Economic assessment of best management practices for banana growing

Report to the Department of Environment and Heritage Protection through funding from the Reef Water Quality Science Program

RP140B Technical Report 2017

Source: Kukulies, T, “Banana farm grassed inter-rows”, 2015.

Queensland Government

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Executive summary

This technical report presents the methodology and findings of the representative economic study modelling the economic and water quality implications of Banana Best Management Practices (BMP) adoption. The findings indicated that in general, BMP adoption led to reductions in dissolved inorganic nitrogen (DIN) and total suspended sediment (TSS) leaving banana farms, while at the same time improving the profitability of farming businesses.

The modelling approach used in this report involved developing representative farm scenarios to explore the economic and water quality implications of adopting stepwise management improvements, as well as exploring the impact of enterprise variability on profitability. A range of scenarios were developed to represent typical banana growing farms in the Tully and Innisfail regions, with variation in sizes, soil types and slopes. Data used in the modelling was collected from publications, industry sources, extension officers and workshops held with growers.

The modelling found that improved management practices were generally associated with higher farm gross margins per hectare (up to $1,381/ha when changing nutrient rate from D to B class), but not all management practice improvements had a positive impact on farm gross margin. Farm gross margins were higher for farms on Dermosol soils compared to Ferrosol soils (mainly due to higher irrigation costs in Ferrosols) and larger farms had higher farm gross margins than smaller farms (due to several areas where economies of scale could be realised by larger farms).

Investment analyses revealed that, in general, the transition to improved farming systems (e.g. all D class to all C class) showed a positive impact on farm profitability. However, some individual practice changes showed a negative impact on farm profitability. For example, transitioning ground cover from D to C class resulted in a negative impact on farm profitability (-$243/ha/yr). The implementation of BMPs is generally characterised as having a low risk of adverse production outcomes, however at present there is a limited number of studies to accurately define the production implications for some of these practices. To analyse possible production implications, a risk analysis was undertaken which revealed that the economic outcomes were very sensitive to changes in production.

The water quality modelling results found that reducing fertiliser rates was the single most important driver of DIN abatement on all farms (up to 32.2kg N/ha/yr reduction moving from D to B class rates was responsible for 88 per cent of total DIN reduction on Ferrosol soils) and delivered substantial economic benefits. Increasing ground cover on inter-rows and headlands was the most important practice in terms of reducing sediment loads in runoff (up to 10.8 t/ha/yr reduction moving from D to B class ground cover was responsible for 82 per cent of total TSS reduction on Ferrosol soils). Shifting ground cover from D to C class dramatically reduced soil erosion by a factor ~10, mainly due to addition of grassed inter-rows.

The pesticides modelled were glyphosate, chlorothalonil and glufosinate-ammonium for the Dermosol and Ferrosol soils. Pesticide loss behaviour was similar for the three pesticides with most pesticide lost in runoff, compared to leaching. These results imply that management of erosion and sediments would not be effective in significantly reducing pesticide runoff losses. Given that total runoff cannot be managed, the only effective way to reduce losses would be to reduce application rates or frequency of applications.

While this report provides an insight to the water quality and economic benefits of selected improved management practices for a range of representative scenarios modelled, there are several considerations that should be taken into account beyond these benefits. The adoption of improved management practices, new technologies and innovations is a complex process that can take many years to achieve. Providing funding to support the process is no guarantee that it will occur, even if a practice has been demonstrated to generate positive economic benefits. A number of other factors may limit the uptake of an improved management practice, including its compatibility with a grower's existing farming system, its perceived relative advantage over the current farming system, the perceived level of risk associated with the practice, whether the practice is observable and trialable, and whether the practice aligns with the grower's values.

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List of acronyms

- ABARES – Australian Bureau of Agricultural and Resource Economics and Sciences
- ABCD – Aspirational, Best, Conventional, Dated
- ABGC – Australian Banana Growers Council
- AEB – Annualised Equivalent Benefit
- ASRIS – Australian Soil Resource Information System
- BMP – Best Management Practice
- BOM – Bureau of Meteorology
- DAF – Department of Agriculture and Fisheries
- DCF – Discounted Cash Flow
- DEM – Digital Evaluation Map
- DIN – Dissolved Inorganic Nitrogen
- DNRM – Department of Natural Resources and Mines
- EEF – Enhanced Efficiency Fertilisers
- FGM – Farm Gross Margin
- FSS – Fine Suspended Sediment
- GBR – Great Barrier Reef
- GST – Good and Services Tax
- HAL – Horticulture Australia Limited
- IPM – Integrated Pest Management
- K – Potassium
- N – Nitrogen
- NPV – Net Present Value
- NRM – National Resource Management
- P – Phosphorus
- PN – Particulate Nitrogen
- RACQ – Royal Automotive Club of Queensland
- RUSLE – Revised Universal Soil Erosion Equation
- RWQ – Reef Water Quality
- SRTM – Shuttle Radar Topography Mission
- SWD – Soil Water Deficit
- TN – Total Nitrogen
- TP – Total Phosphorus
- TSS – Total Suspended Sediments
- WOF – Whole of Farm

1 Background

1.1 Project overview

The RP140B project aims to provide government, industry and banana growers with greater confidence as to the likely profitability and water quality implications of the various management practice options for Banana Best Management Practices (BMP). For improving the relative risk of poor water quality to the Great Barrier Reef, the Scientific Consensus Statement (2013) identified reducing fertiliser nitrogen (dissolved inorganic nitrogen, DIN) as the highest management priority in the Wet Tropics region. The land use that contributes the highest anthropogenic dissolved inorganic nitrogen (tonnes per year) is sugarcane, with bananas the second highest contributor from the Johnstone sub-catchment, in the Wet Tropics region (Queensland Government 2014: 83). The main pollutants identified as priority for the banana industry are nutrients in the form of DIN, particulate nitrogen (PN) and total suspended sediments (TSS) (Terrain NRM 2015, Masters *et al* 2017). In order to achieve these reductions, a best management framework has been developed to transition farmers to improved practices. Implementing BMP involves changes to capital machinery, inputs and management, which have economic implications on the farmer.

The RP140B project consists of five major components: synthesis reports (initial and final), three grower case studies, adoption innovation survey, representative economic study and the communication and extension of project findings. This technical report presents the methodology and findings of the representative economic study. The aim of the study is to model the economic and water quality effects of adopting improved management practices for banana growers in the Wet Tropics. By combining both water quality and economic analysis, the study aims to present a measure of cost-effectiveness of pollutant abatement at the farm level. Firstly, this report presents background information on the Queensland banana industry and Banana practice frameworks, along with the methodology and assumptions used in the analysis and the economic and water quality modelling results. The results section includes details on the economic and risk analyses study, sediment and nitrogen abatement, and combined results to estimate the cost-effectiveness of nitrogen and sediment abatement. Additionally, there are results for the pesticide modelling. Finally, limitations for the project findings, areas for future research and policy implications are discussed.

1.2 Management practice selection

The management practices selected for modelling were based on those identified by the Paddock to Reef Water Quality Risk Framework as being important in determining DIN and sediment loads in runoff. For each management practice, the framework identifies three levels based on their risk to water quality: high risk (D), moderate risk (C) and moderate-low risk (B). Table 1 shows the details of the management practices.

Table 1: Paddock to Reef Water Quality Risk Framework - Bananas

Management	Indicative Practice Levels		
	High Risk (D)	**Moderate Risk (C)**	**Moderate-Low Risk (B)**
	Superseded	Minimum	Best Practice
Crop Removal	Banana crop is removed through being knocked down and repeated disc ploughing.	Banana crop is removed through mulching and/or light discing which minimises soil disturbance.	Banana crop is killed with herbicide and plants are left to break down in the row area before cultivation.
Fallow management	Land is maintained bare between crop cycles, or there is no fallow period between crop cycles	Weedy fallow grows between banana crop cycles	Fallow crop is planted between banana crop cycles, or a volunteer grass fallow is maintained between crop cycles.
Tillage - plant crop	Whole block is cultivated in preparation for planting.	Minimum tillage of whole block area, with row area only subject to more cultivation necessary to establish row profile and plant.	Crop planted into permanent beds. Row area only receives minimum tillage necessary for establishment.
Ground cover	Inter-rows and headlands are sprayed or cultivated bare.	Living or dead, at least 60% cover is maintained in inter-row space and headlands.	Living ground cover is maintained in the inter-row space and headlands.
Controlling runoff - contouring	Production areas with gradient of 3% or more, but no control structures in place.	For gradient over 3%, MOST blocks planted on the contour and incorporating diversion banks and constructed waterways.	For gradient over 3%, ALL blocks planted on the contour and incorporating diversion banks and constructed waterways.
Controlling runoff - drains	Constructed drains are mostly box drains with straight sides.	Most constructed drains are vegetated shallow spoon drains. Any box drains have a batter suited to the soil type to minimise soil erosion.	All constructed drains are vegetated shallow spoon drains.
Sediment traps	No sediment trapping structures in place.	Some sediment trapping structures. Insufficient capacity and/or design issues mean that significant amount of sediment can leave the farm in heavy events.	Expert advice informs design, construction and location of sediment traps that are effective across the entire production area.
Soil testing	No soil testing before planting.	Soil testing before planting is infrequent and/or does not occur on all blocks being planted.	All blocks are soil tested pre-planting. Fertiliser rates for plant crop are adjusted based on soil test results.
Matching nutrient supply to crop demand	Nitrogen and phosphorus fertiliser rates are based on historical target rates with infrequent testing and/or no adjustment for yield potential.	Nitrogen and phosphorus fertiliser rates are supported by soil and leaf testing and yield monitoring.	Fertiliser program based on recommended rates for nitrogen and phosphorus and supported by leaf and soil testing and yield monitoring. Revised annually to ensure targets are achieved.

Management	Indicative Practice Levels		
	High Risk (D)	**Moderate Risk (C)**	**Moderate-Low Risk (B)**
	Superseded	Minimum	Best Practice
Fertiliser application frequency	Fertiliser is applied less frequently than monthly.	Monthly fertiliser applications all year around.	Aim to apply fortnightly during high growth periods and less frequently during low growth periods.
Fertiliser application method	Fertiliser broadcast over rows and inter-row spaces.	Banded surface fertiliser application on row area only.	All fertigation. Banded surface application if wet weather rules out fertigation.
Irrigation method	Some overhead irrigation.	All irrigation is drip or micro sprinkler system, manually operated.	All irrigation is automated drip/micro sprinkler system underneath trees.
Irrigation scheduling	No soil moisture monitoring tools are used in scheduling irrigation.	Irrigation schedules are based on capacitance probes or tensiometers. Manually operated.	Irrigation schedules are based on capacitance probes and weather stations and are fully automated.

1.3 Queensland banana industry

The primary variety of bananas grown in Australia is Cavendish. This is followed by Lady Finger and other cultivars with niche markets. Bananas are a perennial crop with an all-year-round supply. Figure 1 illustrates the Wet Tropics and Australia's total banana production over eight years (2007-08 to 2014-15). The overall level of banana production has trended upwards over those eight years and the lower production years during this time can be explained by tropical cyclones (Larry 2006, Yasi 2011 and Ita 2014) and seasonal conditions.

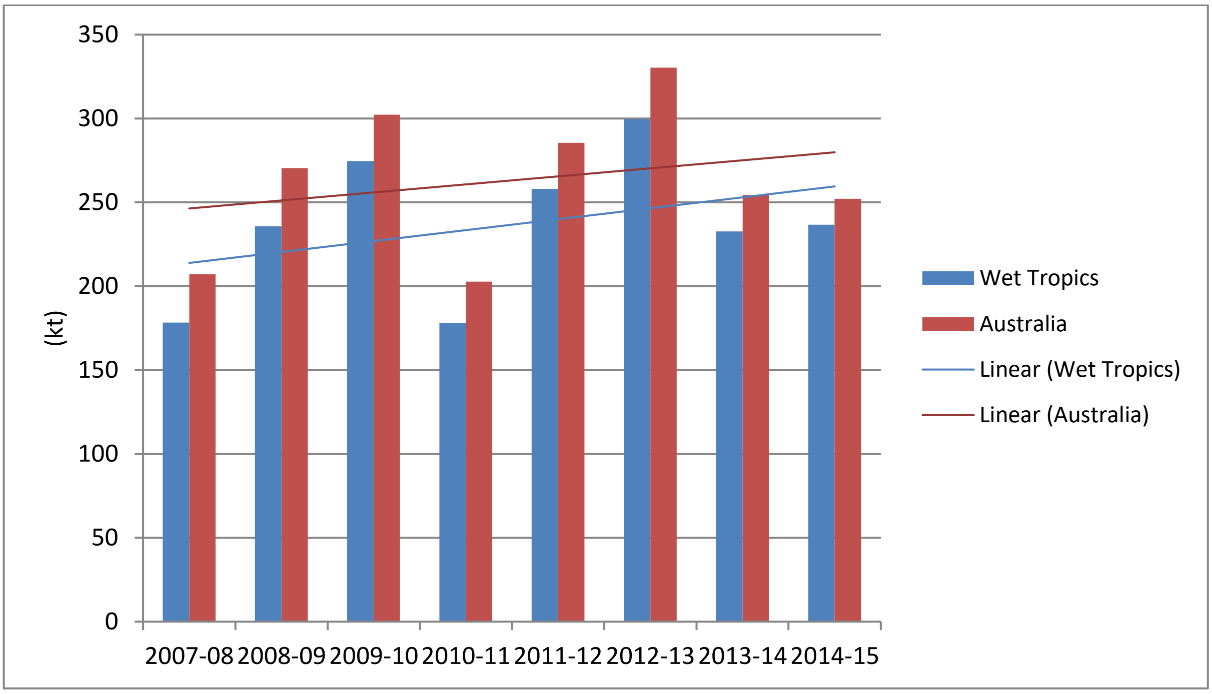

Figure 1: Australian Banana Production

Source: Australian Bureau of Statistics, (2016a).

