallow period and, therefore, it is assumed in the investment analysis in CS3 that cane yield per hectare increases (by a 20% increase across all crop classes) and that, in turn, overall farm production is maintained after BMP adoption.

As detailed above, in CS5 the grower's historical production data over the period 2012 to 2016 the grower's cane yields on the home farm have on average been 18 tonnes of cane per hectare (tch) above the productivity zone. Therefore, a 27% yield improvement was examined in the investment analysis.

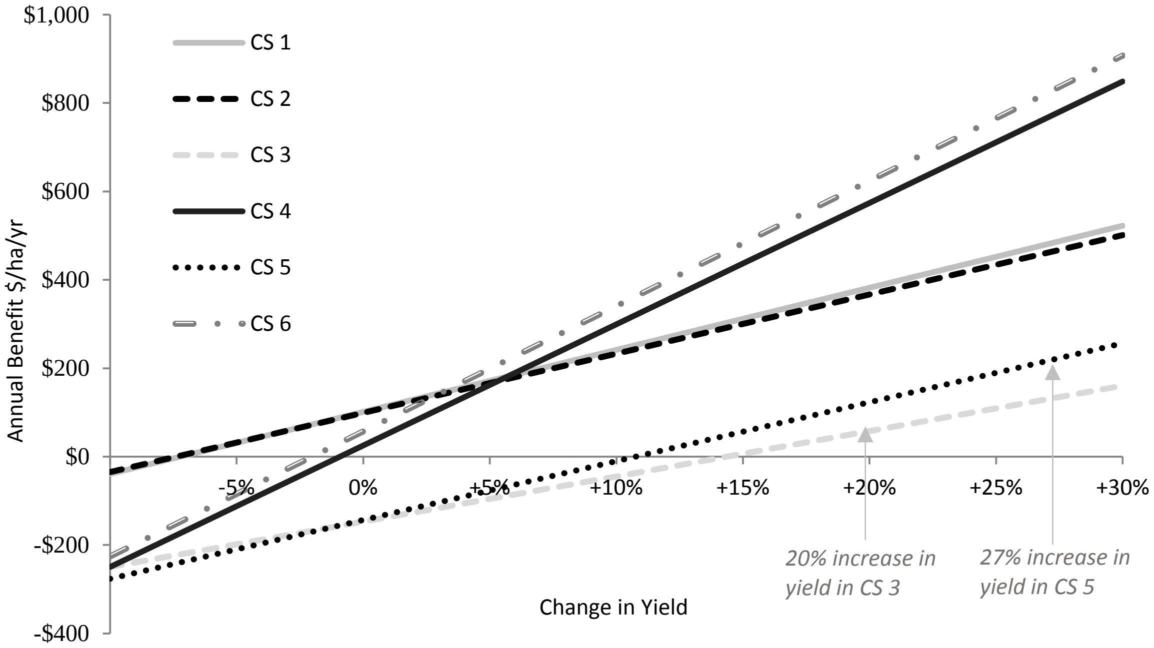


Figure 5 Sensitivity of annual benefit to changes in cane yields (t/ha)

Key variable costs incorporated in the calculation of annual benefit include levies and harvesting costs that are calculated per tonne. Therefore, the trend in the results of the sensitivity analyses (section 6.1) is linear.

If we consider CS6 and CS4, should a 10% improvement in yield be experienced by both growers, the sensitivity analysis suggests that the annual benefit can increase substantially. For example, the grower in CS4 would derive an annual benefit of $299/ha instead of $25/ha without a yield change and the grower in CS6 would derive an annual benefit of $199/ha instead of $57/ha. Whilst the change in annual benefit per hectare would be more substantial for the grower in CS4 than the grower in CS6, the grower in CS6 has a much larger farm size and would therefore realise a substantially larger increase in the overall annual benefit.

6.2. Environmental implications of BMP adoption

The changes in the environmental impact indicators as a result of BMP adoption are summarised in Table 6. The results should not be used for the purposes of comparing the farming businesses given that each farming system is unique and the starting point (before BMP changes) and finishing point (after BMP changes) is different for each grower.

For most of the environmental categories assessed, BMP adoption resulted in reduced impacts. So, the results have been presented in Table 6 as the amount of impact reduction, reported as the percentage reduction, the amount of reduction per tonne of harvested cane, the amount of reduction per hectare, and the amount of reduction for the whole farm per year.

For some farms, the scale of some impact reductions for the farm per year or per hectare may be small compared to other farms due to a small farm size (as in CS5), but the impact reductions per tonne of cane can still be very substantial. Vice versa, for larger farms the scale of impact reduction for the farm per year may be relatively large because of the large size of the farm (as in CS1 and CS6), but the reductions per tonne of cane may be relatively small. This is due to differences in the extent of changes adopted and assumed yields before and after BMP adoption. The impact reductions expressed per tonne of cane produced, is the more useful indicator of the scale of environmental improvements because is it normalized against the common unit of production.

Water quality impacts due to losses of nutrients to water (eutrophication potential) were estimated to reduce due to BMP adoption for all the case study farms. The reduced impacts are due to a reduced potential for N loss to surface water runoff and leaching because less nitrogen (N) has been applied. There were some slight changes to P application rates, but these were less substantial than the changes in N application rates. In most of the case studies, N application rates were reduced to those specified by the SIX-EASY-STEPS nutrient management guidelines. In some cases, a legume break crop was introduced or the area of the legume crop expanded, in which case N application rates were adjusted to account for the N provided by the legume crop. The potential for nutrient losses (per tonne cane) reduced by as little as 2% but as high as 31%, depending on the extent to which N application rates were reduced.

