Cost-effectiveness of management activities for water quality improvement in sugarcane farming (RRRD039)

An output of RRRD039 Integrated assessment of BMP cost-effectiveness and decision tool for regions and landholders

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The Reef Rescue Research and Development Program (Reef Rescue R&D) was funded under the Australian Government's Caring for our Country program, and consisted of 18 projects. The Reef Rescue R&D is designed to improve our understanding of the link between land management practices and environmental impacts, and improve water quality across the Great Barrier Reef by informing on-ground projects to reduce the amounts of nutrients, pesticides and sediments reaching the Reef from agricultural lands.

This report is available from the Reef Rescue R&D website: http://www.reefrescueresearch.com.au

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Acronyms

AEB	Annualised equivalent benefit
APSIM	Agricultural Production Systems sIMulator
BMP	Best management practice
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCF	Discounted cash flow
DSEWPaC	Department of Sustainability, Environment, Water, Population and Community
FEAT	Farm Economic Analysis Tool
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
NPV	Net present value
NRM	Natural Resource Management
DAF	Queensland Department of Agriculture and Fisheries
RRRC	Reef and Rainforest Research Centre Limited
RRRD	Reef Rescue Research & Development

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Executive Summary

There is now an extensive amount of literature (see Devlin and Lewis 2011 for a synthesis) documenting, in increasing detail and confidence, the sources and potential implications for pollutants entering the Great Barrier Reef (GBR) lagoon. Land uses that contribute to this are dominated by diffuse source agricultural pollutants, with the primary source differing by industry: sediments are primarily generated by grazing activities whilst nutrients are largely attributed to cropping activities, which is dominated by sugarcane production. Agricultural chemicals are exported by both industries although the type of chemicals (active ingredient) differs. Reducing the level of pollutant exports will require the widespread adoption of improved management practices and continued research and development into innovative solutions to minimise diffuse-source agricultural pollutants. The focus in this Reef Rescue Research and Development project "Integrated assessment of BMP cost-effectiveness and decision tool for regions and landholders" is to evaluate the financial-economic and water quality implications of changing management practices, including their cost-effectiveness, as well as the barriers and opportunities offered by a variety of practice changes.

Estimates of the relative cost and effectiveness of improved practices are becoming available for various practices and locations. Within the cane industry, results from recent economic research suggest that some practices are likely to increase the returns to landholders once adopted. However, adoption of these practices varies considerably; there has been strong adoption among some groups of farmers and in some locations, but relatively little in others. We hypothesise that this may be the case because previous approaches do not adequately represent the diversity of farm enterprises across land types, operating structures, or transition costs. Furthermore, gains may not be sufficiently large to either motivate change or to be identified by landholders amongst other sources of production variability and risk. Therefore, the generalised results of previous studies may not apply universally, and instead some groups of landholders may experience greater than expected gains from adoption, while adoption may impose costs on others. Such differences may be driven by an elaborate combination of biophysical and enterprise variables. Biophysical variables are likely to include soil type, rainfall and other weather variables. Enterprise variables are likely to include structural factors involving farm size and operating strategy, capital and labour constraints, and the farmers' operating objectives.

The component reported in this report is part of the broader RRRD039 project. The focus of this particular report is to analyse socio-economic, institutional and financial-economic datasets to:

- Provide context regarding landholders' perceptions of, and experiences with, processes of change in their farming operation and their experience with participating in government programs such as the Reef Rescue;
- Extend cost-effectiveness estimates to include three NRM regions growing sugarcane, major land types, enterprise variations, and a range of management activities - this work consequently extends the work carried out in existing project;
- Identify real and perceived limiting factors regarding specific management practices and/ or relative advantages in adopting these practices, such as the requirement for capital, the complexity of the practice, or how the practice may impact on profitability; and

- Provide financial-economic inputs to an integrative regional model.

Key findings

The social-institutional analysis conducted as part of this project identified several aspects that were influential in the decisions made by growers to participate in the incentive-based Reef Rescue program, as well as revealing insights into the experience of growers who participated. These aspects broadly include:

- The availability of government funds and explicit environmental goals of the funding agency appear to have limited involvement by farmers in the early years of the program-roll out but was less influential in latter rounds as trust improved;
- The presence of cost-sharing arrangements and the role of social rewards and recognition were influential factors in participation, however the requirement for up-front capital to match that provided by the government precluded participation by some growers, effectively creating a financial threshold;
- Importance of local trusted advisors in providing the information and practical support needed to apply for the funds in a decentralised implementation of the program; and
- Influence (often constraining) of existing local economic relationships between growers and their contractors and harvesting groups, which is not taken into account in program design. This makes it difficult for landholders to change harvest or other group practices independently of the 'group'.

The financial-economic analysis highlighted a few key messages to support the notion that accounting for biophysical and enterprise-structural variability (heterogeneity) in natural resource management (NRM) is likely to be cost-effective:

- There appears to be significant variation in farm gross margins <u>between</u> regions and (to a lesser extent) across farm sizes. This indicates that a single representative farm model is likely to misrepresent the actual financial-economic consequences of changing management;
- Variation in farm gross margins <u>within</u> regions is relatively modest for the practices evaluated, particularly with the relative economic benefit as a proportion of the average farm gross margin. This tends to highlight the importance of factors such as transaction costs, risk, and other relative (dis-)advantages associated with practice change;
- The above point also highlights the fact that the direct financial consequences associated with changed practices are potentially difficult to distinguish from other factors impacting on variability in business performance (e.g. price volatility and productivity influences);
- Economies of scale are evident (between small, medium and large farms, operational efficiencies are higher for larger farms where greater asset utilisation is possible);
- Changed practices that achieve environmental and economic benefits were identified but trade-offs also exist and may require different policy approaches; and
- For the combinations of practices analysed in this research, a more targeted nutrient management strategy may prove to have the best cost-effectiveness in improving water quality. The extent to which this affects both financial and environmental outcomes varies between regions, soil types and farm sizes and current management

systems. The results indicate that moving beyond the existing commercially tested nutrient management is likely to come at a cost to the farmer.

More specific management practice related messages generated from these studies include:

- Six-Easy-Steps nutrient management regime resulted in the highest farm gross margins across all comparative scenarios;
- Farm gross margins tended to be relatively higher for low tillage scenarios, and relatively lower for legume fallows in the absence of yield improvement;
- Changing from old industry recommended rates to Six-Easy-Steps provides both financial and overall water quality benefits (total DIN reduction);
- Changing from Old Industry recommended rates to N-Replacement nutrient management rates provides a water quality benefit. This change also provides a financial benefit in a legume fallow system, however comes at a cost in a bare fallow system;
- Changing from Six-Easy-Steps to N-Replacement nutrient management provides substantial water quality improvement in the Wet Tropics and Mackay Whitsunday regions, and with limited cases in the Burdekin, while also generally resulting in a financial cost to the farmer;[1]In the absence of yield improvement, results indicate that moving from a bare fallow to a legume fallow cover crop will generally result in a financial cost to the farmer (especially for small farms due to the required capital expenditures), and will only improve DIN in limited cases (dependant on nutrient and tillage management); and
- Moving from high tillage to low tillage will generally provide financial benefits, where water quality benefits are variable and regionally specific.

There are some significant areas of convergence between the social-institutional and financial-economic analyses above.

- First, the relatively modest variation in FGMs within regions highlights the need to consider any specific transaction costs and risk associated with each practice change. This emphasises the importance of engagement with growers through extension networks, which help to promote grower participation in practice change programs.
- Second, it is generally more efficient for larger operators to implement changes, which is often exacerbated by the dependence of small-medium size operators on collective harvesting and contracting relationships. Accordingly, individual-level and aggregate risks associated with change may not be shared by larger operators due to the existence of economies of scale identified in the financial analysis.

Benefits and application of work

There are ample opportunities within the sugarcane producing industry to reduce pollutant exports to the Great Barrier Reef (GBR) lagoon. These opportunities include, but are not

[1] The change in financial benefits from switching to Six-Easy-Steps compared to a further step to N-Replacement suggests there may be a lower financial cost middle ground with environmental benefits such as adjusting Six-Easy-Steps to apply block yield potential rather than district yield potential. Unfortunately the project was not able to test this possibility in the time and resources available, and focused on N-replacement as the 'A' class practice.

limited to, implementing management practices such as modifying nutrient application rates and methods, reducing tillage, and trapping sediment. However, implementing a process of management change across the farming system often requires substantial capital investment combined with the uptake of additional operational expertise and time spent managing the process itself. Hence, the main objective of the research in this component of the RRRD039 project is to evaluate the financial-economic implications for landholders when changing their management practices to those that have the potential to reduce the loss of sediment and nutrients to the GBR lagoon. This research builds on previous economic work undertaken using single representative farms by taking into account the unique aspects of each region, such as the heterogeneity (variability) in soil types, climatic zones, and farm sizes.

The information generated from this research is relevant to the interests of numerous stakeholders, including:

- Landholders who are considering implementing changed practices and thus seeking to understand the potential financial-economic and environmental consequences associated with that change;
- Extension officers who aim to focus attention upon win-win practice changes;
- NRM regional bodies considering potential mechanisms to support (win-win, as well as) win-lose options;
- Policy makers who seek to understand the potential, direct private financial consequences of targeting improvement in water quality; and
- Researchers who seek to understand the trade-offs associated with practice change with a view to developing new technologies with potential for win-win outcomes.

Future directions

A number of potential avenues for future research are created by this work. First, while only a limited number of nutrient management practices have been subject to investigation, others may exist with the potential to achieve greater improvements in water quality. It will be interesting to determine the on-ground implications of any new technologies including profitability and water quality outcomes. Second, further research could be undertaken using a different approach, whereby actual nutrient efficiency targets are developed to determine the required practice change to achieve a desired level of water quality. Moreover, what are the economic implications of achieving these targets via any particular strategy? Here an understanding of the relative costs and benefits, in social and institutional terms as well as financial and economic terms, of different delivery strategies (e.g. individualised, group-based, industry-based) could be ascertained to improve program implementation in different regional contexts. Third, the impact of a change in industry structure (size of farms, location and number of farms) on water quality could be investigated. Finally, given the level of heterogeneity between and within regions, spatial targeting is likely to lead to the most cost-efficient way of improving water quality while maintaining a healthy industry. Accordingly, the information presented through this research can be further used to evaluate and monitor cost-effective policy instruments, institutional settings, delivery mechanisms, and ways of targeting local community support to achieve desirable water quality levels emanating from a heterogeneous industry and landscape.

1. Introduction

There is now an extensive amount of literature (see Devlin and Lewis 2011 for a synthesis) documenting, in increasing detail and confidence, the sources and potential implications for pollutants entering the Great Barrier Reef lagoon. Pollution sources that contribute to this are dominated by diffuse source agricultural pollutants, with the primary source differing by industry: sediments are primarily generated by grazing activities whilst nutrients are largely attributed to cropping activities, which is dominated by sugarcane production. Agricultural chemicals are exported by both industries although the type of chemicals (active ingredient) differs. Reducing the level of pollutant exports will require the widespread adoption of improved management practices and continued research and development to create innovative solutions to minimise diffuse agricultural pollutants (see Thorburn et al. 2013). The focus in this Reef Rescue Research and Development project "Integrated assessment of BMP cost-effectiveness and decision tool for regions and landholders" (RRRD039, Whitten) is to evaluate the financial-economic and water quality implications of changing management practices, including their cost-effectiveness, as well as identifying the barriers (including risk) as well as the opportunities offered by a variety of practice changes.

Estimates of the relative cost and effectiveness of Best Management Practices (BMPs) are becoming available for various practices and locations. Results from recent economic research suggest that some sugarcane industry practices are likely to increase the returns of landholders once adopted. However, adoption of these practices has been patchy at best. There has been strong adoption among some groups of farmers and in some locations, but relatively little in others. We hypothesise that this may be occurring because existing approaches do not adequately represent the diversity of farm enterprises across land types, operating structures, or transition costs. Furthermore, gains may not be sufficiently high to motivate farmers to change or to be identified by landholders amongst other production variability. Therefore, the generalised results of previous studies may not apply universally, and some groups of landholders may experience greater than expected gains from adoption, while adoption may impose costs on others. Such differences may be driven by an elaborate combination of biophysical and enterprise variables. Biophysical variables are likely to include soil type, rainfall, and other weather variables. Enterprise variables are likely to include structural factors involving farm size and operating strategies, capital and labour constraints, and farm operating objectives.

The results included in this report are part of the broader RRRD039 project. The focus for this particular component was to analyse socio-economic, institutional and financial-economic datasets to 1) provide context regarding landholders' perceptions of, and experiences with, processes of change in their farming operation and their experience with participation in government programs such as the Reef Rescue; 2) extend cost-effectiveness estimates of various cane growing practices to include three NRM regions, major land types, enterprise variations, and a range of management options. This work consequently extends the work carried out in existing economic projects such as the Marine and Tropical Research Facility Project 3.7.5 (van Grieken et al., 2010b, 2010c) and the Paddock to Reef Monitoring and Modelling Metrics (van Grieken et al., 2010a); 3) Identify the relative advantages and perceived limiting factors for specific management practices, such as the requirements for capital, the complexity of the practice, and how the practice may impact on profitability, and; 4) Provide financial-economic inputs to an integrative regional model.

2. Methods and results

The strategy to achieve the aims of this project was to undertake research involving the identification of enterprise diversity, regional variability, and transition costs; to quantify the impact on pollutants by management practices for each soil type and region; and to identify the costs and (perceived) limiting factors of changing management practices for each region and enterprise-structure (farm size). We are therefore adapting existing farm production system models to account for enterprise diversity. As such, we are not seeking to conduct a statistically representative survey of landholders. Rather, we are drawing on the knowledge of a set of participants to adjust a prior average or median farm model to accommodate the range in variability we identified in the cane farming community.

In order to deliver these outcomes, the data collection, modelling and analysis has been broken down in a number of elements:

1. Data Collection Part 1: Farmer workshops 1
    a. Questionnaire to identify regional and enterprise structural variation;
    b. Region specific practice and product questions (what, why, how much);
    c. Semi-structured interviews on Reef Rescue and regional issues (with Component 4);
2. Data Collection Part 2: Review of farm financial and production data
    a. Collection of specific regional farm financial and production data through agribusiness, agronomists and industry organisations.
3. Data Collection Part 3: Farmer workshops 2
    a. Questionnaire to identify practice specific adoption limiting factors, relative advantage and trialability.
4. Data Modelling Part 1: APSIM Modelling
    a. Productivity indicators – crop yields;
    b. Environmental indictors – N losses.
5. Data Modelling Part 2: FEAT Modelling
    a. Financial-economic information.
6. Data Analysis Part 1: Investment analysis
    a. Discounted Cash Flow (DCF);
    b. Net Present Value (NPV; including sensitivity analysis);
    c. Equivalent Annual Annuity (EAA) approach and the Annualised Equivalent Benefit (AEB).
7. Data Analysis Part 2: Cost-Effectiveness analysis
    a. Marginal Abatement Cost Curve (MACC).

This research has been conducted in the NRM regions of the Wet Tropics, Mackay Whitsundays and Burdekin Dry Tropics (see Figure 1). Data collection has taken place in Tully, Ayr and Mackay and has complied with the guidelines of ethics in human research.

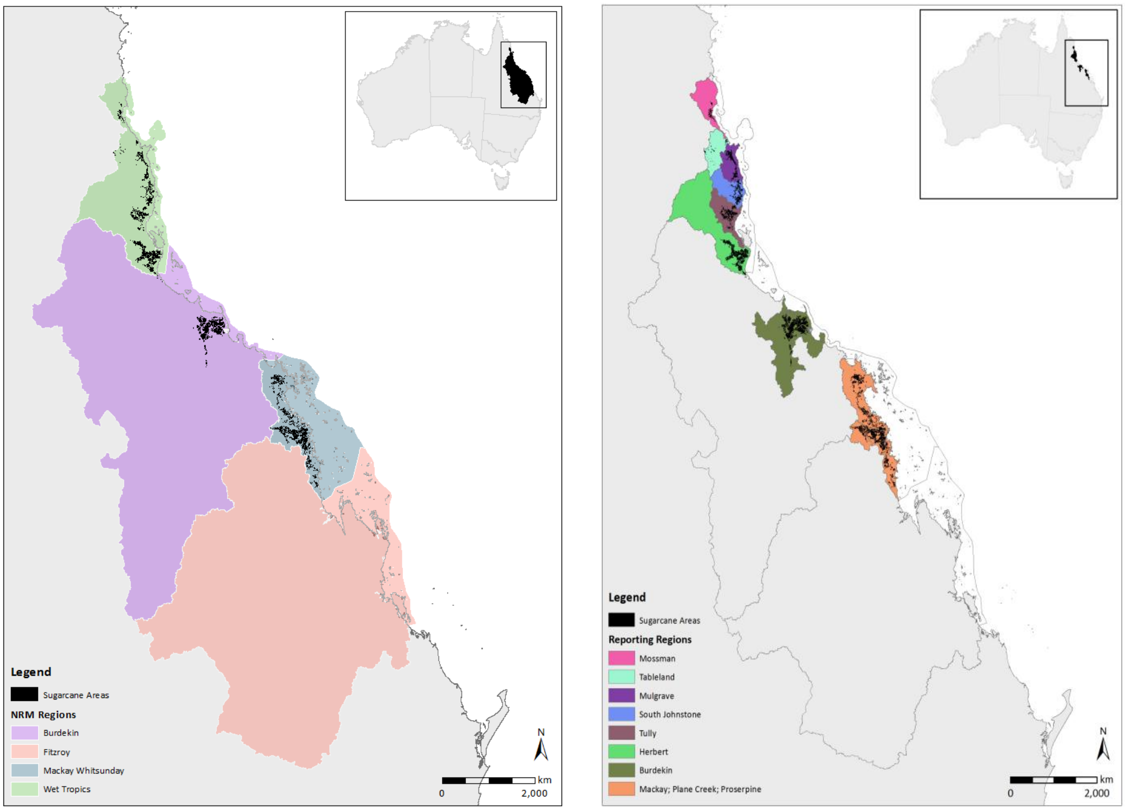


Figure 1: Sugarcane land in the NRM regions (left) and reporting regions (right)

2.1 Data collection Part 1: Farmer workshops 1

In this section we present the results of the participatory workshops as well as formulate conclusions from this qualitative analysis. The intention of these workshops was to collect information regarding current agricultural practices of sugarcane growers, specifically those relating to nutrient and soil management, to develop a base on which to evaluate the variations in financial indicators (i.e. farm gross margins, transition costs, and other socio-economic implications) as a consequence of heterogeneity, or differences, between regions and differences in farm enterprise size. Accordingly, three separate workshops were held in each of the three NRM regions and each landholder was categorized on the basis of their enterprise size: small (<100ha), medium (100ha-200ha) and large (>200ha).

The total number of participants was 34, which consisted of 29 farmers and 5 extension officers. Extension officer participants were drawn from a range of agencies including state government agricultural agencies (DAF), sugar industry funded research and development and extension organisations (BSES and Productivity Boards), and advisors working with local sugar milling companies. Grower participants in the workshops were nominated by the extension officers and then invited by the research team to attend the workshops. In addition to being drawn from diverse growing districts including wet, dry and semi-tropical production environments, there was also a large range in the scale of their farming operations among the growers. This range extended from growers running small, family farming businesses consisting of approximately 50ha of cane, through to large scale commercial enterprises spanning several properties with total farming areas of 250ha and larger.

2.1.1 Part 1: Digital questionnaire

This section presents the results of Part 1 of the workshop session involving a (digital) questionnaire, in order to evaluate practices the participants currently deploy on their farms (i.e. to define a baseline). The purpose of conducting this part of the study was twofold: 1) to get an idea of whom ‘were in the room’; and, 2) to identify regional variability in practices that are common in the regions. Results from this evaluation were used to inform the final financial-economic analysis to be undertaken using the Farm Economic Analysis Tool (FEAT; Cameron 2005), which is described in detail later in this report. The results, including general background information, and the use of specific nutrient management strategies, are discussed as follows.

Background information
Of the 29 farmers questioned during the workshop-session, most farm sugarcane exclusively; although two in the Wet Topics region reported having a mixed farm with horticulture) and two in Mackay Whitsundays had a grazing enterprise. These farmers reported having between 50-75% and 75-100% of their farming land dedicated to growing sugar cane (so sugarcane is the main activity for all the farmers).

The majority of the respondents in all the regions have been involved in their cane farming businesses for more than 20 years. This was particularly the case within Mackay Whitsundays. Only one ‘small’ farmer in Burdekin Dry Tropics and one ‘medium’ farmer in the Wet Tropics are new to the industry: they have been involved in the cane farming business for less than 5 years.

Within the Wet Tropics and Burdekin Dry Tropics regions the dominant soil texture on the respondent farms is ‘medium’ (loam), with the common slope ranging between 0 and 3%. On the other hand, a variety of soil textures (light (sand)/ medium (loam)/ heavy (clay)) was observed for the Mackay Whitsundays, with four participants indicating that they have farms with a slope ranging between 4 and 9%. Flooding is not common on the respondent farms in the Mackay Whitsundays and Burdekin Dry Tropics regions, unlike the farms in the Wet Tropics. Of the total 29 farms, 9 are affected by flooding once or more times a year.

Within the Wet Tropics and Mackay Whitsundays, the majority of the respondents own their farming land, while just half in the Burdekin Dry Tropics own their own farm. On the other hand, ‘large’ growers present at the workshops typically reported a split ownership situation. In these cases, the land owner doesn’t necessarily play a key role in farming decisions. Nonetheless, a majority of the participants consider themselves as either owner or manager of the farming business and are thus primarily involved with field operations and making decisions regarding the farming business.

Two-thirds of all respondents contract out harvesting operations - being the case for 16 out of the 19 ‘small’ and ‘medium’ farms who do not possess the appropriate on-farm equipment to harvest themselves. Conversely, only four respondents contract out their fertilising operations as farmers typically do possess the appropriate equipment to perform these operations. Similarly, tillage operations are rarely contracted out.

In contrast to farmers in the Wet Tropics and Mackay Whitsundays regions, the majority of Burdekin Dry Tropics respondents reported burning their sugarcane crops prior to harvest. Half of all respondents have their farm under controlled traffic in the all three NRM regions and across farm sizes. Of the other half, 5 farmers (all from the Mackay Whitsundays) are moving towards controlled traffic while 6 are not; 4 of these suggest factors outside of their control are preventing them from moving to controlled traffic.

Nutrient management

Within all three NRM regions, almost every respondent reported having a current nutrient management plan in place, which is documented, and implemented taking the crop age, soil type, block history, and timing into account. Only 6 farmers reported that they do not document their nutrient applications. Half of the farmers in the workshops reportedly prefer to keep their records of nutrient management on paper, while the majority of ‘small’ farmer respondents keep electronic records. There are three farmers that do not keep records and four that keep electronic records and an Integrated Nutrient Management Plan.

Only one respondent from the Burdekin Dry Tropics has a fixed rate of fertiliser application for plant and another for ratoon cane that are each based on historical use, indicating that he does not consider adopting a more targeted rate of fertilizer to be worthwhile. The other farmers from the Burdekin Dry Tropics mostly use a variable rate between cane blocks, based on soil tests and plant/ratoon crop class. Similarly, all Mackay Whitsundays respondents use a variable rate between cane blocks based on soil tests and plant/ratoon crops while in the Wet Tropics they typically apply one rate for plant and another for ratoon cane based on soil tests or soil type. The majority of farmers are also considering adopting a more targeted rate of fertilizer, especially the ‘large’ farm demographic in Mackay Whitsundays, who are considering whether to move to variable rates within blocks. The respondents who don’t consider adopting a more targeted rate of fertiliser use (10 in total) state that they have trialled this practice before, but chose not to adopt it.

With regard to timing, the majority of the Burdekin Dry Tropics respondents apply fertiliser at rates relevant to crop stage (class), irrigation, and weather conditions. In the other regions, some use seasonal forecasting to determine the timing and rate of fertiliser applied along with the crop stage and weather conditions. Others take crop class and weather conditions into consideration; some look at the weather only.

The majority of respondents do not split their fertiliser applications, i.e. apply fertiliser more than once in ratoon crops. Mostly split applications are made to plant cane and a single application to ratoons. All respondents, ‘small’, ‘medium’ and ‘large’ in the Wet Tropics, perform a single soil test per block per crop cycle. In Mackay Whitsundays, only the ‘small’ farm respondents practice this kind of soil testing regime, whereas farmers with ‘medium’ and ‘large’ farms test within blocks based on soil/EM maps every crop cycle. Just two respondents from the Burdekin Dry Tropics perform single soil tests. Among the farmers that practice a single test per block, the majority are not planning to change this soil testing regime. 12 respondents perform multiple soil tests within blocks based on soil/EM mapping every crop cycle.

There is variation between regions but not between farm sizes in regard to the calibration of fertiliser applicators. Respondents from both the Burdekin Dry Tropics and Mackay Whitsundays calibrate their fertiliser applicators for each product and each batch, while those from the Wet Tropics calibrate once per season for each fertiliser product. Generally speaking, most of the participating farmers do not plan to adopt a more frequent calibration regime for their fertiliser applicators.

Planting a legume break crop in the fallow is quite common among the workshop participants (83%). Moreover, it turns out that the five farmers who are not presently doing it plan to do so in future. The common practice among these participants is to mulch the legume crop prior to planting, spray it out or otherwise harvest it, and to incorporate the residue into the soil just prior to planting sugarcane (12 farmers). Less common is to follow the same procedure, but incorporate the residue more than one month prior to planting sugarcane (7 farmers). The farmers who plant a legume break crop in the fallow also adjust the nitrogen rate in the subsequent plant cane crop.

62% of the participants apply fertiliser in the plant cane crop sub-surface beside the stool and 24% apply in sub-surface within the stool (or fertigate). The remainder broadcast the fertiliser and liquid fertilisers are hardly used. The 'large' farm respondents mainly apply fertiliser sub-surface beside the stool.

2.1.2 Part 2: Financial-economic indicators

During the second part of the workshop, a set of questions were put to the respective groups in order to identify regional differences and financial-economic indicators related to farm size for a range of management practices, specifically those aspects relating to nutrient and soil management. These indicators consisted of: 1) various cost elements regarding inputs, labour, capital, and transition costs; 2) product choice and rates; and 3) type and size of implements required.

The results from this group-based, open-ended enquiry have also been used to inform the final financial-economic analysis to be undertaken using the FEAT spreadsheet, which is described in detail later in this report.

2.1.3 Part 3: Semi-structured interviews[2]

A series of semi-structured group interviews were conducted with cane farmers (n=22) and agricultural extension officers (n=5) during six of the workshops undertaken across the three cane growing study regions. Authors also captured dialogue amongst growers and between researchers and growers during the other components of the workshop (Parts 1 and 2

[2] The collection of data that informs the preliminary analysis presented below was conducted in collaboration with the **Component 3** researcher team. As such it is tailored to the context and needs of that work. This same analysis however is also designed to inform and complement the research methods conducted under **Component 4** of the project and should also be viewed in that light.

above) where discussions these discussions were relevant to or could inform data gathered during the interviews. This material was captured by note taking and is therefore referred to in the following analysis as authors' field notes.

The semi-structured interviews ranged from approximately 40 to70 minutes. Questions focused on participants' perceptions of, and experiences with, changes in their farming operations and their experience with participating in government programs such as Reef Rescue. While questions were varied to suit the context and flow of the discussion in each of the particular group interviews, the basic question structure included the following aspects:

1. When a new practice or technology is being promoted in the district, how do you judge for yourself if it is worth doing or how it might benefit your operation? How do you weigh up any risks?
2. If there was financial or technical support being offered from outside groups to help with the change, would it matter who was offering that support [e.g. governments, catchment groups, industry groups]? Would that influence your decision to apply? For what reasons would you not seek that outside support?
3. In your view, are programs like Reef Rescue matched to local growing conditions or ways of farming in the district?
4. Do you think governments are committed in the longer term to support farmers to produce cane in a cost effective and/or environmentally sustainable manner?