There are a number of factors that affect the profitability of banana production, including major aspects such as price volatility, input costs, pest and disease incursion and tropical cyclones (see 'Appendix A – Farm business environment and risk'). Of particular relevance is the incursion of Panama disease tropical race 4 that has the potential to severely affect production in the Wet Tropics. How these risks are managed can have significant economic implications for growers.

More than 90 per cent of Australia's banana production is in the Wet Tropics region of north Queensland. The Wet Tropics has two sub-regions that make up the majority of the banana plantations – Tully and Innisfail. Figure 2 indicates where the banana producing land is located in these two sub-regions, identified as irrigated perennial horticulture (dark purple with parallel diagonal black lines).

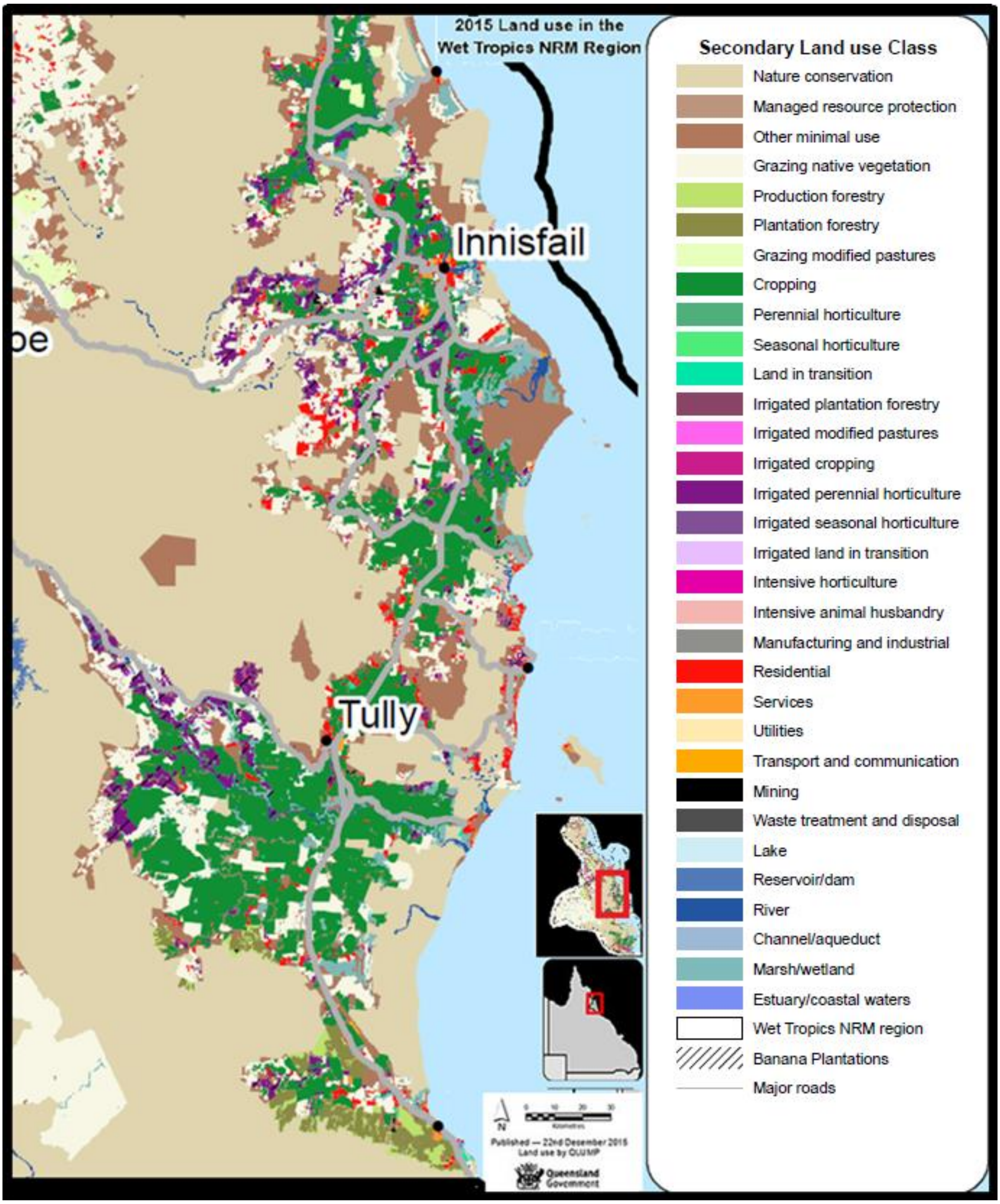

Figure 2: 2015 Land Use in the Innisfail and Tully Region

Source: Department of Science, Information Technology and Innovation, (2016).

1.4 Banana BMP frameworks

There are three separate Banana Practice frameworks for the Queensland banana industry: the Banana Best Management Practice Environmental Guidelines; compiled by Queensland's Department of Agriculture and Fisheries (DAF), in conjunction with Horticulture Australia Limited (HAL) and the Australian Banana Growers' Council (ABGC), the ABCD framework developed by Terrain Natural Resource Management (NRM) and the Paddock to Reef Water Quality Risk Framework, developed as part of the Reef Plan Paddock to Reef Program. These BMP frameworks all share similarities; however there are differences which will be detailed below. The Paddock to Reef framework was chosen as the basis for the practice scenario modelling because of the integration of water quality risk and the ranking of risk.

The Banana BMP Environmental Guidelines (Banana BMP) are aligned with the Freshcare Environmental Code and uses a 'best, okay, improve' criteria (King, 2008) (see 'Appendix B – Banana Practice framework'). This is similar to the ABCD criteria used by NRM groups, except for the exclusion of the A practices. The development of the Banana BMP was part of Reefocus Extension, a Queensland Government Reef Plan initiative, working with growers to increase farm productivity and profitability and improve water quality in the Great Barrier Reef. It has been funded by HAL using the banana industry levy and matched funds from the Australian Government.

NRM bodies have developed a management practice framework of Aspirational, Best, Conventional and Dated (ABCD) practices to classify regionally specific management practices for industries in their catchments (Terrain NRM, 2015). These frameworks assist in identifying land management practices that maximise water quality improvements. The ABCD framework categorises farming practices on a scale of improvement from D to A practices based on their water quality outcomes. Terrain NRM has developed an ABCD framework for banana growers in the Wet Tropics region, which are aligned with the industry's Banana BMP. The ABCD framework provides a basis for identifying practices for project consideration; to be a guide for banana growers adopting improved farming practices.

The Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program is intended to deliver an impartial, collaborative and ongoing assessment of catchment and GBR water quality and marine ecosystem health (Queensland Government, 2015a). The water quality risk framework for bananas is based on the Banana BMP with the classifications of 'high risk', 'moderate risk' and 'moderate-low risk' corresponding to the BMP's 'improve', 'okay' and 'best'. The framework ranks practices from 'low risk' (innovative practices that have the lowest water quality risk) to 'high risk' (superseded practices that have the highest water quality risk) (Queensland Government, 2015b). The specific practices most relevant to water quality risk are collated into a framework that also aligns with the management practice ABCD system utilised by Terrain NRM. Prioritising and weighting these practices for relative water quality risk has been established through consultation with Queensland government scientists, officers from the ABGC, Terrain NRM and DAF banana extension officers. The pollutants of most concern for the banana industry are nutrients and sediments. There is little to no use of residual herbicides, with relatively high ecological toxicities, that are common in other cropping sectors (Queensland Government, 2015c).

2 Methodology

2.1 Overview

The approach used was to develop representative farm scenarios that could be modelled to explore the economic and water quality implications of adopting stepwise management improvements, as well as exploring the impact of enterprise variability on profitability. In addition, information was gathered on the cost to purchase equipment needed to transition to improved management practices, so that an investment analysis could be conducted. A number of scenarios were analysed, specifically the combined core banana-growing regions of Tully and Innisfail.

2.2 Economic concepts and definitions

The economic measures used in this analysis include farm gross margin, net present value, annualised equivalent benefit, payback period and sensitivity analyses to capture risk.

Farm gross margins (FGM) form part of the methodology commonly used to evaluate the impact of a farming system change. Farm gross margin is the revenue generated from production once variable costs have been subtracted from gross revenue (Garside et al. 2009). Farm gross margins do not consider farm overhead costs, which are incurred independently of the level of production and may include items such as permanent salaries, insurance, annual fixed water rates, depreciation of farm assets, land taxes and municipal rates (Garside et al. 2009). For changes in practices that do not require expenditures on fixed capital or additional land, the fixed costs of production are unaffected.

The difference in farm gross margins between the management practice scenarios are used for the Net Present Value (NPV) analyses. NPV can be used to analyse management practice changes that require capital investment by comparing the investment and the stream of benefits it generates to the next best alternative, whilst incorporating the time value of money by applying a discount rate. A positive NPV would indicate that the change of practice is worthwhile as the economic benefit outweighs the costs of implementation. A negative NPV would indicate that the change is not economically acceptable as the costs are higher than the benefits. Another way to analyse management practice changes is using the discounted payback period, which is defined as the number of years required to recover the capital investment.

A transformation of the NPV to a series of equal annual cash flows for the length of the investment is defined as the Annualised equivalent benefit (AEB). In this report, the AEB is useful for determining the cost effectiveness of annual water quality improvements resulting from management practice change. It is also useful for comparing investments with different investment periods. The AEB is interpreted in the same way as the NPV: a positive AEB indicates the investment is worthwhile, while a negative AEB indicates the investment will not meet the required return.

While NPV is a useful economic measure, it is difficult to incorporate the risk and uncertainty so inherent to agricultural production into NPV calculations. This is because assumptions are made about expected future cash flows, future output prices, input costs and yields. There is significant variation or uncertainty in several parts of this analysis, due to the heterogeneous nature of banana farms or due to factors that are difficult to quantify. To counter this, we have included a sensitivity analysis in the results, which explores the impact of variation in specific parameters on the economic results.

2.3 Enterprise variability

For each management practice scenario, separate models were created to account for the impact of variation in soil type, farm size and on farm cost structures. A segregation by region was not undertaken based on the advice provided by local agronomists and growers, indicating that there is no systematic difference in management practices between Tully and Innisfail that is not already captured by soil type and farm size.

Two broad soil types were identified as being the most common for banana farms in Innisfail and Tully: alluvial soils (Dermosols) and red clay (Ferrosols). Dermosol soils tend to be associated with flatter gradients (63 per cent of the area of banana-producing Dermosol soils is on gradients of less than 1 per cent), while Ferrosols are typically on higher gradients (67 per cent on gradients of over 3 per cent). Together, these soil types account for 83 per cent of the area used to grow bananas in Innisfail and Tully (Australian Soil Resource Information System (ASRIS), Brough *et al*. 2006).[1]

Table 2 shows the distribution of farm sizes in Tully and Innisfail. Based on this data, three farm sizes were chosen to be represented in the practice scenario modelling: 15 hectares, 40 hectares, and 100 hectares.

Table 2: Percentage of banana farms by farm size

Area (hectares)	Tully	Innisfail
20 or less	39 per cent	43 per cent
21 to 60	30 per cent	43 per cent
61 or more	31 per cent	14 per cent

Source: ABGC pers. comm., 05/04/17.

The combination of two soil types and three farm sizes results in six representative farms. Each of these farms was modelled for the 19 practice combinations (figure 3), resulting in 114 distinct scenarios.

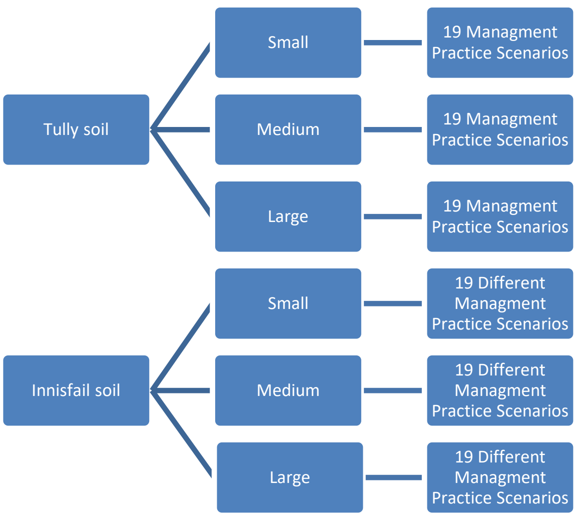

Figure 3: Individual Modelling Scenario Decision Tree

[1] The slope values were derived from the 30 second Shuttle Radar Topography Mission (SRTM) Digital Elevation Map (DEM) resampled to a 100m raster. Average slope values for each soil polygon were taken from this raster.

2.4 Management practice scenarios

In order to create scenarios based on combinations of management practices, some of the practices were grouped together where it was considered impractical or unlikely that an individual practice would be changed in isolation.