Water quality impacts due to losses of pesticides to water (eco-toxicity potential) were estimated to reduce for five of the six case studies. The reduced impacts are due to lower application rates of herbicides, or a change in the type of herbicide active ingredient applied, or in most cases both. The lower application rates were achieved by a change in application method (for example, banded, variable or dual spraying) or electing to apply at a lower dose. Changes in type of herbicides were from residual to knock-down active ingredients with lower toxicity potentials. For these five case studies, the reductions in the amounts of pesticide active ingredients applied ranged from 14% to 48%, and resulting reductions in eco-toxicity potential were between 22% and 78%, depending on the type of changes, which varied greatly across the case study farms. For one case study (CS4) eco-toxicity potential was estimated to increase slightly (9%), even though the overall amount of herbicide AI applied had decreased by 6%. This was due to an increased application of one AI with a higher assumed toxicity potential negating the benefits from reduced application of other AIs. The uncertainty in the eco-toxicity emission factors means that this change may be insubstantial. However, it does flag the importance of understanding the comparative toxicity potential of AIs when changing to alternative pesticide products.

Fossil fuel use over the life cycle of cane production (i.e. including upstream input production as well as on-farm activities) was estimated to reduce by between 10% and 21% across the case studies.

More than half of this reduction is due to avoided fertiliser production because urea application has been reduced (due to the lower N application rates mentioned previously). Avoided urea production is a large saver of fossil fuels because urea production is energy-intensive. The remaining fossil fuel savings are due to reduced diesel use in tractors and harvesters due to wider row spacing and reduced tillage. In most cases the row spacing changed from 1.5m / 1.6m to 1.7m/1.8m, and GPS guidance was installed in machinery, which resulted in less overall travel by tractors / harvester and consequently less fuel use. Tillage intensity was reduced in most cases through zonal ripping and tillage and strategic or no rotary hoeing, which also reduced fuel use through a reduced load on tractors.

Greenhouse gas (GHG) emissions were also estimated to reduce, by between 7% and 23%. The reductions are mostly due to less emissions of nitrous oxide (a strong GHG) due to reduced N application rates and the use of legume crops to supply N which was assumed to have a lower rate of denitrification than N from synthetic fertilisers. Reductions are also due to the previously-mentioned reductions in fossil fuel use for producing and supplying fertilisers (mostly urea), and reduced tractor and harvester operations. For five of the six farms, the annual GHG savings per farm are equivalent to taking 28-86 cars off the road for a year. For the smallest farm, yield increases were considered and the GHG savings from lower N-application and tractor fuel use were partly offset by the higher fuel use required to harvest a bigger crop. Consequently the overall GHG savings were equivalent to taking one car off the road.

The most substantial environmental improvements were generally due to the changed nitrogen application practices (reduced N application rates and alternative sources of N), and changed pesticide application practices. Reduced tractor and harvester operations due to greater row spacing and reduced tillage were less substantial. Improved yields, where they occur, also substantially influence environmental performance. This was the case for CS5, where the scale of impact reductions per hectare were not so large for some aspects, but the improved yields meant that impact reductions per tonne of cane were substantial.

The results of the sensitivity analyses conducted for each case study were reported in the individual case study reports. The sensitivity of the results to changes in cane yields were assessed for all case studies. The sensitivity of the results to uncertainty in the N and P contents of mill mud were assessed only for CS3 and CS4. For brevity, an example of the graphed results of the sensitivity analyses for one case study are reported here (Fig. 6 and Fig. 7). However, the yield drop thresholds derived from the cane yield sensitivity analysis of all the case studies has been reported for all case studies in Table 6. The yield drop threshold referred to in Table 6 is the percentage reduction in cane yield at which there would be no environmental improvements from BMP adoption per tonne of cane.

Table 6 Summary of reduced environmental impacts for case study farms[29]

		CS1	CS2	CS3	CS4	CS 5	CS 6
Farm Size		830 ha	167 ha	240 ha	150 ha	90 ha	760 ha
Reduction in nutrient losses to water (PO_{4-eq})	% (/ t cane)	**18%**	**17%**	**17%**	**31%**	**31%**	**2%**
	kg/yr	1,000	650	833	1,250	250	435
	kg/ha/yr	1.3	3.9	3.5	8.3	2.8	0.6
	kg/t cane	0,06	0.06	0.05	0.10	0.14	0.007
	Yield drop threshold	19%	15%	22%	31%	13%	2%
Reduction in pesticide active ingredient (AI) losses to water	% (/ t cane)	**35%**	**14%**	**21%**	**6%**	**48%**	**36%**
	kg/yr	121	13	41	7	46	370
	g/ha/yr	145	79	172	46	517	483
	g/t cane	7.4	1.3	2.5	0.6	15.1	6.1
Reduction in pesticide-related ecotoxicity potential	% (/ t cane)	**44%**	**78%**	**48%**	**-9%**	**22%**	**53%**
	CTUex10^6/yr	15,762	3,149	2,109	-267	9,126	47,580
	CTUex10^6/ha/yr	19	19	9	-2	101	62
	CTUex10^6/t	0.97	0.30	0.13	-0.02	1.67	0.79
	Yield drop threshold	44%	NA	>45%	2%	0%	NA
Reduction in fossil fuel use (oil$_{-eq}$)	% (/t cane)	**10%**	**18%**	**21%**	**14%**	**18%**	**10%**
	t/yr	30	15	28	11	0.2	35
	kg/ha/yr	36	90	114	75	3	42
	kg/t cane	1.8	1.4	1.7	0.9	1.9	0.5
	Yield drop threshold	24%	24%	40%	23%	12%	15%
Reduction in greenhouse gas emissions (CO_{2-eq})	% (/t cane)	**17%**	**19%**	**23%**	**15%**	**20%**	**7%**
	t/yr	266	123	205	87	1	174
	kg/ha	320	736	856	583	9	228
	kg/t cane	16.4	11.6	12.6	6.8	12.9	2.9
	Yield drop threshold	22%	24%	33%	20%	5%	10%

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[29] Errors in previous publications have been addressed and revised results are reported in this table.