The interviews were digitally recorded and then transcribed, and coded for meaning with the assistance of a qualitative analysis software package (NVivo). The themes from the analysis are presented below, including some extracts from the transcripts to illustrate these major themes and provide evidence.

Theme 1: Who's paying and why

The interviews underscore the importance of distinguishing between the initial reaction of farmers to a given program, and their position during later stages of program implementation. There was some confusion amongst farmers, particularly in the early years of the program, about where the money for the incentive payments was coming from. In some cases this translated into perceptions of risk that growers might be 'opening themselves up' to greater external scrutiny or intrusion by governments. An Ayr grower placed the existing incentive-based program in historical and political context to describe why some growers were tentative in the early years of the program and why that feeling may still persist:

> *…over the last 20 or 30 years, governments of all persuasions have come to cane growers and other rural bodies and said we want you to make a change - or here's some money, but here's its strings… and we have learned that the strings have cost us much more than the little bit of money that they've offered us. So - there has been a real fear of "I'm not going to take that money because - what's the hidden cost". There are still people that won't take Reef Rescue money because for that reason - I don't want to have to open my books up.*

Participants noted that the Queensland State Government was introducing new prescriptive regulations at the same time the incentives program was being designed by the

Commonwealth, regional bodies, and industry partners. This also added to latent levels of mistrust and confusion amongst farmers:

> *…over the years too, DERM (State Government) and the Reef Protection regulations - I think that has probably fuelled that fear as well. There's people I know in our region - there's mistrust out there.*

When asked about the source of the funds - and if it had mattered who was administering the incentives - a common position, now some years into the program, was that it mattered little to their participation in the program where the funds came from. As for the role of regional bodies, farmers perceived these entities as 'working for the government' or an 'extension of government'. In some regions the regional bodies seemed to be largely invisible to growers who were working through 'local' intermediaries such as industry and extension networks to apply for the funds. A Tully grower described it this way:

> *At the end of the day they [regional bodies] still count as government…they're still getting paid by the government - they're just doing it under their name. They are the organisers.*

A number of interviewees expressed concern about taking money from private sector actors (e.g. agri-business or fertiliser companies) to help trial or implement new techniques. Some growers had a view that these companies would 'want something' for providing financial support and that motive may not be aligned with a grower's own interests:

> *Well put it this way, if it's government's all right then you might get something but - if private to do it - it's got to be something for him to…(Tully grower)*

The exception here was a small number of growers who were active in the Catalyst project, where private sector support for 'grower-led innovation' was seen as a major benefit of this kind of funding over more restrictive conditions of public funding. Generally, however, public funding was preferable to private sector sourced funds for improving farming practices.

Growers were also often uneasy and even antagonistic about the explicit goals of the Reef Rescue program being oriented towards environmental water quality in coastal and offshore environments – rather than having goals related to more profitable farming:

> *it's always good to see [the results of trials] – like I said I'm a results person – I like to see, yep, we're growing two tonne to the acre better because we did this; whereas the Reef Rescue never really – it was all about the reef (Tully grower)*

This unease about the program goals has not appeared to hinder the farmers' participation in the medium to longer term. Many farmers suggested that the cost-sharing approach of the program went some way to dispel their concerns about the predominantly environmental focus of the program. In pragmatic terms, they accepted the funds would result in access to improved farming equipment for their businesses.

Theme 2: Cost-sharing, equity and reward

There were three significant lines of argument made by farmers in relation to the design of the incentives instrument. The first related to efficacy of the incentive to encourage farmers to implement a new practice earlier than they would have otherwise:

> *We would have probably eventually done things we've got Reef Rescue funding for, eventually, but with the funding it's probably brought it forward and got it into practice probably a bit quicker than if we were trying to fund it all ourselves (Ayr, grower).*

This capacity of the incentive-based approach to bring the decision forward was central to the intent of the program. Farmers described the incentive as a 'catalyst' or 'opportunity' and that it had 'sped-up' the pace of change. One farmer commenting on the capital costs associated with upgrading equipment for improved herbicide use:

> *If it hadn't been for Reef Rescue we wouldn't have gone near it [upgrading the equipment] – it's too expensive (field notes)*

There was broad acknowledgement, however, that the cost-sharing approach still required farmers to contribute the other half of the cost of upgrading. One Mackay grower commented:

> *In the end we can't pass any of our costs on. The costs are ours - the cost of production is always ours. If we can grow it with less cost inputs then we've [improved]. We've spent a lot, a lot of money to try and better our practices. Admittedly Reef Rescue has contributed but we still put in a lot of our own money in as well. The limiting factor on why people aren't taking it up is not because they don't; agree with it… they just haven't got the dollars disposable to them to put their share into it.*

The second common argument made during group interviews was (mostly) amongst those who had not applied or had been unsuccessful in their application. These farmers asserted the importance of improving access to financial support under the program and emphasised the need to distribute the funds fairly across the industry or district. These claims were linked to particular preferences for 'group-based' extension or trialling of new practices, rather than direct payments to individuals (discussed below).

The third argument was that, whilst the incentives were effective at encouraging adoption (or at least program participation), they did not reward or compensate those growers who had already adopted target technologies or practices in previous years [or in program speak were undertaking 'A' level practices already]. One indicative example of this view from a Tully grower was:

> *[Government funds] a lot of stuff we probably have done off our own backs and you see other people getting money for it. It's no different than when you get disaster funding from the federal government - the bloke, because he managed his property,*

he does everything right, he misses out. They're the sort of things that do let you down.

Theme 3: The role of local advisors and ongoing support

The group interviews also pointed strongly to the importance of local advice and support networks in securing farmer participation in the incentives program. These local relationships between framers and extension service providers or other industry networks were critical to establishing trust, particularly at the outset of the program when concerns over environmental regulations were heightened. The importance of locally credible and knowledgeable advisors to gain acceptance of an initiative in the community was expressed by a Mackay grower:

> *Well I think they've got to understand the sugar industry. It can't be somebody from the university or from a government department down in Sydney or Canberra or wherever it might be. They must understand the sugar industry and have all the checks and balances and things like that. I don't have a problem with that. I'd probably find it difficult if I was talking to somebody from Canberra who didn't know the back from the front of the sugar industry. We're unique people - our business is unique.*

It was clear from several comments made by growers in each of the regions that extension staff was closely involved in the development of the applications made by growers for funds. This involvement included preparing the paperwork, advising and even writing the content of the application to ensure it had the best chance of success:

> *Yeah we do get paperwork - for the last couple of ones [applications] we put in were the easiest ones yet because I only needed to sign my name on it really (Tully grower)*

Growers also commented on the negative impact that short-lived government programs or industry initiatives can have on the ability of growers to maintain a newly adopted practice or change to the farming system beyond the initial uptake of the practice. The following perspective from a grower highlights this tendency for programs to under-emphasise the broader or medium term requirements that arise following initial change on farm:

> *We [growers] often go into things and suddenly find that it's no longer flavour of the month and we are into it and we just lose the support. There's no doubt in my mind these things do need support. For example, with [the yield- decline joint venture] I really think we stopped it too early, because had we gone into it - this is a new farming system - is that there are problems with harvesting for example. I think we needed support on how to get around that.*

Theme 4: Influence of collective structures and economic cooperation

A number of constraints to farmers' participation related to social and economic structures beyond the individual farm unit. These included relationships between farmers and contractors, harvesting groups, peer to peer relationships, or other forms of actual or potential local economic cooperation.

Commenting on the practical issues of moving to precision herbicide application methods (such as banded spraying, hooded sprayers, or variable rate controllers) one Tully grower stated:

> *…there's not many contractors getting round with that sort of equipment so if you want to do it you've got to have the equipment yourself.*

A second Tully grower also commented on how relationships with contractors might limit some growers' ability to shift to newer types of controlled traffic farming promoted under the Reef Rescue program, for instance:

> *Well, I remember going to the last meeting of the latest Reef Rescue [funding] round and other farmers [burred-up] at this because the bloke mentioned that preference would be given [to applications proposing to shift to 1.9m row spacing] – he was only spouting out the truth but a lot of blokes stood up and said well, we're wasting our time coming here because we don't want to go with 1.9 metre controlled traffic because there's a limited amount of contractors in the area that plant 1.9, so, especially the small farmers can't afford to buy the harvester and billet planter to go to 1.9 because you can't use a stick planter so they're obviously ruled-out of the grant system straight up!*

Another grower, this time from the Ayr district, described some of the constraints imposed by working within harvesting group structures:

> *…for example, change in row spacing from 1.5, which is the convention and we harvest our cane in groups. One of [the group members'] biggest complaints about doing what he did, he's gone further than most of us have, was getting his harvest operator to be able to harvest it, because he's only one farm amongst five or six in the group.*
> *In our group, we went the whole way - all of us went the same way and we had our own harvesting group. Now that started to fall apart a bit, some other people did some change in ownership and young fellows coming on. I didn't realise this, but the other day, one of our blokes was debating strongly whether he was going to go back to five foot [rows] and one of the reasons he mentioned he admitted was, he didn't want to get hung out suddenly finding he was the only person to get his cane cut in a group he wanted to be in that was 1.83, which is difficult to do with a five foot harvester. Easy to harvest five foot row spaces with a 1.83 harvester, the other way round is a bit more difficult. He saw that as a hell of a problem and I hadn't thought of that, because blindly I was heading down the track the rest of us will, somehow we'll handle it. But that was a real issue for him.*

Another grower, in a separate discussion, suggested a model of government financial support that was more responsive to the collective economic and social character of the industry. In this case, the approach involves managing the business risk associated with changing practices and financial risks associated with capital expenditure through government-backed commercial trials:

For example if you're being encouraged to move to 2.4m rows government could underwrite a commercial scale trial as it's likely to be the bigger farms that do it. Need to get groups of growers involved, not individuals, so they can afford to (collectively) buy the new harvester and haul-outs to match. If it works then growers can buy the governments share out – because we can see the returns. Then the middle size guys would see it working and get their group to go. (field notes)

These ideas of collective risk-sharing and more collaborative approaches to trailing and learning in the industry was also emphasised, perhaps unsurprisingly, by extension officers who participated in the interviews. For instance, one extension officer commented on the benefits that might accrue through more support for peer-based learning approaches to program design:

That's how we learn. Growers learn from each other - they learn from one grower to another. I think if the government wants to change [its] program, then find some more support and expert [knowledge] and then support [the grower]to do some trials and once we prove it and we make some money, then pass it to other growers… then there's no middle man. It goes straight to the growers.

Another grower, in the Tully district, also described how improvements to the Reef Rescue program might be made through more collective approaches; but this time, emphasising the role of local information service providers and the benefits of more equitable access to the funds:

One thing that I think should possibly happen with the funding to spread it around more would be better if it went to like a group, so the BSES or someone to work with farmers so they could build something and try that as a group so that everyone can have access to it, so that, it seems to be, and I know my father's got a couple of the grants, but a lot of people don't – it seems to be the same people get the grants – a couple of different ideas to get a better benefit and then done with the BSES cooperation, or pest board cooperation seeing the results from the trials.

There was also a persistent, but often subtle theme in growers' responses to several of the questions that underlined the social risks or undesirability of being out of step with the norms of farming and timing of farming operations in their districts. For example, if a grower decided to delay an operation for environmental reasons or do something different that resulted in a delay, one grower commented:

…it's pretty difficult for example to sit around and watch everyone else around you planting and you're waiting on a planter to come (field notes)

Summary of interviews

This analysis identified several factors that are influential in the decisions of growers to participate in the incentive-based programs such as Reef Rescue that support adoption of specific best management practices that contribute to off-site water quality benefits. These factors broadly include: i) the source and goal-orientation of funders; ii) the presence of cost-sharing arrangements, and the role of social reward and recognition; iii) the importance of local trusted advisors in providing the information networks and practical support to apply for the funds in decentralised program implementation; and iv) the often constraining influence of existing local economic relationships between growers and their contractors and harvesting groups, which is not accounted for in program design.

2.2 Data Collection Part 2: Review of farm financial and production data

Based on results from the participatory workshops described earlier (Data Collection Part 1), as well as through the collection of regional specific farm financial and production data through agribusiness, agronomists, and industry organisations, and previous research (Paddock to Reef M&M Metrics, MTSRF 3.7.5, CSIRO's RWQO project, Reef Rescue ABCD Framework and Industry BMP Guidelines), a number of key principles and corresponding practices were identified as having the potential to improve water quality (or facilitate this process). These practices are summarised below in Table 1.

As Table 1 illustrates, the method of analysis involves the integration of data from several models. Accordingly, the Agricultural Production System Simulation model (APSIM; Keating et al., 2003) was used initially to determine variation in production (yields) as a consequence of operating the farm under various combinations of management practices, on specific sites within each of the regions. APSIM provides a basis for measuring the resulting environmental consequences using Dissolved Inorganic Nitrogen (DIN) and plot scale soil loss as proxies. Using the production data outputs from the APSIM modelling, the FEAT spreadsheet was subsequently used to calculate farm gross margins under various combinations of management practices. Both the APSIM and the FEAT modelling are explained in detail in the following sections (Data Modelling Part 1 and Part 2).

Table 1: Identified sugarcane nutrient and soil management practices.

Key Principle/ Activity	Practice	Code	FEAT Modelling	APSIM Modelling
Application rate management	Variable rates between blocks (based on N-Replacement theory). Calibrates once per season for each fertiliser product	AA	Y	Y
	Variable rates between blocks (based on Six-Easy-Steps). Calibrates once per season for each fertiliser product	AB	Y	Y
	One rate for plant and another for ratoons based on soil type (based on Old Industry recommendations). Calibration is less than once per season	AC	Y	Y
Fallow management	Grain legume crop	FA	N	Y
	Cover legume crop	FB	Y	Y
	Bare fallow	FC	Y	Y
Application management	Split application in plant and ratoons	SA	N	N
	Split application in plant cane only	SB	Y	Y
Application	Sub-surface application within the stool	MB	Y	Y

Key Principle/ Activity	Practice	Code	FEAT Modelling	APSIM Modelling
method	Surface application banded	MC	Y	N
Application timing	The use of climate forecasting along with crop stage, irrigation and weather conditions	TA	N	N
	Crop stage, irrigation and weather conditions	TB	N	N
	Weather conditions only	TC	N	N
Record keeping and planning	Electronic records, mandatory requirements and NMP	RA	N	N
	Electronic records and mandatory requirements	RB	N	N
	Paper records and mandatory requirements	RC	N	N
Tillage management	Low (reduced) tillage	GB	Y	Y
	High (conventional) tillage (assuming 1.8m row spacing)	GC	Y	Y

Each of the key activities that are managed within a whole farm system is outlined in Table 1. It is noted that while individual activities can change within a particular farming system, a system generally cannot operate without the full set of these activities. For instance, growing a crop requires the landholder to fertilise it at a certain application rate (coded prefix letter A) that may be applied at the surface or sub-surface level (coded prefix letter M) in either a single or split application (coded prefix letter S). The landholder must also decide how to manage their fallow (coded prefix letter F) and cultivate the land with more or less operations (coded prefix letter G). The suffix codes, A, B and C, reflect the class rating of the practice in terms of its perceived potential to improve water quality outcomes. It should be noted that an A class rating represents a higher degree of risk to the landholder because they are not commonly undertaken on a commercial basis in the sugarcane industry. Due to practical restrictions on the modelling, not all of the identified practices listed in

Table 1 have been included in the analysis. Accordingly, each of the disregarded practices is highlighted in grey. In addition the management practices modelled in this project are only one of a range of possible scenarios that could equally suit each management class. From a policy perspective, it is important to note that the results in this report are not prescriptive of every landholder. The following section outlines the procedure followed to collate and integrate the results of the modelling as well as providing specific details about the subsequent financial-economic analyses. [for me, it would be better to identify activities by a number and the management option by a letter]

2.3 Data Collection Part 3: Farmer workshops 2

In order to gain an understanding of the (perceived) limiting factors regarding the adoption of certain management practices, landholders were surveyed to quantify their perceptions. The survey forms were distributed to sugarcane growers at 6 workshops held in the Mackay Whitsundays catchment (workshops were also held in the Wet Tropics and Burdekin Dry Tropics but the results are not presented in this report). Specifically, one workshop was held in Koumala, one in Sarina, two in Walkerston and two in Proserpine. These workshops were run by researchers from component 4 of this project. For results and specific detail not described in this section, refer to the report by Harvey et al. (2013).

The structure of the survey allowed for the collection of socio-demographic characteristics of participants, as well as information regarding current management practices used within their farming systems (for the practices of interest see Table 1[3]). In particular, two questions were asked in order to identify the participant's perceptions regarding the impact of certain practices on elements of the landholders' enterprise (Q46), as well as any limitations to the adoption of certain practices (Q47). The results from this work should be read in conjunction with the financial-economic analysis, as it provides additional insights into why farmers may or may not adopt certain practices, given that it would most likely be profitable to do so. For a full set of the questions, refer to Harvey et al. (2013).

In regard to Q46, landholders were asked to indicate, on a scale of 1 to 5, the impact that specific practices did have or may have had (depending on their specific situation) on their farm enterprise, with 1 being very poor or negative impacts through to 5 being very good or positive impacts. Table 2 shows the results of a comparison between means, whereby landholders are separated into two categories: adopters (Ad.), and the non-adopters (Non-Ad.).

Table 2: Impact of specific practices on the cane growing enterprise – Comparison of means.

	Costs of production		Cane production		Risk of lower yields	
	Non-ad.	Ad.	Non-ad.	Ad.	Non-ad.	Ad.
AA (Variable nutrient rates within blocks)	3.7	3.9	3.6	3.8	3.2	3.6
AB (Variable nutrient rates between blocks)	3.5	4.1	3.3	3.8	2.9	3.6
FB (Cover legume crop)	3.7	4.1	4.0	4.6	3.4	3.7
MB (Sub-surface application of nutrients)	3.0	3.6	3.3	4.1	3.2	3.9
GB (Low/reduced tillage, e.g. zonal)	4.1	4.4	3.2	3.4	3.6	3.3

Note: 1 = Negative, 3 = Neutral, 5 = Positive.

The results in Table 2 reflect the general view that these specific practices impact positively on the farm enterprise: Growers gave an average score of 3.8 (out of 5) to indicate their belief that costs of production are positively influenced (i.e. reduced costs) by these practices. In addition, there was a score of 3.7 that these practices positively influence cane production and 3.4 that the risk of lower yields is reduced. Moreover, on average, adopters tended to report a more positive view towards the impact of the various practices on their enterprises compared with those that have not adopted. (There was one exception to this: the impact of moving to a low tillage system due to the risk of lower yields). Intuitively, the perceptions of those adopters that have previously implemented the changes may be regarded as a 'real' impact score, while the responses from non-adopters are indicative of a 'perceived' impact score.

[3] For practice AA, questions were asked regarding variable nutrient rates within blocks, e.g. using EM mapping. For the financial-economic analysis as well as the APSIM modelling, AA was assumed using nutrient rates based on N-replacement theory.

A parametric statistical test (Wald test) was performed to determine the probability of falsely rejecting the null-hypothesis (using a Chi^2 test) that these farm characteristics (production costs, cane production, and yield variability) are positively correlated with the adoption of a specific practice. This test is typically run using a 95% confidence level ($p\ Chi^2 = 0.05$). At this confidence level, none of the farm characteristics were found to be statistically significant in explaining adoption. By increasing the probability threshold to 10%, the test indicates that the parameter "production costs" offers a statistically significant explanation ($p = 0.06$) for the adoption of practice AB (nutrient rates between blocks varied based on Six-Easy-Steps). In other words, a reduction in production costs explains, at least in part, the adoption of this practice. The test results are presented below in Table 3.

Table 3: Results of the Wald test ($p\ Chi^2 < 0.10$).

	AA		AB		FB		MB		GB	
	Value	**p**	**Value**	**p**	**Value**	**p**	**Value**	**p**	**Value**	**p**
Production costs	0.23	0.67	**1.34**	**0.06**	0.21	0.66	0.16	0.76	0.22	0.69
Cane production	-0.01	0.99	-0.16	0.77	0.72	0.17	0.05	0.94	0.01	0.98
Yield variability	0.01	0.99	-0.04	0.94	-0.11	0.83	0.93	0.25	-0.19	0.71

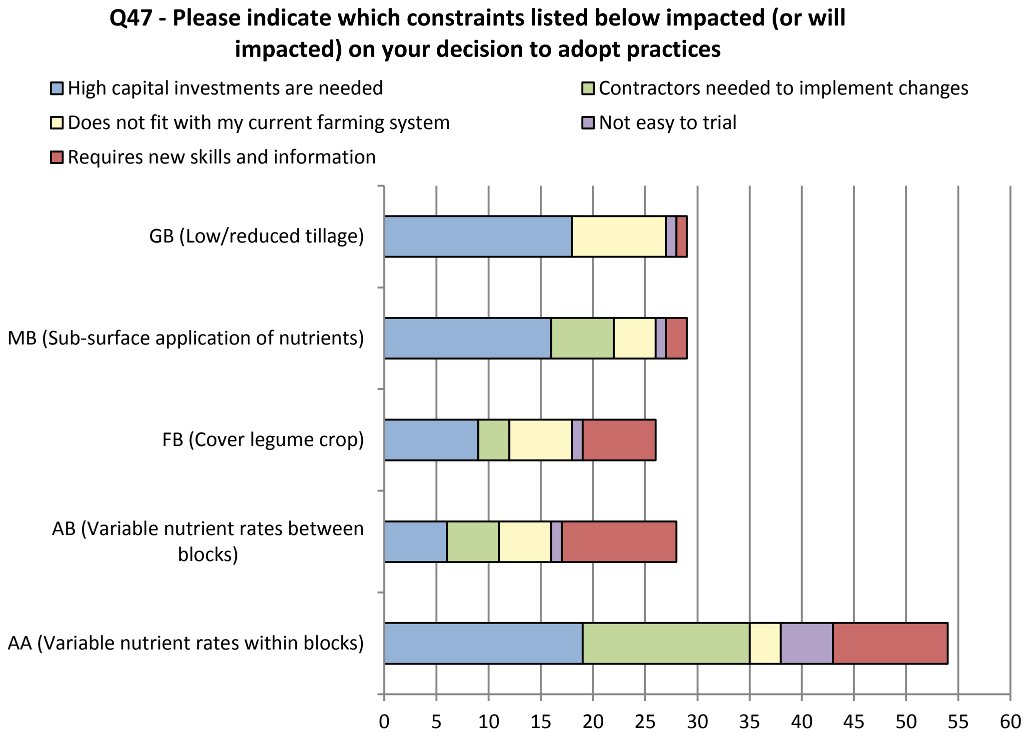


Figure 2 presents the results from Question 47, which relates to the factors considered by the growers to be constraints to adopting new practices. Again, the practices are those outlined in Table 1. In the survey, the respondents were asked to 'tick' the practices they perceived as relevant (and leave blank if not relevant). The total number of ticks and the number of ticks per constraint category are presented on the X-axis. The practices under consideration are presented on the Y-axis.

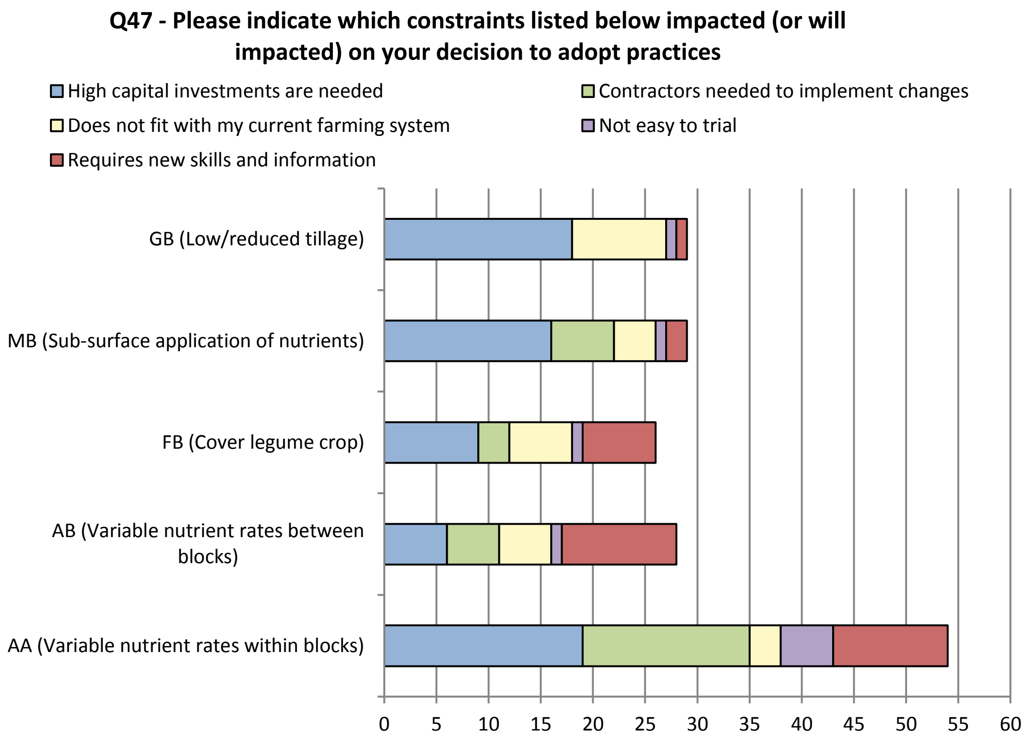


Figure 2: Management practice specific perceived limitations to adoption.

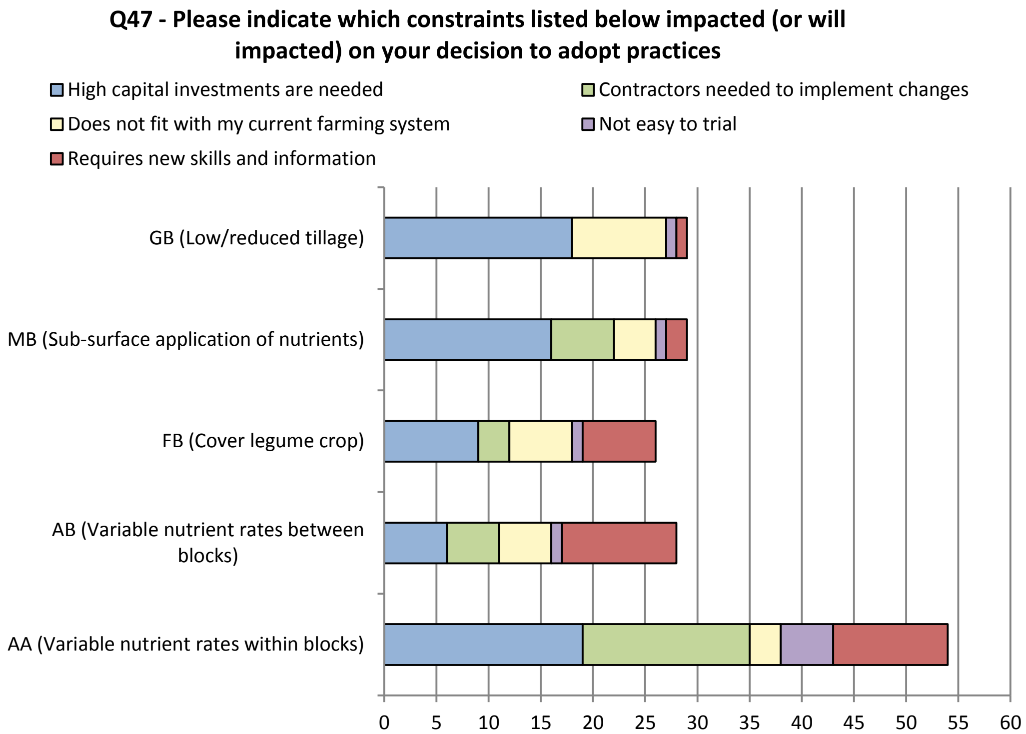


Figure 2 indicates the number of farmers who ticked each constraint. “High capital investments are needed” and “Requires new skills and information” were reported as the two most important constraints to adoption. Perceptions about potential constraints, such as “Contractors needed to implement changes”, “Does not fit with my current farming system”, and “Not easy to trial on a small area of the farm” are reportedly less important than other factors.