Table 3 outlines the management practice groups. The management practices ‘controlling runoff – contouring’, ‘controlling runoff – drains’ and ‘sediment traps’ were combined under the group ‘water control structures’, as advice was received that growers would typically address these issues together by commissioning a whole-of-farm design which would be progressively implemented as each block moves into fallow. ‘Soil testing’ and ‘matching nutrient supply to crop demand’ are closely related practices, and were therefore grouped under ‘nutrient rate’. ‘Fertiliser application frequency’ and ‘fertiliser application method’ were grouped under ‘nutrient application’ as the latter could not be represented in the water quality modelling. The same applied to ‘irrigation method’, which was grouped with ‘irrigation scheduling’ to form the group ‘irrigation’.

Table 3: Management practice groups and related individual practices

Individual practice	Practice group
Crop removal	Crop removal
Fallow management	Fallow management
Tillage – plant crops	Tillage
Ground cover (inter-row)	Ground cover
Controlling runoff – contouring	Water control structures
Controlling runoff – drains	
Sediment traps	
Soil testing	Nutrient rate
Matching nutrient supply to crop demand	
Fertiliser application frequency	Nutrient application
Fertiliser application method	
Irrigation method	Irrigation
Irrigation scheduling	

Table 4 shows the management practice scenarios that were modelled. These models were created with all of the practice groups (above) at B level, C level and D level, and to examine the impact on farm profitability of each practice in isolation, models were created based on all practice groups at C with individual practice groups at B, all practice groups at D with individual practice groups at C and all practice groups at D with individual practice groups at B.

Table 4: Management practice scenarios modelled

Management practice scenarios
All B
All C
All D
All D, except ***crop removal*** is C
All D, except ***fallow*** is C
All D, except ***tillage*** is C
All D, except ***ground cover*** is C
All D, except ***water control structures*** is C
All D, except ***nutrient rate*** is C
All D, except ***nutrient application*** is C
All D, except ***irrigation*** is C
All D, except ***crop removal*** is B
All D, except ***fallow*** is B
All D, except ***tillage*** is B
All D, except ***ground cover*** is B
All D, except ***water control structures*** is B
All D, except ***nutrient rate*** is B
All D, except ***nutrient application*** is B
All D, except ***irrigation*** is B
All C, except ***crop removal*** is B
All C, except ***fallow*** is B
All C, except ***tillage*** is B
All C, except ***ground cover*** is B
All C, except ***water control structures*** is B
All C, except ***nutrient rate*** is B
All C, except ***nutrient application*** is B
All C, except ***irrigation*** is B

2.5 Economic data sources

To gather cost data and specify the farm operations that are implied by each management practice level, two grower workshops were held (December 2016, January 2017). Nine banana growers attended the workshops from Innisfail and Tully, as well as representatives from ABGC and DAF banana extension staff. Following the workshops, additional information relating to water control structure costs and irrigation costs was collected from industry consultants in the region. Details of the farming operations and other costs associated with the management practice changes are provided in 'Appendix C – economic and water quality model parameters'.

It should be noted that the economic modelling does not include any potential yield impacts of BMP adoption as there has been insufficient trial research done in the banana industry to quantify such effects. However, a recent study demonstrates that there is generally no significant difference in yield between C class and B class for N application and inter-row management (Masters *et al*, 2017). In addition, a number of costs (in particular investment costs of installing water control structures and irrigation systems), vary significantly from farm to farm. In these cases, a break-even analysis or sensitivity analysis has been conducted to explore the impact of the variation of costs.

In order to calculate farm gross margins (FGM), the remaining farm practices and variable costs (not covered by the management practice groups in Table 2) needed to be defined and quantified. These were selected to represent B level practices for the different farm types and were based on information gathered from extension officers, the December and January grower workshops, and the three grower case studies. Additional parameters, which are subject to risk (discussed in more detail in 'Risk analysis' on page 32), are as follows:

- Banana price: $1.34/kg[2]
- Diesel: $0.938/L[3]
- Labour: $30/hr[4]
- Banana yields: 20,100 kg/ha (plant), 31,300 kg/ha (ratoons)[5]
- Fertiliser and chemicals prices were sourced from local resellers.

[2] 5-year average local value of production divided by total production (Australian Bureau of Statistics 2016a, Australian Bureau of Statistics 2016b). This represents the 'farm gate' price, and does not include freight, ripening fees or marketing commissions. See 'Appendix D – additional parameter calculations' for calculations.

[3] 5-year average price for Tully and Innisfail, net of GST and fuel tax credit (RACQ 2017, Australian Taxation Office 2016). See 'Appendix D – additional parameter calculations' for calculations.

[4] The labour rate was sourced from growers during the December and January workshops, and represents the typical cost of temporary labour including oncosts. While there are a range of labour sourcing arrangements used by growers, including how much farm work the owner/manager does, the single rate was chosen to provide consistency across farm models.

[5] Yields for plant and ratoons were based the average yield per producing hectare, Cassowary Coast 2012-13, published by CDI Pinnacle (Hall 2014). The difference between plant and ratoons was based on unpublished research conducted by Department of Agriculture and Fisheries.

2.6 Biophysical integration

2.6.1 Water quality modelling setup

Agricultural systems models (or paddock scale models) allow explicit representation of the collection of management options available to a producer, such as: crop rotations, planting, irrigation and nutrient applications. Importantly, the ability to simulate management practices on a daily time step means that there are interactions between the timing of management events and climate conditions. The paddock model used to represent banana management was HowLeaky, which was recently adapted for bananas (Rattray *et al*, 2016).

The HowLeaky model (Rattray *et al*. 2004, Robinson *et al*. 2010) was selected for modelling water quality for bananas because of its capacity to represent the key features of agronomic practices in the Paddock to Reef Water Quality Framework. Banana modelling presented in this report was run using the HowLeaky model version 5.49.19.

HowLeaky is a water balance simulation model for exploring the impact of land use and management on water quality and water balance. A daily water balance model accounts for water flows – rainfall, evaporation, runoff, transpiration and deep drainage using simple mathematical relationships. HowLeaky has a number of sub-models including irrigation, erosion, nitrogen, phosphorus and pesticide loss models.

The two soil types identified as being the most common for banana farms in Innisfail and Tully: alluvial soils (Dermosols) and red clay (Ferrosols) were modelled based on parameters derived from, and based on, the ASRIS Database (Brough *et al*. 2006). The Dermosol soil was modelled on a slope of 1 per cent, while the Ferrosol was modelled at 2 per cent and 4.5 per cent (Rattray *et al*, 2016).

A daily climate file specifying inputs including rainfall, radiation and temperature was sourced from an interpolated gridded dataset available at 0.05 degree coverage from the SILO climate database (Jeffrey *et al*. 2001). A location central to the region was chosen at S17.750 E146.05 for the period 1967 - 2016. The model has previously been validated against real data (Rattray *et al*, 2016).

2.6.2 HowLeaky management files

The cover model option (green cover and residue cover) in HowLeaky was used to model the banana system. A general banana cropping cycle was defined based on common features of production (Rattray *et al*., 2016). For each practice type, scenarios were defined to represent management in the model. The key elements of the management practice framework can be summarised and grouped as covering:

- Crop removal, fallow management, tillage and ground cover, all modelled by varying crop and residue cover levels within the model.
- Contour banks, sediment traps and drains. Modelled by varying sediment delivery via a practice factor.
- Soil testing, matching crop nitrogen demand and fertiliser frequency, modelled by varying the rate and timing of fertiliser application.
- Irrigation scheduling, modelled by varying the frequency and rate of irrigation application.

In the banana modelling framework presented here the crop system has been defined by three components that are modelled separately:

1. The row of the cropping cycle;
2. The inter-row of the cropping cycle; and
3. The fallow period between cropping cycle.

The row and inter-row areas of a banana crop are modelled separately so that management practices that pertain to them can be modelled explicitly (Table 5). The water quality from a banana farm is the total of the water quality load from the proportions of area made up of these three components.

Table 5: Water Quality Risk Framework cover model descriptions

Practice	Practice level	Model description
Crop removal (Fallow model)	B: Banana crop is killed with herbicide and plants are left to break down in the row area before cultivation.	Green cover is reduced to 10% but residue cover is maintained at 80% at crop removal period.
	C: Banana crop is removed through mulching and/or light discing which minimises soil disturbance	Green cover is reduced to 10% but residue cover is maintained at 50% at crop removal period.
	D: Banana crop is removed by being knocked down and repeated disc ploughing	Green and residue cover levels reduced to 10-20% at crop removal period
Fallow management (Fallow model)	B: Fallow crop is planted between banana crop cycles, or a volunteer grass fallow is maintained between crop cycles.	Green cover returns to 50% over fallow period
	C: Weedy fallow grows between banana crop cycles	Green cover returns to 50% over fallow period
	D: Land is maintained bare between crop cycles, or there is no fallow period between crop cycles	Green and residue cover levels maintained at 10-20% over fallow period
Tillage – plant crops (Row model)	B: Crop planted into permanent beds. Row area only receives minimum tillage necessary for establishment	No reduction in green and residue cover at planting
	C: Minimum tillage of whole block area, with row area only subject to more cultivation necessary to establish row profile and plant.	Green cover maintained but residue cover reduced to 20% at planting
	D: Whole block is cultivated in preparation for planting	Green and residue cover levels maintained at 10-20% at planting
Ground cover (Inter-row model)	B: Living ground cover is maintained in the inter-row space and headlands.	Cover is maintained at 50-60% at all times. Residue cover at 10%.
	C: Living or dead, at least 60% cover is maintained in inter-row space and headlands.	Green cover is maintained at 40-50% at all times. Residue cover at 20%.
	D: Inter-rows and headlands are sprayed or cultivated bare.	Green and residue cover at <10% at all times

There are currently no specific fertiliser nitrogen rates in the Banana BMP because they are determined by soil testing. The fertiliser nitrogen rates used for the water quality and economic modelling in this report were based on those the Paddock to Reef program currently uses in its modelling for the Wet Tropics region. Nitrogen rates of application modelled were 250, 350 and 450 kg N/ha per annum for B, C and D practice respectively (Rattray et al, 2016). Application frequency modelled was 14 days (fortnightly), 28 days (monthly) and 56 days (every two months) for B, C and D practice respectively.

The method of fertiliser application (broadcast, banded in row or fertigation) was not modelled because there is no compatible data available on the difference in losses between application practices.

Irrigation method was not explicitly modelled in HowLeaky. All water applied is treated the same in regards to an addition to the water balance. Irrigation scheduling methods were modelled based on a soil water deficit approach (SWD), where we aim to apply irrigation every 1-2 days in summer (when not raining) and every 2-3 days in winter. Practices for B, C and D aimed to apply 6-8, 10-12 and 11-13 ML/ha/yr respectively.

Suspended sediment estimates assume a 20 per cent delivery ratio, which is 20 per cent of the hillslope eroded sediment delivered off-farm, with 80 per cent being deposited on-farm. Results presented here for sediment before deposition, referred to as hillslope erosion (t/ha), and after deposition, referred to as total suspended sediment (t/ha). The application of sediment control practices was implemented in the model by adjusting the Revised Universal Soil Loss Equation (RUSLE) P-factor in the soil erosion model. A P-factor of 0.6 and 0.8 was applied where sediment control practices have been implemented for B and C practices, effectively reducing suspended sediment delivery by 40 per cent and 20 per cent respectively. Total nitrogen and total phosphorus loss estimates were made based on suspended sediment loads multiplied by soil nitrogen and phosphorus concentrations. For nitrogen, 0.27 per cent and 0.12 per cent were used for Ferrosol and Dermosol soils respectively, and for phosphorus 0.17 and 0.04 per cent were used for Ferrosol and Dermosol soils respectively.

DIN in runoff estimates were taken from data used in the Paddock to Reef report (Masters *et al* 2017). DIN in drainage estimates were made using recently developed methods (Rattray *et al*, 2016) that account for fertiliser application rates and timing, mineralisation, plant uptake and denitrification losses. Excess nitrogen is accounted for on a daily basis, with DIN in drainage a function of the excess available and daily drainage rate. This modelling capacity is still in development and subject to validation based on field monitoring.

The model run combinations are given in Table 6. The model component changed between runs and the set-up summary is provided.

Table 6: Management practice scenarios modelled[6]

Management practice scenario	Model component changed	Model set-up Summary
All B	n.a.	B soil cover and B irrigation. N fertiliser - 250 kg N/ha/yr fortnight
All C	n.a.	C soil cover and C irrigation. N fertiliser - 350 kg N/ha/yr month
All D	n.a.	D soil cover and D irrigation. N fertiliser - 450 kg N/ha/yr every 2 months
All D, except ***crop removal*** is C	Fallow model	Same as D except: Residue at 50% at crop removal. Reduce down to 10-20% over fallow.
All D, except ***fallow*** is C	Fallow model	Same as D except: Reside and cover down to 10-20% but increase back up to 50% over fallow
All D, except ***tillage*** is C	Row model	Same as D except: Residue reduced to 20% at planting.
All D, except ***ground cover*** is C	Inter-row model	Same as D except: Green cover is maintained at 40-50% at all times
All D, except ***water control structures*** is C	Inter-row model + Row model + Fallow model	Same as D except: All suspended sediment multiplied by 0.7 factor
All D, except ***nutrient rate*** is C	Row model	Same as D except: N fertiliser - 350 kg N/ha/yr every 2 months
All D, except ***nutrient application*** is C	Row model	Same as D except: N fertiliser - 450 kg N/ha/yr every month
All D, except ***irrigation*** is C	Row model	Same as D except: C irrigation
All C, except ***crop removal*** is B	Fallow model	Same as C except: Residue at 80% at crop removal. Allowed to reduce down to 50% over fallow.
All C, except ***fallow*** is B	Fallow model	Same as C except: Reside and cover down to 50% - stays at 50% over fallow
All C, except ***tillage*** is B	Row model	Same as C except: Residue maintained at 50% at planting.
All C, except ***ground cover*** is B	Inter-row model	Same as C except: Green cover is maintained at 50-60% at all times
All C, except ***water control structures*** is B	Inter-row model + Row model + Fallow model	Same as C except: All suspended sediment multiplied by 0.7 factor
All C, except ***nutrient rate*** is B	Row model	Same as C except: N fertiliser - 250 kg N/ha/yr every month
All C, except ***nutrient application*** is B	Row model	Same as C except: N fertiliser - 350 kg N/ha/yr every fortnight
All C, except ***irrigation*** is B	Row model	Same as C except: B irrigation

[6] Please note that the changes from D to B are the same as the changes from C to B, however the practices which are not changed are held at D level instead of C level.