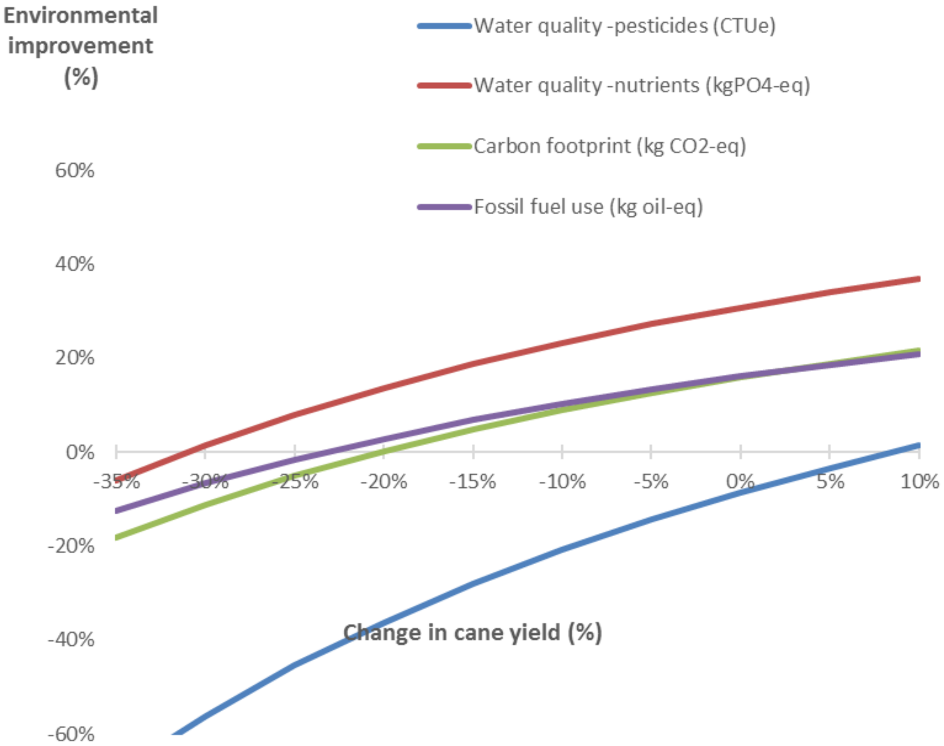

Figure 6 Sensitivity of environmental impact to changes in cane yield (for CS3)

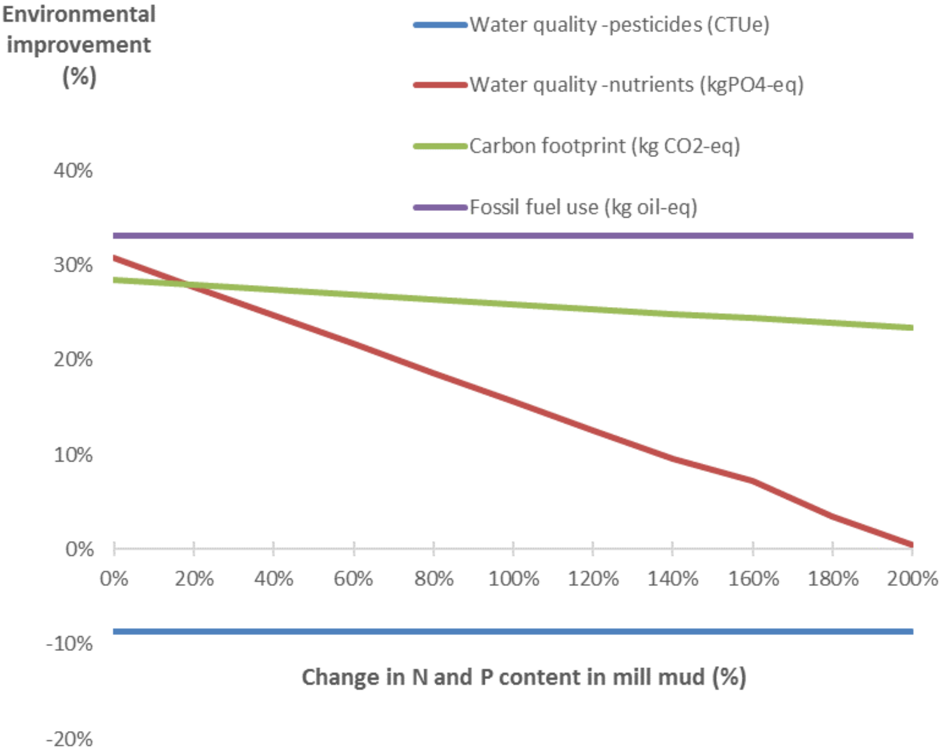

Figure 7 Sensitivity of environmental impact to higher N and P contents of mill mud (for CS3)

The cane yield sensitivity results show that the improvements in fossil fuel use, GHG emissions and nutrient-related water quality impacts are fairly resilient to potential reductions in cane yields (see yield change thresholds in Table 4). In four of the six case studies, cane yields would have to reduce by 15-40% for there to be no improvements. For the other two farms (CS5 and CS6) there is more chance that environmental improvements could be compromised by reduced cane yields, with yields only needing to reduce by a 5-15% for there to be no gains, depending on the impact category. For CS5, a cane yield increase of 27% were observed in practice after BMP adoption, and so environmental impacts per tonne of cane were reduced. For CS6, the sensitivity to yield is because the farm was already quite eco-efficient before BMP adoption and so the scale of improvements were lower and hence more sensitive to any yield decline.

The yield response of pesticide-related water quality impacts is much more variable. For four of the six case studies, cane yield reductions in excess of 45% would be needed before there was no improvement. For the other two farms the changed herbicide practices were less substantial, and yields would need to reduce 5% and 20% respectively for there to be no improvement.

The sensitivity analysis related to mill mud assessed the influence that the N and P contents would have on environmental improvements (Fig. 7). The risk is that N and P contents may actually be higher than the values assumed in this study. So the sensitivity analysis covered N and P contents greater than those assumed. For mill mud nutrients, the N and P contents would need to be 90% and 200% higher (for CS3 and CS4 respectively) than the assumed values for there to be no net improvement in eutrophication potential. Greenhouse gas implications were not found to be greatly influenced by uncertainty in the assumed N and P contents.