Table 4 shows a comparison of means using a Mann-Whitney test to test the (perception of) constraints between adopters and non-adopters. Consistent with what might Intuitively be expected, for most of the practices, this number is higher for the non-adopters than for the adopters. The exception is the AA practice, where adopters state a higher level of constraints.

Table 4: Limitations to adoption of specific practices - Comparison of means

	Average number of constraints		p-value*
	Non-adopters	Adopters	
AA (Variable nutrient rates within blocks)	1.41	**1.46**	< 0.0001
AB (Variable nutrient rates between blocks)	**0.9**	0.68	0.281
FB (Cover legume crop)	**1.1**	0.54	0.053
MB (Sub-surface application of nutrients)	**1.2**	0.7	0.175
GB (Low/reduced tillage)	**1**	0.7	0.178

* Comparison of scores for perceptions about constraints for adopters and non-adopters with a Mann-Whitney test

2.4 Data Modelling Part 1: APSIM Modelling

Cane yields and Nitrogen (N) losses for management practices considered were simulated with the APSIM (version 7.3) cropping systems model (Keating et al., 2003; http://www.apsim.info) for a combination of soils, meteorological stations and management systems relevant to the Burdekin, Mackay and Tully (Wet Tropics) regions. APSIM was used to simulate the impact of different management systems on sugarcane yield and N lost via deep drainage or runoff. This model was chosen because of its proven capability for modelling N cycling in complex farming systems including sugarcane (Thorburn et al., 2005) within the same or similar regions of Australia as this work refers to. APSIM has the capacity to represent important features of sugarcane production systems and the related environment. These features include; residue decomposition procedures to capture accurately the specific dynamics of green cane trash blanketed systems (Thorburn et al., 2001); improved nitrification and denitrification parameters (Meier et al., 2006; Thorburn et al., 2010); predictions of N in runoff (Thorburn et al., 2011b) and deep drainage (Stewart et al., 2006); and improved simulation of legume break crops used in rotation with sugarcane (Park et al., 2010).

Parameters for soil types were derived from previous experiments in each region (Table 5) and long-term historical climate data obtained for representative meteorological stations per region. Simulated N lost via denitrification, nitrate-nitrogen (NO_3-N) lost via deep drainage and NO_3-N lost via runoff was provided as annual totals. The simulated yields based on historical climate data, were compared with regional average yield production for the last ten years in each region to ensure predictions were consistent with local experience.

Table 5: Details of the soil types collected from detailed experimental work and soils reports in each region

Region	soilCode	Soil type	Experi-ment location	Reference	Maximum available water (mm)[1] (whole profile)	Drainable water (mm)[2] (whole profile)	Lower limit of plant available water (m^3water/m^3soil) (0-300 mm)	Total carbon (%) (0-300 mm)	pH range (whole profile)	C:N (0-300 mm)
Burdekin BRIA	bh-01	Medium Clay	19°51'S, 147°11'E	Thorburn et al. (2011b)	148	166	0.25	0.9	6.3 – 8.9	15
Burdekin DELTA	bk-03	Silty clay loam / light clay	19°33'S, 147°27'E	Thorburn et al. (2011b)	162	199	0.23	1.1	7.8 – 8.1	17
Mackay (MWS)	mk-03	Heavy clay loam	21°12'S, 148°57'E	Masters et al. (2008)	148	174	0.13	1.2	6.0 - 7.5	12.6
Tully (WT)	tu-02	Silty clay loam / clay loam	na	Cannon et al., (1992)	203	130	0.22	1.2	5.0 - 6.0	12.2

[1] Maximum volume of water held by the soil between the drained upper limit (or field capacity) and the lower limit (water retained at a pressure of -1,500 kPa)
[2] Maximum volume of water held by the soil between saturation and the drained upper limit (or field capacity)

Information needed to parameterise the APSIM soil modules was obtained from previous studies undertaken in each region. Although the soils from these locations were selected primarily because of their data quality, they also represented some of the dominant soils typical in the region.

Daily climate data (maximum and minimum temperature, rainfall, vapour pressure, solar radiation and evaporation) from 1889 to 2011 were obtained from the SILO climate data archive (Jeffery et al., 2001) maintained by the Queensland Climate Change Centre of Excellence. The data are available from specific meteorological stations. Stations were chosen to represent the climatic conditions in each region based on a comparison of rainfall distribution for a number of stations with good quality long-term data. The median annual rainfall for this period was 999 mm in Bundaberg, 868 mm in the Burdekin River Irrigation Area, 999 mm in the Burdekin Delta, 1518 mm in Mackay and 3665 mm in Tully.

2.4.1 Sugarcane crop cycle

For the simulations, a general sugarcane cropping cycle was defined based on common features of production in each region. Sugarcane is a semi-perennial crop. In these regions it is generally planted in autumn (April - June) and harvested 14 to 15 months later. In the Burdekin, if a fallow grain crop was grown planting was delayed by one month and the plant crop was harvested after 13 months. The crop is then allowed to re-grow (ratoon) and harvested approximately 13 months later (harvesting season is June to December). All crops are harvested mechanically. The crop loses vigour after three to five harvests. So, for the sake of simplifying the simulations, the crop is destroyed after the fourth harvest in the Burdekin and the fifth harvest in other regions, and the field is fallowed for six months until the next sugarcane crop is planted. This sequence, planting to planting, is called a cropping cycle, with the crops denoted plant crop, first ratoon crop, etc. In the simulations, sugarcane was planted at 150 mm soil depth and all crop residues were retained on the surface after harvest except in the Burdekin where residues were burnt.

2.4.2 Management practices

Three different fertiliser recommendations were used (see Table 1) in the simulations. Firstly, the “N-replacement” strategy (Thorburn et al., 2004; Thorburn et al., 2011a) where the amount of fertiliser N applied with the N replacement strategy (NREP) was 1.0 kg N (tonne of cane)$^{-1}$ removed in the previous harvest or 1.3 kg N (tonne of cane)$^{-1}$ in the case of a burnt trash system as used in the Burdekin simulations. Secondly the current industry nutrient recommendation (known as “Six-Easy-Steps”; Schroeder et al., 2010) was also investigated. The “Six-Easy-Steps” (N6ES) system uses soil specific nutrient guidelines based on the soil carbon content amongst other factors to determine N application rate. Thirdly, the historical industry nutrient recommendations for each region were included.

The period between crop cycles consisted of either a bare fallow or a legume crop which was treated as a ‘cover’ crop. The purpose of having a legume crop instead of a bare fallow was to provide the benefits of a ‘break crop’, such as improved soil health and increased yields of subsequent sugarcane crops (Pankhurst et al., 2005). In Tully a cowpea crop was planted rather than a soybean in the fallow. The ‘cover’ crop was allowed to ‘die’ or was ‘killed’ in the model (to represent application of herbicides). Thus, crop residues were left on the soil surface. Since this residue would contain substantial amounts of N, potentially more than the N requirements for a sugarcane plant crop (Park et al., 2010), the amount of fertiliser N applied to the ‘plant’ crop was reduced. In the case of the NREP strategy the rate was reduced by the amount of N in the fallow crop residues returned to the soil surface. While the N6ES N application was reduced by 90 kg N ha^{-1} per additional 2 Mg above-ground soybean biomass (BSES, 2008; DERM, 2009). In all scenarios a minimum amount of N (25 kg N ha^{-1}) was applied due to unavoidable additions due to fertiliser blends commonly used in a region at planting.

Two tillage levels for the purposes of residue incorporation or weed control were simulated. Controlled traffic management (Drewry et al., 2008) was included in the simulations which are designed to reduce soil compaction and improve infiltration. In controlled traffic farming, sugarcane is commonly planted in dual rows (0.8 m apart) into permanent 2 m beds. Controlled traffic was simulated through a reduced Curve Number. There is evidence that controlled traffic management together with a fallow break crop increases crop yields by ~5% in the Mackay-Whitsunday region (Garside A., pers. comm.). The mechanisms behind these yield improvements is uncertain, and in the face of this uncertainty we represented the improved crop growth in controlled traffic management scenarios by increasing radiation use efficiency by 5 % in APSIM-Sugarcane.

2.4.3 Model description

The APSIM model was configured with modules for soil N and C (APSIM-SoilN; Probert et al., 1998), soil water (APSIM-SoilWat; Probert et al., 1998), sugarcane growth (APSIM-Sugarcane; Keating et al., 1999), soybean growth (Robertson et al., 2002) and sugarcane residue (within APSIM-SurfaceOM; Probert et al., 1998).

All modules are one-dimensional, use a daily time-step and are driven by climatic data. The dynamics of water, N, C and roots are simulated in soil layers. The soil water module (SoilWat) is a 'cascading bucket' water balance model (Probert et al., 1998), with water (and associated nitrate) moving between layers where gradients exist. In the SoilWat module, runoff is determined based on the Curve Number approach, described in more detail below. The presence of plant residues on the soil surface affects runoff (and hence infiltration) and evaporation. Tillage also affects infiltration and runoff, and can incorporate surface residues into the soil organic matter pools.

The crop module uses intercepted radiation to produce assimilates, which are partitioned into the different plant components. These processes are responsive to radiation and temperature, as well as water and N supply. If water logging occurs, the proportion of the root system exposed to soil water condition at saturation or near saturation is calculated and used to calculate a water logging stress factor. This factor reduces photosynthetic activity via an effect on radiation use efficiency.

To ensure the outcomes of the simulation work was relevant to the region, APSIM-Sugarcane parameters controlling crop lodging and rooting depth were set so that the predicted long term average sugarcane yield (and hence crop water and N uptake) for the conventional combination of practices (i.e. traditional fertiliser specific to the region; conventional traffic management; bare fallow; moderate level of tillage) was similar to the regional average yield production for the last 10 years. Lodging is common in sugarcane crops and reduces yields through stalk death and constraining photosynthetic activity and the production of assimilates (Singh et al., 2002; Park et al., 2005). These processes are represented in APSIM-Sugar through two factors; the first decreases stalk number after lodging, and the second that decreases radiation use after lodging. Crops were considered to have lodged when stalk dry weight exceeded 10 t ha^{-1} (Bundaberg) or 20 t ha^{-1} (Burdekin, Mackay and Tully) and daily rainfall was greater than 20 mm (Singh et al., 2002). Maximum sugarcane rooting depth varied with soil type from 0.5 to 2.0 m.

The soil was divided into six or more soil layers to a total depth of 1.5 or 2.0 m. N dynamics, as affected by soil moisture and temperature, are explicitly described in each layer. N lost via deep drainage was the nitrate flux from the lowest soil layer based on water movement and soil N concentration in the deepest soil layer. Movement of nitrate-N via run off was modelled using the APSIM-Erosion module (following Thorburn et al., 2011b). The amount of N removed from the soil was dependant on the soil N concentration and an enrichment factor parameter. The value of this parameter was set based on the experience of Thorburn et al. (2011b). The N in the top soil layer was reduced by the amount of N removed in the runoff event using the 'Profile reduction' feature in the EROSION module in APSIM. Denitrification is calculated in each soil layer as a function of NO_3^-, active C, moisture and temperature using parameters developed by Thorburn et al., (2010).

2.4.4 Parameterisation of runoff

For each of the soils selected, a Curve Number was assigned for 'conventional practice', defined as regularly tilled soil and an industry standard row configuration (single row of sugarcane planted in the centre of 1.5 m wide beds). For most of the soils, the curve numbers for 'conventional practice' were based on soil texture (USDA, 1985). For the heavy clay loam in Mackay, the curve number was determined by simulating measured runoff from that soil under different tillage practices (Masters et al., 2008). In the Mackay region, controlled traffic has been found to reduce runoff by 40% compared with conventional management (Masters et al., 2008). To parameterise this reduced runoff, the experiment of Masters et al. (2008) was simulated with APSIM and the Curve Number parameters calibrated for this management. The result was that Curve Number was reduced by 15% compared with the 'conventional practice' treatment. The same proportional reduction in Curve Number was applied to the other soils simulated.

Many of the tillage operations that are used during sugarcane production not only incorporate surface residues but also increase infiltration by disturbing the soil surface. In APSIM, the effect of tillage operations on infiltration can be represented by changing the Curve Number following tillage, with the extent of the change dependent on the 'severity' of the tillage. Three levels of impact of tillage on infiltration were identified, with tillage operations classified as;

- low impact, represented by no change in Curve Number; or,
- medium impact, represented by reducing Curve Number by 15 and gradually restored to the original value after 200 mm of rainfall, or
- high impact; represented by reducing Curve Number by 50 and restored to the original value after 1300 mm of rainfall.

The definition and parameterisation of these impacts was based on previous simulation of runoff in sugarcane production systems (Thorburn et al., 2011b).

2.4.5 Simulation analysis

Simulated N lost via denitrification (kg N $ha^{-1}yr^{-1}$), nitrate-nitrogen (NO_3-N) lost via deep drainage (kg N $ha^{-1}yr^{-1}$), NO_3-N lost via runoff (kg N $ha^{-1}yr^{-1}$) and sediment loss (t ha^{-1}) were provided as annual totals. Cane yields were also simulated and provided as yield at harvest. To ensure on any given year all stages of a crop cycle (i.e. fallow, plant and each ratoon) were represented the simulations were started on six different years (referred to as start years; 1902 - 1907).

2.4.6 N-losses

For all analysed management practice combinations, Figure 3 and Figure 4 show whisker-box diagrams for N losses, the environmental indicators analysed within this project, including the average values, for the Mackay Whitsundays region. The boxes represent the 25% above (2Q Box) and 25% below (3Q Box) the median value. The difference between the average (mean; represented by the diamond in this graph) values and the median (50% chance of occurrence based on the available data) values indicates that there is substantial skew within the data (the presence of outliers cause the distribution to be non-uniform). A full list of graphs presenting the environmental indicators for all regions can be found in Appendix 2.

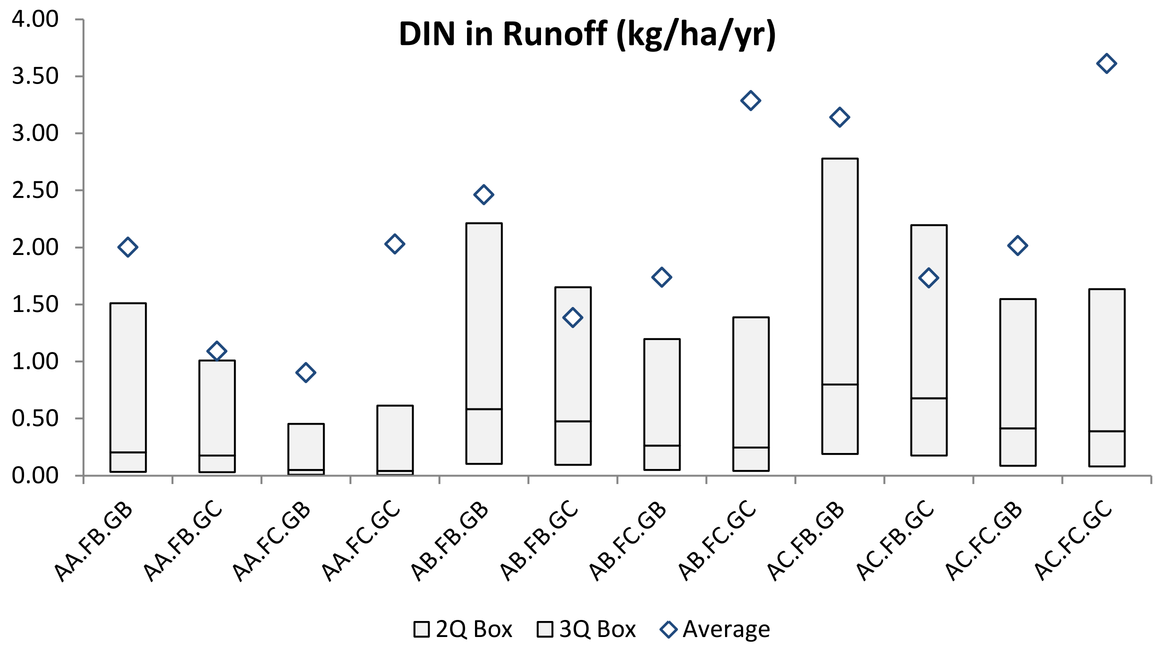


Figure 3: Nitrate in Runoff (kg/ha/yr) for Mackay-Whitsunday region.

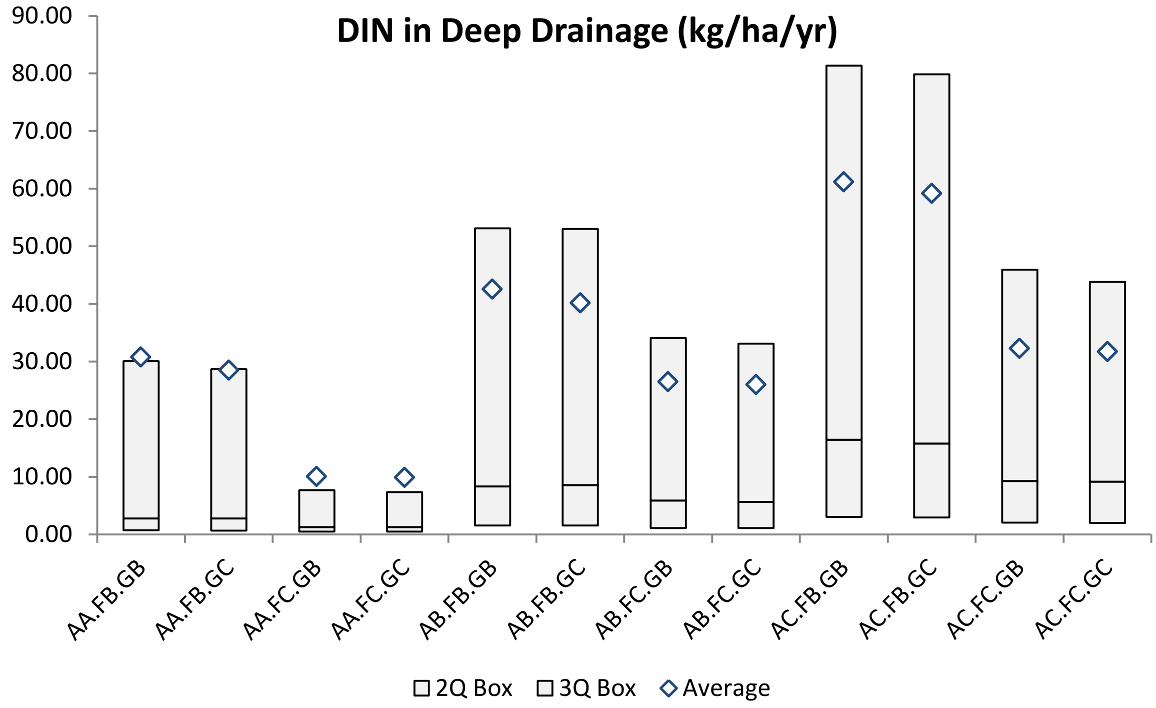


Figure 4: Mackay Whitsundays Nitrate in Deep Drainage (kg/ha/yr).

From the figures showing N losses in the Mackay Whitsundays region, we can see that the main driver for N losses is the N Application rate, where application rates based on the N-replacement strategy (AA) have the lowest amount of N available to leave the system. These are followed by application rates based on Six-Easy-Steps (AB) and application rates following Old Industry’s recommendations (AC). Furthermore, fallow management seems to have substantial influence on the N available to leave the paddock, where more N is available in the system after growing a legume crop (FB). It must be noted that any benefits to soil health from growing a legume in the fallow and its potential for improving yields were not analysed in this project. In the Mackay Whitsunday region (Figure 5), a small benefit of minimum tillage over conventional tillage was only apparent when a bare fallow was used. However when a legume was grown during the fallow many of the more severe tillage events typically used to manage weeds and prepare planting beds during a bare fallow were not required. In fact the first conventional tillage event of any significance to N loss would not occur for many months after the legume fallow ceased. In contrast a minimum tillage system incorporates residues via a tillage event only once within a crop cycle and this occurs only 10 days after the legume crop has ceased. The timing of residue incorporation in relation to seasonal rainfall and crop cover could affect N losses. Another facet to this varying effect of tillage on N loss seen here is that higher levels of tillage within the simulations will temporarily increase infiltration resulting in less runoff and hence less N lost via runoff and also improve drainage in the soil surface which is the source of the majority of N lost via denitrification. Another factor that maybe contributing to this would be that the size of the legume crops may vary according to the management system and hence return differing amounts of residue and N to the soil surface prior to the sugarcane planting.

Figure 5 shows the average N losses from various management practices via the different pathways (runoff, deep drainage, and denitrification). For this region, deep drainage is the pathway through which most N leaves the paddock. This is the case for most regions, except the Burdekin River Irrigation Area, where denitrification is the pathway of greatest loss (see Figure 29, Appendix 2).

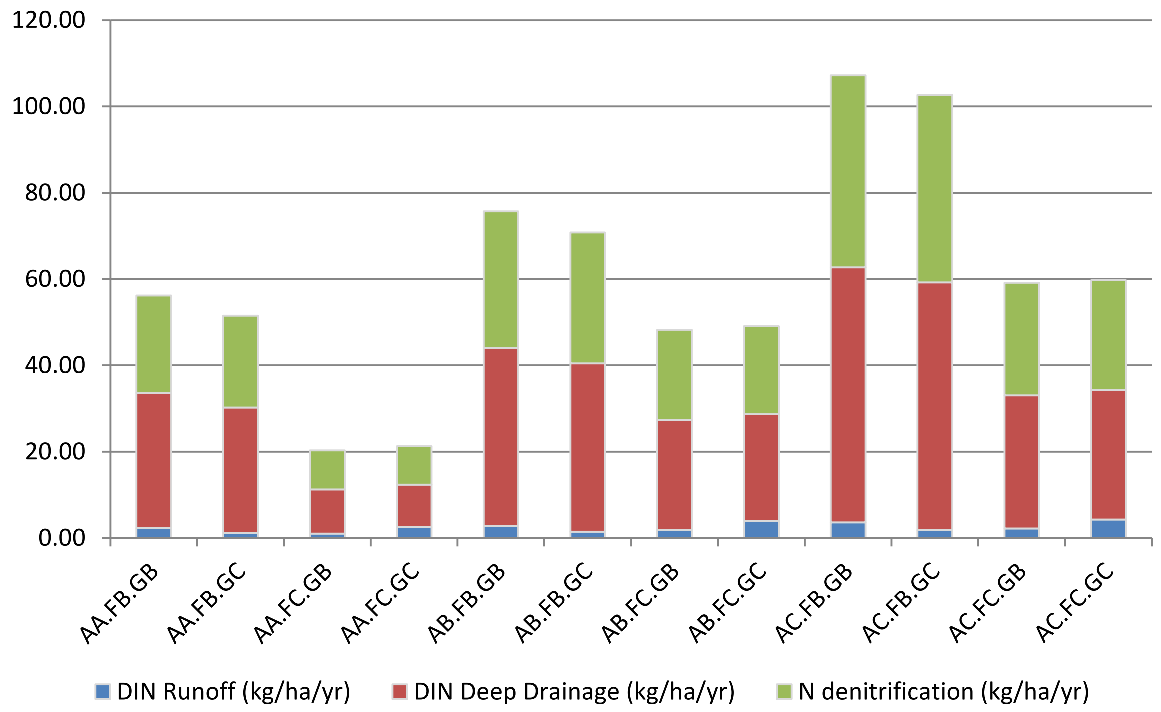


Figure 5: Average N losses from various management practices via the different pathways (runoff, deep drainage, and denitrification) for the Mackay-Whitsunday Region (kg/ha/yr).

For the cost-effectiveness estimates in this project, we look at the combination of dissolved inorganic N (DIN) in runoff as well as in deep drainage. Since we only use farm gate (paddock) estimates, we do not take any catchment scale delivery ratios into account.

2.5 Data Modelling Part 2: FEAT Modelling

The procedure in carrying out the financial-economic analysis was two-fold. First, after integrating the production data from the APSIM modelling, the annual Farm Gross Margins (FGMs) were calculated for representative farms under various combinations of management practices using the FEAT spreadsheet. The difference between each calculation quantifies the implications for farm cash flows when changing to improved management practices (from a water quality point of view). In this study, we are focussing on the marginal change in cash flows and therefore fixed costs (excluding permanent labour) are not considered in this analysis. Second, these results are subjected to an investment analysis using the Discounted Cash Flow (DCF) method to determine the Net Present Value (NPV) of specific farm changes. In order to standardise these values for reasons of comparison with the environmental data, the Equivalent Annual Annuity (EAA) method is applied to determine the Annualised Equivalent Benefit (AEB). Details of the specific methods used in the economic analysis are explained further in Poggio et al. (2014), which provide a rigorous derivation of the capital budgeting framework underpinning this work.

2.5.1 Farm Gross Margin Analysis

Profit is the fundamental measure of economic performance at a farm level. Profitability indicators measure the relationship between revenues of the farm enterprise and the costs of the inputs (resources) required to produce its output. The Farm Gross Margin (FGM) is a common economic measure used for evaluating the financial performance of farming activities. The gross margin is the marginal income derived from production once variable costs have been deducted from gross revenue. The gross margin is a particularly useful guide when evaluating the financial impact of farming system adjustments. It is, however, only a relative concept of profitability as it does not take overhead costs into account.

The change in the FGM essentially provides a measure of financial performance that is independent of the effects of financing and accounting decisions (such as capital structure and the treatment of depreciation for tax purposes) of which are beyond the scope of this project. Hence, this relative change is used to gauge the financial-economic implications for farm profitability when adopting a new system of management practices that does not require additional capital expenditures on land or fixed capital. The financial-economic implications arising from the purchase of new capital items required to implement changes within the farming system is described further on in this report.

The FGM analysis involves constructing multiple representative farm scenarios using the FEAT spreadsheet. In total, 288 different scenarios were built according to the following schema:

4 regions (Wet Tropics, Burdekin Delta, Burdekin River Irrigation Area, Mackay Whitsundays) x 3 farm sizes (small, medium, large) x 24 practice combinations (3 rates x 2 fallow options x

1 split option x 2 surface/subsurface application options x 2 tillage options; see Table 1) = 288 FEAT files.

Parameters and assumptions

Since each farming business is essentially unique, the generalised parameters and assumptions used in this economic analysis may not necessarily reflect each farm's particular circumstances. Some landholders may have higher or lower costs of transitioning to improved practices and some landholders may end up with higher or lower gross margins that those provided here even if similar operations are practiced. However, the consideration of these particular circumstances is warranted in order to make an informed investment decision at the individual farm level. Accordingly, the generalised economic parameters used in the economic analysis include:

- Net sugar price: $410/t IPS. This is the 5 year average sugar price from 2007 to 2011 for the QSL Seasonal Pool (Source: ABARES & Queensland Sugar Limited);
- Sugarcane yields provided by APSIM;
- Fuel price: $1/litre (net of GST and excise rebate);
- Input costs (nutrients & chemical) based on 2012 data provided by local Agribusiness;
- Field labour cost = $30/hour;
- Electricity prices: 2012 prices from Ergon Energy
- Crop cycle consists of fallow, plant and four ratoon cane crops in the Wet Tropics and Mackay Whitsundays, three ratoon crops in the Burdekin Dry Tropics. Each part of the crop cycle has an equal proportion of land area;
- Lime is applied in the fallow area of all management classes;
- The information presented on A class management practices is based on practices under research and not thoroughly tested on a commercial scale; and,
- Figures are exclusive of GST where applicable.

Results

Table 6 presents the results of the FGM calculations for all the management-practice scenarios analysed for medium sized farms in each of the regions. A full list of FGM tables including the various farm sizes is provided in Appendix 1.