3 Results

3.1 Farm gross margin analysis

Table 7 shows the farm gross margin results from the economic modelling. Generally, per hectare farm gross margins increased with farm size, reflecting greater economies of scale (though these are somewhat limited due to the labour intensive nature of banana farming). Higher farm gross margins were generally associated with improving management practices. Due to large investment costs for some management practices, some practice changes resulted in a decrease in farm gross margin, which are highlighted with red text.

There was a relatively larger increase in farm gross margin when shifting from all C to all B, compared to shifting from all D to all C. Overall, farm gross margins were higher on Dermosol soils compared to Ferrosols, primarily due to the higher irrigation requirements on the more freely draining Ferrosols. Further farm gross margin analysis and charts are provided in 'Appendix E – additional results' and the change in farm gross margin is shown in Table 22.

Table 7: Farm gross margin results

Management practice scenario	Farm gross margin ($/ha)					
	Dermosol			Ferrosol		
	15 ha	40 ha	100 ha	15 ha	40 ha	100 ha
All B	11,093	11,527	11,766	10,570	11,008	11,251
All C	9,716	10,252	10,519	8,801	9,467	9,801
All D	9,115	9,650	9,918	8,133	8,799	9,134
All C, ***crop removal*** B	9,721	10,257	10,524	8,806	9,472	9,806
All C, ***fallow*** B	9,704	10,239	10,507	8,788	9,454	9,789
All C, ***tillage*** B	9,722	10,258	10,525	8,809	9,475	9,810
All C, ***ground cover*** B	9,716	10,252	10,519	8,801	9,467	9,801
All C, ***water control*** B	9,722	10,258	10,525	8,807	9,473	9,807
All C, ***nutrient rate*** B	10,407	10,943	11,210	9,492	10,158	10,492
All C, ***nutrient app.*** B	9,802	10,337	10,605	8,886	9,552	9,887
All C, ***irrigation*** B	10,313	10,748	10,987	9,788	10,226	10,469
All D, ***crop removal*** C	9,110	9,646	9,913	8,129	8,795	9,130
All D, ***fallow*** C	9,133	9,668	9,936	8,152	8,818	9,153
All D, ***tillage*** C	9,118	9,653	9,921	8,132	8,798	9,133
All D, ***ground cover*** C	8,872	9,407	9,675	7,891	8,557	8,892
All D, ***water control*** C	9,126	9,661	9,929	8,145	8,811	9,145
All D, ***nutrient rate*** C	9,805	10,340	10,608	8,824	9,490	9,825
All D, ***nutrient app.*** C	8,994	9,529	9,797	8,013	8,679	9,014
All D, ***irrigation*** C	9,355	9,890	10,158	8,443	9,109	9,444
All D, ***crop removal*** B	9,115	9,651	9,918	8,134	8,800	9,135
All D, ***fallow*** B	9,120	9,656	9,923	8,139	8,805	9,140
All D, ***tillage*** B	9,124	9,659	9,927	8,141	8,807	9,142
All D, ***ground cover*** B	8,872	9,407	9,675	7,891	8,557	8,892
All D, ***water control*** B	9,129	9,665	9,932	8,148	8,814	9,149
All D, ***nutrient rate*** B	10,496	11,031	11,299	9,515	10,181	10,515
All D, ***nutrient app.*** B	9,082	9,617	9,885	8,101	8,767	9,102
All D, ***irrigation*** B	9,952	10,386	10,625	9,430	9,868	10,111

3.2 Investment analysis and risk

3.2.1 Investment costs

Several practice changes require investment costs. Investment costs required for changing from D to C level management practices are shown in Table 8.

- Investment cost for 'water control structures' represents the cost of installing effective waterways, diversion banks and sediment traps on most of the farm. As the Banana BMP framework did not quantify what percentage of the farm 'most' referred to, this was set at 75 per cent. Costs were higher on Ferrosol soils due to their steeper gradients, requiring more diversion banks and increased protective structures in waterways. Per hectare costs did not vary significantly between farm sizes.
- 'Irrigation' investment costs include the installation of soil moisture probes, as well as the cost of converting remaining overhead irrigation to micro sprinklers.[7]
- 'Nutrient application' investment represents the cost of purchasing a fertiliser spreader capable of applying fertiliser directly onto the beds.

Table 8: Investment costs, changing from D to C

Practice group	Description of investment	Investment cost ($)					
		Dermosol			Ferrosols		
		15 ha	40 ha	100 ha	15 ha	40 ha	100 ha
Water control structures	Contouring, drains and sediment traps	4,646	11,140	26,726	11,038	28,186	69,340
Nutrient application	Purchase spreader capable of banded application	5,500	5,500	5,500	5,500	5,500	5,500
Irrigation	Install soil moisture probes, convert remaining overhead irrigation to micro sprinklers	1,408	3,336	8,339	1,408	3,336	8,339

Table 9 shows the investment costs of changing from C to B level management practices.

- 'Water control structure' costs represent the remaining 25 per cent of the cost of installing effective control structures across the whole farm.
- The 'nutrient application' investment is the cost of adding fertigation capability to the existing irrigation system. This was the same regardless of farm size, as growers on larger properties would tend to install the same size fertigation tank as smaller farms, and would simply refill the tank more frequently.

[7] The Water Quality Risk Framework defines D level for irrigation method as including 'some overhead irrigation'. For the purpose of this analysis, the percentage of overhead irrigation was set at 4.2%. This figure is based on a survey of BMP adoption (Sing, N.C., 2012) and represents the average area under overhead irrigation among survey respondents.

- 'Irrigation' investment is the cost to automate the existing irrigation system. It is assumed that the 40 hectare and 100 hectare farms are installing the same Netafim system with radio towers,[8] while the 15 hectare farm is assumed to install a cheaper control system.

Table 9: Investment costs, changing from C to B

Practice group	Description of investment	Investment cost ($)					
		Dermosol			Ferrosols		
		15 ha	40 ha	100 ha	15 ha	40 ha	100 ha
Water control structures	Contouring, drains and sediment traps	1,549	3,713	8,909	3,679	9,395	23,113
Nutrient application	Fertigation infrastructure	10,000	10,000	10,000	10,000	10,000	10,000
Irrigation	Upgrade to automatic irrigation system	14,000	29,500	29,500	14,000	29,500	29,500

Table 10 shows the investment costs of changing practice groups from D to B. These represent the sum of the above two tables.

Table 10: Investment costs, changing from D to B

Practice group	Description of investment	Investment cost ($)					
		Dermosol			Ferrosols		
		15 ha	40 ha	100 ha	15 ha	40 ha	100 ha
Water control structures	Contouring, drains and sediment traps	6,195	14,854	35,634	14,718	37,581	92,453
Nutrient application	Purchase spreader capable of banded application; fertigation infrastructure	15,500	15,500	15,500	15,500	15,500	15,500
Irrigation	Install soil moisture probes; convert remaining overhead irrigation to micro sprinklers; upgrade to automatic irrigation system	15,408	32,836	37,839	15,408	32,836	37,839

[8] While the cost of installing an irrigation system from scratch would increase with farm size, upgrading to an equivalent automatic system would not necessarily be more expensive for larger farms. One of the main drivers of the cost of irrigation automation is the number of valves in the system, which determines the number of towers, solenoids and automatic valves that need to be installed. For a well-designed system, pump capacity and diameter of pipes both increase to cover larger areas, but the number of valves doesn't necessarily change.

3.2.2 Investment Analysis

The previous investment costs will be analysed in the following tables (Table 11 and Table 12) for 40 hectare farms on Dermosol and Ferrosol soils. As the dollar per hectare results for 15 and 100 hectare farms are largely the same as 40 hectare farms, these have been included in 'Appendix E – additional results' for reference to reduce overlap. The key differences in the investment outcomes between farms sizes are outlined in the summary sections below Table 11 and 12.

Table 11: Investment analysis, 40 hectare farm, Dermosol soil

Original practice	New practice	CAPEX ($/ha)	Change in FGM ($/ha)	Net present value over 10 yrs ($/ha)	Payback period (yrs)	Break even CAPEX ($/ha)
All C	All B	1,080	1,276	7,880	1	8,961
All D	All C	499	602	3,727	1	4,226
All D	All B	1,580	1,877	11,607	1	13,187
All C	All C, ***crop removal*** B	0	5	35	-	35
All C	All C, ***fallow*** B	0	-13	-88	-	N.A.
All C	All C, ***tillage*** B	0	6	42	-	42
All C	All C, ***ground cover*** B	0	0	0	-	0
All C	All C, ***water control*** B	93	6	-52	>10	41
All C	All C, ***nutrient rate*** B	0	691	4,852	-	4,852
All C	All C, ***nutrient appl.*** B	250	85	349	4	599
All C	All C, ***irrigation*** B	738	496	2,748	2	3,486
All D	All D, ***crop removal*** C	0	-4	-31	-	N.A.
All D	All D, ***fallow*** C	0	18	129	-	129
All D	All D, ***tillage*** C	0	3	22	-	22
All D	All D, ***ground cover*** C	0	-243	-1,705	-	N.A.
All D	All D, ***water control*** C	279	11	-201	>10	77
All D	All D, ***nutrient rate*** C	0	690	4,848	-	4,848
All D	All D, ***nutrient appl.*** C	138	-121	-985	>10	N.A.
All D	All D, ***irrigation*** C	83	240	1,602	1	1,686
All D	All D, ***crop removal*** B	0	1	6	-	6
All D	All D, ***fallow*** B	0	6	41	-	41
All D	All D, ***tillage*** B	0	9	64	-	64
All D	All D, ***ground cover*** B	0	-243	-1,705	-	N.A.
All D	All D, ***water control*** B	371	15	-268	>10	103
All D	All D, ***nutrient rate*** B	0	1,381	9,701	-	9,701
All D	All D, ***nutrient appl.*** B	388	-33	-617	>10	N.A.
All D	All D, ***irrigation*** B	821	736	4,350	2	5,171

Investment analysis summary (40 ha farm, Dermosol soil):

All C to all B:

- Total capital expenditure was $1,080 per hectare, which, combined with an improvement in annual farm gross margin of $1,276 per hectare, resulted in an NPV of $7,880 per hectare over the 10 year investment horizon. The investment would be paid back in one year and a total of $8,961 per hectare could have been spent before the investment became unprofitable.

All D to all C:

- The capital expenditure of $499 per hectare and the increase in farm gross margin of $602 per hectare resulted in an NPV of $3,727 per hectare and a payback period of one year. The break-even capital expenditure was $4,226 per hectare.

All D to all B:

- Total capital expenditure was $1,580 per hectare, which, combined with an improvement in annual farm gross margin of $1,877 per hectare, resulted in an NPV of $11,607 per hectare over the 10 year investment horizon. The investment would be paid back in one year and a total of $13,187 per hectare could have been spent before the investment became unprofitable.

All C, changing individual practices from C to B:

- ‘Nutrient rate’ had an NPV of $4,852 per hectare, due to an improvement in farm gross margin of $691 per hectare and no capital investment requirement.
- ‘Irrigation’ had an NPV of $2,748 per hectare and a payback period of two years despite having the highest investment cost of $738 per hectare (upgrading to an automated system). Up to $3,486 per hectare could be spent before the investment became unprofitable.
- ‘Water control structures’ had an investment cost of $93 per hectare and an improvement in farm gross margin of $6 per hectare, which resulted in a negative NPV of -$52 per hectare. While this would indicate the investment was not worthwhile, a number of benefits that may result from improved water control structures have not been captured in this analysis. These are discussed in more detail in ‘Risk analysis’ on page 32.
- ‘Fallow’ was the only B level practice that caused a decrease in farm gross margin, due to the cost of planting Rhodes grass, which resulted in an NPV of -$88 per hectare.
- ‘Ground cover’ is unusual in that it has no investment cost or change in farm gross margin. This is because the increase in ground cover specified by B level is achieved through better drainage resulting from the investments made under ‘water control structures’, as well as laser levelling on flatter gradients (which is not within the scope of ‘water control structures’ in the current Water Quality Risk Framework). Additionally, there is no change in management costs as both C and B level practices for ground cover involve the same amount of slashing–all inter-rows need to be slashed under both practice levels, despite C level having less overall grass coverage.

All D, changing individual practices from D to C:

- ‘Nutrient rate’ had an NPV of $4,848 per hectare, due to an improvement in farm gross margin of $690 per hectare and no capital investment requirement.