One imperative of the BMP program is to protect water quality by reducing nutrient and pesticide losses to waterways. The analysis suggests that BMP adoption makes good in-roads to achieving these outcomes. BMP adoption also provides added benefits of reduced fossil fuel use and greenhouse gas emissions over the life cycle of sugarcane production, through associated reductions in demand for fertilizer production and machinery usage.

6.3. Discussion

Preliminary comments in relation to the four research questions detailed in section 2 (Project objectives) are detailed below, followed by further discussion of insights from the research and areas for additional research.

The case study examples can assist growers in evaluating the implications of adopting BMPs and clarify the potential relative advantage of BMPs (compared to conventional practices).[30] In particular, while past research on the economic implications of BMP adoption has generally considered production implications, the case study evaluations provide insights regarding the profitability implications of BMP adoption.

The variation in results between case studies (for example, AEB results ranging from $24/ha/yr to $220/ha/yr) and the sensitivity of economic results to production change, point towards the uniqueness of each case study transition towards BMP including, for example:

- Variations between farms regarding biophysical variables including soil type, rainfall and climatic variables;
- Variations between farms regarding enterprise variables such as farm size, capital and labour constraints, and management objectives;
- Variations between farms regarding the types of management practices implemented, the length of time over which they were implemented, how they were implemented (for example, with new equipment or modifications to existing equipment) and how they fit into the existing farming system.[31]

For growers who already have well-established and efficient farming systems, the annual benefits (for example, due to yield improvements and/or cost savings) derived from the adoption of new BMPs may be relatively small on a per hectare basis, when compared to the annual benefit realised by growers who make substantial changes to their farming system in their transition towards BMP. However, even if annual benefits are relatively small on a per hectare basis, once they are realised across a large farm, the total annual benefits can impact overall farm profitability substantially. A grower's perceived relative advantage of practice changes may depend on whether they are inclined to consider benefits in the short term or long term, and it is noted that some assumptions made in the case study evaluations may result in a possible understatement of annual benefits (for example, the life of machinery and equipment is conservatively assumed to be no more than 10 years).

Another important aspect that appears to influence profitability is the cost of implementation relative to farm size. Depending on the practice being considered, taking a collective approach and sharing costs of implementation with a neighbouring farm may assist in reducing the cost of implementation and ensuring a positive annual benefit after BMP adoption. It is noted that it is recommended in previous research (Poggio, 2008) that different business structures be investigated to minimise risk and enable farm expansion (for example, co-operatives or grower managed corporate farms with private investment in land or crops). Farm funding models and business

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[30] As noted in section 1 (background), within the literature on adoption of innovations (practices), it is suggested that the relative advantage of adopting a new practice is a key motivator of adoption (Rogers, 2003).

[31] Given such variations, the capacity to compare and benchmark farms is limited and variations between farms and regions must be carefully considered when applying information to a grower's individual circumstances.

structures have been the subject of a recent Australian Farm Institute research report by Heath and Tomlinson (2016) and have also received attention from the Australian Government's "Farming Together" farm co-operatives and collaboration pilot program.[32] Further research may be required, however, as approaches that may work for a particular industry or area may not necessarily be suitable for sugarcane growers in the wet tropics. In areas where wet weather frequently results in limited windows of opportunity for growers to complete farm operations sharing machinery between growers may not be practical or viable.

Whilst grant funding provided to some case study participants was not incorporated into the case study analysis, access to grants would also likely reduce the costs of implementation for growers, thus contributing towards a positive annual benefit and encouraging BMP adoption. In particular, growers who work together to co-apply for such grants may be able to include larger landholdings in the value propositions in their applications (depending on grant selection criteria and its purpose) and ensure that the economic and environmental benefits of adopted practices are realised across larger areas.

Some practice changes in the case studies were implemented over a number of years. Progressive decision making may provide growers with more information to evaluate and, in turn, help growers manage risks and reduce aversion towards the risk of BMP changes. For example, in some instances the benefits of a practice change can be trialled and evaluated on one block before implementing the changes on other blocks. Similarly, after making one BMP change, the benefits can be evaluated and further BMP changes can be considered. Increased and ongoing involvement in extension activities may assist in the progressive implementation of practice changes. Productivity service meetings, for example, can provide opportunities for growers to engage with local extension officers and find information on BMPs relevant to their area.

The process of adoption can involve a complex decision-making process that involves evaluating trial and non-trial information. Given the uniqueness of each farming business that has been highlighted by the case study examples, the stand-alone value of project case studies and other resources is limited without trusted extension staff to support growers in evaluating and applying the information at hand.

The use of BMPs that have been scientifically validated lessen the production risks of BMP adoption. However, the sensitivity of results to changes in production suggest that one-on-one support is necessary to assist growers to adopt BMPs suited to their farms and ensure the necessary transfer of skills and knowledge to implement new management practices effectively. Due to variations between farms and regions, growers may be better positioned to make informed decisions if local (and, ideally, productivity zone or farm-specific) agronomic research is available for consideration. The case study reports can be used by growers as a tool to prepare for discussions with their advisors about the implications of BMP adoption on their individual properties.

As production can be impacted by a range of biophysical factors, seasonal fluctuations in yield may need to be accounted for when examining the economic implications of BMP adoption. Monitoring and comparing farm production data with the productivity zone (if available) may assist growers in isolating and evaluating the production outcomes of BMP changes. Such comparisons may be appropriate if the assumption that a grower's farm is representative of the greater productivity zone is reasonable. Future industry research could benefit from such evaluations, particularly in

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[32] The program will run until June 2018 and further details are available at the Farming Together website. https://agworks.com.au/

circumstances where BMP adoption is followed by periods of adverse weather conditions that may impact production. It is noted that the capacity to attribute causal links between BMP adoption and changes in production or profitability is limited (correlation may not necessarily indicate causation).