The results in Table 6 show that the degree of variation in FGMs for various practices within each region is a relatively small proportion of the average gross margin (e.g. up to 14% in the Wet Tropics and 6% in the Burdekin Dry Tropics Delta). The FGMs for various practices vary by a maximum of $161/ha in Mackay-Whitsundays, $135/ha in the Wet Tropics, $198/ha in the Burdekin Delta and $104/ha in the Burdekin River Irrigation Area. There is a substantial difference in the gross margin per hectare across cane growing regions. In the Wet Tropics, for example, FGMs are around AU$1,000 per hectare per year, whereas in the Burdekin Dry Tropics Delta they are typically above AU$3,000 per hectare per year. The variation in FGMs between regions is mostly attributable to the characteristics of the farming systems for that specific location as well as its soil type and the corresponding production modelled by APSIM. For example, the Burdekin Dry Tropics Delta site displayed the highest production levels because of the irrigated cane and fertile soil type. From Tables 9 to 12 in Appendix 2, comparing FGMs between farm sizes in each region, it is apparent that, unsurprisingly, large farmers are likely to achieve relatively greater FGMs per hectare due to economies of scale, mainly due to better efficiency in machinery-use.

Table 6: FGMs (AU$/ha/yr) for medium sized farms in the various NRM regions

Nutrient	Fallow	Split	Surface	Tillage	MWS	WT	Delta	BRIA
AA	FB	SB	MB	GB	1322	1021	3190	1899
AA	FB	SB	MB	GC	1265	956	3137	1850
AA	FB	SB	MC	GB	1329	1027	3186	1905
AA	FB	SB	MC	GC	1271	963	3143	1861
AA	FC	SB	MB	GB	1283	996	3231	1925
AA	FC	SB	MB	GC	1241	930	3150	1851
AA	FC	SB	MC	GB	1290	1002	3238	1932
AA	FC	SB	MC	GC	1248	937	3156	1857
AB	FB	SB	MB	GB	1339	1059	3240	1903
AB	FB	SB	MB	GC	1284	992	3169	1876
AB	FB	SB	MC	GB	1346	1065	3246	1909
AB	FB	SB	MC	GC	1291	999	3175	1883
AB	FC	SB	MB	GB	1358	1043	3274	1948
AB	FC	SB	MB	GC	1314	977	3200	1867
AB	FC	SB	MC	GB	1364	1050	3280	1954
AB	FC	SB	MC	GC	1320	992	3206	1873
AC	FB	SB	MB	GB	1259	1012	3156	1847
AC	FB	SB	MB	GC	1203	945	3082	1780
AC	FB	SB	MC	GB	1265	1018	3162	1854
AC	FB	SB	MC	GC	1209	952	3088	1786
AC	FC	SB	MB	GB	1307	1024	3245	1926
AC	FC	SB	MB	GC	1261	958	3164	1852
AC	FC	SB	MC	GB	1313	1032	3251	1933
AC	FC	SB	MC	GC	1267	966	3170	1858
				Average FGM	$1,290	$997	$3,189	$1,880
				Minimum FGM	$1,203	$930	$3,082	$1,780
				Maximum FGM	$1,364	$1,065	$3,280	$1,954
				Range as a proportion (%) of Average FGM	12%	14%	6%	9%

To assist in interpreting the data presented above, Figure 6 to Figure 9 show the grouped results from Table 6. Within each plot, the variation in FGM for specific management practices within systems is illustrated by the minimum, maximum and average (the average is shown by the blue diamond in the Figure) values of FGM for a medium farm size in each region.

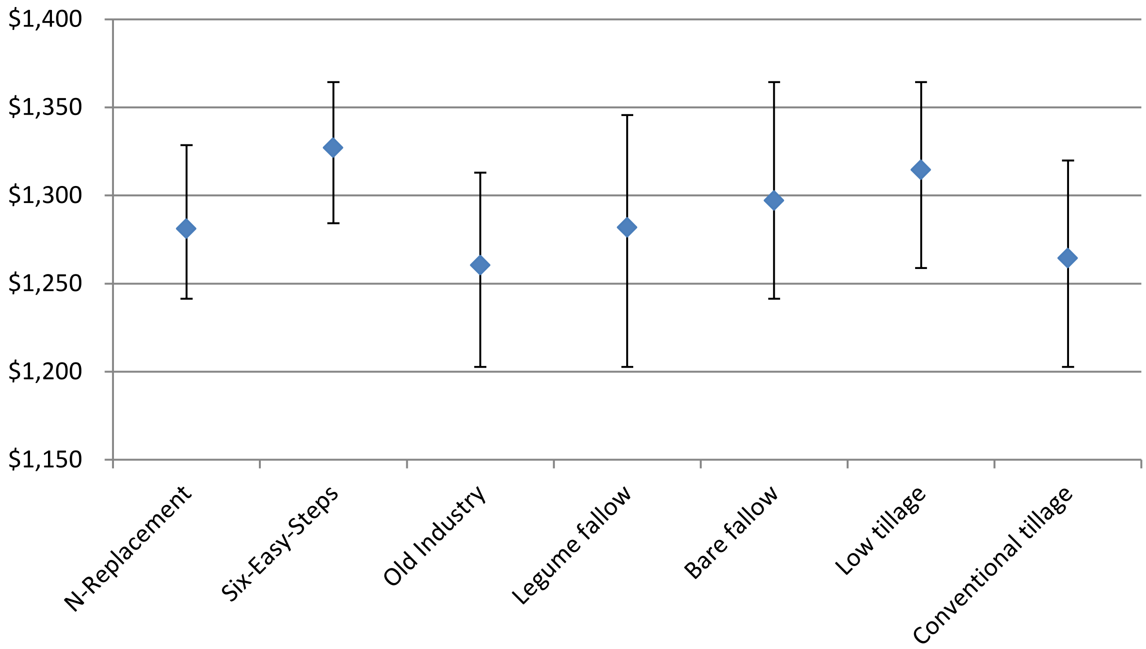


Figure 6: Farm Gross Margins ($/Ha/Yr) for the Mackay Whitsundays region.

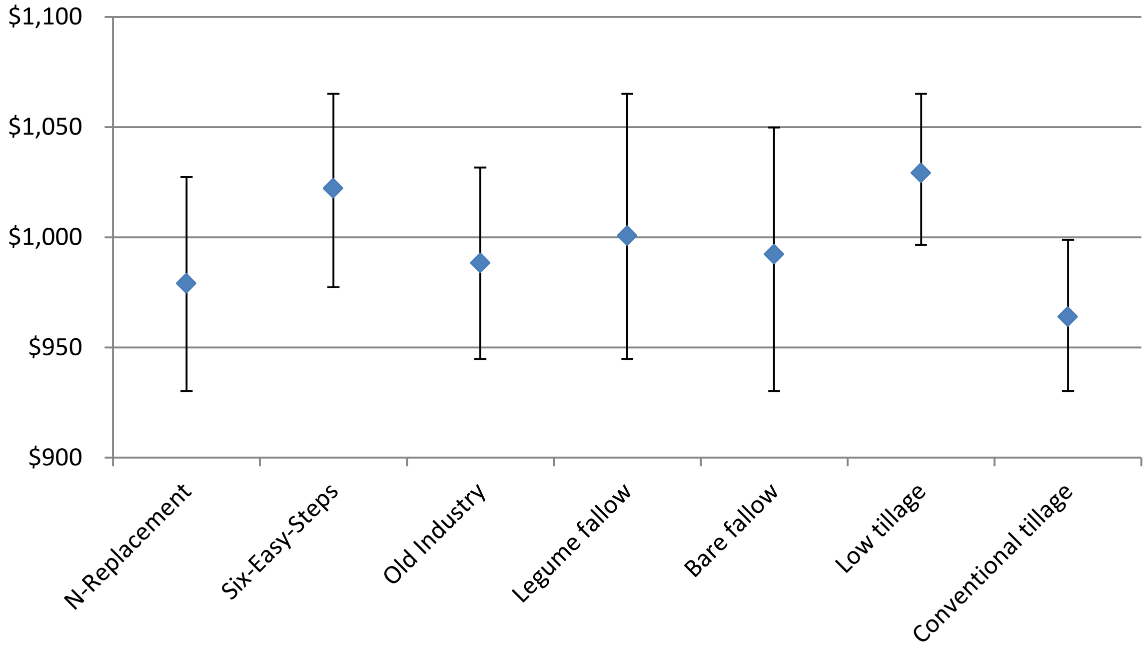


Figure 7: Farm Gross Margins ($/Ha/Yr) for the Wet Tropics region.

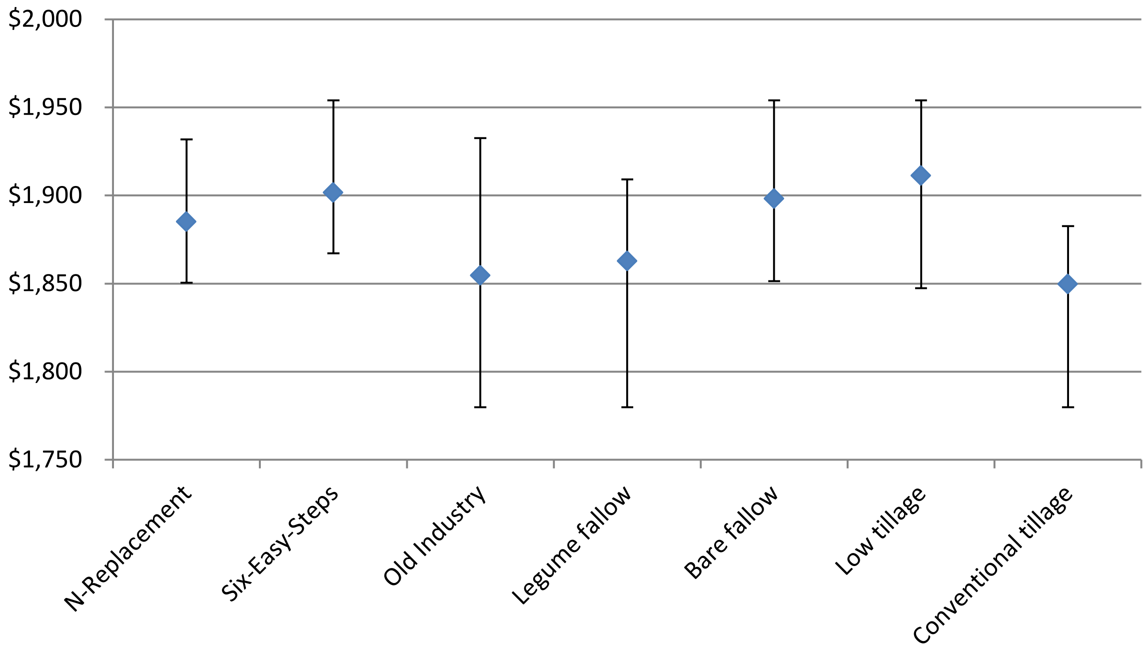


Figure 8: Farm Gross Margins ($/Ha/Yr) for the Burdekin River Irrigation Area

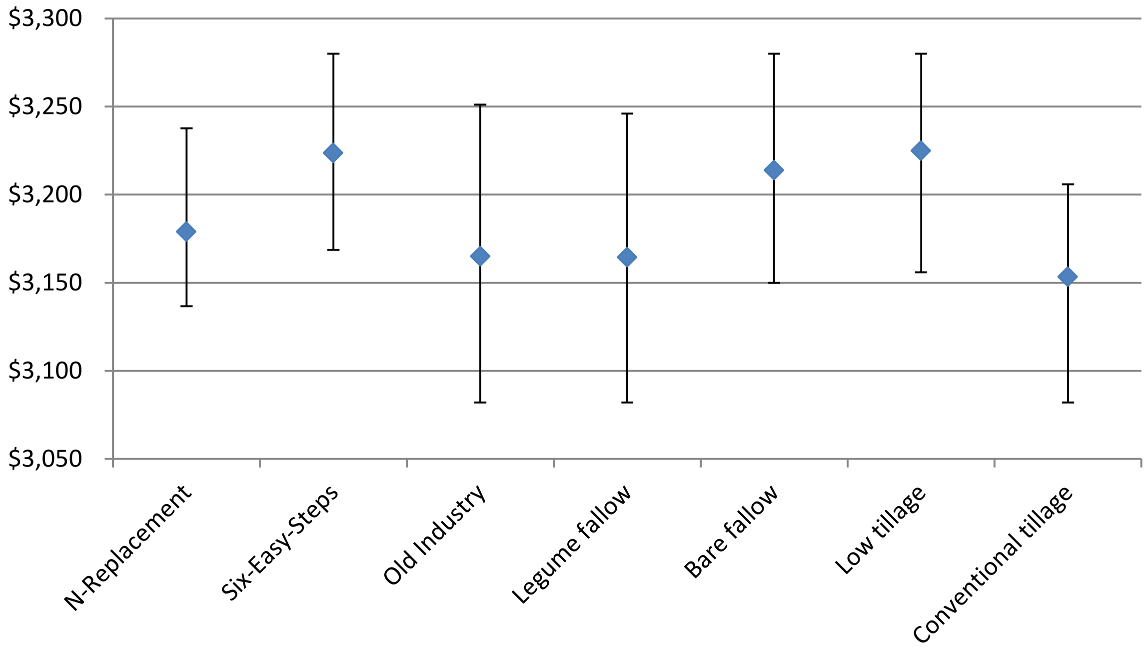


Figure 9: Farm Gross Margins ($/Ha/Yr) for the Burdekin Delta region.

When comparing between applications rates (N-Replacement, Six-Easy-Steps and Old Industry rate), it can be observed that Six-Easy-Steps provides the highest FGM on average. In addition to this, the N-Replacement rate displays a higher FGM compared to the Old Industry rate, except in the Wet Tropics. With the exception of the Wet Tropics, a bare fallow tends to yield higher average FGMs than a legume fallow. This may be explained, at least in part, by the difference in farm operations between regions to grow a legume crop. Furthermore, APSIM simulated yields do not account for potential soil health implications on production. Production parameters used from the results of the APSIM modelling showed similar production levels for bare and legume fallow; however, results from field research indicate that a legume fallow may indeed increase production. In all four regions reducing the number of tillage operations results in higher average FGMs.

In summary, the results graphically illustrate the range in the FGMs across the selected management-practice scenarios and regions. As it turns out, the pattern across these graphs tends to be a fairly consistent across regions and between FGMs involving the same management practice combinations. However, this needs to be placed in the context of the specific magnitude of FGM that, on the other hand, varies quite considerably. For instance, FGMs range between $908 and $1,047 per hectare within the Wet Tropics region, and between $3,082 and $3,280 within the Burdekin Dry Tropics Delta region.

2.6 Data Analysis Part 1: Investment Analysis

In order to evaluate the cost-effectiveness of changing management practices, the appropriate capital expenditures to undertake the change need to be taken into account. These capital expenditures relate to the purchase of certain implements required to facilitate the change between practices for each scenario.

2.6.1 Discounted Cash Flow (DCF)

A fundamental concept of financial-economics is the relationship between the present and future value of money. The time value of money (see, for example, Kidwell et al., 2011) implies that a dollar amount of money to be received in the future is worth less than the *same* dollar amount today; this is because money today may be invested so that it will grow over time at a rate of interest. What this rate of interest *should be* will depend on what is referred to as the opportunity cost. The opportunity cost represents the consideration foregone when investing funds into one project rather than into another that assumes the same element of risk. For this reason, the interest rate applied to discount the value of a future cash flow to determine its present value is often referred to as the required rate of return.

When analysing an investment that provides cash flows in recurrent periods, the Discounted Cash Flow (DCF) technique is the traditional method used to evaluate the present value of a stream of future cash flows (or the flow of economic benefits) over a predetermined investment horizon. The total number of periods (i.e. the economic horizon) of the cash flow stream is thus contingent on the operative life span of the investment. For example, an economic horizon of ten years is appropriate for an investment in capital (e.g. farm machinery) of which has a useful life of ten years.

2.6.2 Net Present Value (NPV)

A Net Present Value (NPV) analysis provides a set of objective criteria used to inform an investor whether or not a specific change in management practices is acceptable from a financial-economic perspective. The analysis includes a range of financial indicators such as the internal rate of return, payback period, break-even capital requirements, and benefit to cost ratio (see also Poggio et al., 2014). In practical terms, the NPV is an extension to the DCF method that takes into account capital expenditure requirements. Implementing new management practices across the farming enterprise will typically involve purchasing new capital, which also depends on the size and scale of the farming operations. The NPV figure is the difference between the present market value of the future benefits from a capital investment and its cost.

In defining what is acceptable, it is critical to distinguish between an investment that is viable from an accounting perspective and one that is profitable from a financial-economic perspective. An investment may indeed be viable and/or cost-effective from an accounting perspective if the financial benefit covers the explicit costs; however, it is profitable from a financial-economic perspective only if it provides also a satisfactory rate of return.

Changes to management practices that result in a positive NPV are considered to be acceptable; this is in the sense that they are likely to provide a return on investment that is greater than the required rate of return. Conversely, those resulting in a negative NPV should be rejected, as this indicates that the return on investment is less than the assigned hurdle rate of return. A required rate of return of six per cent (6%) and an investment horizon of 10 years is applied in this project in order to maintain consistent reporting in line with related projects.

Capital expenditures

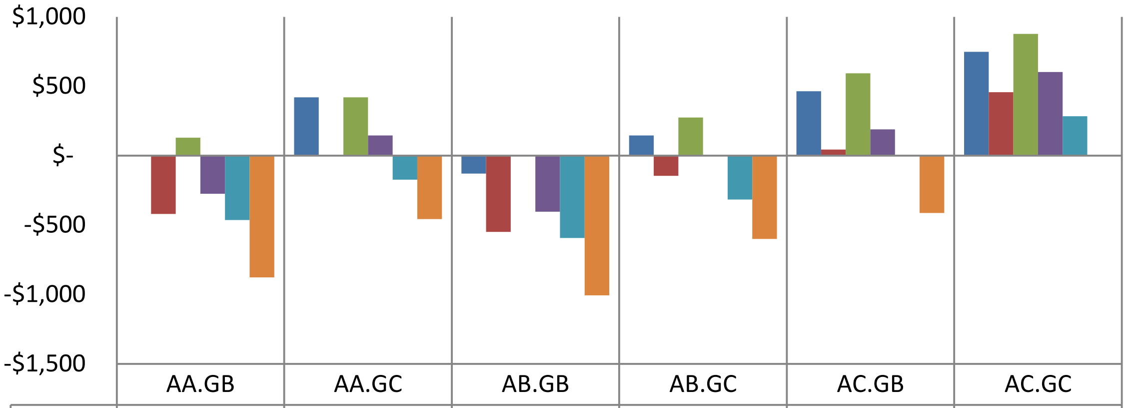
Capital expenditure at market prices is presented in Table 7 along with the equipment description. These prices were obtained from various industry sources that supply equipment within each of the regions investigated and are thus assumed to be equally applicable across those regions.

Table 7: Capital expenditure requirements

Farm size	AC to AB	AC to AA	AB to AA	MC to MB	FC to FB	GC to GB
Small	-	-	-	$47,273	$25,000	$12,500
Medium	-	-	-	$50,000	$25,000	$19,500
Large	-	-	-	$57,273	$25,000	$67,500
Description	-	-	-	Stool splitter fertilizer box	Legume planter	Zonal ripper/ rotary hoe

Results for net present value analyses (NPV/ha)

Figure 10 below presents the NPVs (per hectare) of changing between a specific set of management practices in the Mackay Whitsunday region isolation. In particular, we looked at the implications for farm profitability when investing in various combinations of nutrient application rates and tillage management. The Y-axis represents the NPV, which when positive indicates an acceptable investment. The X-axis refers to the various starting point practices; in addition the NPV of the corresponding changes are catalogued in the data table underneath the graph. For example, the first item in the first row is labelled AA.GB, which refers to nutrient rates according to the N-replacement technology (AA) in combination with a low tillage practice under controlled traffic (GB). The cells directly underneath this cell present the NPV values for changing to the practice combinations in the far left column. In this instance, changing from AA.GB to AA.GC will lead to a negative NPV of $421 per hectare over 10 years at a 6% required rate of return. This is also illustrated in the graph with respect to the red bar. All other elements of the farming system are assumed equal across the analysis at B-level (i.e. FB, SB and MB, see Table 1 of this report).

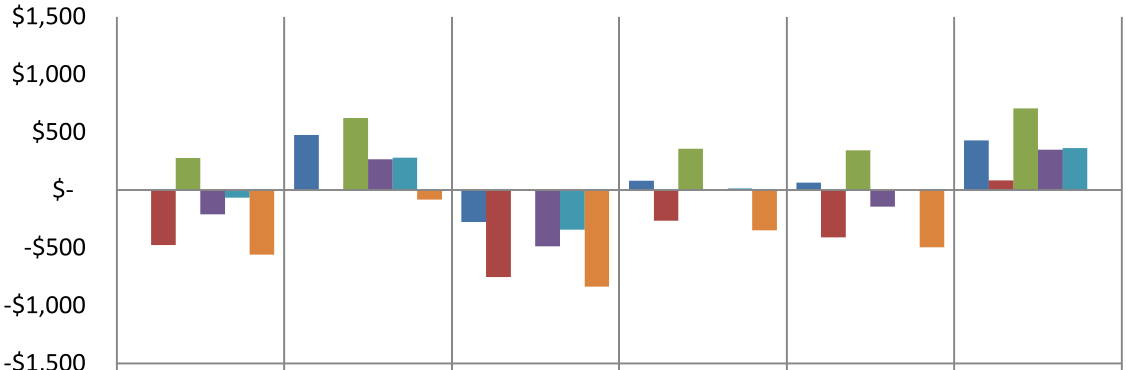


	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$421	-$129	$146	$464	$747
AA.GC	-$421	$-	-$550	-$145	$43	$456
AB.GB	$129	$420	$-	$275	$592	$876
AB.GC	-$276	$145	-$405	$-	$188	$601
AC.GB	-$464	-$173	-$592	-$318	$-	$283
AC.GC	-$877	-$456	-$1,006	-$601	-$413	$-

Figure 10: NPV of changing practices ($/ha/10yr) on a medium-sized farm in Mackay Whitsundays

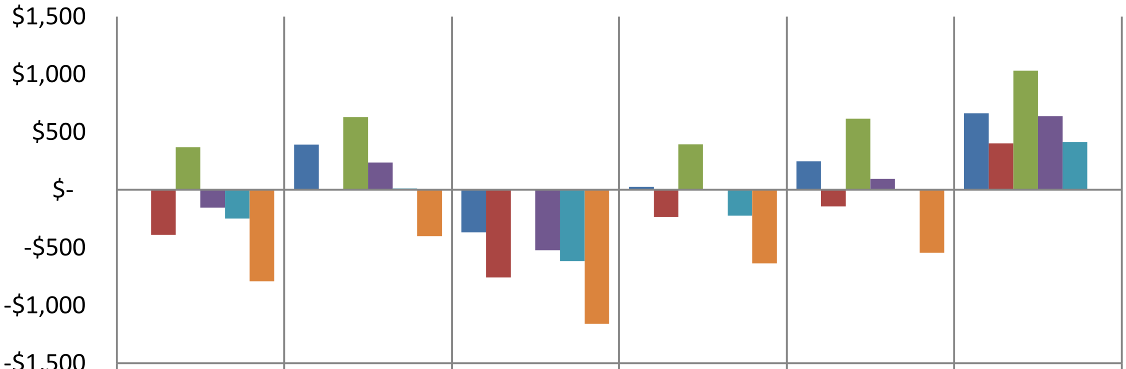
The results tend to indicate that if a landholder is currently practicing nutrient management according to Old Industry recommendations (AC) and using frequent tillage under controlled traffic (GC), all practice combinations analysed are likely to provide an acceptable benefit. In contrast, for a landholder that is currently fertilizing with a nutrient rate based on the Six-Easy-Steps methodology (AB), and they are presently using a low till system (GB), it is unlikely that changing to any of the other practices will provide an acceptable economic return.

Figure 11, Figure 12 and Figure 13 present the NPVs of changing practices for medium farms in the Wet Tropics, Burdekin River Irrigation Area and Burdekin Delta regions, respectively. (A complete list of graphs presenting the NPV changes for various farm sizes across the different regions is presented in Appendix 2.) Together these graphs show similar inter-regional patterns - although there are some stark differences in their magnitude. This reinforces the notion that there is significant variation in investment returns between regions, which should not be overlooked. For example, starting from scenario AA.GC in the Mackay Whitsundays, there are fewer acceptable options for changing practices that will likely result in a positive NPV than there are in the Wet Tropics, where almost all scenarios examined are acceptable from an economic perspective.



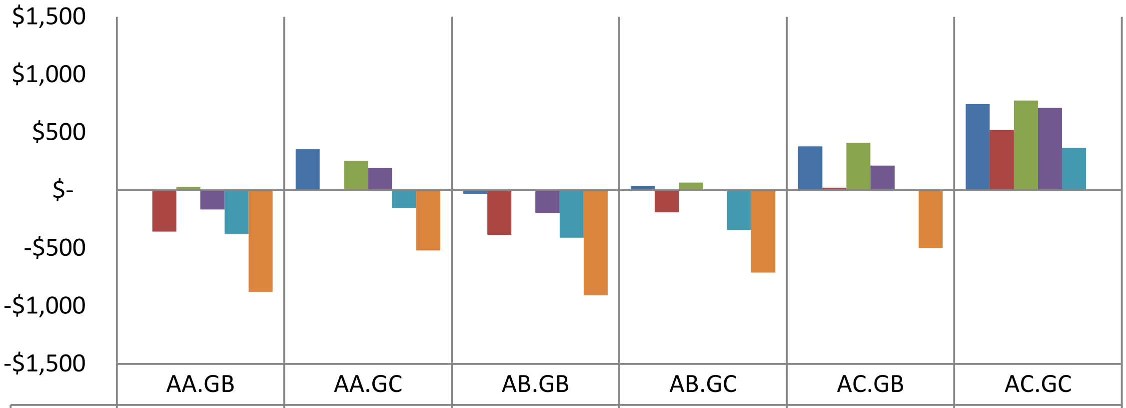
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$476	-$277	$80	$65	$430
AA.GC	-$476	$-	-$753	-$266	-$410	$84
AB.GB	$277	$623	$-	$358	$343	$707
AB.GC	-$210	$266	-$488	$-	-$145	$350
AC.GB	-$65	$280	-$343	$15	$-	$364
AC.GC	-$560	-$84	-$837	-$350	-$494	$-

Figure 11: Wet Tropics medium sized farm NPV of changing practice ($/ha/10yr).



	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$390	-$369	$24	$248	$662
AA.GC	-$390	$-	-$759	-$236	-$142	$402
AB.GB	$369	$629	$-	$393	$616	$1,030
AB.GC	-$154	$236	-$523	$-	$94	$638
AC.GB	-$248	$12	-$616	-$224	$-	$414
AC.GC	-$792	-$402	-$1,160	-$638	-$544	$-

Figure 12: BDK Delta medium sized farm NPV of changing practice ($/ha/10yr).



	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$356	-$30	$36	$380	$747
AA.GC	-$356	$-	-$386	-$190	$23	$521
AB.GB	$30	$256	$-	$65	$409	$777
AB.GC	-$166	$190	-$195	$-	$214	$711
AC.GB	-$380	-$153	-$409	-$344	$-	$367
AC.GC	-$877	-$521	-$907	-$711	-$497	$-

Figure 13: Burdekin River Irrigation Area medium sized farm NPV of changing practice ($/ha/10yr).

Sensitivity analysis

Due to the subjective nature of assigning a discount rate for the investment analysis, a sensitivity analysis is performed across the results assuming interest rates of 3%, 6% and 10%. We recall that a real interest rate of 6% over a 10-year investment horizon was applied as the base case and that only changes indicating a positive NPV are acceptable in order to meet the required rate of return. Accordingly, Figure 14 shows the NPV of several projects (changing nutrient rate and fallow management) at discount rates of 3%, 6% and 10%. The options have been ordered by increasing NPV per hectare.