- ‘Ground cover’ had a negative NPV of -$1,705 per hectare, due to the ongoing cost associated with replacing herbicide control of inter-row weeds with slashing. For the purpose of this analysis, it was assumed all growers would own a slasher regardless of their management practice level. For any growers that operate at D level for ground cover and don’t already own a slasher, moving to C level would also involve the capital expense of purchasing a slasher.
- ‘Nutrient application’ had a negative NPV of -$985 per hectare, resulting from the investment cost of purchasing a spreader capable of banded application, and the increased cost associated with monthly fertiliser applications. It should be noted that increasing the frequency of fertiliser applications may facilitate the lowering of nutrient rates, as increased application frequencies can improve nutrient efficiency and lower the risk of fertiliser losses during significant rainfall events. If the two practice improvements were implemented together, the fertiliser savings from reducing rates would far outweigh the costs of more frequent applications.
- ‘Water control structures’ had an investment cost of $279 per hectare and an improvement in farm gross margin of $11 per hectare, which resulted in a negative NPV of -$201 per hectare. However, as with the shift from C to B, there are benefits from this practice change that have not been captured in this analysis.

All D, changing individual practices from D to B:

- ‘Nutrient rate’ had an NPV of $9,701 per hectare, due to an improvement in farm gross margin of $1,381 per hectare and no capital investment requirement.
- ‘Nutrient application’ had a negative NPV of -$617 per hectare, resulting from the investment cost of purchasing a spreader capable of banded application, and the increased cost associated with monthly fertiliser applications. It should be noted that increasing the frequency of fertiliser applications may facilitate the lowering of nutrient rates, as increased application frequencies can improve nutrient efficiency and lower the risk of fertiliser losses during significant rainfall events. If the two practice improvements were implemented together, the fertiliser savings from reducing rates would far outweigh the costs of more frequent applications.
- ‘Irrigation’ had an NPV of $4,350 per hectare and a payback period of 2 years despite having the highest investment cost of $821 per hectare (upgrading to an automated system). Up to $5,171 per hectare could be spent before the investment became unprofitable.
- ‘Water control structures’ had an investment cost of $371 per hectare and an improvement in farm gross margin of $15 per hectare, which resulted in a negative NPV of -$268 per hectare. While this would indicate the investment was not worthwhile, a number of benefits that may result from improved water control structures have not been captured in this analysis. These are discussed in more detail in ‘Risk analysis’ on page 32.

Impact of farm size:

- The key differences between farm sizes are NPVs per hectare for ‘nutrient application’ (moving from C to B, and D to C) are higher for 100 hectare farms as the total investment cost is spread over a greater area (the reverse is true for 15 hectare farms). In addition, the NPV associated with moving from C to B for ‘irrigation’ also increases slightly with farm size for the same reason.

Table 12: Investment analysis, 40 hectare farm, Ferrosol soil

Original practice	New practice	CAPEX ($/ha)	Change in FGM ($/ha)	Net present value over 10 yrs ($/ha)	Payback period (yrs)	Break even CAPEX ($/ha)
All C	All B	1,222	1,541	9,603	1	10,825
All D	All C	926	667	3,760	2	4,686
All D	All B	2,148	2,208	13,363	2	15,511
All C	All C, ***crop removal*** B	0	5	35	-	35
All C	All C, ***fallow*** B	0	-13	-88	-	N.A.
All C	All C, ***tillage*** B	0	8	59	-	59
All C	All C, ***ground cover*** B	0	0	0	-	0
All C	All C, ***water control*** B	235	6	-193	>10	42
All C	All C, ***nutrient rate*** B	0	691	4,852	-	4,852
All C	All C, ***nutrient appl.*** B	250	85	349	4	599
All C	All C, ***irrigation*** B	738	759	4,595	2	5,332
All D	All D, ***crop removal*** C	0	-4	-31	-	N.A.
All D	All D, ***fallow*** C	0	18	129	-	129
All D	All D, ***tillage*** C	0	-1	-9	-	N.A.
All D	All D, ***ground cover*** C	0	-243	-1,705	-	N.A.
All D	All D, ***water control*** C	705	11	-626	>10	79
All D	All D, ***nutrient rate*** C	0	690	4,848	-	4,848
All D	All D, ***nutrient appl.*** C	138	-121	-985	>10	N.A.
All D	All D, ***irrigation*** C	83	310	2,091	1	2,174
All D	All D, ***crop removal*** B	0	1	6	-	6
All D	All D, ***fallow*** B	0	6	41	-	41
All D	All D, ***tillage*** B	0	7	52	-	52
All D	All D, ***ground cover*** B	0	-243	-1,705	-	N.A.
All D	All D, ***water control*** B	940	15	-834	>10	105
All D	All D, ***nutrient rate*** B	0	1,381	9,701	-	9,701
All D	All D, ***nutrient appl.*** B	388	-33	-617	>10	N.A.
All D	All D, ***irrigation*** B	821	1,069	6,685	1	7,506

Investment analysis summary (40 ha farm, Ferrosol soil):

Overall, the investment results for Ferrosol soils were similar to Dermosol soils. Key differences are:

- Changing from 'all C' to 'all B' led to a higher increase in farm gross margin, resulting in a larger NPV ($9,603 per hectare, compared to $7,880 per hectare for Dermosol soils). 'Irrigation' accounted for the higher improvement in farm gross margin, due to farms on Ferrosol soils having higher overall irrigation costs, and thus realising greater labour savings from switching to automation. Changing from C to B for irrigation had an NPV of $4,595 per hectare, compared to $2,748 per hectare for Dermosol soils.
- Changing from all D to all C had a slightly higher NPV ($3,760 per hectare compared to $3,727 for Dermosol soils). The higher change in farm gross margin for nutrient rate from D to C mainly accounted for the difference.

- Changing from ‘all D’ to ‘all B’ led to a higher increase in farm gross margin, resulting in a larger NPV ($13,363 per hectare, compared to $11,607 per hectare for Dermosol soils). ‘Irrigation’ accounted for the higher improvement in farm gross margin, due to farms on Ferrosol soils having higher overall irrigation costs, and thus realising greater labour savings from switching to automation. Changing from D to B for irrigation had an NPV of $6,685 per hectare, compared to $4,350 per hectare for Dermosol soils.

Impact of farm size:

- As with Dermosol soils, the key differences are NPVs per hectare for ‘nutrient application’ (moving from C to B, and D to C) are higher for 100 hectare farms as the total investment cost is spread over a greater area (the reverse is true for 15 hectare farms). In addition, the NPV associated with moving from C to B for ‘irrigation’ also increases slightly with farm size for the same reason.

3.2.3 Risk analysis

Risk is a fundamental consideration when assessing the economic impact of management practice changes, and can be important in understanding the likelihood of BMP adoption. In particular, price and yield variation are key sources of risk for banana farms. In the Australian banana industry, individual growers are largely price-takers, as they have limited bargaining power in negotiating supply contracts. Thus, management practice changes do not typically affect the price per carton of bananas that growers are able to receive.

Conversely, there is potential for certain management practice changes to affect yields. However, limited published research exists on this so it is useful to include a sensitivity analysis on this parameter. The following analysis examines the sensitivity of the economic outcome to changes in yield resulting from a progressive shift in management practices. Figure 4 shows the degree to which a change in yield caused by improving management practices affects the NPV of the practice change. As the chart shows, changing from all C to all B and from all D to all B class practices resulted in a positive NPV for the range of yield changes in the -4% to 4% range for both Dermosol and Ferrosol soils. The smallest yield change, which resulted in a negative NPV, was 1.8 per cent, when moving from all D to all C class practices.

In all cases, the sensitivity of each NPV to yield changes (indicated by the slope of the line) is the same, with the NPV increasing by just over $4,000 per hectare for every 2 per cent increase in yield. This means that a given change in yield results in the same change in NPV, regardless of the size of the initial NPV. This is because the sensitivity of the NPV to yield changes is driven by the initial yield level and the price (both of which are assumed constant across all scenarios), but is unaffected by the parameters that are used to calculate the NPV (the change in farm gross margin resulting from the practice change, and the investment amount).

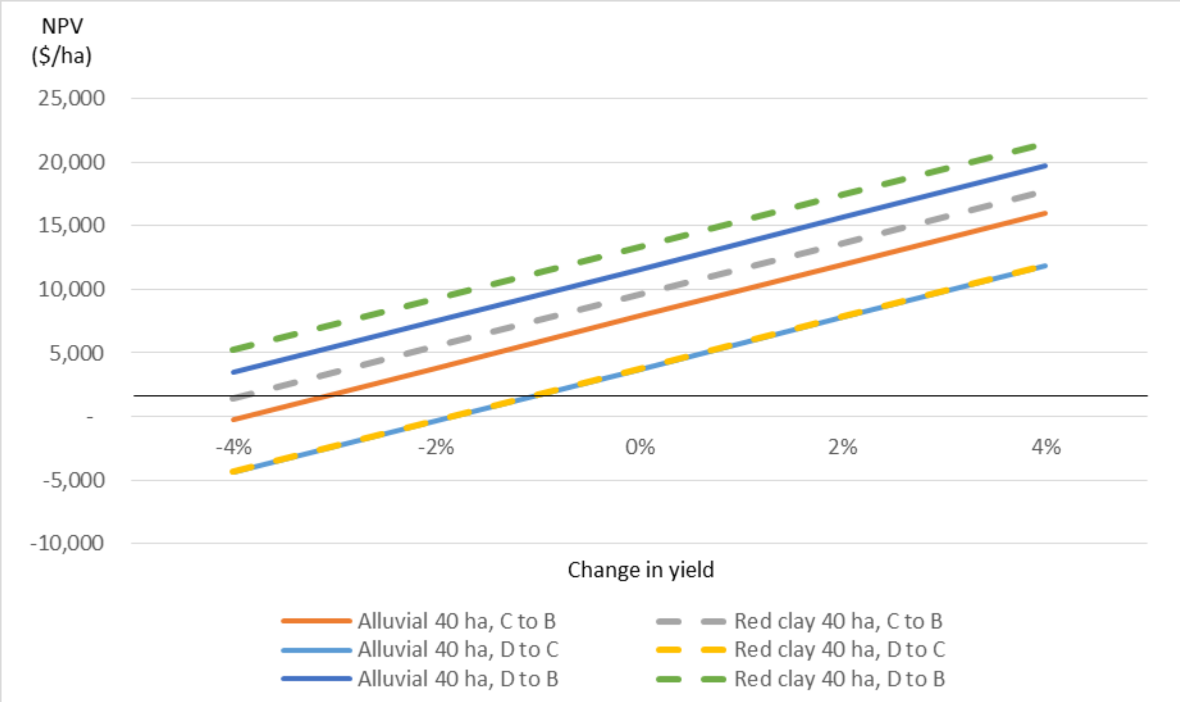

Figure 4: Sensitivity of NPV to changes in yield resulting from practice change

A key difference highlighted by the sensitivity analysis is the point at which the sensitivity curves cross the horizontal axis, which indicates the break-even point of the investment, or the yield change at which the NPV is equal to zero. Table 13 shows the break-even yield changes for each of the practice change scenarios by farm size and soil type. The break-even results mirror the NPV results, with higher NPVs associated with greater break-even yield decreases. The risk analysis indicates that increases in yield are required in order to break-even and realise a NPV of zero for some individual practice changes, as marked in red in Table 13. For example, transitioning ground cover from D to C class requires a 0.8% increase in yield (across all farm sizes and both soil types considered) before a NPV of zero is realised.

Table 13: Change in yield that would result in an NPV of zero

Original practice	New practice	Dermosol			Ferrosol		
		15 ha	40 ha	100 ha	15 ha	40 ha	100 ha
All C	All B	-3.9%	-3.9%	-4.1%	-5.2%	-4.7%	-4.7%
All D	All C	-1.7%	-1.8%	-1.9%	-1.7%	-1.8%	-1.9%
All D	All B	-5.7%	-5.7%	-5.9%	-7.0%	-6.6%	-6.6%
All C	All C, ***crop removal*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All C	All C, ***fallow*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All C	All C, ***tillage*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All C	All C, ***ground cover*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All C	All C, ***water control*** B	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%
All C	All C, ***nutrient rate*** B	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%
All C	All C, ***nutrient appl.*** B	0.0%	-0.2%	-0.2%	0.0%	-0.2%	-0.2%
All C	All C, ***irrigation*** B	-1.6%	-1.3%	-1.5%	-3.0%	-2.3%	-2.2%
All D	All D, ***crop removal*** C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All D	All D, ***fallow*** C	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
All D	All D, ***tillage*** C	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All D	All D, ***ground cover*** C	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
All D	All D, ***water control*** C	0.1%	0.1%	0.1%	0.3%	0.3%	0.3%
All D	All D, ***nutrient rate*** C	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%	-2.4%
All D	All D, ***nutrient appl.*** C	0.6%	0.5%	0.4%	0.6%	0.5%	0.4%
All D	All D, ***irrigation*** C	-0.8%	-0.8%	-0.8%	-1.0%	-1.0%	-1.0%
All D	All D, ***crop removal*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All D	All D, ***fallow*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All D	All D, ***tillage*** B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
All D	All D, ***ground cover*** B	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
All D	All D, ***water control*** B	0.2%	0.1%	0.1%	0.4%	0.4%	0.4%
All D	All D, ***nutrient rate*** B	-4.8%	-4.8%	-4.8%	-4.8%	-4.8%	-4.8%
All D	All D, ***nutrient appl.*** B	0.6%	0.3%	0.2%	0.6%	0.3%	0.2%
All D	All D, ***irrigation*** B	-2.4%	-2.1%	-2.3%	-4.0%	-3.3%	-3.2%

While the above analysis is useful in examining the yield decrease each practice change could sustain before it becomes unprofitable, it does not indicate how likely a yield change, of particular magnitude, would be. While there is limited research data available to quantify the decrease, or the possible increase, in the economic risk associated with adopting BMP, a desktop assessment of the relative economic risk of changing management practices is nevertheless worthwhile. Table 14 provides a qualitative assessment of the economic risk associated with each practice change modelled, including a risk level rating and justification. The risk level rating is low for nearly all practice changes because there is either no change in yield required or only a minor change required for an NPV of zero (Table 13) . The risk level rating is medium for ground cover practice changes because it requires the highest increase in yield for an NPV of zero (Table 13) and other factors.