The ongoing collection of farm data and operational details may assist growers and their advisors in having the necessary information at hand to evaluate production and profitability outcomes after BMP adoption using tools such as FEAT.

The impact of BMP changes on soil health, yield and the number of profitable ratoons in a production cycle also warrants further consideration where data is available.[33] Some of the methods and approaches used in this research can be utilised in future projects such as SRA Project 2017/005 "Measuring soil health, setting benchmarks and driving practice change in the sugar industry." The measurement of environmental aspects of soil health is discussed further in this section below.

Interactions between practice changes mean that it can be preferable to consider the combined impact of practice changes as well as considering the economic, environmental, agronomic and social changes. For example, improved drainage can improve field conditions. This would not only be expected to improve soil health (environmental aspects) by limiting waterlogging and compaction but also help a grower to make nutrient and herbicide applications on time when they are needed. In turn, production could be improved (agronomic and economic aspects) and the grower could also save time and be better organised to manage various tasks (social and economic aspects).

Changes may become more manageable as growers build on existing knowledge and relationships with advisors. In particular, if BMP adoption helps growers save time then, depending on individual circumstances, this time can be used by growers to take a step back from managing day-to-day tasks "in the farming business" to research, evaluate and trial further changes "on the farming business."[34]

Changes in expenses after BMP adoption can also be due to multiple factors depending on the practices implemented. For example, both wider row spacing and reduced tillage can reduce fuel consumption, repairs and maintenance costs (and result in longer life for equipment).

For the environmental component of the study, it was possible to generate a relatively robust picture of the environmental implications of BMP adoption. The CaneLCA method was able to simulate many of the resource use and emissions consequences of BMP adoption and the associated impacts (Renouf et al., 2018). The uncertainty of the results due to potential cane yield changes was addressed through a sensitivity analysis, and has been discussed earlier. Additional uncertainties also need to be noted due to the limitations of the CaneLCA method.

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[33] Longer ratoons may help minimise average annual expenses as the per hectare expenses for ratoon crops are typically less than plant crops. However, for additional ratoons to be profitable it is also important for production and commercial cane sugar in later ratoons to be maintained (which may decline as ratoons become older). The extent to which accurate and precise data is available can limit analysis. For example, mills may report production on fourth "and older" ratoons in which case a separate analysis of fourth and fifth ratoons is not possible. The analysis of ratoons can be further complicated by variation in the payment formula of mills (for example, a mill may pay bonuses if the cane that is harvested is "cleaner" with less soil which may be relevant for older ratoons).

[34] Previous research, for example by Thompson et al. (2014), indicates that a range of socio-economic factors can influence perceptions regarding BMP adoption. Recent research by Rolfe and Harvey (2017) further highlights the heterogeneity in the social motivations and factors influencing BMP adoption.

Some environmental implications of BMP adoption could not be simulated by the CaneLCA tool. In particular, the effects on soil quality from changes to tractor movement, tillage intensity, trash management, and use of mill mud. Methods and indicators for quantifying soil quality (compaction, erosion, soil organic carbon) are not yet well established and so are not currently included in CaneLCA. Soil quality changes are also known to influence nitrous oxide emissions, soil carbon exchanges and even pesticide emissions (Masters et al., 2013, Page et al., 2013, Bessou et al., 2010, Luis Antille et al., 2015). However, easily quantifiable relationships between soil quality and these emissions have not yet been established, and are hence not currently accounted for in the CaneLCA tool. This means that some greenhouse gas and water quality implications were omitted, and the significance of this is not known.

There is also a recognised uncertainty in the emission factors used in CaneLCA to estimate losses of nitrogen species, phosphorus and pesticides to the environment (Renouf et al., 2018). While they are based on best available published values and estimates relevant to sugarcane growing, emission factors are known to be highly influenced by site-specific, climatic and soil factors, which could not be fully accounted for in the study, due to lack of case-specific emission factors. A consistent set of emission factors were applied to all case studies and to the before and after scenarios, so the uncertainty inherent in the emissions factors was equivalent when comparing impacts before and after BMP adoption. Our focus on the change in impacts rather than the absolute value of the impacts means that the influence of the uncertainty will be less substantial.

The analysis further confirmed the substantial environmental improvements that can be achieved through better nitrogen management, which had been predicted in earlier work (Renouf et al. 2010). This is because it influences a number of impact categories – water quality, but also energy use and greenhouse gas emissions. The expected pesticide-related water quality improvement from BMP adoption in the Wet Tropics region can be expected to very substantial. The scale of the nutrient-related water quality improvements expected through BMP adoption in this region makes a valuable contribution to the water quality improvement targets for the protection of the Great Barrier Reef (State of Queensland, 2017). From one of the case studies we observed that the benefits of eco-toxicity reductions from reducing the amounts of pesticide active ingredients applied may be compromised if the changes involve a switch to and AI with a higher eco-toxicity potential. It is important to investigate the comparative toxicity potential of AIs when changing to alternative pesticide products.

The remainder of this section addresses the specific research questions outlined in section 2.

"Are cane businesses in the Wet Tropics likely to be more profitable after adopting the Smartcane BMPs being analysed?"

The positive economic and environmental results of each of the case studies suggest win-win outcomes may be obtained after BMP adoption if yields are maintained or, in some instances, improved. The analyses were based on real case studies of BMP adoption using actual farm data, contributing towards certainty about the scope and nature of changes to the farming systems.

"Of the prioritised Smartcane BMPs, which individual or suites of practices contribute to profitability and environmental performance in the Wet Tropics?" and "*Which individual or suites of BMPs present a win-win situation for profitability and environmental outcomes?"*

The case study results indicated improvements in economic and environmental indicators after BMP adoption (depending on yields being maintained and in some instances improved). However, because the parameters and individual circumstances of each case farm varied considerably (for example, management and biophysical characteristics and climatic conditions varied between farms) it was impractical to isolate which suite of practices was optimal.