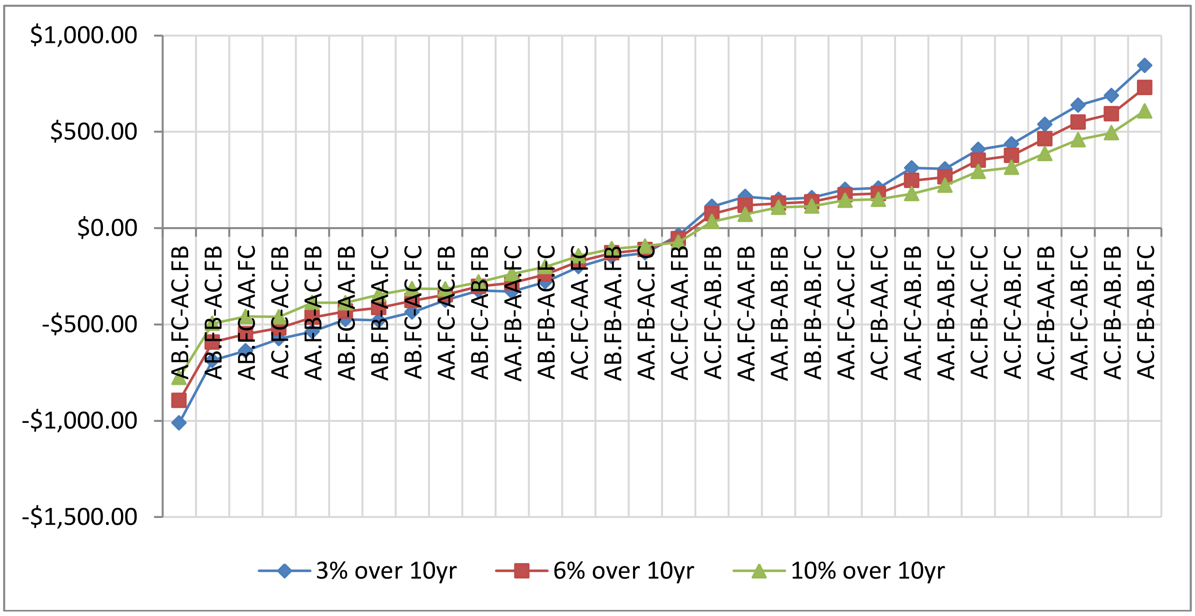


Figure 14: Mackay Whitsundays NPV analysis ($/ha/10yr).

The results in Figure 14 reflect the inverse relationship between present value and the discount rate. By using a lower (higher) interest rate, this mathematically results in a higher (lower) present value for the stream of changes to gross margin. This implies that the fixed investment costs used to calculate the NPV become proportionally less (greater) relative to the present value of the future cash flows. It follows that when the present value is positive (negative) the economic benefits (costs) become larger.

2.7 Data Analysis Part 2: Cost-Effectiveness Analysis

To determine the practices that are most cost-effective to improve water quality (either by reducing DIN or soil loss) we combine the information from previous sections. We present this in such a way that practices are considered on the basis of their potential to improve water quality at least cost. To enable a direct comparison to be made between the environmental and financial-economic information we standardise both the physical and monetary measures in terms of area (i.e. hectares) and time (i.e. per year).

2.7.1 Equivalent Annual Annuity approach and the Annualised Equivalent Benefit

The Equivalent Annual Annuity (EAA) approach (see, for example, annual equivalent cost and annual equivalent benefit in Ross et al., 2011) is a transformation of the NPV analysis, which is especially useful to compare capital investments that provide economic benefits/costs over different economic horizons (capital investments typically have different life spans; this implies that their cash flow streams tend to vary accordingly). The AEB approach provides an annualised measure of the NPV for each scenario in terms of dollars, per hectare, per year ($/ha/yr) thus enabling a comparative assessment to be made with respect to the N delivery rates that are measured in terms of grams, per hectare, per year (g/ha/yr).
For the purpose of simplifying the analyses, each capital investment is assumed to have an economic horizon of ten years and a zero salvage value. This is on the basis that taking into account the sale of redundant farm machinery and equipment and predicting the useful life of capital introduces a dimension to the economic modelling that warrants a more subjective and indeed dynamic analysis. By the same token, over time through improved knowledge and technical innovation, the management practice scenarios selected for this project (including the respective capital expenditure items) may be rendered obsolete.

2.7.2 Marginal Abatement Cost Curve (MACC)

This section presents an alternative way of integrating the environmental and financial-economic information by deriving a Marginal Abatement Cost Curve (MACC). MACCs are typically used to graphically depict the opportunities to reduce greenhouse gases (GHG) emissions, particularly CO_2, in regard to the potential level of physical abatement and its respective cost. In this project we analyse DIN abatement rather than CO_2 emissions, but the MACC works in much the same way. In particular, the horizontal axis represents the DIN abatement potential (kg/ha/yr) and the vertical axis the abatement cost per unit ($/kg/yr).

We first select the projects that indicate a reduction in DIN is possible. (We ignore those projects where DIN increases). We then rank these projects by abatement cost (measured as the AEB). The first block on the left hand side of the graphic has the lowest abatement cost and the last one on the right hand side has the highest abatement cost. The area within each block represents the total cost of the improvement through practice change: abatement cost ($/kg/yr) x DIN abatement (kg/ha/yr) = total cost of the improvement ($/ha/yr).

The blocks below the horizontal axis indicate the benefits of abatement. For example, in Figure 15, the first blocks (from left to right) show DIN reductions as well as a negative abatement cost (a negative economic cost is equivalent to an economic benefit). We can consider these practices as “win-win” practices. In general, the blocks above the horizontal axis still reduce DIN, however, they have also a positive abatement cost. Thus a trade-off between water quality improvement and economic cost can be established.

Figure 15 to Figure 18 show the MACC for medium sized farms across each region. For this example, and to keep these graphs interpretable, we only look at practice combinations associated with nutrient application rates and tillage management. The other elements of the system are assumed to be constant at B-level; i.e. a single fertiliser application in ratoon cane (SB), sub-surface application of nutrients (MB), and a legume fallow (FB). The Y-axis presents the abatement costs ($/ha/yr) and the X-axis presents the DIN abatement (kg/ha/yr). Please note that these values are not cumulative, and therefore the individual values are presented in brackets next to the code.

Following each Figure, the Tables present the AEB per unit DIN, as well as the total potential DIN improvement per hectare per year. They have been ordered according to profitability, where a negative value (negative cost) presents a benefit. For example, the first row in Table 8; CC/BB, i.e. moving from Old industry rates/High tillage Six-Easy-Steps/Low tillage, allows a total abatement of 15.2 kg of DIN per hectare per year, at a cost of AU$ -7.9 per kg per hectare per year (a negative cost represents a benefit). The total cost from reducing the dissolved inorganic nitrogen available to leave the farm is equal to the surface area of the block and equates to -AU$120 (15.2 x -$7.9), and therefore presents a benefit (negative cost).

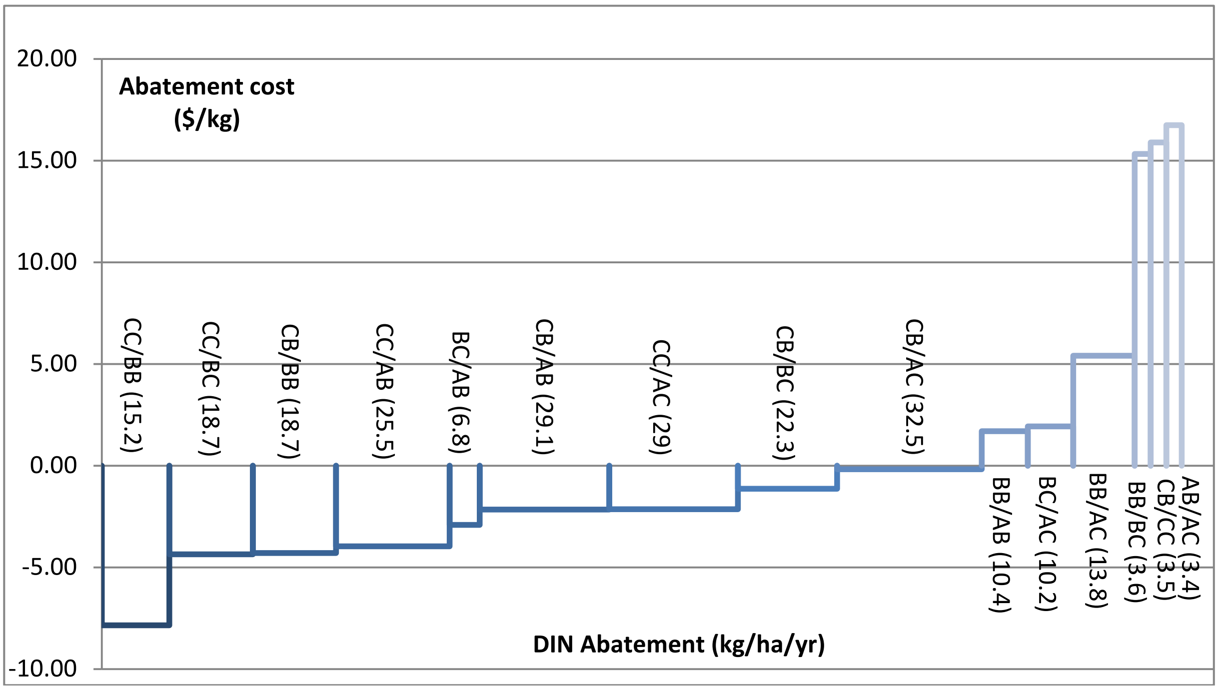


Figure 15: Mackay Whitsundays MACC for medium sized farm

Table 8: AEB/DIN ($/kg/yr) and DIN abatement (kg/ha/yr) for the Mackay Whitsundays region

Code	*From*	*To*	*Annualised Equivalent benefit/cost ($/ha/yr)*	*DIN Abatement (kg/ha/yr)*	*AEB/DIN ($/kg)*
CC/BB	AC.FB.SB.MB.GC	AB.FB.SB.MB.GB	119.0	15.2	-7.9
CC/BC	AC.FB.SB.MB.GC	AB.FB.SB.MB.GC	81.7	18.8	-4.4
CB/BB	AC.FB.SB.MB.GB	AB.FB.SB.MB.GB	80.5	18.7	-4.3
CC/AB	AC.FB.SB.MB.GC	AA.FB.SB.MB.GB	101.5	25.6	-4.0
BC/AB	AB.FB.SB.MB.GC	AA.FB.SB.MB.GB	19.8	6.8	-2.9
CB/AB	AC.FB.SB.MB.GB	AA.FB.SB.MB.GB	63.0	29.1	-2.2
CC/AC	AC.FB.SB.MB.GC	AA.FB.SB.MB.GC	62.0	29.0	-2.1
CB/BC	AC.FB.SB.MB.GB	AB.FB.SB.MB.GC	25.5	22.3	-1.1
CB/AC	AC.FB.SB.MB.GB	AA.FB.SB.MB.GC	5.8	32.5	-0.2
BB/AB	AB.FB.SB.MB.GB	AA.FB.SB.MB.GB	-17.5	10.4	1.7
BC/AC	AB.FB.SB.MB.GC	AA.FB.SB.MB.GC	-19.7	10.2	1.9
BB/AC	AB.FB.SB.MB.GB	AA.FB.SB.MB.GC	-74.7	13.8	5.4
BB/BC	AB.FB.SB.MB.GB	AB.FB.SB.MB.GC	-55.0	3.6	15.3
CB/CC	AC.FB.SB.MB.GB	AC.FB.SB.MB.GC	-56.2	3.5	15.9
AB/AC	AA.FB.SB.MB.GB	AA.FB.SB.MB.GC	-57.2	3.4	16.7

In the Mackay Whitsunday region, the most profitable changes to reduce DIN come from reducing fertiliser from rates based on Old Industry's recommendations to rates based on Six-Easy-Steps (AC to AB), and to a lesser extent reducing fertiliser from rates based on Old Industry's recommendations to rates based on N-Replacement (AC to AA) and from rates based on Six-Easy-Steps to rates based on N-Replacement (AB to AA). Reducing the amount of tillage operations is also a profitable option. The largest environmental improvements result from reducing fertiliser from rates based on Old Industry's recommendations to rates based on N-Replacement (AC to AA).

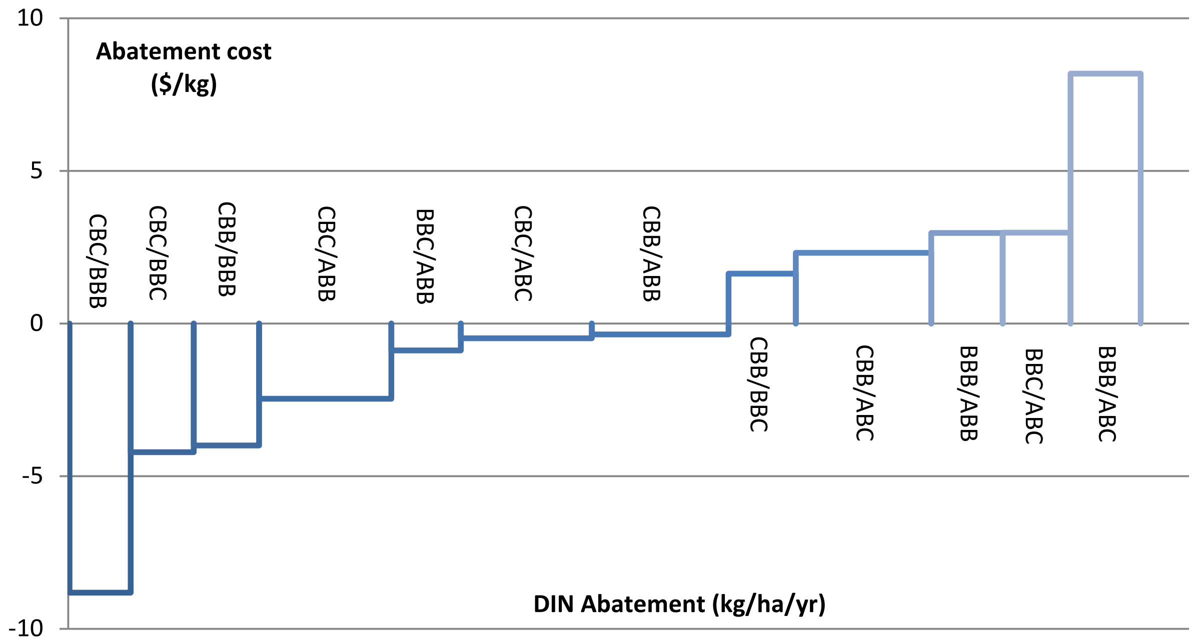


Figure 16: Wet Tropics MACC for medium sized farms

Table 9: AEB/DIN (&/kg/yr) and DIN abatement (kg/ha/yr) for the Wet Tropics region.

Code	*From*	*To*	*Annualised Equivalent benefit/cost ($/ha/yr)*	*DIN Abatement (kg/ha/yr)*	*AEB/DIN ($/kg/yr)*
CC/BB	AC.FB.SB.MB.GC	AB.FB.SB.MB.GB	96.1	10.9	-8.8
CC/BC	AC.FB.SB.MB.GC	AB.FB.SB.MB.GC	47.5	11.3	-4.2
CB/BB	AC.FB.SB.MB.GB	AB.FB.SB.MB.GB	46.6	11.7	-4.0
CC/AB	AC.FB.SB.MB.GC	AA.FB.SB.MB.GB	58.4	23.6	-2.5
BC/AB	AB.FB.SB.MB.GC	AA.FB.SB.MB.GB	10.9	12.4	-0.9
CC/AC	AC.FB.SB.MB.GC	AA.FB.SB.MB.GC	8.9	23.4	-0.5
CB/AB	AC.FB.SB.MB.GB	AA.FB.SB.MB.GB	11.4	24.4	-0.4
CB/BC	AC.FB.SB.MB.GB	AB.FB.SB.MB.GC	-19.7	12.0	1.6
CB/AC	AC.FB.SB.MB.GB	AA.FB.SB.MB.GC	-55.8	24.2	2.3
BB/AB	AB.FB.SB.MB.GB	AA.FB.SB.MB.GB	-37.7	12.7	3.0
BC/AC	AB.FB.SB.MB.GC	AA.FB.SB.MB.GC	-36.1	12.1	3.0
BB/AC	AB.FB.SB.MB.GB	AA.FB.SB.MB.GC	-102.3	12.5	8.2

Similar to the Mackay Whitsunday region, in the Wet Tropics the most profitable changes to reduce DIN come from reducing fertiliser rates from Old Industry rates (AC) to Six-Easy-Steps rates (AB), and to a lesser extent reducing from Old Industry rates (AC) to N-Replacement rates (AA) and from Six-Easy-Steps rates (AB) to N-Replacement rates (AA). Reducing the amount of tillage operations are a profitable option. The biggest environmental improvements are the result of changing fertiliser rates from Old Industry rates (AC) to N-Replacement rates (AA).

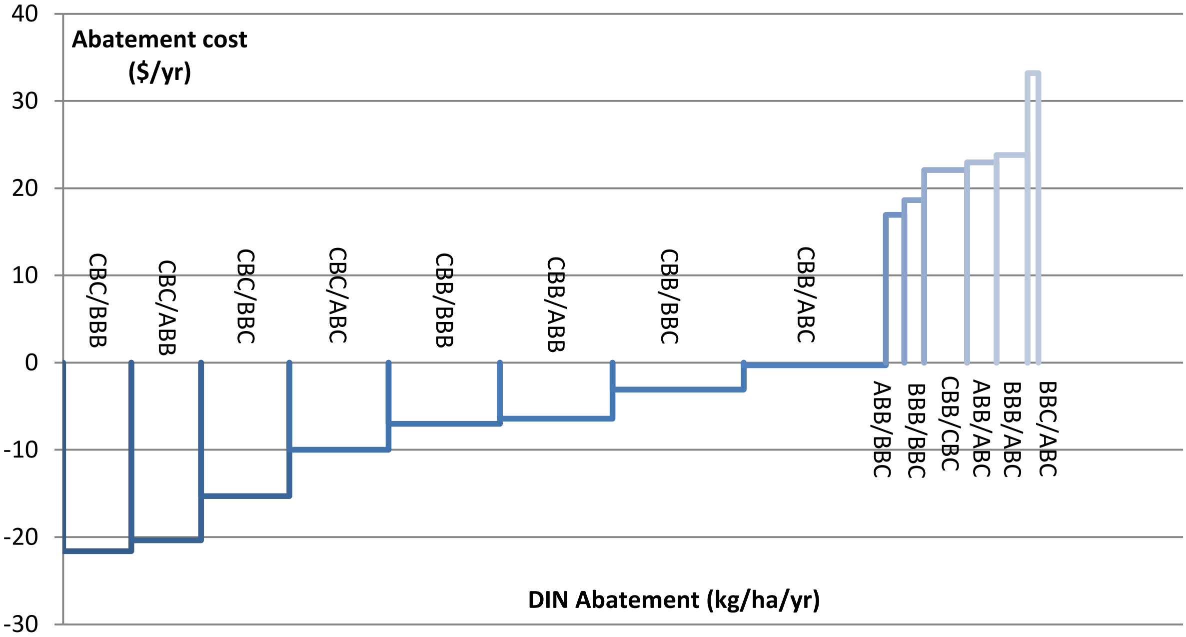


Figure 17: Burdekin River Irrigation Area MACC for medium sized farms

Table 10: AEB/DIN (&/kg/yr) and DIN abatement (kg/ha/yr) for the Burdekin River Irrigation Area.

Code	*From*	*To*	*Annualised Equivalent benefit/cost ($/ha/yr)*	*DIN Abatement (kg/ha/yr)*	*AEB/DIN ($/kg/yr)*
CC/BB	AC.FB.SB.MB.GC	AB.FB.SB.MB.GB	105.5	4.88	-21.60
CC/AB	AC.FB.SB.MB.GC	AA.FB.SB.MB.GB	101.5	4.98	-20.37
CC/BC	AC.FB.SB.MB.GC	AB.FB.SB.MB.GC	96.6	6.31	-15.32
CC/AC	AC.FB.SB.MB.GC	AA.FB.SB.MB.GC	70.7	7.09	-9.98
CB/BB	AC.FB.SB.MB.GB	AB.FB.SB.MB.GB	55.6	7.94	-7.00
CB/AB	AC.FB.SB.MB.GB	AA.FB.SB.MB.GB	51.6	8.04	-6.41
CB/BC	AC.FB.SB.MB.GB	AB.FB.SB.MB.GC	29.1	9.37	-3.10
CB/AC	AC.FB.SB.MB.GB	AA.FB.SB.MB.GC	4.0	10.15	-0.31
AB/BC	AA.FB.SB.MB.GB	AB.FB.SB.MB.GC	-22.5	1.33	16.95
BB/BC	AB.FB.SB.MB.GB	AB.FB.SB.MB.GC	-26.6	1.42	18.65
CB/CC	AC.FB.SB.MB.GB	AC.FB.SB.MB.GC	-67.6	3.06	22.07
AB/AC	AA.FB.SB.MB.GB	AA.FB.SB.MB.GC	-48.4	2.11	22.96
BB/AC	AB.FB.SB.MB.GB	AA.FB.SB.MB.GC	-52.4	2.20	23.80
BC/AC	AB.FB.SB.MB.GC	AA.FB.SB.MB.GC	-25.9	0.78	33.20

In the Burdekin River Irrigation Area, the most profitable changes to reduce DIN come from reducing fertiliser from rates based on Old Industry's recommendations to rates based on Six-Easy-Steps (AC to AB), while at the same time reducing the number of tillage operations, followed by reducing fertiliser from rates based on Old Industry's recommendations to rates based on N-Replacement (AC to AA) while at the same time reducing the number off tillage operations. The largest environmental improvements result from reducing fertiliser from rates based on Old Industry's recommendations to rates based on N-Replacement (AC to AA).

Figure 18: Burdekin Dry Tropics (Delta) MACC for medium sized farms

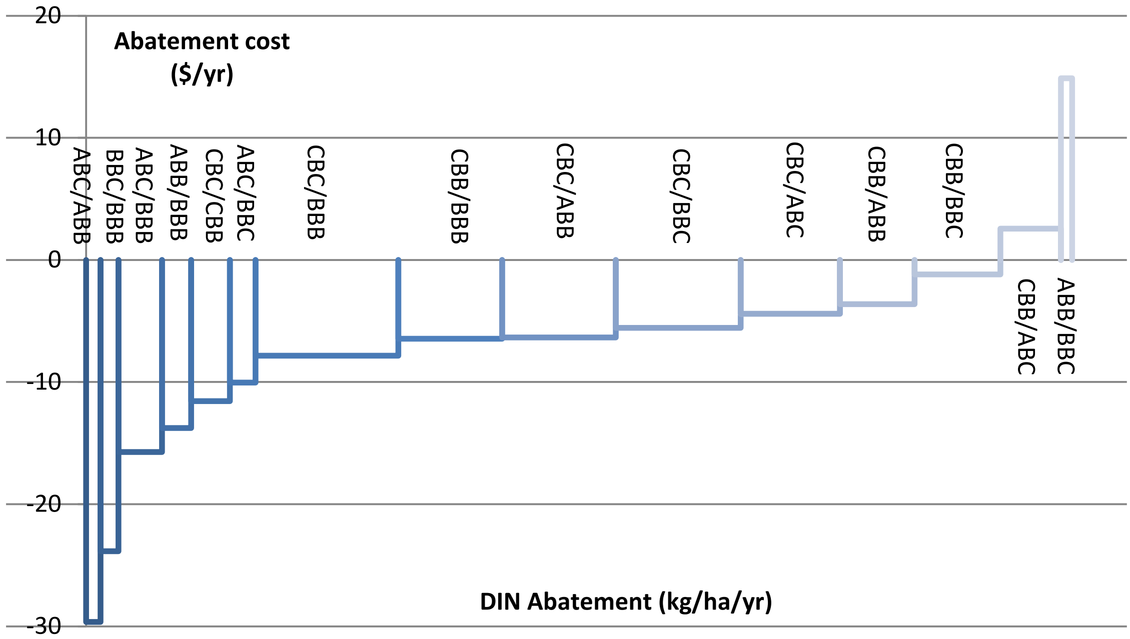


Table 11: AEB/DIN ($/kg/yr) and DIN abatement (kg/ha/yr) for the BDK Delta region.

Code	*From*	*To*	*Annualised Equivalent benefit/cost ($/ha/yr)*	*DIN Abatement (kg/ha/yr)*	*AEB/DIN ($/kg/yr)*
AC/AB	AA.FB.SB.MB.GC	AA.FB.SB.MB.GB	53.0	1.79	-29.65
BC/BB	AB.FB.SB.MB.GC	AB.FB.SB.MB.GB	53.4	2.24	-23.85
AC/BB	AA.FB.SB.MB.GC	AB.FB.SB.MB.GB	85.4	5.43	-15.73
AB/BB	AA.FB.SB.MB.GB	AB.FB.SB.MB.GB	50.1	3.64	-13.75
CC/CB	AC.FB.SB.MB.GC	AC.FB.SB.MB.GB	56.2	4.87	-11.56
AC/BC	AA.FB.SB.MB.GC	AB.FB.SB.MB.GC	32.1	3.19	-10.04
CC/BB	AC.FB.SB.MB.GC	AB.FB.SB.MB.GB	140.0	17.83	-7.85
CB/BB	AC.FB.SB.MB.GB	AB.FB.SB.MB.GB	83.7	12.97	-6.46
CC/AB	AC.FB.SB.MB.GC	AA.FB.SB.MB.GB	89.9	14.19	-6.33
CC/BC	AC.FB.SB.MB.GC	AB.FB.SB.MB.GC	86.6	15.60	-5.55
CC/AC	AC.FB.SB.MB.GC	AA.FB.SB.MB.GC	54.6	12.40	-4.40
CB/AB	AC.FB.SB.MB.GB	AA.FB.SB.MB.GB	33.6	9.32	-3.61
CB/BC	AC.FB.SB.MB.GB	AB.FB.SB.MB.GC	12.7	10.73	-1.19
CB/AC	AC.FB.SB.MB.GB	AA.FB.SB.MB.GC	-19.4	7.54	2.57
AB/BC	AA.FB.SB.MB.GB	AB.FB.SB.MB.GC	-20.9	1.41	14.89

In the Burdekin Delta district, almost all options for reducing DIN at the farm level are profitable (although the importance of the starting point or point of reference should again be emphasised). The biggest environmental benefits are associated with changing fertiliser rates from AC to AB and AC to AA. Contrary to the other regions, changing from AA to AB may result in water quality improvement in some cases.

2.7.3 Costs and effectiveness of management change

In this section, the costs and effectiveness of management change is examined in relative terms to compare the environmental and financial-economic outcomes when making specific changes to farming practices. The environmental outcomes are represented by the relative percentage change in DIN loads from the initial starting point, which corresponds with a positive or negative financial-economic outcome. Presenting the information in this way is useful to illustrate the degree to which the separate principles are linked. In other words, the effectiveness and costs or benefits from a certain change depend on how you manage the other principles within the farming system.

For Table 12 to Table 15 the first column indicates specific changes to farming practices. For instance, in the first block ofTable 12 this refers to changing from Six-Easy-Steps rates (N6ES) to N-Replacement rates (NREP). The cells underneath describe the rest of the system. For example the first coloured row presents the % DIN (kg/ha/yr) and AEB (AU$/ha) values for a situation where one changes from Six-Easy-Steps rates to N-Replacement rates, while growing a legume cover crop in the fallow period and having a minimal number of tillage operations.

Table 12: Wet Tropics Environmental and Economic indicators of change.