Table 14: Economic Risk Rating and Justification

Original practice	New practice	Economic Risk rating	Economic risk level justification
All C	All B	Low	Mostly low risk and water control is medium.
All D	All C	Low	Mostly low risk and water control is medium.
All D	All B	Low	Mostly low risk and water control is medium.
All C	All C, *crop removal* B	Low	The impacts on costs are very low relative to total FGM, and they are expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All C	All C, *fallow* B	Low	There is a minor negative impact on total FGM but it is expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All C	All C, *tillage* B	Low	The impacts on costs are very low relative to total FGM, and they are expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All C	All C, *ground cover* B	Low	Not expected to result in adverse impacts to yield. No change when varying farm size. No capital outlay.
All C	All C, *water control* B	Medium	Requires significant capital outlay, but the benefits are diffuse and relatively hard to measure. No change when varying farm size.
All C	All C, *nutrient rate* B	Low	Lowering nutrient rates has the potential to decrease yield, however this risk can be managed through the correct application of soil and leaf testing methodology, which ensures that nutrient supply is well matched to crop demand. Risk from lowering rates is also reduced by combining with improved nutrient application practices. No change when varying farm size. No capital outlay.
All C	All C, *nutrient appl.* B	Low	Higher frequency applications improve nutrient efficiency and minimise the risk of large losses due to significant rainfall events. Results in a positive total FGM.
All C	All C, *irrigation* B	Low	Associated with high capital costs, the investment is relatively low in risk as the benefits due to reduced labour costs are well established and easily quantified.
All D	All D, *crop removal* C	Low	There is a minor negative impact on total FGM but it is expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.

All D	All D, *fallow* C	Low	The impacts on costs are very low relative to total FGM, and they are expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All D	All D, *tillage* C	Low	For Ferrosol soil there is a minor negative impact on total FGM whereas on Dermosol soil there is a minor positive impact on total FGM. For both soils, it is expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All D	All D, *ground cover* C	Low	Despite typically representing a net cost to farming businesses, it is not expected to result in adverse impacts to yield. No change when varying farm size. No capital outlay.
All D	All D, *water control* C	Medium	Requires significant capital outlay, but the benefits are diffuse and relatively hard to measure.
All D	All D, *nutrient rate* C	Low	Lowering nutrient rates has the potential to decrease yield; however this risk can be managed through the correct application of soil and leaf testing methodology, which ensures that nutrient supply is well matched to crop demand. Risk from lowering rates is also mitigated by combining with improved nutrient application practices. No change when varying farm size. No capital outlay.
All D	All D, *nutrient appl.* C	Low	Higher frequency applications improve nutrient efficiency and minimise the risk of large losses due to significant rainfall events. Results in a negative total FGM.
All D	All D, *irrigation* C	Low	Low risk driven by low capital cost and improved matching of water volume to crop requirement, which would likely deliver lower pumping costs and/or improved yields. No change when varying farm size.
All D	All D, *crop removal* B	Low	The impacts on costs are very low relative to total FGM, and they are expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All D	All D, *fallow* B	Low	The impacts on costs are very low relative to total FGM, and they are expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.
All D	All D, *tillage* B	Low	The impacts on costs are very low relative to total FGM, and they are expected to result in improvements to yield due to their positive impact on soil health. No change when varying farm size. No capital outlay.

All D	All D, *ground cover* B	Low	Despite representing a net cost, it is not expected to result in adverse impacts to yield. No change when varying farm size. No capital outlay.
All D	All D, *water control* B	Medium	Requires significant capital outlay, but the benefits are diffuse and relatively hard to measure. No change when varying farm size.
All D	All D, *nutrient rate* B	Low	Lowering nutrient rates has the potential to decrease yield, however this risk can be managed through the correct application of soil and leaf testing methodology, which ensures that nutrient supply is well matched to crop demand. Risk from lowering rates is also reduced by combining with improved nutrient application practices. No change when varying farm size. No capital outlay.
All D	All D, *nutrient appl.* B	Low	Higher frequency applications improve nutrient efficiency and minimise the risk of large losses due to significant rainfall events. Results in a negative total FGM.
All D	All D, *irrigation* B	Low	Associated with high capital costs, however the investment is relatively low in risk as the benefits due to reduced labour costs are well established and easily quantified.

Water control structures - Break-even farm gross margin analysis

Anecdotal reports from growers who have implemented best management practices for water control structures suggest that the investment results in positive economic benefits overall, but the benefits are difficult to estimate. These benefits can include lower vehicle repairs and maintenance costs, increased speed of operations, lower remedial works required to address inter-row bogs, reduced fruit damage during harvesting, and the potential for additional ratoons. Longer-term benefits can include the preservation of top soil and reduced soil movement, which inadvertently could reduce the risk of spreading soil borne pests such as nematodes and diseases such as Panama disease tropical race 4.

In order to explore how much additional benefit would be required to offset the cost of improving water control structures, Table 15 shows the increase in farm gross margin that would be required to make the investment worthwhile for each of the farm types modelled. The ‘change in FGM’ column shows the improvement in farm gross margin already included in the analysis above, which is due to the estimated savings in vehicle repairs and maintenance. While the break-even change in farm gross margin is substantially more than the change in FGM, the final column shows that this represents a relatively small percentage of each farm’s total farm gross margin. This increase could potentially come from increased revenue (through lower fruit damage) and/or from lower production costs.

Table 15: Increase in FGM required to offset cost of water control structures

From	To	Soil type	Farm size	Capital cost ($)	Change in FGM ($/ha)	Break even change in FGM ($/ha)	Break even change as a % of FGM
All C	All C, ***water control structures*** B	Dermosol	15 ha	1,549	6	15	0.1%
			40 ha	3,713	6	13	0.1%
			100 ha	8,909	6	13	0.1%
		Ferrosol	15 ha	3,679	6	35	0.3%
			40 ha	9,395	6	33	0.3%
			100 ha	23,113	6	33	0.3%
All D	All D, ***water control structures*** C	Dermosol	15 ha	4,646	11	44	0.5%
			40 ha	11,140	11	40	0.4%
			100 ha	26,726	11	38	0.4%
		Ferrosol	15 ha	11,038	11	105	1.2%
			40 ha	28,186	11	100	1.1%
			100 ha	69,340	11	99	1.0%
All D	All D, ***water control structures*** B	Dermosol	15 ha	6,195	15	59	0.5%
			40 ha	14,854	15	53	0.5%
			100 ha	35,634	15	51	0.5%
		Ferrosol	15 ha	14,718	15	140	1.3%
			40 ha	37,581	15	134	1.2%
			100 ha	92,453	15	132	1.2%

In addition to the above uncertainties relating to benefits, the cost of implementing best management practices relating to water control structures varies significantly from one farm to another, and is heavily dependent on each individual farm's layout and topography. An initial analysis was conducted to examine the effect on the economic outcome of changing the investment amount. It was found that even with significant variation in the investment cost the AEB remained negative in the absence of including additional benefits as discussed above.

3.3 Integration of economic and water quality results

3.3.1 Water quality impact

Modelled water quality constituent losses included hillslope erosion, total suspended sediments (TSS), total nitrogen, total phosphorus, and dissolved inorganic nitrogen (DIN). Surface water runoff and drainage (DIN only) results for Dermosol and Ferrosol soils, including varying degrees of slope, are presented in Tables 16 to 18. Shifting ground cover from D to C class dramatically reduced soil erosion by a factor ~10, mainly due to addition of grassed inter-rows. The difference between C and B practices was modest. In regards to phases of the crop, the in-crop component of the system contributes a greater proportion of the soil erosion (data not presented here), mainly due to greater amount of time banana systems are in crop compared to fallow.

The effect of soil conservation structures (implemented by use of a P factor of 0.6 and 0.8) was to reduce soil erosion by 20 per cent and 40 per cent for C and B practices respectively compared to D practice soil erosion rates.

The DIN losses in runoff in bananas were small compared to the application rates and averaged less than 0.5 per cent across all treatments. There were no large differences between soil types, with losses correlated and their runoff characteristics. There was a clear effect of management on the modelled runoff loads in deep drainage, with a trend for increased DIN losses with increased fertiliser rate and reduced frequency of application. This result is consistent with the observed data used to develop the model where the concentrations of DIN between management practices are higher and where higher rates and less frequent applications are made (Masters *et al* 2017).

Similarly, there was a clear and substantial effect of management on the modelled DIN in drainage loads, with a trend for increased DIN losses with increased fertiliser rate. Frequency of application was not observed to be as significant as rate. This result is also consistent with the observed data used to develop the model where there are large differences in DIN loads between rate trials.

Table 16: Dermosol (1% slope) erosion, sediment and associated nutrient loads,[9] and DIN loads

Combination description	Hillslope Erosion (t/ha)	Total Suspended Sediment (t/ha)	Total Nitrogen (kg N/ha)	Total Phosphorus (kg P/ha)	DIN Runoff (kg N/ha)	DIN drainage (kg N/ha)
All B	2.3	0.5	0.6	0.19	0.76	4.2
All C	3.9	0.8	0.9	0.31	1.08	16.5
All D	52.7	10.5	12.6	4.22	1.79	34.4
All C, ***crop removal*** B	48.5	9.7	11.6	3.88	No change	No change
All C, ***fallow*** B	47.8	9.6	11.5	3.83	No change	No change
All C, ***tillage*** B	52.5	10.5	12.6	4.2	No change	No change
All C, ***ground cover*** B	11.1	2.2	2.7	0.89	No change	No change
All C, ***water control structures*** B	42.2	8.4	10.1	3.37	No change	No change
All C, ***nutrient rate*** B	No change	No change	No change	No change	1.7	18.5
All C, ***nutrient application*** B	No change	No change	No change	No change	1.64	32.5
All C, ***irrigation*** B	No change	No change	No change	No change	1.79	31.5
All D, ***crop removal*** C	48.2	9.6	11.6	3.9	No change	No change
All D, ***fallow*** C	47.6	9.5	11.4	3.8	No change	No change
All D, ***tillage*** C	52.4	10.5	12.6	4.2	No change	No change
All D, ***ground cover*** C	10.9	2.2	2.6	0.9	No change	No change
All D, ***water control structures*** C	31.6	6.3	7.6	2.5	No change	No change
All D, ***nutrient rate*** C	No change	No change	No change	No change	1.58	7.4
All D, ***nutrient application*** C	No change	No change	No change	No change	1.57	32.5
All D, ***irrigation*** C	No change	No change	No change	No change	1.6	27.6
All D, **crop removal** B	3.6	0.7	0.9	0.29	No change	No change
All D, **fallow** B	3.8	0.8	0.9	0.3	No change	No change
All D, ***tillage*** B	3.8	0.8	0.9	0.3	No change	No change
All D, ***ground cover*** B	3.6	0.7	0.9	0.29	No change	No change

[9] 'Total nitrogen' and 'total phosphorus' in Table 16, Table 17 and
Table 18 account for particulate nitrogen and phosphorus transported with total suspended sediment (TSS). These are a fixed percentage of TSS in the model (0.12% for total nitrogen and 0.04% for total phosphorus) so that the abatement results for TSS presented below also represent the relative abatement of total nitrogen and total phosphorus.