Prior to commencing the project it was contemplated that there may be case study participants who had recently made single practice changes and that the impact of such changes could be evaluated. Subsequently, it was found that unless changes were done in isolation it was difficult to determine the impact from individual changes, and even if such changes were done in isolation, the interactions between other practice changes in each unique farming system can limit the conclusions that can be drawn regarding the implications of a single practice change. Similarly, the environmental impacts attributable to certain practice changes are difficult to identify and the interactions between farming practices can complicate the analysis.

"What are the variables that influence profitability and environmental performance at the farm level?"

As profitability depends not only on costs, production and price but also on the biophysical, enterprise and socio-economic variables that can vary considerably between farms, isolating key variables that *will* influence profitability (in terms of a majority of farms in a particular region) is challenging if not impossible. However, common examples of practice changes that *can* lead to cost savings can be identified from the case study analyses. For example, in case studies where growers transitioned to reduced tillage or wider row spacing considerable cost savings could be attributed to these changes. A grower's skills and approach to implementation can also be relevant. For example, modifications to existing equipment, instead of purchasing new equipment, can potentially reduce costs of implementation. Contributions to changes in farm operating costs (related to, for example, capital goods, fuel, oil and labour, fertilisers, herbicides, insecticide, fungicides, planting and harvesting, supply of agro-chemicals, drainage) varies depending on the practice changes implemented.

The findings of the case studies are specific to the individual businesses evaluated and therefore the parameters and assumptions used in each case study reflect the particular grower's situation only. Consideration of individual circumstances must be made before case study findings are applied to another situation. The variance in outcomes between case studies and the sensitivity of economic results to production changes highlights the uniqueness and complexity of farming systems. This suggests that "one-size-fits-all" policy or extension approaches that fail to regard variability between farms and potential production changes will be of limited effectiveness.

7. CONCLUSIONS

Best Management Practices (BMPs) aim to improve the productivity, profitability and sustainability of sugarcane farms. To better understand the economic and environmental implications of BMP adoption in the Wet Tropics, this project undertook a literature review and developed six case studies of different sized commercial farms located between Ingham and Mossman that had adopted various BMPs. Practice changes ranged between farms but included practices associated with soil health, nutrition, pest control and drainage. The cost of implementing the BMPs ranged between $2,200 and $735,000 and depended on the individual circumstances of each farm, types of practice changes and cost of required equipment or earthworks. Economic, biophysical and farm operational data were collected from participating growers to undertake FEAT and CaneLCA analyses both before and after BMP adoption to determine the farm profitability and environmental implications of the BMP changes. Sensitivity analyses were also undertaken to determine if the economic and environmental implications were sensitive to increases or decreases in cane yield.

Results from the investment and environmental analyses indicated that BMP implementation in the Wet Tropics can be a win-win for both economic and environmental outcomes. The economic benefit from BMP adoption was found to be positive on all farms indicating a profitable investment but varied among the farms (between $25 and $220 per hectare per year), while the payback period ranged between two and ten years. Farm profitability was found to be sensitive to cane yield changes, which highlights the need to manage risks. The case studies provided examples of growers managing risks using various methods when adopting BMPs including the progressive implementation of practice changes over time (step-by-step approach) and co-investment with neighbouring farmers to reduce capital investment costs.

The environmental results indicate that BMP adoption can improve water quality and energy efficiency as well as mitigate greenhouse gas emissions. The case studies indicated that the environmental benefits were not too sensitive to cane yield reductions. For five of the six farms assessed, yields would need to reduce quite considerably (15-40%) for the environmental improvements to be compromised. The sensitivity of environmental results to potential changes in yield was higher in the case of the remaining farm that was already quite eco-efficient before BMP adoption (and the degree of change in environmental impacts after BMP adoption was relatively small for that farm). On the other hand, cane yield improvements drove environmental benefits considerably higher.

The case study results overwhelmingly show that BMP adoption in the Wet Tropics can result in improved profitability and environmental improvements. Nevertheless, decision makers need to take into account risks such as potential yield changes. Using a whole-of-farm methodology when evaluating the implications to profitability and the environment as well as interactions between practice changes can help manage specific risk factors. The case studies were extended via the distribution of case study reports to industry and extension networks as well as presentations at a number of workshops in the Wet Tropics. Further communication of the project’s findings is planned and may encourage growers to consider further BMP adoption, while extension of the methods employed in this project could be applied to develop case studies in other regions.

8. PUBLICATIONS

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d) Chris Bosworth;
e) Walter Giordani; and
f) David Singh.

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10. REFERENCES

The literature review (Appendix 3) includes a self-contained list of references. References contained in the body of this report are detailed below.

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11. APPENDIX

11.1. Appendix 1 ABBREVIATIONS AND ACRONYMS

AARES	-	Australasian Agricultural and Resource Economics Society
AEB	-	Annualised equivalent benefit (sometimes referred in presentations or factsheets etc. as annual benefit or annual economic benefit)
AI	-	Active ingredient
ASSCT	-	Australian Society of Sugar Cane Technologists
BMP	-	Best Management Practice[35]
CaneLCA	-	Cane Lifecycle Analysis Eco-Efficiency Calculator
CS	-	Case study
CTWG	-	Cane Technical Working Group
DAF	-	Department of Agriculture and Fisheries (formerly Department of Agriculture, Fisheries and Forestry; Department of Employment, Economic Development and Innovation; Department of Primary Industries and Fisheries; Department of Primary Industries)
FEAT	-	Farm Economic Analysis Tool
GPS	-	Global positioning system
HCPSL	-	Herbert Catchment Productivity Services Ltd
ISSCT	-	International Society of Sugar Cane Technologists
MSF	-	Maryborough Sugar Factory Ltd
SRA	-	Sugar Research Australia Limited
SRDC	-	Sugar Research and Development Corporation[36]
Terrain	-	Terrain Natural Resource Management (Terrain NRM)
Tch	-	Tonnes of cane per hectare
TCPSL	-	Tully Cane Productivity Services Ltd
Tully Sugar	-	Tully Sugar Limited
WTSIP	-	Wet Tropics Sugar Industry Partnership

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[35] Throughout this report, BMPs typically refer to Best Management Practices as defined by Smartcane BMP. https://smartcane.com.au/

[36] SRDC and BSES Limited were succeeded by SRA, Sugar Research Australia Limited.