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Legume fallow / Low tillage	54%	52%	39%	17%	-$37.09	-$37.70	-$37.81
Legume fallow / High tillage	55%	52%	41%	17%	-$26.90	-$36.10	-$36.22
Bare fallow / Low tillage	47%	49%	32%	16%	-$46.22	-$46.82	-$46.95
Bare fallow / High tillage	55%	47%	34%	18%	-$46.58	-$47.17	-$47.31
Change: Old Industry to N6ES	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	70%	73%	64%	47%	$45.59	$46.59	$46.79
Legume fallow / High tillage	69%	75%	65%	45%	$45.80	$47.51	$47.00
Bare fallow / Low tillage	100%	94%	98%	86%	$17.10	$19.35	$18.30
Bare fallow / High tillage	99%	93%	98%	82%	$7.73	$11.61	$13.27
Change: Old Industry to Nrep	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	38%	38%	25%	8%	$8.50	$8.89	$8.98
Legume fallow / High tillage	38%	38%	26%	8%	$18.90	$11.41	$10.78
Bare fallow / Low tillage	47%	47%	31%	14%	-$29.12	-$27.47	-$28.65

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Bare fallow / High tillage	55%	44%	33%	15%	-$38.86	-$35.57	-$34.04
Change: Bare fallow to legume	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Nrep / Low tillage	114%	124%	106%	127%	-$43.57	$1.71	$10.78
Nrep / High tillage	59%	122%	109%	119%	-$33.39	$3.29	$12.36
N6ES / Low tillage	99%	117%	88%	123%	-$52.71	-$7.42	$1.64
N6ES / High tillage	60%	112%	90%	126%	-$53.08	-$7.78	$1.27
Old Industry / Low tillage	141%	151%	135%	226%	-$81.20	-$34.66	-$26.85
Old Industry / High tillage	85%	139%	137%	228%	-$91.15	-$43.68	-$32.46
Change: High tillage to low	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
NREP / Legume fallow	117%	109%	94%	110%	$58.00	$64.65	$62.88
Nrep / Bare fallow	61%	107%	97%	103%	$34.22	$48.57	$27.78
N6ES / Legume fallow	118%	107%	100%	109%	$34.23	$48.58	$27.79
N6ES / Bare fallow	71%	103%	102%	112%	$33.86	$48.22	$27.42
Old Industry / Legume fallow	116%	110%	101%	106%	$34.44	$49.50	$28.00
Old Industry / Bare fallow	71%	101%	102%	107%	$24.48	$40.47	$22.39

Table 13: Mackay Whitsundays Environmental and Economic indicators of change.

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Legume fallow / Low tillage	81%	35%	72%	34%	-$16.85	-$17.50	-$17.67
Legume fallow / High tillage	79%	37%	71%	32%	-$19.17	-$19.67	-$20.00
Bare fallow / Low tillage	52%	19%	38%	21%	-$73.90	-$74.67	-$74.83
Bare fallow / High tillage	62%	17%	38%	22%	-$71.67	-$72.17	-$72.17
Change: Old Industry to N6ES	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	78%	73%	69%	50%	$79.58	$80.50	$80.67
Legume fallow / High tillage	80%	70%	68%	54%	$81.00	$81.67	$82.17
Bare fallow / Low tillage	86%	63%	82%	63%	$50.24	$51.17	$51.33
Bare fallow / High tillage	91%	63%	82%	62%	$42.32	$46.17	$47.69
Change: Old Industry to Nrep	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	64%	26%	50%	17%	$62.73	$63.00	$63.00
Legume fallow / High tillage	63%	26%	48%	17%	$61.83	$62.00	$62.17
Bare fallow / Low tillage	45%	12%	31%	13%	-$23.65	$23.50	-$23.50
Bare fallow / High tillage	56%	11%	31%	14%	-$29.35	$26.00	-$24.48

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Change: Bare fallow to legume	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Nrep / Low tillage	222%	413%	308%	223%	-$29.29	$16.02	$25.08
Nrep / High tillage	54%	420%	290%	218%	-$43.10	$0.69	$8.41
N6ES / Low tillage	142%	222%	161%	142%	-$86.34	-$41.14	-$32.09
N6ES / High tillage	42%	194%	154%	152%	-$95.60	-$51.81	-$43.75
Old Industry / Low tillage	156%	193%	190%	178%	-$115.68	-$70.48	-$61.42
Old Industry / High tillage	48%	175%	187%	173%	-$134.28	-$87.31	-$78.23
Change: High tillage to low	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
NREP / Legume fallow	184%	117%	108%	101%	$54.15	$57.17	$60.67
Nrep / Bare fallow	44%	119%	102%	99%	$6.38	$24.17	$7.32
N6ES / Legume fallow	178%	123%	106%	97%	$17.87	$37.34	$21.65
N6ES / Bare fallow	53%	107%	102%	104%	$8.61	$26.67	$9.98
Old Industry / Legume fallow	181%	118%	103%	104%	$19.29	$38.50	$23.15
Old Industry / Bare fallow	56%	107%	102%	101%	$0.68	$21.67	$6.34

Table 14: Burdekin Delta Environmental and Economic indicators of change.

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Legume fallow / Low tillage	156%	117%	123%	113%	-$49.63	-$50.11	-$50.23
Legume fallow / High tillage	140%	107%	117%	114%	-$31.52	-$32.07	-$32.22
Bare fallow / Low tillage	108%	106%	112%	108%	-$48.65	-$42.21	-$42.33
Bare fallow / High tillage	109%	100%	113%	109%	-$49.03	-$49.60	-$49.72
Change: Old Industry to N6ES	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	43%	58%	53%	42%	$83.93	$83.75	$83.74
Legume fallow / High tillage	43%	74%	52%	40%	$86.62	$86.63	$86.63
Bare fallow / Low tillage	116%	80%	78%	52%	$36.19	$28.90	$29.01
Bare fallow / High tillage	118%	89%	77%	57%	$26.34	$29.08	$26.82
Change: Old Industry to Nrep	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	67%	67%	65%	48%	$34.40	$33.64	$33.52
Legume fallow / High tillage	60%	79%	61%	45%	$55.10	$54.56	$54.42
Bare fallow / Low tillage	125%	85%	88%	56%	-$12.46	-$13.31	-$13.31
Bare fallow / High tillage	128%	89%	87%	62%	-$22.68	-$20.52	-$22.91

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Change: Bare fallow to legume	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Nrep / Low tillage	69%	106%	104%	103%	-$113.69	-$64.50	-$48.12
Nrep / High tillage	90%	119%	107%	107%	-$81.10	-$35.99	-$23.60
N6ES / Low tillage	48%	96%	94%	98%	-$112.81	-$56.60	-$40.22
N6ES / High tillage	70%	111%	103%	102%	-$98.61	-$53.53	-$41.11
Old Industry / Low tillage	128%	134%	138%	120%	-$160.55	-$111.45	-$94.95
Old Industry / High tillage	194%	134%	152%	147%	-$158.89	-$111.07	-$100.93
Change: High tillage to low	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
NREP / Legume fallow	70%	57%	94%	84%	$51.24	$53.00	$45.96
Nrep / Bare fallow	91%	64%	97%	87%	$49.86	$63.84	$33.80
N6ES / Legume fallow	63%	52%	89%	84%	$35.28	$53.37	$27.29
N6ES / Bare fallow	92%	60%	98%	87%	$49.48	$56.44	$26.40
Old Industry / Legume fallow	62%	67%	88%	79%	$37.97	$56.25	$30.18
Old Industry / Bare fallow	94%	67%	97%	96%	$39.64	$56.62	$24.21

Table 15: Burdekin River Irrigation Area Environmental and Economic indicators of change.

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Legume fallow / Low tillage	108%	82%	85%	80%	-$3.48	-$4.05	-$4.17
Legume fallow / High tillage	95%	90%	87%	83%	-$24.54	-$25.87	-$15.74
Bare fallow / Low tillage	143%	75%	89%	83%	-$21.64	-$22.22	-$22.34
Bare fallow / High tillage	121%	78%	100%	92%	-$15.27	-$15.84	-$15.96
Change: Old Industry to N6ES	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	54%	71%	57%	57%	$55.66	$55.62	$55.62
Legume fallow / High tillage	58%	65%	57%	57%	$95.90	$96.62	$86.36
Bare fallow / Low tillage	62%	76%	61%	59%	$21.47	$21.43	$21.43
Bare fallow / High tillage	62%	79%	58%	67%	$6.04	$8.78	$10.17
Change: Old Industry to Nrep	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Legume fallow / Low tillage	58%	58%	49%	46%	$52.18	$51.57	$51.44
Legume fallow / High tillage	55%	58%	49%	48%	$71.36	$70.74	$70.62
Bare fallow / Low tillage	89%	57%	55%	49%	-$0.17	-$0.78	-$0.91
Bare fallow / High tillage	74%	62%	59%	61%	-$9.22	-$7.07	-$5.80

Change: N6ES to NREP	**Avg DIN in Runoff**	**Med DIN in Runoff**	**Avg DIN in Drainage**	**Med DIN in Drainage**	**AEB Small farms**	**AEB Medium farms**	**AEB Large farms**
Change: Bare fallow to legume	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
Nrep / Low tillage	61%	118%	108%	101%	-$100.52	-$49.26	-$30.92
Nrep / High tillage	117%	122%	105%	99%	-$70.59	-$23.47	-$9.06
N6ES / Low tillage	81%	107%	113%	105%	-$118.68	-$67.42	-$49.08
N6ES / High tillage	149%	107%	121%	110%	-$61.32	-$13.44	-$9.28
Old Industry / Low tillage	93%	116%	121%	109%	-$152.87	-$101.61	-$83.27
Old Industry / High tillage	159%	131%	125%	127%	-$151.18	-$101.28	-$85.47
Change: High tillage to low	Avg DIN in Runoff	Med DIN in Runoff	Avg DIN in Drainage	Med DIN in Drainage	AEB Small farms	AEB Medium farms	AEB Large farms
NREP / Legume fallow	167%	100%	89%	91%	$46.58	$48.38	$41.30
Nrep / Bare fallow	318%	104%	86%	89%	$42.54	$56.51	$26.48
N6ES / Legume fallow	146%	109%	91%	94%	-$8.45	$8.90	-$6.95
N6ES / Bare fallow	268%	109%	97%	98%	$48.91	$62.89	$32.85
Old Industry / Legume fallow	156%	100%	89%	94%	$31.79	$49.89	$23.79
Old Industry / Bare fallow	266%	113%	92%	111%	$33.48	$50.23	$21.59

These tables allows for the identification of win-win as well as win-lose (and lose-win and lose-lose) practice changes, from a current situation. It must also be noted that a change may be beneficial in reducing DIN from run-off, however it could increase DIN entering the waterways via deep drainage. This becomes especially apparent in changes from high tillage to low tillage, where the reduced soil disturbance allows easier runoff of nutrients, however (therefore) reduces the amount of DIN available for deep drainage leeching.

3. Conclusion and discussion

There is now an extensive amount of literature (See Devlin and Lewis, 2011), documenting, in increasing detail and confidence, the sources and potential implications for pollutants entering the Great Barrier Reef lagoon. Land resources that contribute to this are dominated by diffuse source agricultural pollutants, with the primary source differing by industry: sediments are primarily generated by grazing activities whilst nutrients are largely attributed to cropping activities, which are dominated by sugar cane production. Achieving reductions to nutrient exports will require a coordinated effort from industry and government to enhance the adoption of improved management practices and to identify innovative solutions (Thorburn et al., 2013). The focus in this component of the whole project is thus to examine the financial-economic implications arising from changing management practices to reduce nutrient exports along with the effectiveness in doing so.

Due to the heterogeneity within cane farming operations across the northern sugarcane industry, there is a significant variation in the range of management practices available that are suitable to reduce pollutant exports. To address this complex issue, we explored closely the subtleties of the interactions between management practices in relation to their corresponding socio-economic, institutional, financial and environmental characteristics. More specifically, our approach aimed to take account of enterprise diversity, regional variability, and differences in transition costs in order to quantify the impact on both nutrient losses and farm profitability from changing farm management practices. These findings have thus extended current knowledge by evaluating the impact of farm diversity across regions and types of farming enterprises as well as considering barriers to adoption (equipment, technology or other constraints) and differences in enterprise structure.

The component reported here is part of the broader RRRD039 project. The focus for this particular component is to analyse socio-economic, institutional, and financial-economic datasets to:

- Provide context regarding landholder perceptions of, and experiences with, changes in their farming operation and their experience with participating in government programs such as the Reef Rescue.
- Extend cost-effectiveness estimates to include three NRM regions, major land types, enterprise variability, and a range of management activities. This work consequently extends the work carried out in existing economic projects such as the Marine and Tropical Research Facility Project 3.7.5 (van Grieken et al., 2010b, 2010c) and the Paddock to Reef Monitoring and Modelling Metrics (van Grieken et al., 2010a);
- Identify relative advantages and limiting factors constraining the adoption of specific management practices , such as the requirement for capital, the complexity of the practice, or how the practice may impact on profitability; and
- Provide financial-economic inputs to an integrative regional model, as delivered by Component 1. Parts 2 and 3, in cooperation with Component 4 of the overall project.

The social-institutional analysis conducted as part of this project identified several aspects that were influential in the decisions made by growers to participate in the incentive-based Reef Rescue program, as well as revealing insights into the experience of growers who participated. These aspects broadly include:

- The availability of government funds and explicit environmental goals of the funding agency appear to have limited involvement by farmers in the early years of the program-roll out but was less influential in latter rounds as trust improved;
- The presence of cost-sharing arrangements and the role of social rewards and recognition were influential factors in participation, however the requirement for up-front capital to match that provided by the government precluded participation by some growers, effectively creating a financial threshold;
- Importance of local trusted advisors in providing the information and practical support needed to apply for the funds in a decentralised implementation of the program; and;
- Influence (often constraining) of existing local economic relationships between growers and their contractors and harvesting groups, which is not taken into account in program design.

The financial-economic analysis highlighted a few key messages to support the notion that accounting for biophysical and enterprise-structural variability (heterogeneity) in natural resource management is likely to be cost-effective:

- There appears to be significant variation in farm gross margins <u>between</u> regions and (to a lesser extent) across farm sizes. This may indicate that a single representative farm model is likely to misrepresent the actual financial-economic consequences of changing management;
- Variation in farm gross margins <u>within</u> regions is relatively modest for the practices evaluated, particularly with the relative economic benefit as a proportion of the average farm gross margin. This tends to highlight the importance of factors such as transaction costs, risk, and other relative (dis-)advantages associated with practice change;
- The above point also highlights the fact that the direct financial consequences associated with changed practices are potentially difficult to distinguish from other factors impacting on variability in business performance (e.g. price volatility and productivity influences);
- Economies of scale are evident (with small, medium and large farms indicating that operational efficiencies are higher for larger farms where better asset utilisation is possible);
- Changed practices that achieve environmental and economic benefits were identified but trade-offs also exist and may require different policy approaches;
- For the combinations of practices analysed in this research, a more targeted nutrient management strategy may prove to have the best cost-effectiveness in improving water quality. The extent to which this affects both financial and environmental outcomes varies between regions, soil types and farm sizes and current management systems. The results indicate that moving beyond commercially tested nutrient management is likely to come at a cost;

Some more specific and management practice related messages are as follows:

- Six-Easy-Steps nutrient management regime resulted in the highest FGM across all comparative scenarios;
- Farm gross margins tended to be relatively higher for low tillage scenarios, and relatively lower for legume fallows in the absence of yield improvement;

- Changing from old industry recommended rates to Six-Easy-Steps provides both financial and overall water quality benefits (total DIN reduction);
- Changing from Six-Easy-Steps to N-Replacement nutrient management provides substantial water quality improvement in the Wet Tropics and Mackay Whitsunday, and with limited cases in the Burdekin, while also generally resulting in a financial cost to the farmer;
- Changing from Old Industry recommended rates to N-Replacement nutrient management rates provides a water quality benefit. This change also provides a financial benefit in a legume fallow system, however comes at a cost in a bare fallow system;
- In the absence of yield improvement, results indicate that moving from a bare fallow to a legume fallow cover crop will generally result in a financial cost to the farmer (especially for small farms due to the required capital expenditures), and will only improve DIN in limited cases (dependant on nutrient and tillage management);
- Moving from high tillage to low tillage will generally provide financial benefits, where water quality benefits are variable and regionally specific.

There are some significant areas of convergence between the social-institutional and financial-economic analyses above.

- First, the relatively modest variation in farm gross margins within regions and the resulting emphasis on transaction costs and risks associated with changing practices emphasises the important role of engagement and extension networks as mechanisms to buffer the risk for growers participating in practice change programs. and ensure there are benefits from participation even where transactions costs might be perceived as high;
- Second, it is generally more efficient for larger operators to implement changes, which is often exacerbated by the dependence of small-medium size operators on collective harvesting and contracting relationships. Accordingly, individual-level and aggregate risks associated with change may not be shared by larger operators due to the existence of economies of scale identified in the financial analysis.

The economic modelling applied in this research involves applying conventional capital budgeting techniques and making a number of simplifying assumptions. Therefore, a number of general caveats with respect to interpreting and distributing the information from this report are considered as follows:

- First, it is exceedingly difficult to calculate the NPV of investment opportunities under uncertainty. These difficulties are particularly salient while attempting to estimate expected future changes to the FGM based on the assumption that volatile variables such as future output prices, input costs and yields can be forecasted with sufficient accuracy. Moreover, the information presented on A-Class management practices is based on practices under research and not thoroughly tested on a commercial scale.
- Second, the production yield data used within this project is estimated using APSIM, which provides an indication of yield potential that is not necessarily representative of anecdotal production averages within each cane district (or region for that matter). Furthermore, APSIM ignores the potential for improvement to cane yields as a consequence of growing a legume fallow. Recent case studies indicate growing a

well-managed legume fallow crop can increase yields through improved soil health by breaking the sugarcane monoculture cycle.

- Third, it is thus important to consider that each farming business is essentially unique and therefore each of the generalised parameters and assumptions used in this analysis may not necessarily reflect each farm's particular circumstances. Landholders may indeed have higher or lower costs of transitioning to improved practices; even despite practicing similar operations some may end up with higher or lower gross margins than those that form the basis of the investment analysis. Accordingly, due consideration of circumstances unique to each farm is warranted to make an informed and rational investment decision at the individual farm level.
- The nutrient management scenarios were developed after (grey) literature review and in consultation with growers and local agronomists from each particular region. The scenarios are based on common practices used within the region. They also take into account regional specific details such as common fertiliser products, the soil type modelled for this project and farming system requirements.
- Last, the research reported on has only analysed the concept of profitability at the farm level. However, it is important to consider more broadly the potential impacts that changing farming systems may have on other areas of the cane industry. Those areas that may be affected include, for example, harvesting contractors and millers, as well as agri-businesses linked throughout the local supply chain.

Future directions

A number of potential avenues for future research may be gleaned from this work. First, while only a limited number of (prioritized) nutrient management practices were subject to this investigation, others may exist with the potential to achieve greater improvement in water quality. On the basis that those practices are subsequently identified, it will be interesting to determine the farm-level implications of those new technologies on profitability and water quality outcomes. Third, the impact of a change in industry structure (size of farms, number of farms, and their location) on water quality outcomes could be investigated. Last, given the level of heterogeneity between and within regions, spatial targeting is likely to lead to the most cost-efficient way of improving water quality while at the same time maintaining a healthy industry. Accordingly, the information presented through this research can be further used to evaluate and monitor cost-effective policy instruments, institutional settings, delivery mechanisms, targeting and local community support to achieve water quality targets within a heterogeneous industry and landscape.

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Appendix 1: Tables

FGMs for small, medium and large farms in each of the analysed regions and all of the analysed management practice combinations

Table 16: FGMs ($/ha/yr) for small, medium and large farms in the Mackay Whitsundays

Nutrient	*Fallow*	*Split*	*Surface*	*Tillage*	*Small*	*Medium*	*Large*
AA	FB	SB	MB	GB	1293	1322	1351
AA	FB	SB	MB	GC	1239	1265	1290
AA	FB	SB	MC	GB	1302	1329	1356
AA	FB	SB	MC	GC	1248	1271	1295
AA	FC	SB	MB	GB	1254	1283	1312
AA	FC	SB	MB	GC	1214	1241	1268
AA	FC	SB	MC	GB	1263	1290	1317
AA	FC	SB	MC	GC	1223	1248	1273
AB	FB	SB	MB	GB	1310	1339	1369
AB	FB	SB	MB	GC	1258	1284	1310
AB	FB	SB	MC	GB	1319	1346	1373
AB	FB	SB	MC	GC	1267	1291	1315
AB	FC	SB	MB	GB	1328	1358	1387
AB	FC	SB	MB	GC	1285	1314	1340
AB	FC	SB	MC	GB	1337	1364	1392
AB	FC	SB	MC	GC	1295	1320	1345
AC	FB	SB	MB	GB	1230	1259	1288
AC	FB	SB	MB	GC	1177	1203	1228
AC	FB	SB	MC	GB	1239	1265	1293
AC	FB	SB	MC	GC	1186	1209	1233
AC	FC	SB	MB	GB	1278	1307	1336
AC	FC	SB	MB	GC	1224	1261	1281
AC	FC	SB	MC	GB	1287	1313	1341
AC	FC	SB	MC	GC	1243	1267	1293

Table 17: FGMs ($/ha/yr) for small, medium and large farms in the Wet Tropics

Nutrient	Fallow	Split	Surface	Tillage	Small	Medium	Large
AA	FB	SB	MB	GB	1001	1021	1051
AA	FB	SB	MB	GC	943	956	989
AA	FB	SB	MC	GB	1010	1027	1056
AA	FB	SB	MC	GC	943	963	994
AA	FC	SB	MB	GB	976	996	1027
AA	FC	SB	MB	GC	908	930	963
AA	FC	SB	MC	GB	984	1002	1031
AA	FC	SB	MC	GC	917	937	968
AB	FB	SB	MB	GB	1038	1059	1089
AB	FB	SB	MB	GC	969	992	1025
AB	FB	SB	MC	GB	1047	1065	1094
AB	FB	SB	MC	GC	979	999	1030
AB	FC	SB	MB	GB	1022	1043	1074
AB	FC	SB	MB	GC	955	977	1010
AB	FC	SB	MC	GB	1032	1050	1079
AB	FC	SB	MC	GC	974	992	1021
AC	FB	SB	MB	GB	992	1012	1042
AC	FB	SB	MB	GC	924	945	978
AC	FB	SB	MC	GB	1001	1018	1047
AC	FB	SB	MC	GC	933	952	983
AC	FC	SB	MB	GB	1005	1024	1056
AC	FC	SB	MB	GC	937	958	992
AC	FC	SB	MC	GB	1015	1032	1061
AC	FC	SB	MC	GC	947	966	997

Table 18: FGMs ($/ha/yr) for small, medium and large farms in the Burdekin Delta

Nutrient	*Fallow*	*Split*	*Surface*	*Tillage*	*Small*	*Medium*	*Large*
AA	FB	SB	MB	GB	3163	3190	3231
AA	FB	SB	MB	GC	3112	3137	3185
AA	FB	SB	MC	GB	3172	3186	3236
AA	FB	SB	MC	GC	3121	3143	3190
AA	FC	SB	MB	GB	3209	3231	3266
AA	FC	SB	MB	GC	3125	3150	3195
AA	FC	SB	MC	GB	3218	3238	3271
AA	FC	SB	MC	GC	3134	3156	3200
AB	FB	SB	MB	GB	3212	3240	3282
AB	FB	SB	MB	GC	3143	3169	3218
AB	FB	SB	MC	GB	3221	3246	3286
AB	FB	SB	MC	GC	3152	3175	3222
AB	FC	SB	MB	GB	3257	3274	3308
AB	FC	SB	MB	GC	3174	3200	3245
AB	FC	SB	MC	GB	3259	3280	3313
AB	FC	SB	MC	GC	3183	3206	3250
AC	FB	SB	MB	GB	3128	3156	3198
AC	FB	SB	MB	GC	3057	3082	3131
AC	FB	SB	MC	GB	3137	3162	3203
AC	FB	SB	MC	GC	3066	3088	3136
AC	FC	SB	MB	GB	3221	3245	3279
AC	FC	SB	MB	GC	3138	3164	3213
AC	FC	SB	MC	GB	3230	3251	3284
AC	FC	SB	MC	GC	3147	3170	3218

Table 19: FGMs ($/ha/yr) for small, medium and large farms in the Burdekin River Irrigation Area

Nutrient	*Fallow*	*Split*	*Surface*	*Tillage*	*Small*	*Medium*	*Large*
AA	FB	SB	MB	GB	1868	1899	1945
AA	FB	SB	MB	GC	1821	1850	1903
AA	FB	SB	MC	GB	1877	1905	1949
AA	FB	SB	MC	GC	1834	1861	1912
AA	FC	SB	MB	GB	1901	1925	1962
AA	FC	SB	MB	GC	1824	1851	1899
AA	FC	SB	MC	GB	1910	1932	1967
AA	FC	SB	MC	GC	1832	1857	1903
AB	FB	SB	MB	GB	1871	1903	1949
AB	FB	SB	MB	GC	1846	1876	1919
AB	FB	SB	MC	GB	1880	1909	1954
AB	FB	SB	MC	GC	1855	1883	1924
AB	FC	SB	MB	GB	1922	1948	1984
AB	FC	SB	MB	GC	1839	1867	1915
AB	FC	SB	MC	GB	1931	1954	1989
AB	FC	SB	MC	GC	1848	1873	1920
AC	FB	SB	MB	GB	1816	1847	1893
AC	FB	SB	MB	GC	1750	1780	1833
AC	FB	SB	MC	GB	1825	1854	1898
AC	FB	SB	MC	GC	1759	1786	1838
AC	FC	SB	MB	GB	1901	1926	1963
AC	FC	SB	MB	GC	1824	1852	1900
AC	FC	SB	MC	GB	1910	1933	1968
AC	FC	SB	MC	GC	1833	1858	1905

Appendix 2: Figures

Dissolved Inorganic Nitrogen in run-off and deep drainage presented below for all analysed regions. Presented are the 2nd quarter (2Q) and 3rd quarter (3Q) box, as well as the median (line between 2Q and 3Q) and the mean (diamond).