Combination description	Hillslope Erosion (t/ha)	Total Suspended Sediment (t/ha)	Total Nitrogen (kg N/ha)	Total Phosphorus (kg P/ha)	DIN Runoff (kg N/ha)	DIN drainage (kg N/ha)
All D, ***water control structures*** B	2.9	0.6	0.7	0.23	No change	No change
All D, ***nutrient rate*** B	No change	No change	No change	No change	1.07	4.9
All D, ***nutrient application*** B	No change	No change	No change	No change	1.06	15.9
All D, ***irrigation*** B	No change	No change	No change	No change	1.08	14

Table 17: Ferrosol (2% slope) erosion, sediment and associated nutrient loads, and DIN loads

Combination description	Hillslope Erosion (t/ha)	Total Suspended Sediment (t/ha)	Total Nitrogen (kg N/ha)	Total Phosphorus (kg P/ha)	DIN Runoff (kg N/ha)	DIN drainage (kg N/ha)
All B	1.8	0.4	1	0.62	0.84	5.2
All C	3	0.6	1.6	1.04	1.19	19.5
All D	38.6	7.7	20.8	13.11	1.91	40.6
All C, ***crop removal*** B	35.4	7.1	19.1	12.04	No change	No change
All C, ***fallow*** B	34.9	7	18.9	11.88	No change	No change
All C, ***tillage*** B	38.4	7.7	20.7	13.05	No change	No change
All C, ***ground cover*** B	8.5	1.7	4.6	2.88	No change	No change
All C, ***water control structures*** B	30.9	6.2	16.7	10.49	No change	No change
All C, ***nutrient rate*** B	No change	No change	No change	No change	1.8	21.9
All C, ***nutrient application*** B	No change	No change	No change	No change	1.73	38.2
All C, ***irrigation*** B	No change	No change	No change	No change	1.91	37
All D, ***crop removal*** C	35.2	7	19	11.98	No change	No change
All D, ***fallow*** C	34.8	7	18.8	11.82	No change	No change
All D, ***tillage*** C	38.3	7.7	20.7	13.02	No change	No change
All D, ***ground cover*** C	8.3	1.7	4.5	2.81	No change	No change
All D, ***water control structures*** C	23.1	4.6	12.5	7.87	No change	No change
All D, ***nutrient rate*** C	No change	No change	No change	No change	1.65	8.7
All D, ***nutrient application*** C	No change	No change	No change	No change	1.64	38.4
All D, ***irrigation*** C	No change	No change	No change	No change	1.68	32.4

Combination description	Hillslope Erosion (t/ha)	Total Suspended Sediment (t/ha)	Total Nitrogen (kg N/ha)	Total Phosphorus (kg P/ha)	DIN Runoff (kg N/ha)	DIN drainage (kg N/ha)
All D, ***crop removal*** B	2.8	0.6	1.5	0.96	No change	No change
All D, ***fallow*** B	3	0.6	1.6	1.01	No change	No change
All D, ***tillage*** B	3	0.6	1.6	1.01	No change	No change
All D, ***ground cover*** B	2.9	0.6	1.5	0.97	No change	No change
All D, ***water control structures*** B	2.3	0.5	1.2	0.78	No change	No change
All D, ***nutrient rate*** B	No change	No change	No change	No change	1.17	6.2
All D, ***nutrient application*** B	No change	No change	No change	No change	1.17	18.7
All D, ***irrigation*** B	No change	No change	No change	No change	1.19	16.5

Table 18: Ferrosol (4.5% slope) erosion, sediment and associated nutrient loads, and DIN loads

Combination description	Hillslope Erosion (t/ha)	Total Suspended Sediment (t/ha)	Total Nitrogen (kg N/ha)	Total Phosphorus (kg P/ha)	DIN Runoff (kg N/ha)	DIN drainage (kg N/ha)
All B	3.8	0.8	2.1	1.3	0.84	5.2
All C	6.4	1.3	3.5	2.17	1.19	19.5
All D	80.9	16.2	43.7	27.51	1.91	40.6
All C, ***crop removal*** B	74.3	14.9	17.82	5.94	No change	No change
All C, ***fallow*** B	73.3	14.7	17.59	5.86	No change	No change
All C, ***tillage*** B	80.5	16.1	19.32	6.44	No change	No change
All C, ***ground cover*** B	17.7	3.5	4.26	1.42	No change	No change
All C, ***water control structures*** B	80.9	11.3	13.59	4.53	No change	No change
All C, ***nutrient rate*** B	No change	No change	No change	No change	1.78	21.9
All C, ***nutrient application*** B	No change	No change	No change	No change	1.71	38.2
All C, ***irrigation*** B	No change	No change	No change	No change	1.88	37
All D, ***crop removal*** C	73.9	14.8	39.9	25.13	No change	No change
All D, ***fallow*** C	72.9	14.6	39.4	24.79	No change	No change
All D, ***tillage*** C	80.3	16.1	43.4	27.31	No change	No change
All D, ***ground cover*** C	17.4	3.5	9.4	5.9	No change	No change

Combination description	Hillslope Erosion (t/ha)	Total Suspended Sediment (t/ha)	Total Nitrogen (kg N/ha)	Total Phosphorus (kg P/ha)	DIN Runoff (kg N/ha)	DIN drainage (kg N/ha)
All D, ***water control structures*** C	48.5	9.7	26.2	16.51	No change	No change
All D, ***nutrient rate*** C	No change	No change	No change	No change	1.65	8.7
All D, ***nutrient application*** C	No change	No change	No change	No change	1.64	38.4
All D, ***irrigation*** C	No change	No change	No change	No change	1.68	32.4
All D, ***crop removal*** B	5.9	1.2	3.2	2.01	No change	No change
All D, ***fallow*** B	6.2	1.2	3.4	2.12	No change	No change
All D, ***tillage*** B	6.3	1.3	3.4	2.13	No change	No change
All D, ***ground cover*** B	6	1.2	3.2	2.04	No change	No change
All D, ***water control structures*** B	4.8	1	2.6	1.63	No change	No change
All D, ***nutrient rate*** B	No change	No change	No change	No change	1.17	6.2
All D, ***nutrient application*** B	No change	No change	No change	No change	1.17	18.7
All D, ***irrigation*** B	No change	No change	No change	No change	1.19	16.5

3.3.2 Cost effectiveness of changing management practices

The following figures and tables combine the water quality and economic results to give an indication of the cost effectiveness of each management practice change. DIN runoff and DIN drainage have been combined into a single figure for DIN abatement, and the economic results are presented using the AEB (the annual transformation of the NPV) so that it is comparable in timeframe to the water quality results. This report contains no complete measure of cost-effectiveness, such as dollars per kg of DIN abated, but rather sets out separately the abatement in tonnes or kilograms per hectare per year and the cost or increase to profit in dollars per hectare per year. This approach has been taken because some management practices modelled result in an increase in profit (e.g. negative costs of implementation with reduced nutrient rates) and some a decrease in profit (e.g. positive costs of implementation with ground cover) and when divided by the amount of abatement (a positive amount of kg/ha/year) cannot be compared with each other (Taylor 2012). For example, a $/kg/year metric would be low if the abatement reduction was high and the cost of implementing it was positive and small but the metric would also be low with a small abatement reduction and a large negative cost of implementation (e.g. increased AEB from implementing the practice). This measurement would be inadequate because, when negative cost measures are ranked with positive cost measures, practices delivering low abatement could be favoured over practices that have high abatement, which could result in an incorrect ranking and 'a potential failure to achieve the best-value outcome' (Taylor 2012: 431).

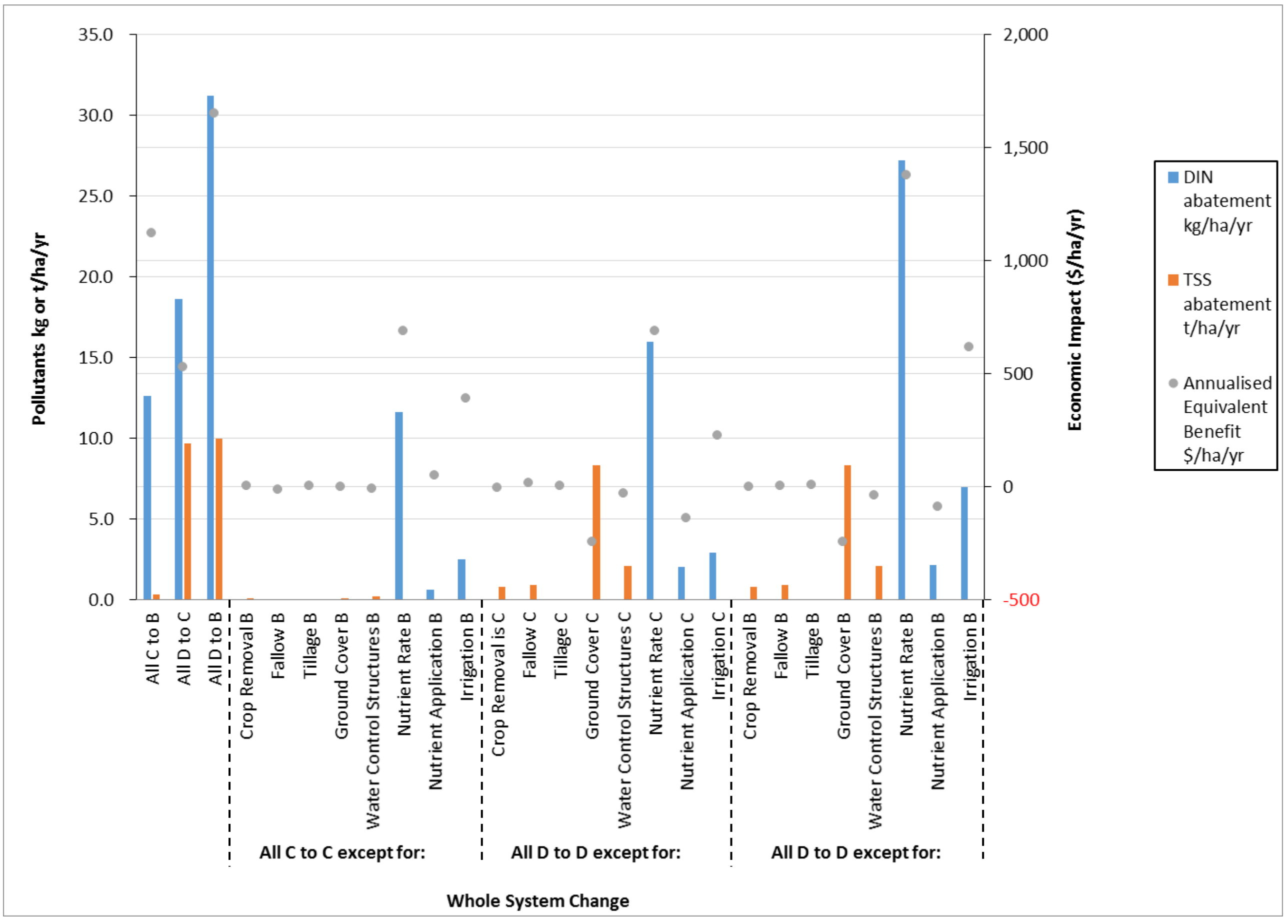

Figure 5: Cost effectiveness, 40 hectare farm, Dermosol soil

Table 19: Cost effectiveness, 40 hectare farm, Dermosol soil

Original practice	New practice	DIN abatement (kg/ha/yr)	TSS abatement (t/ha/yr)	AEB ($/ha/yr)
All C	All B	12.6	0.3	1,122
All D	All C	18.6	9.7	531
All D	All B	31.2	10.0	1,653
All C	All C, ***crop removal*** B	0.0	0.1	5
All C	All C, ***fallow*** B	0.0	0.0	-13
All C	All C, ***tillage*** B	0.0	0.0	6
All C	All C, ***ground cover*** B	0.0	0.1	0
All C	All C, ***water control structures*** B	0.0	0.2	-7
All C	All C, ***nutrient rate*** B	11.6	0.0	691
All C	All C, ***nutrient application*** B	0.6	0.0	50
All C	All C, ***irrigation*** B	2.5	0.0	391
All D	All D, ***crop removal*** C	0.0	0.8	-4
All D	All D, ***fallow*** C	0.0	0.9	18
All D	All D, ***tillage*** C	0.0	0.0	3
All D	All D, ***ground cover*** C	0.0	8.3	-243
All D	All D, ***water control structures*** C	0.0	2.1	-29
All D	All D, ***nutrient rate*** C	16.0	0.0	690
All D	All D, ***nutrient application*** C	2.1	0.0	-140
All D	All D, ***irrigation*** C	2.9	0.0	228
All D	All D, ***crop removal*** B	0.0	0.8	1
All D	All D, ***fallow*** B	0.0	0.9	6
All D	All D, ***tillage*** B	0.0	0.0	9
All D	All D, ***ground cover*** B	0.0	8.3	-243
All D	All D, ***water control structures*** B	0.0	2.1	-38
All D	All D, ***nutrient rate*** B	27.2	0.0	1,381
All D	All D, ***nutrient application*** B	2.1	0.0	-88
All D	All D, ***irrigation*** B	7.0	0.0	619

Cost effectiveness summary (40 ha farm, Dermosol soil)

All C to all B:

- Changing all practices from C to B resulted in DIN abatement of 12.6 kg/ha/year, TSS abatement of 0.3 t/ha/year, and an AEB of $1,122 per hectare.

All D to all C:

- Changing all practices from D to C resulted in higher DIN abatement of 18.6 kg/ha/year and significantly higher TSS abatement of 9.7 t/ha/year. However, the associated AEB was lower at $531 per hectare.

All D to all B:

- Changing all practices from D to B resulted in DIN abatement of 31.2 kg/ha/year, significantly higher TSS abatement of 10.0 t/ha/year, and an AEB of $1,653 per hectare.

All C, changing individual practice groups from C to B:

- The only ‘C to B’ management practice change to impact on DIN abatement was ‘nutrient rate’, due to the impact of lowering fertiliser rates from 350 kg/N/ha to 250 kg/N/ha. The resulting savings in fertiliser costs also gives ‘nutrient rate’ the highest AEB of $691 per hectare.
- ‘Crop removal’ was responsible for TSS abatement of 0.1 t/ha/year, and had an AEB of $5 per hectare, driven by a reduction in tillage operations.
- ‘Ground cover’ also led to a reduction in TSS load of 0.1 t/ha/year, however the AEB was zero–as previously mentioned, moving from C to B for ground cover doesn’t involve any direct management practice change.