11.2. Appendix 2 METADATA DISCLOSURE

Table 7 Metadata disclosure 1

Data	Farm Economic Analysis Tool spreadsheets for Case Studies 1 to 6
Stored Location	Department of Agriculture and Fisheries (Queensland) (DAF)
Access	Restricted access to DAF employees
Contact	Caleb Connolly Agricultural Economist, DAF

Table 8 Metadata disclosure 1

Data	Investment Analysis spreadsheets for Case Studies 1 to 6
Stored Location	Department of Agriculture and Fisheries (Queensland) (DAF)
Access	Restricted access to DAF employees
Contact	Caleb Connolly Agricultural Economist, DAF

Table 9 Metadata disclosure 2

Data	Environmental parameters spreadsheets for Case Studies 1 to 6
Stored Location	Department of Agriculture and Fisheries (Queensland) (DAF)
Access	Restricted access to DAF employees
Contact	Caleb Connolly Agricultural Economist, DAF

Table 10 Metadata disclosure 2

Data	CaneLCA eco-efficiency calculator spreadsheets for Case Studies 1 to 6
Stored Location	Lifecycles (Victoria)
Access	Restricted access to Lifecycles employees
Contact	Marguerite Renouf Senior Scientist, Lifecycles

11.3. Appendix 3 LITERATURE REVIEW

Department of Agriculture and Fisheries

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

Submitted to Sugar Research Australia (SRA) as part of SRA Project 2014/15 (Measuring the profitability and environmental implications when growers transition to Best Management Practices).

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Sugar Research Australia

Life Cycle Strategies

Queensland Government

This publication has been compiled by Alison Collier, Mark Poggio and Eamon Holligan (Department of Agriculture and Fisheries) and Marguerite Renouf (University of Queensland).

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Table of Contents

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.

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[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

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[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).

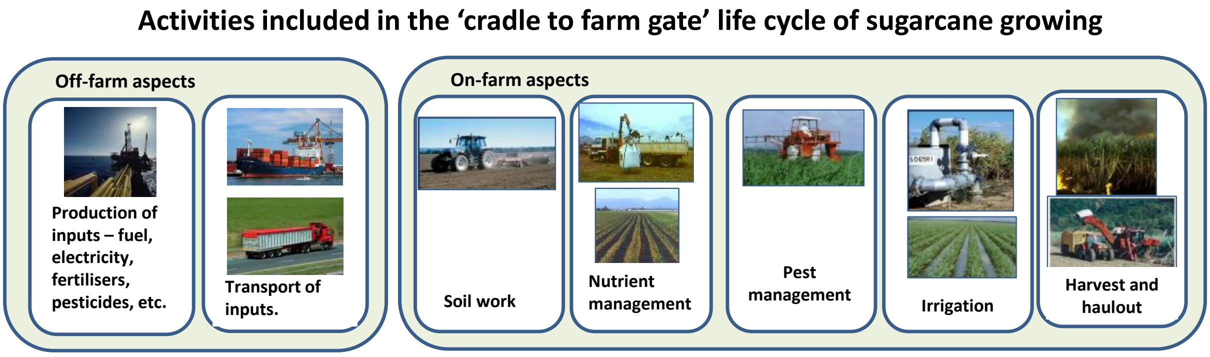

Figure 1: Aspects of the 'cradle to farm gate' life cycle of sugarcane growing included in the scope of the CaneLCA tool

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.

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[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

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[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.

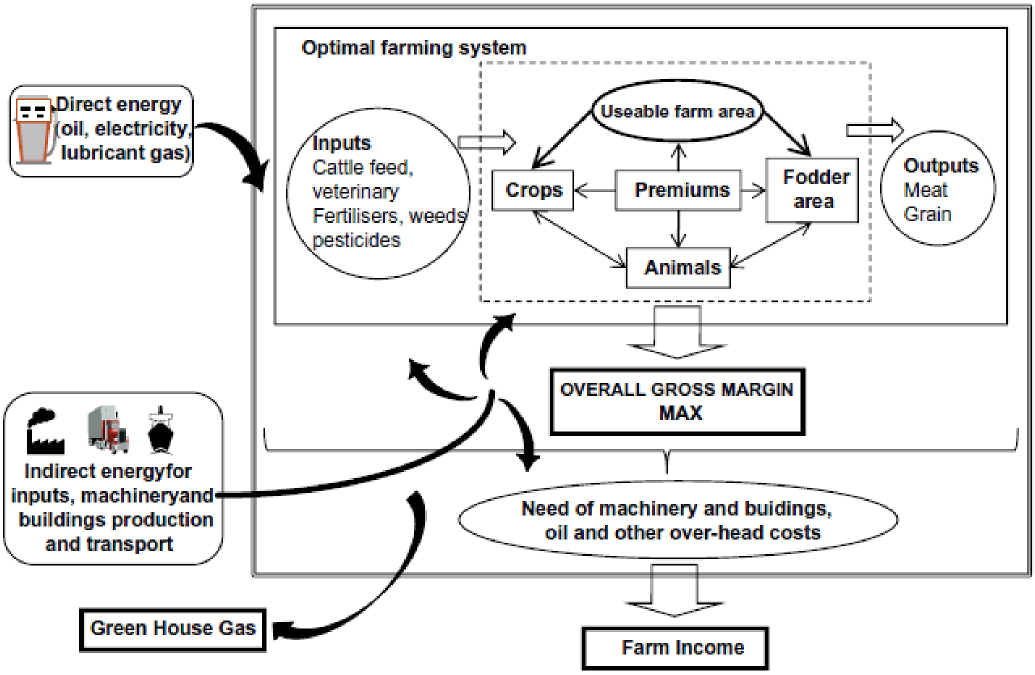
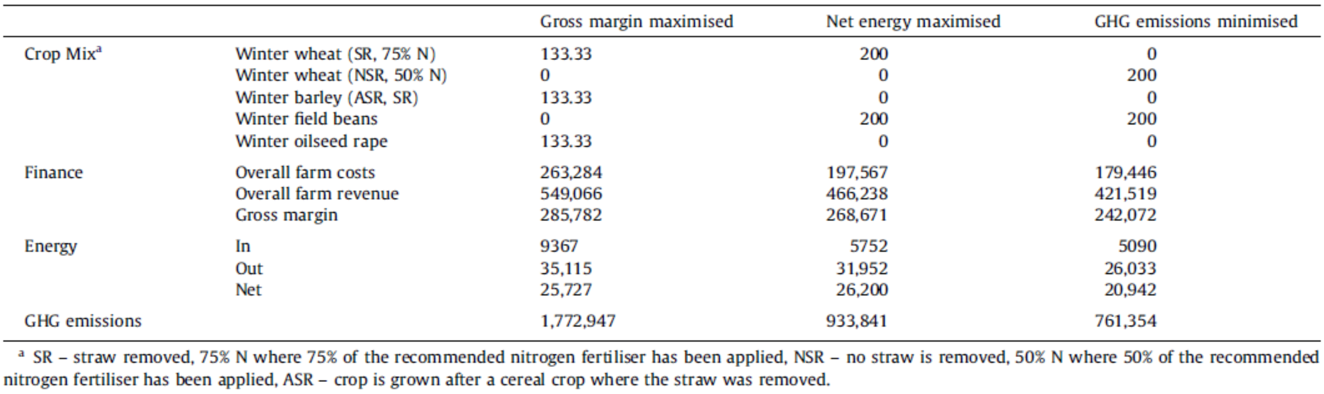