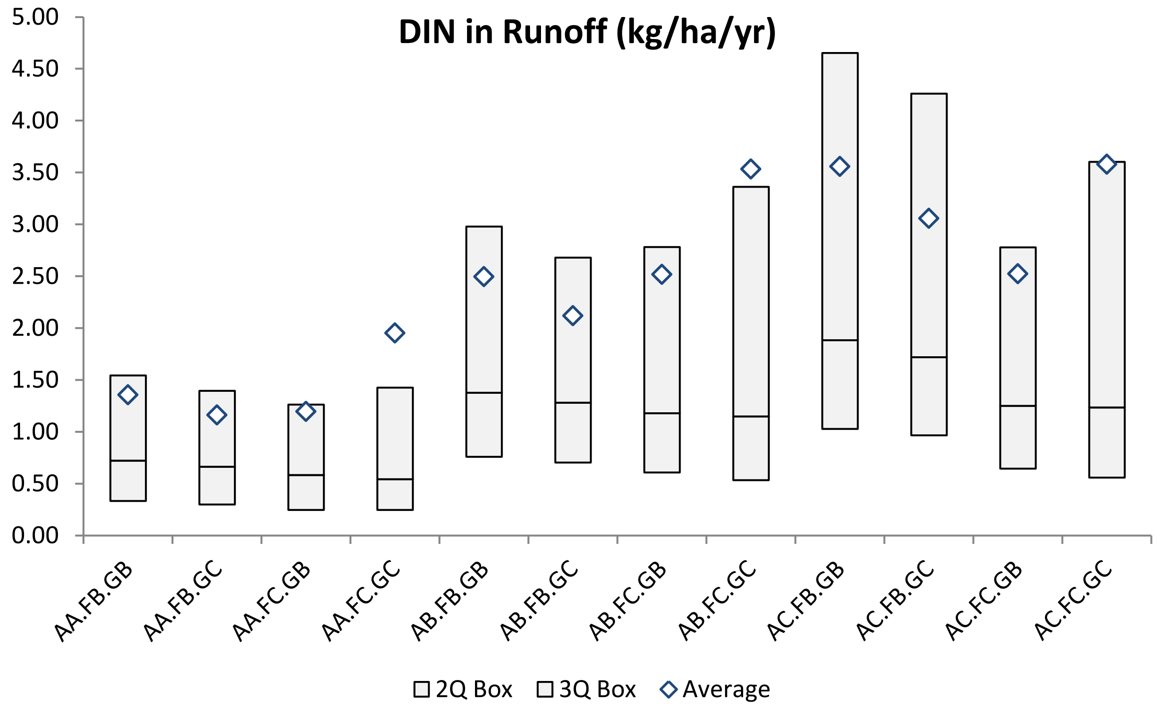


Figure 19: Wet Tropics DIN in Runoff (kg/ha)

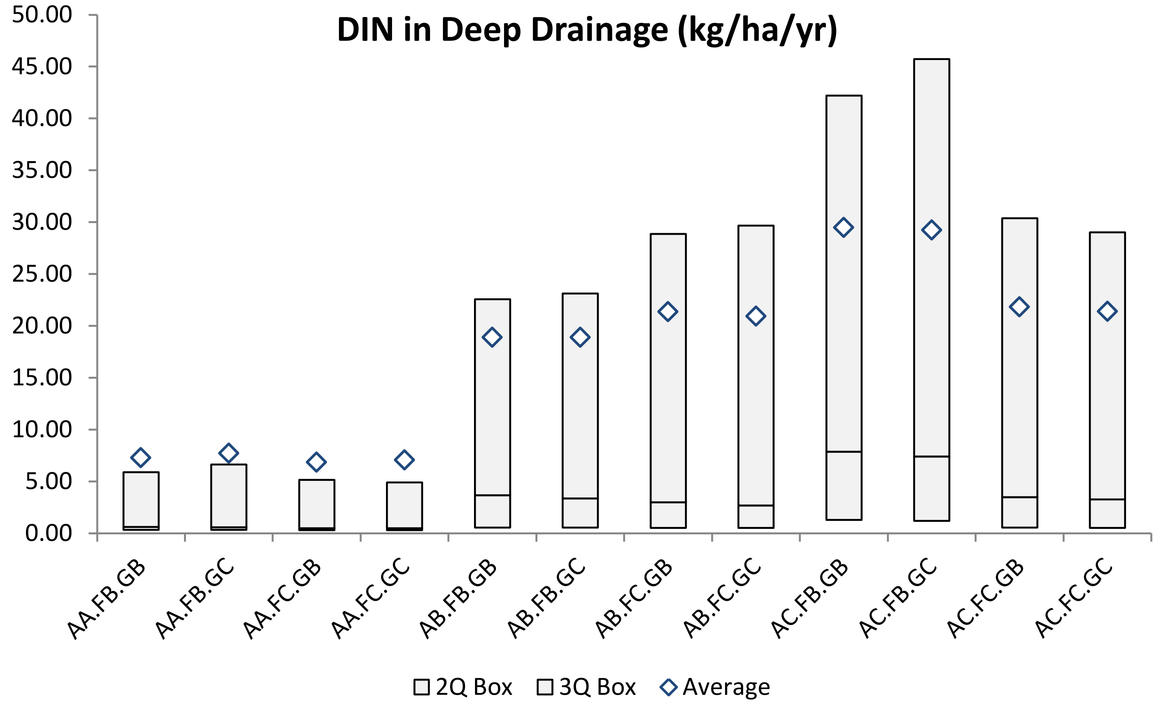


Figure 20: Wet Tropics DIN in Deep Drainage (kg/ha)

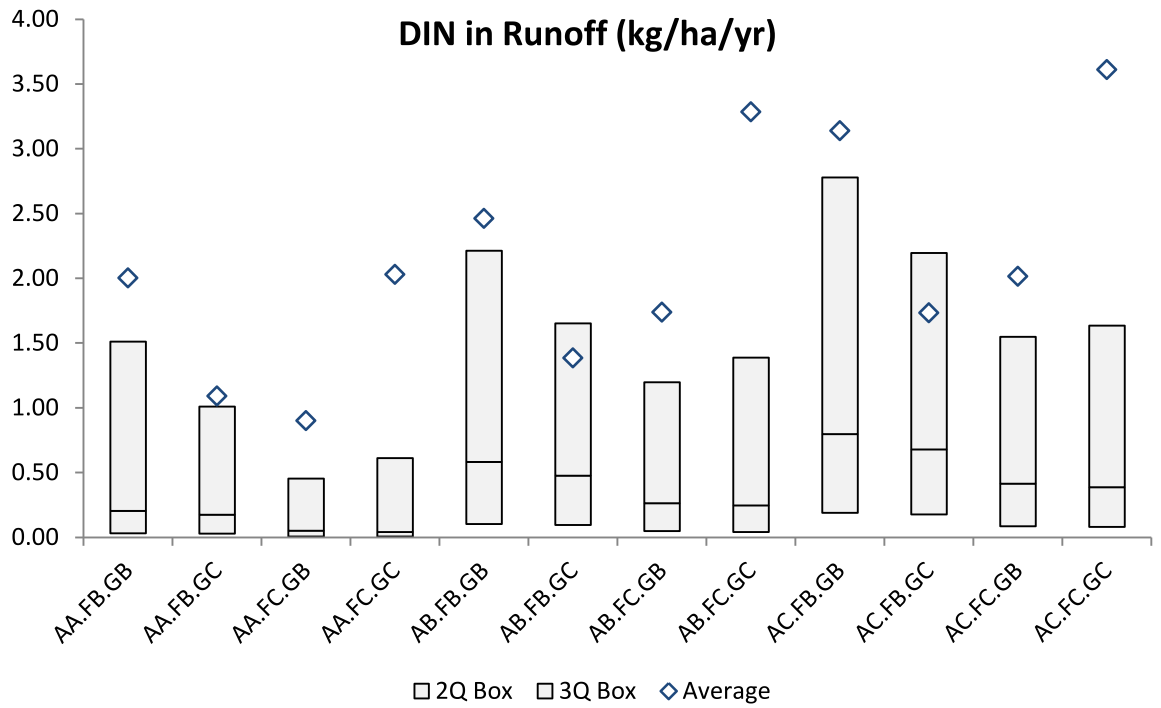


Figure 21: Mackay Whitsundays DIN in Runoff (kg/ha/yr)

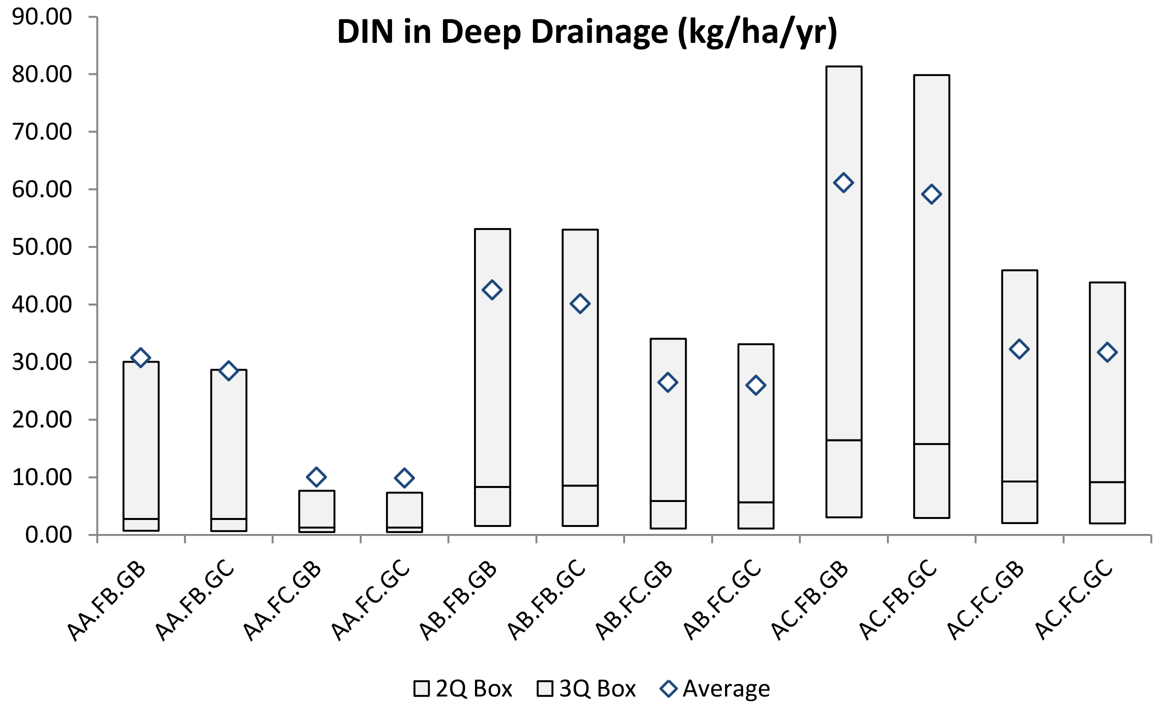


Figure 22: Mackay Whitsundays DIN in Deep Drainage (kg/ha/yr)

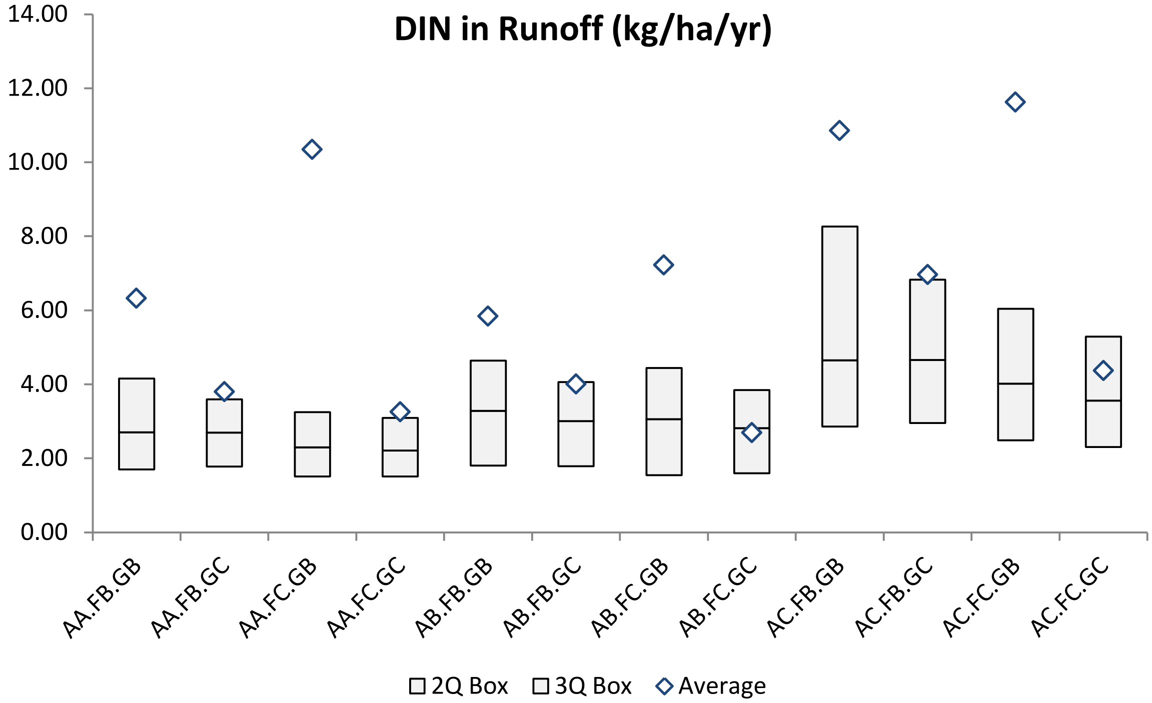


Figure 23: Burdekin River Irrigation Area DIN in Runoff (kg/ha/yr)

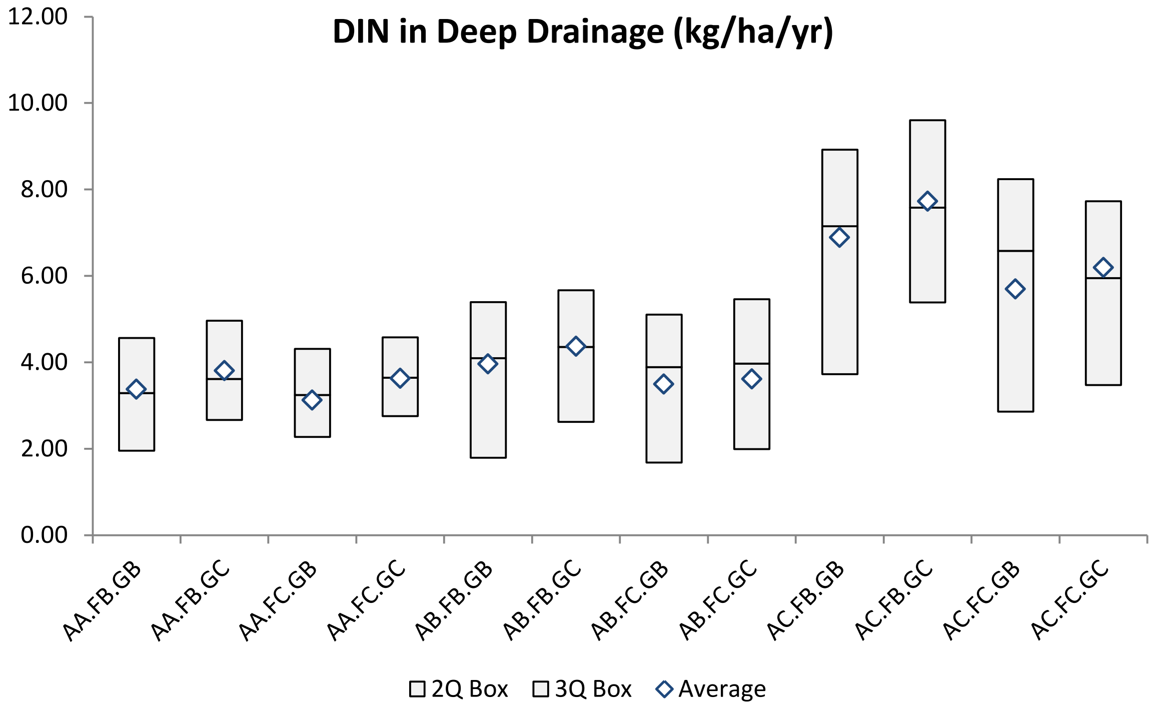


Figure 24: Burdekin River Irrigation Area DIN in Deep Drainage (kg/ha/yr)

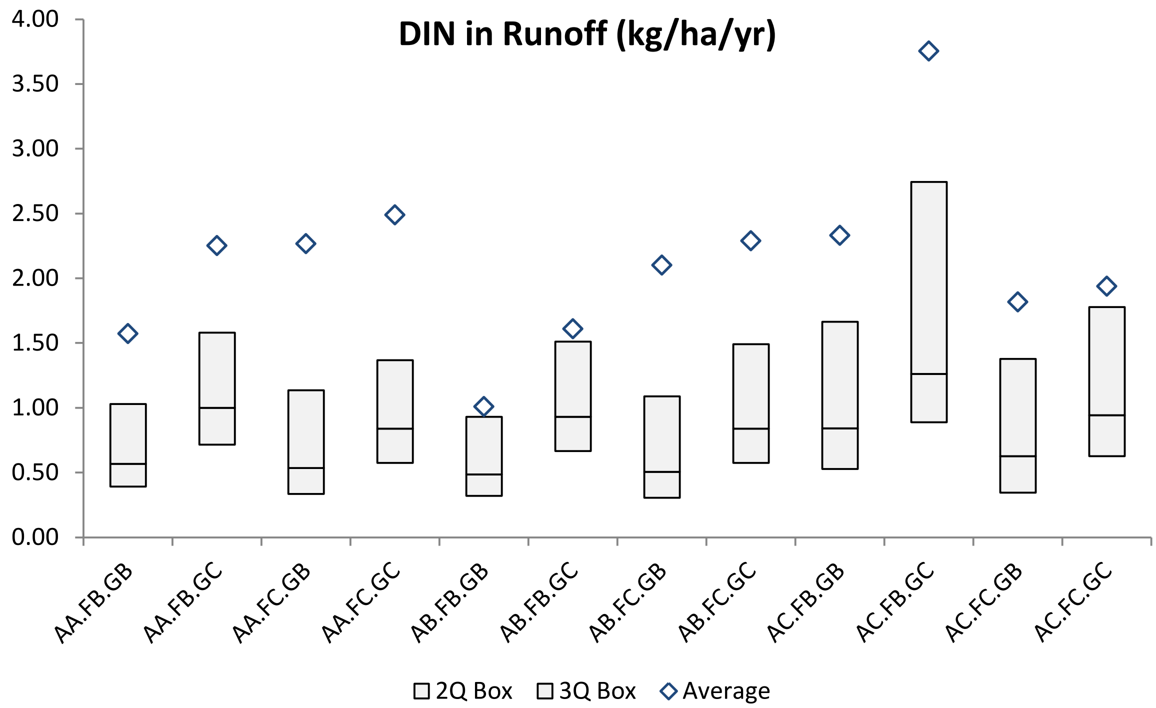


Figure 25: Burdekin Delta DIN in Runoff (kg/ha/yr)

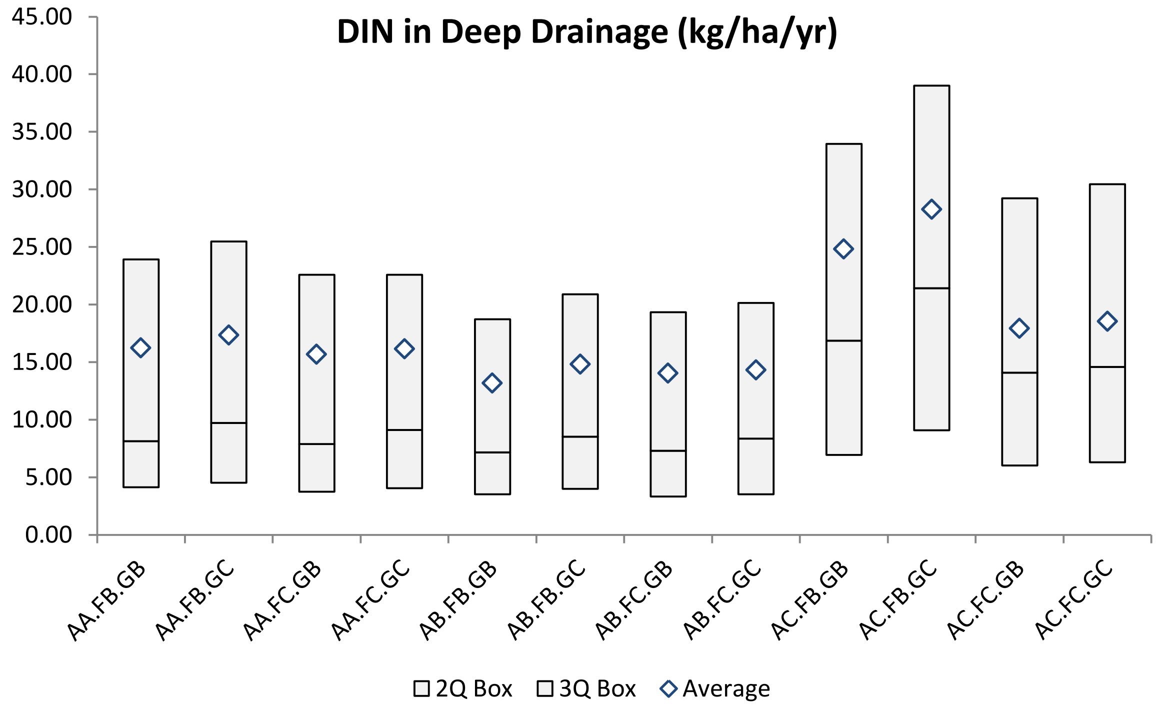


Figure 26: Burdekin Delta DIN in Deep Drainage (kg/ha/yr)

Dissolved Inorganic Nitrogen in run-off, deep drainage as well as N lost via denitrification presented below for all analysed regions. Presented are the mean values for the various pathways.

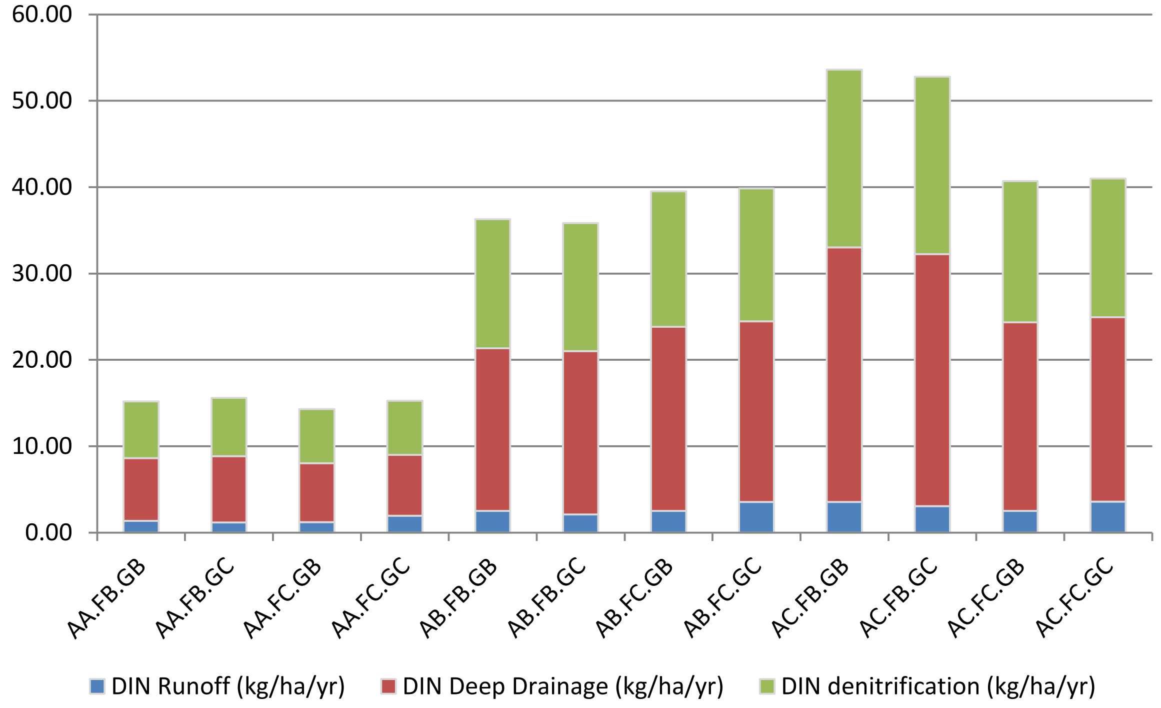


Figure 27: Wet Tropics N pathways (kg/ha/yr)

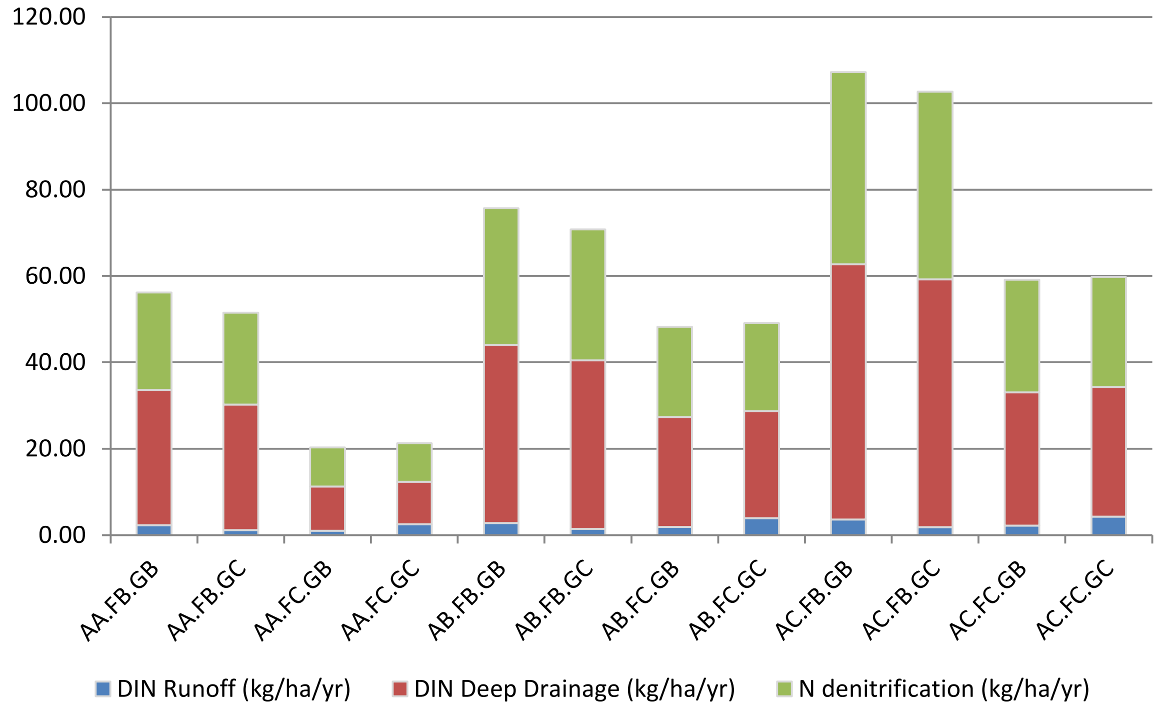


Figure 28: Mackay Whitsundays N pathways (kg/ha/yr)

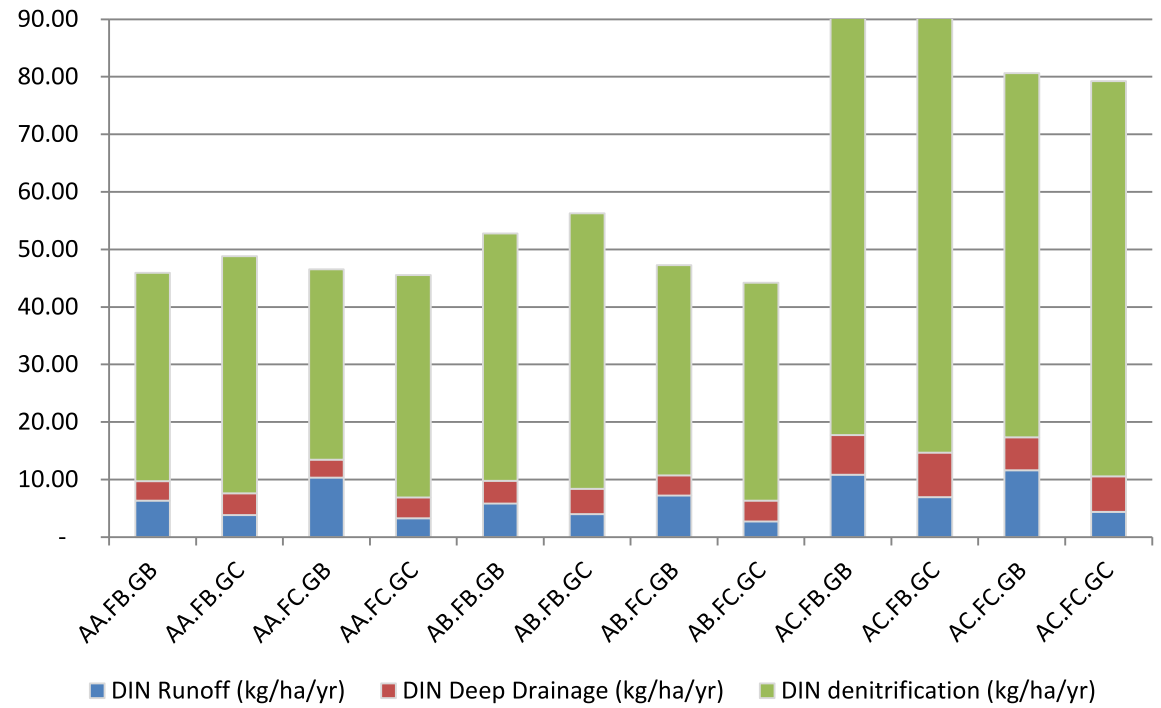


Figure 29: Burdekin River Irrigation Area N pathways (kg/ha/yr)