Figure 2: Examples of a qualitative trade-off analysis (taken from Veysset et al. (2010))



		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))

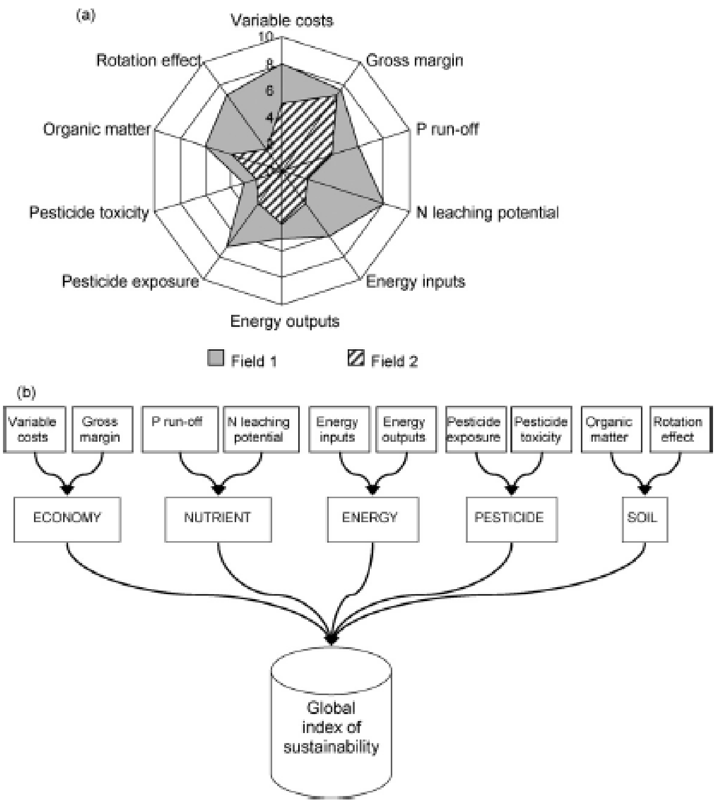
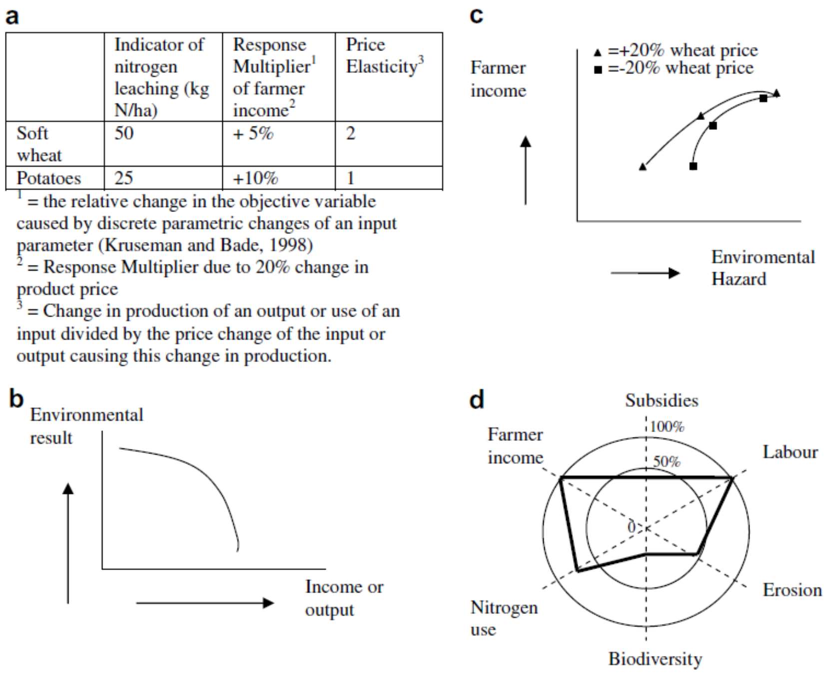


Figure 4: Examples of an integrated sustainability assessment combining agro-ecological and economic indicators (taken from Castoldi and Becchini (2010)).



	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

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[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