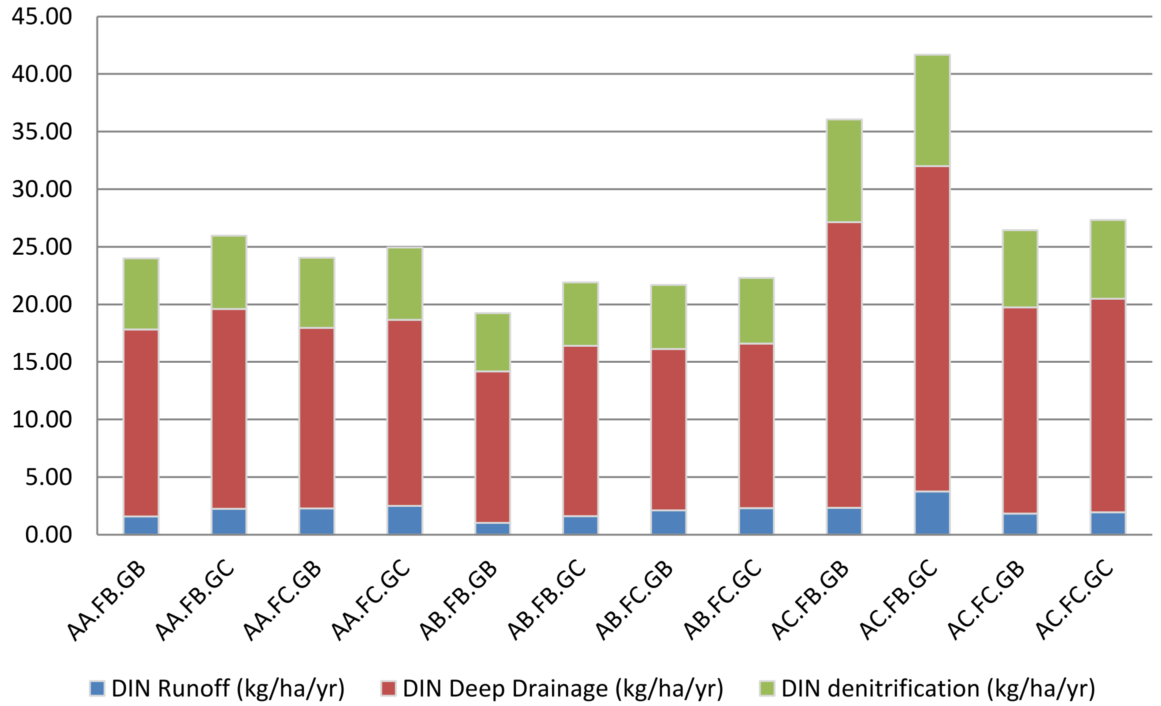
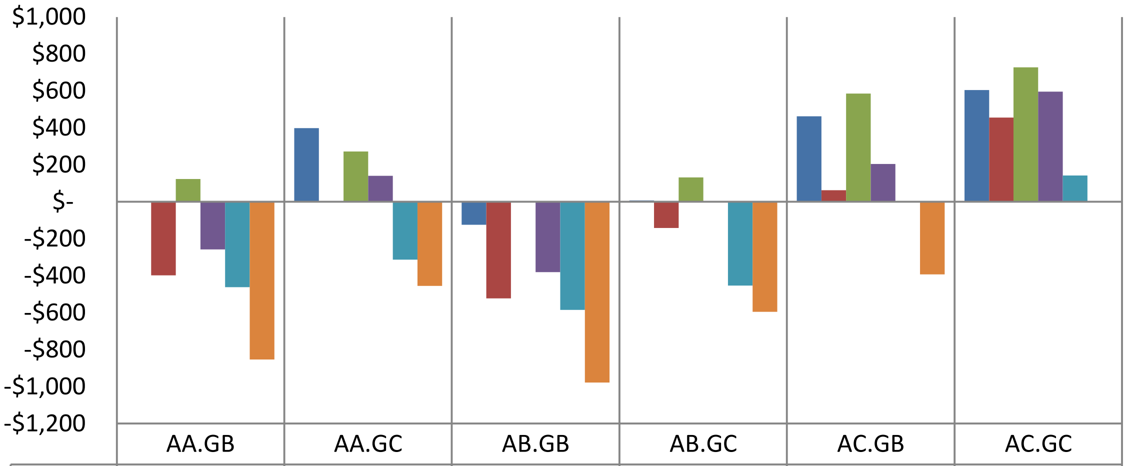


Figure 30: Burdekin Delta N pathways (kg/ha/yr)

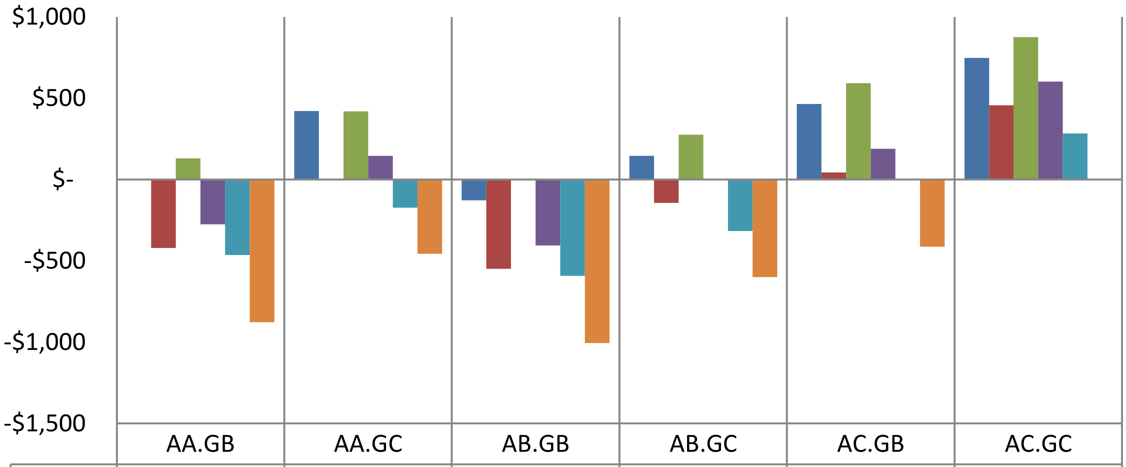
NPV of practice change presented below for all analysed farm sizes and regions

The list of Figures below indicates NPV of change between nutrient rate-tillage combinations (Ax.Gx).



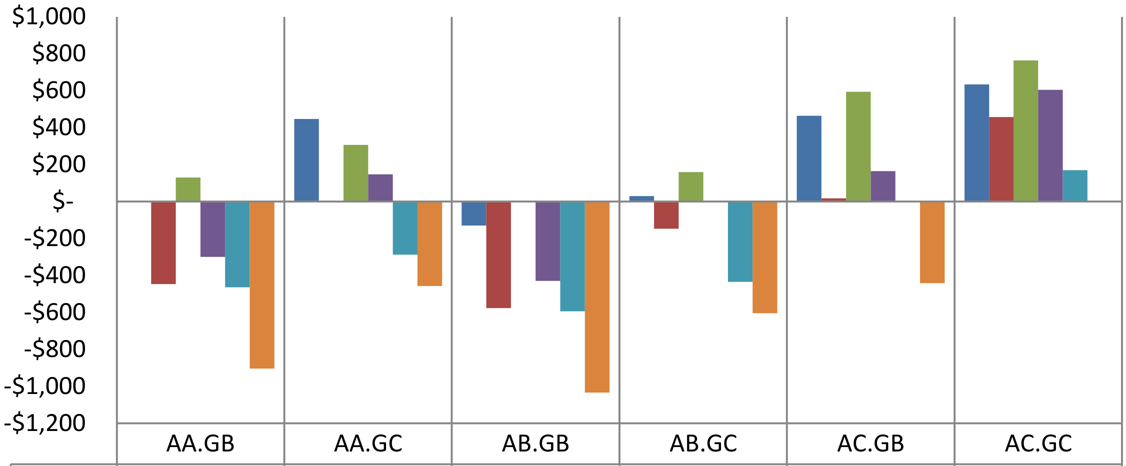
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$399	-$124	$8	$462	$604
AA.GC	-$399	$-	-$523	-$141	$63	$455
AB.GB	$124	$273	$-	$131	$586	$728
AB.GC	-$258	$141	-$381	$-	$204	$596
AC.GB	-$462	-$313	-$586	-$454	$-	$142
AC.GC	-$854	-$455	-$978	-$596	-$392	$-

Figure 31: Mackay Whitsundays Small farm NPV of changing practice ($/ha/10yr)



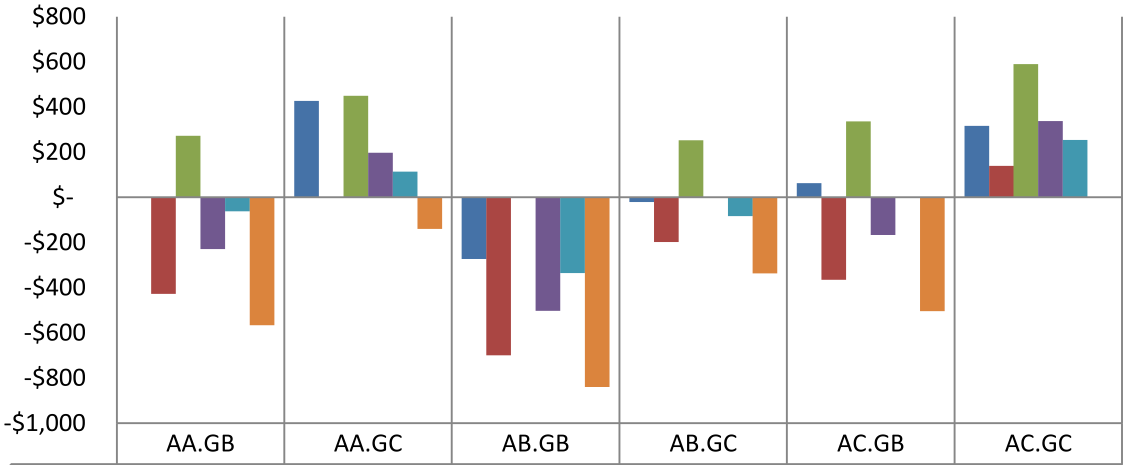
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$421	-$129	$146	$464	$747
AA.GC	-$421	$-	-$550	-$145	$43	$456
AB.GB	$129	$420	$-	$275	$592	$876
AB.GC	-$276	$145	-$405	$-	$188	$601
AC.GB	-$464	-$173	-$592	-$318	$-	$283
AC.GC	-$877	-$456	-$1,006	-$601	-$413	$-

Figure 32: Mackay Whitsundays medium sized farm NPV of changing practice ($/ha/10yr)



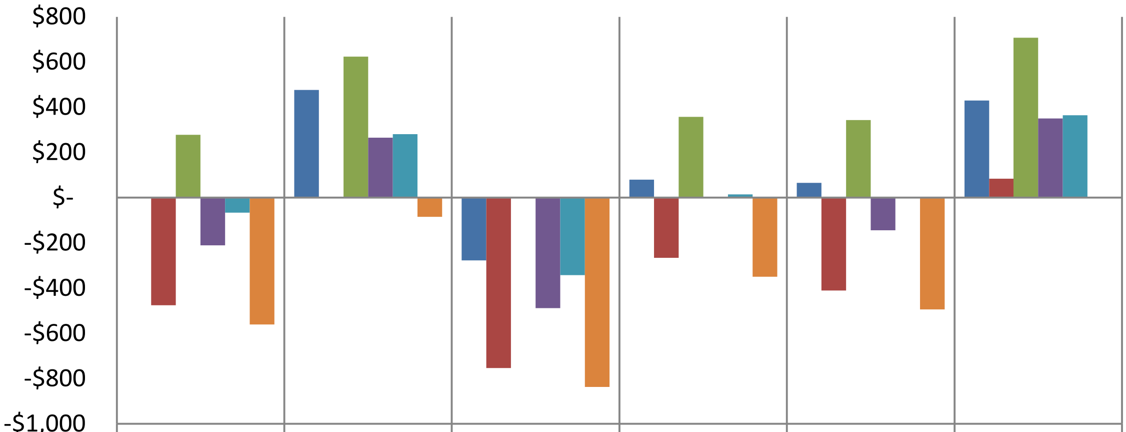
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$447	-$130	$29	$464	$634
AA.GC	-$447	$-	-$577	-$147	$17	$458
AB.GB	$130	$307	$-	$159	$594	$764
AB.GC	-$299	$147	-$429	$-	$164	$605
AC.GB	-$464	-$287	-$594	-$434	$-	$170
AC.GC	-$904	-$458	-$1,034	-$605	-$440	$-

Figure 33: Mackay Whitsundays large farm NPV of changing practice ($/ha/10yr)



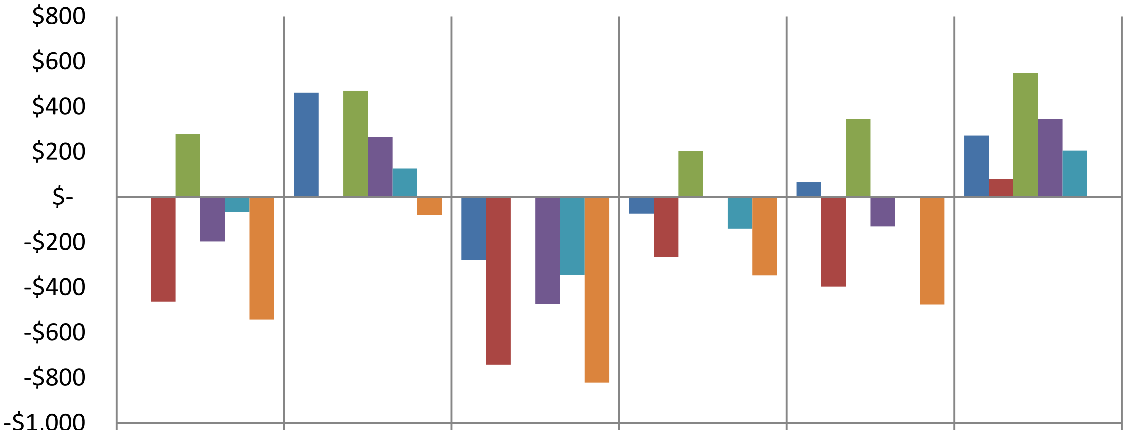
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$427	-$273	-$21	$63	$316
AA.GC	-$427	$-	-$700	-$198	-$364	$139
AB.GB	$273	$450	$-	$252	$336	$589
AB.GC	-$229	$198	-$502	$-	-$166	$337
AC.GB	-$63	$114	-$336	-$84	$-	$253
AC.GC	-$566	-$139	-$839	-$337	-$503	$-

Figure 34: Wet Tropics Small farm NPV of changing practice ($/ha/10yr)



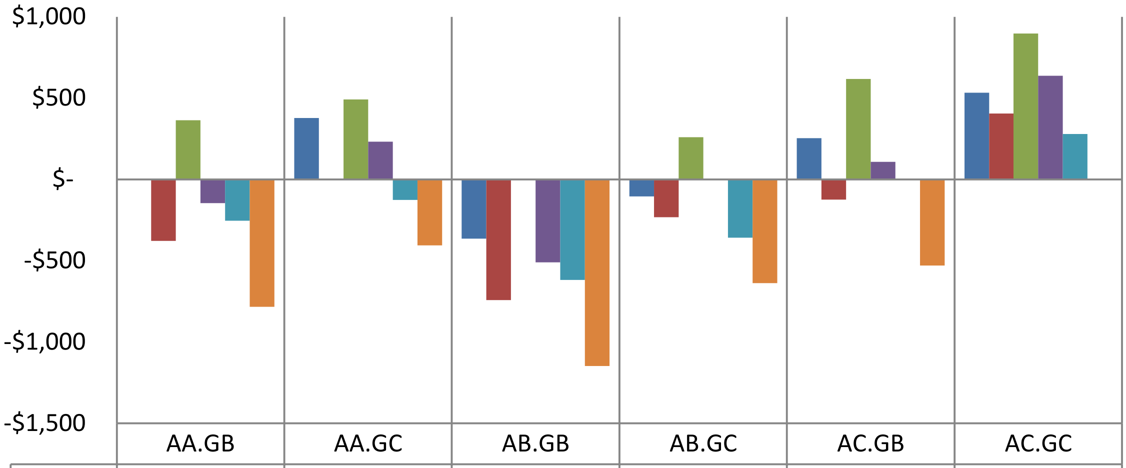
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$476	-$277	$80	$65	$430
AA.GC	-$476	$-	-$753	-$266	-$410	$84
AB.GB	$277	$623	$-	$358	$343	$707
AB.GC	-$210	$266	-$488	$-	-$145	$350
AC.GB	-$65	$280	-$343	$15	$-	$364
AC.GC	-$560	-$84	-$837	-$350	-$494	$-

Figure 35: Wet Tropics medium sized farm NPV of changing practice ($/ha/10yr)



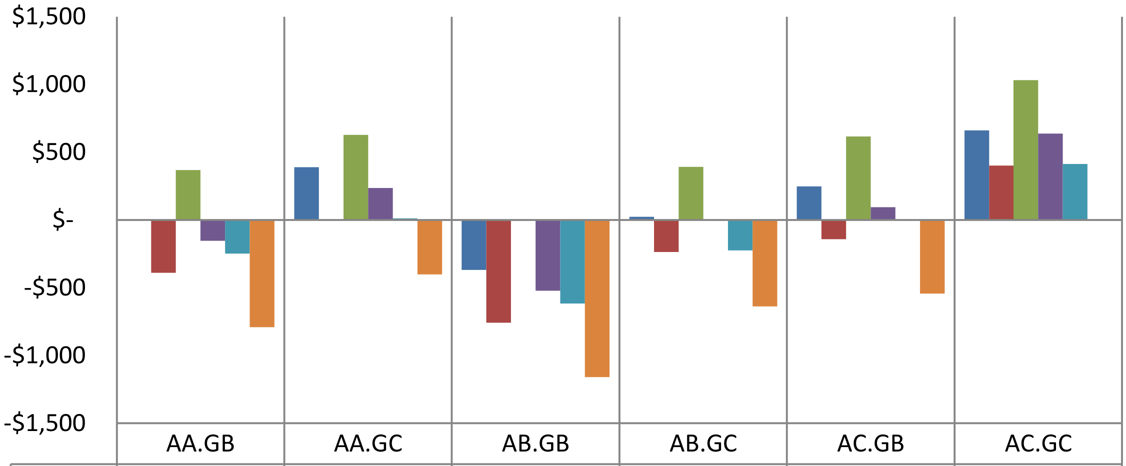
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$463	-$278	-$74	$66	$272
AA.GC	-$463	$-	-$741	-$267	-$397	$79
AB.GB	$278	$471	$-	$205	$344	$550
AB.GC	-$196	$267	-$475	$-	-$130	$346
AC.GB	-$66	$127	-$344	-$140	$-	$206
AC.GC	-$542	-$79	-$820	-$346	-$476	$-

Figure 36: Wet Tropics large farm NPV of changing practice ($/ha/10yr)



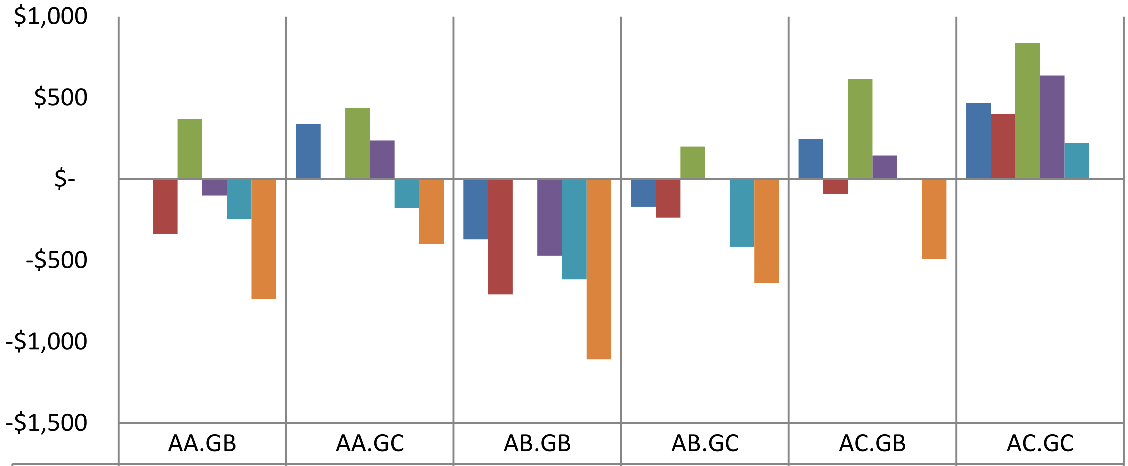
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$377	-$365	-$105	$253	$533
AA.GC	-$377	$-	-$742	-$232	-$124	$406
AB.GB	$365	$492	$-	$260	$618	$897
AB.GC	-$145	$232	-$510	$-	$108	$638
AC.GB	-$253	-$126	-$618	-$358	$-	$279
AC.GC	-$783	-$406	-$1,147	-$638	-$529	$-

Figure 37: BDK Delta Small farm NPV of changing practice ($/ha/10yr)



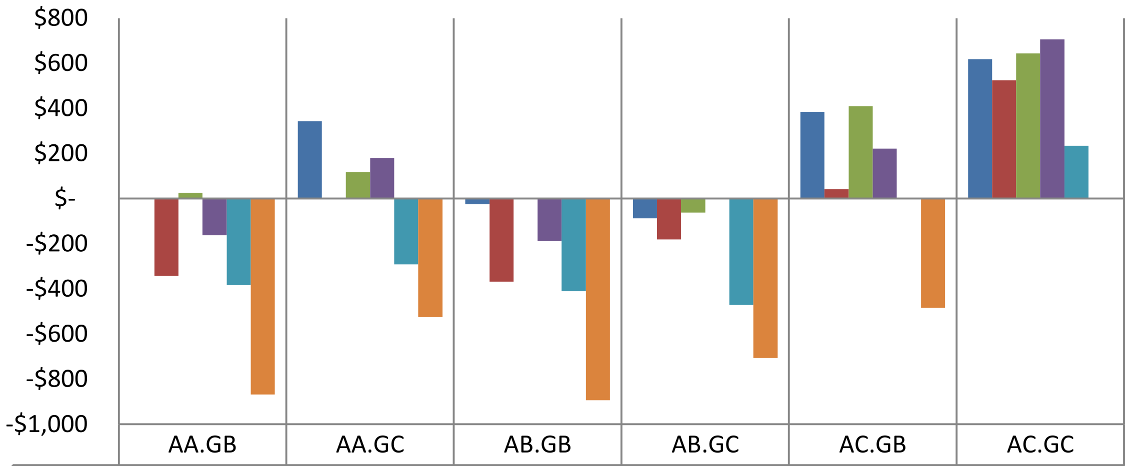
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$390	-$369	$24	$248	$662
AA.GC	-$390	$-	-$759	-$236	-$142	$402
AB.GB	$369	$629	$-	$393	$616	$1,030
AB.GC	-$154	$236	-$523	$-	$94	$638
AC.GB	-$248	$12	-$616	-$224	$-	$414
AC.GC	-$792	-$402	-$1,160	-$638	-$544	$-

Figure 38: BDK Delta medium sized farm NPV of changing practice ($/ha/10yr)



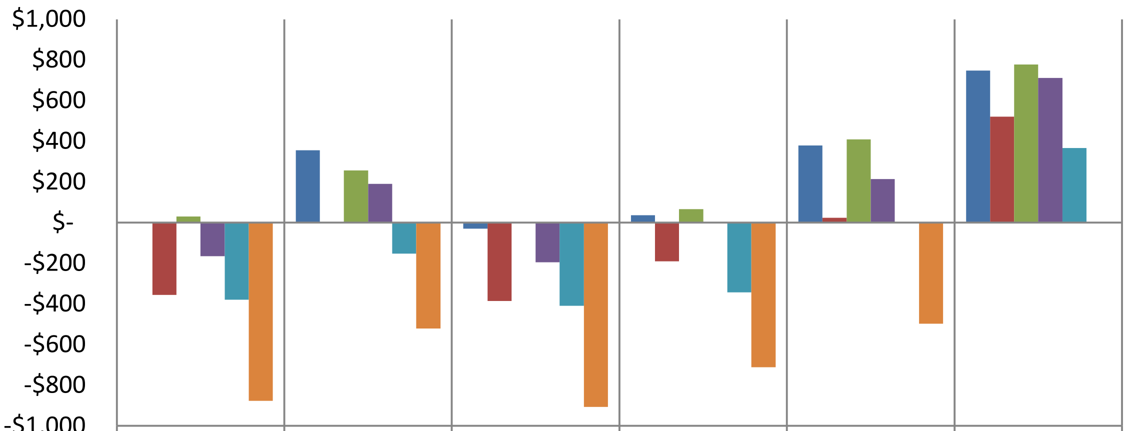
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$338	-$370	-$169	$247	$469
AA.GC	-$338	$-	-$708	-$237	-$92	$401
AB.GB	$370	$438	$-	$201	$616	$838
AB.GC	-$101	$237	-$471	$-	$145	$638
AC.GB	-$247	-$178	-$616	-$415	$-	$222
AC.GC	-$739	-$401	-$1,108	-$638	-$492	$-

Figure 39: BDK Delta large farm NPV of changing practice ($/ha/10yr)



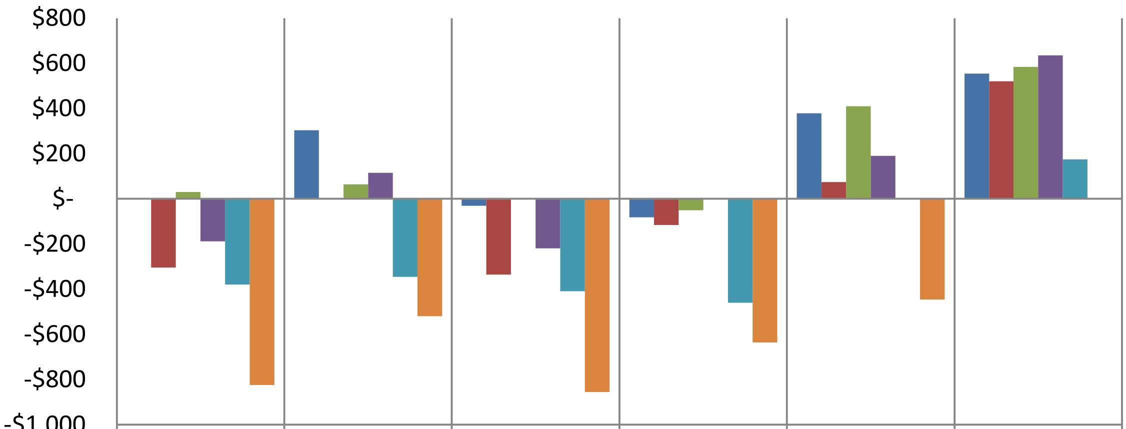
	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$343	-$26	-$88	$384	$618
AA.GC	-$343	$-	-$368	-$181	$41	$525
AB.GB	$26	$118	$-	-$62	$410	$644
AB.GC	-$162	$181	-$188	$-	$222	$706
AC.GB	-$384	-$291	-$410	-$472	$-	$234
AC.GC	-$868	-$525	-$894	-$706	-$484	$-

Figure 40: Burdekin River Irrigation Area small farm NPV of changing practice ($/ha/10yr)



	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$356	-$30	$36	$380	$747
AA.GC	-$356	$-	-$386	-$190	$23	$521
AB.GB	$30	$256	$-	$65	$409	$777
AB.GC	-$166	$190	-$195	$-	$214	$711
AC.GB	-$380	-$153	-$409	-$344	$-	$367
AC.GC	-$877	-$521	-$907	-$711	-$497	$-

Figure 41: Burdekin River Irrigation Area medium sized farm NPV of changing practice ($/ha/10yr)



	AA.GB	AA.GC	AB.GB	AB.GC	AC.GB	AC.GC
AA.GB	$-	$304	-$31	-$82	$379	$554
AA.GC	-$304	$-	-$335	-$116	$75	$520
AB.GB	$31	$65	$-	-$51	$409	$584
AB.GC	-$188	$116	-$219	$-	$190	$636
AC.GB	-$379	-$345	-$409	-$460	$-	$175
AC.GC	-$824	-$520	-$854	-$636	-$445	$-

Figure 42: Burdekin River Irrigation Area large farm NPV of changing practice ($/ha/10yr)