All D, changing individual practice groups from D to C:

- The largest impact on DIN loads was ‘nutrient rate’, due to the drop in fertiliser rates from 450 kg/N/ha to 350 kg/N/ha. This also led to ‘nutrient rate’ again having the highest AEB of $690 per hectare.
- ‘Irrigation’ led to DIN abatement of 2.9 kg/ha/year due to the lower volume of water applied, and an AEB of $228 per hectare.
- ‘Nutrient application’ caused a reduction in DIN of 2.1 kg/ha/year because of the increased application frequency (from every two months to monthly), however the AEB was -$140 per hectare due to the investment in the banded spreader and increased application costs.
- ‘Ground cover’ had the largest impact on sediment loads, with the change from bare to grassed inter-rows and headlands resulting in TSS abatement of 8.3 t/ha/year. This was associated with a negative AEB of -$243 due to the cost of slashing.
- ‘Water control structures’ resulted in 2.1 t/ha/year of TSS abatement, and had a negative AEB of -$29 per hectare.

All D, changing individual practice groups from D to B:

- The largest impact on DIN loads was ‘nutrient rate’, due to the drop in fertiliser rates from 450 kg/N/ha to 250 kg/N/ha. This also led to ‘nutrient rate’ again having the highest AEB of $1,381 per hectare.
- ‘Ground cover’ had the largest impact on sediment loads, with the change from bare to grassed inter-rows and headlands resulting in TSS abatement of 8.3 t/ha/year. This was associated with a negative AEB of -$243 due to the cost of slashing.
- ‘Water control structures’ resulted in 2.1 t/ha/year of TSS abatement, and had a negative AEB of -$38 per hectare.
- ‘Nutrient application’ caused a reduction in DIN of 2.1 kg/ha/year because of the increased application frequency, however the AEB was -$88 per hectare due to the investment in the banded spreader and increased application costs.
- ‘Irrigation’ led to DIN abatement of 7.0 kg/ha/year due to the lower volume of water applied, and an AEB of $619 per hectare.

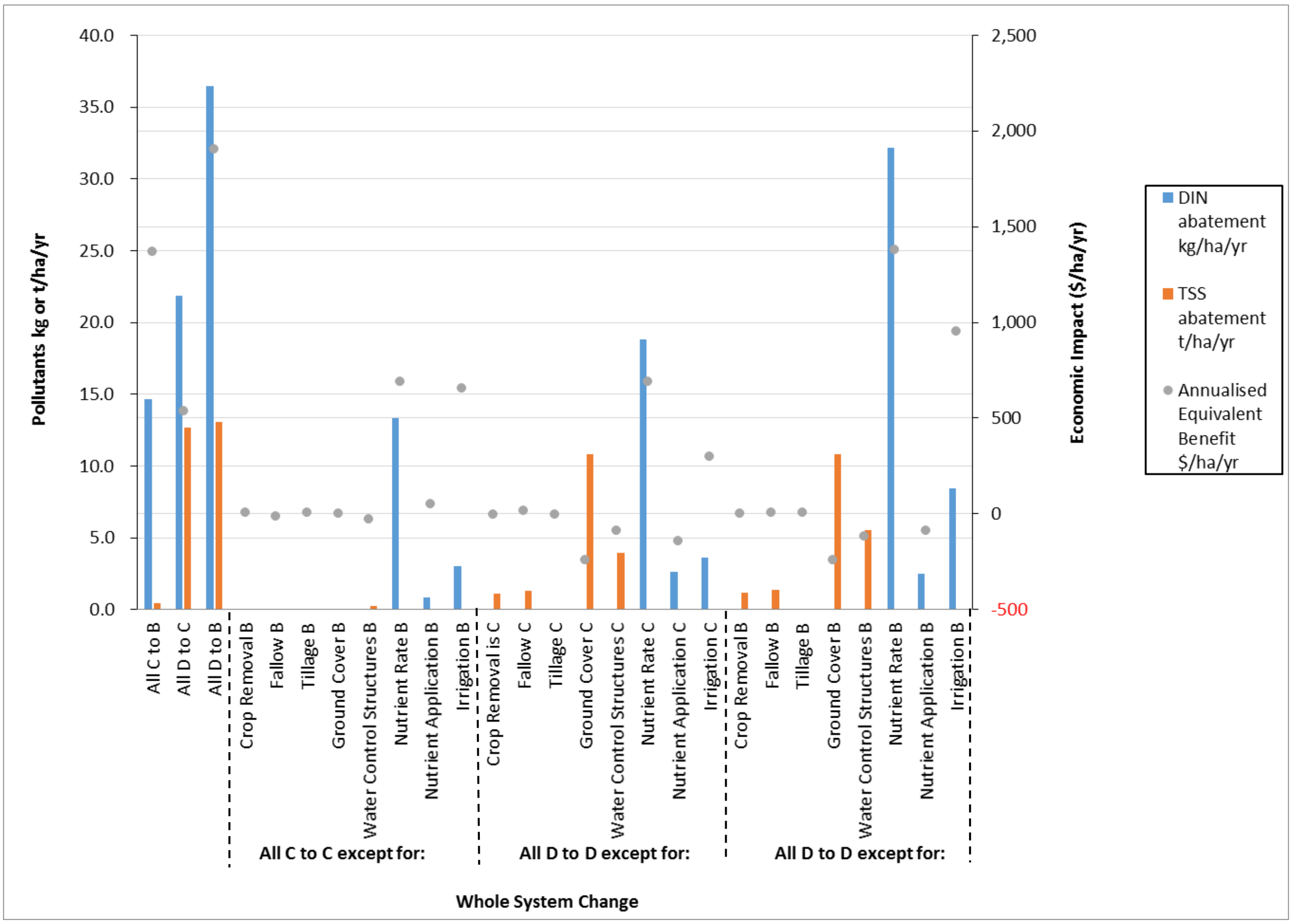

Figure 6: Cost effectiveness, 40 hectare farm, Ferrosol soil

Table 20: Cost effectiveness, 40 hectare farm, Ferrosol soil

Original practice	New practice	DIN abatement (kg/ha/yr)	TSS abatement (t/ha/yr)	AEB ($/ha/yr)
All C	All B	14.7	0.4	1,367
All D	All C	21.8	12.7	535
All D	All B	36.5	13.1	1,903
All C	All C, ***crop removal*** B	0.0	0.1	5
All C	All C, ***fallow*** B	0.0	0.1	-13
All C	All C, ***tillage*** B	0.0	0.0	8
All C	All C, ***ground cover*** B	0.0	0.1	0
All C	All C, ***water control structures*** B	0.0	0.2	-28
All C	All C, ***nutrient rate*** B	13.3	0.0	691
All C	All C, ***nutrient application*** B	0.8	0.0	50
All C	All C, ***irrigation*** B	3.0	0.0	654
All D	All D, ***crop removal*** C	0.0	1.1	-4
All D	All D, ***fallow*** C	0.0	1.3	18
All D	All D, ***tillage*** C	0.0	0.1	-1
All D	All D, ***ground cover*** C	0.0	10.8	-243
All D	All D, ***water control structures*** C	0.0	3.9	-89
All D	All D, ***nutrient rate*** C	18.8	0.0	690
All D	All D, ***nutrient application*** C	2.6	0.0	-140
All D	All D, ***irrigation*** C	3.6	0.0	298
All D	All D, ***crop removal*** B	0.0	1.2	1
All D	All D, ***fallow*** B	0.0	1.3	6
All D	All D, ***tillage*** B	0.0	0.1	7
All D	All D, ***ground cover*** B	0.0	10.8	-243
All D	All D, ***water control structures*** B	0.0	5.5	-119
All D	All D, ***nutrient rate*** B	32.2	0.0	1,381
All D	All D, ***nutrient application*** B	2.5	0.0	-88
All D	All D, ***irrigation*** B	8.4	0.0	952

Cost effectiveness summary (40 ha farm, Ferrosol soil)

The cost effectiveness results for Ferrosol soils are similar to Dermosol soils. Key differences are:

- DIN abatement moving from 'all C' to 'all B' is higher (14.7 kg/ha/year compared to 12.6 kg/ha/year for Dermosol soils). TSS abatement was higher by 0.1 and the AEB was higher at $1,367 per hectare (compared to $1,122 per hectare for Dermosol soils).
- Changing from 'all D' to 'all C', DIN and TSS abatement were both higher (at 21.8 kg/ha/year and 12.7 t/ha/year respectively) and AEB was slightly higher at $535 per hectare compared to Dermosol soils.
- Changing from 'all D' to 'all B', DIN (36.5 kg/ha/year) and TSS abatement (13.1 t/ha/year) were both higher but AEB was higher at $1,903 per hectare compared to Dermosol soils.
- 'Nutrient rate' resulted in greater DIN abatement on Ferrosol soils for all 'C to B', 'D to C' and 'D to B' (13.3 kg/ha/year, 18.8 kg/ha/year and 32.2 kg/ha/year respectively).

- 'Irrigation' led to higher DIN abatement for all 'C to B', 'D to C' and 'D to B' (3 kg/ha/year, 3.6 kg/ha/year and 8.4 kg/ha/year respectively).
- Changing individual practices from 'D to C' and 'D to B', TSS abatement was higher on Ferrosol soils compared to Dermosol soils (for practice changes that affected sediment loads).

As the water quality results are the same for all farm sizes, and the variation in economic results between farm sizes has already been discussed, the cost effectiveness tables for 15 and 100 hectare farms and charts for cost effectiveness have been included in 'Appendix E – additional results'.

3.4 Pesticide modelling

As pesticides have not yet been incorporated into the Paddock to Reef Water Quality Risk Framework, they were not included as part of the management practice change modelling. However, a number of pesticides were included in the models for this project as part of the background practices based on typical products that are applied in the Innisfail and Tully regions. The following section presents preliminary water quality modelling of a sub-set of these pesticides.

3.4.1 Pesticides included in representative models

Six pesticides were included as part of the background practices in the economic models:

- **Glyphosate**: a non-selective herbicide
- **Chlorothalonil**: a broad spectrum fungicide
- **Glufosinate-ammonium**: a broad-spectrum herbicide
- **Imidacloprid**: an insecticide
- **Mancozeb**: a fungicide
- **Omethoate**: An insecticide and acaricide.

A summary of the pesticides properties, including parameters important to understanding possible loss pathways in the environment, including half-life, soil adsorption and leaching potential are outlined below (Lewis *et al*., 2016). The pesticides modelled used these half-lives and sorption co-efficient (Kd – a parameter describing soil and water binding potential, where a higher value indicates a higher propensity to bind to soil).

Glyphosate

Glyphosate is a non-selective common and effective herbicide. It is highly soluble in water, relatively volatile and does not normally leach to groundwater. It is not persistent in soils but may be in aquatic systems under certain conditions. It is moderately toxic to birds, most aquatic organisms, earthworms and honeybees.

- Soil degradation half-life is 25 days (non-persistent)
- Plant matrix half-life 10 days
- Soil adsorption and mobility is 21 Kd (slightly mobile)
- Leaching potential is low
- The potential for particle bound transport is medium.

Chlorothalonil

Chlorothalonil is a broad spectrum fungicide. It has a low aqueous solubility, is volatile and would not be expected to leach to groundwater. It is slightly mobile. It tends not to be persistent in soil systems but may be persistent in water. Chlorothalonil is moderately toxic to birds, honeybees and earthworms but considered to be more toxic to aquatic organisms.

- Soil degradation half-life is 9.2 days (non-persistent)
- Plant matrix half-life 5.4 days
- Soil adsorption and mobility is 43 Kd (slightly mobile)
- Leaching potential is low
- The potential for particle bound transport is medium.

Glufosinate-ammonium

Glufosinate-ammonium is a broad spectrum herbicide. It is highly soluble in water, volatile and has a low risk of leaching to groundwater. It is non-persistent in soils but may be persistent in aquatic systems. It is moderately toxic to mammals and considered to be a neurotoxin. It shows a moderate to low toxicity to birds, most aquatic organisms, earthworms and honeybees.

- Soil degradation half-life is 7.4 days (non-persistent)
- Plant matrix half-life 4 days
- Soil adsorption and mobility is 6 Kd (slightly mobile)
- Leaching potential is low
- The potential for particle bound transport is low.

Imidacloprid

Imidacloprid is an insecticide. It is highly soluble, non-volatile and persistent in soil. It is moderately mobile. It has a low risk of bio-accumulating. It is highly toxic to birds and honeybees. Moderately toxic to mammals and earthworms. It is non-toxic to fish.

- Soil degradation half-life is 191 days (non-persistent)
- Plant matrix half-life 4.8 days
- Soil adsorption and mobility is 2.2 Kd (slightly mobile)
- Leaching potential is high
- The potential for particle bound transport is medium.

Mancozeb

Mancozeb is a fungicide. It has a low solubility, is quite volatile and not expected to leach to groundwater. It is not persistent in soil systems but may be persistent in water under certain conditions. It is highly toxic to fish and aquatic invertebrates, and moderately toxic to birds and earthworms. The toxicity of mancozeb to honeybees is low.

- Soil degradation half-life is 0.1 days (non-persistent)
- Plant matrix half-life 5.9 days
- Soil adsorption and mobility is 9.7 Kd (slightly mobile)
- Leaching potential is low
- The potential for particle bound transport is low.

Omethoate

An insecticide and acaricide is used to control a wide range of pests on fruit, hops and other crops.

- Soil degradation half-life is 14 days (non-persistent)
- Soil adsorption and mobility is 0.5 Kd (slightly mobile)
- Leaching potential is low
- The potential for particle bound transport is low.

3.4.2 Pesticides modelled

Pesticides were modelled in HowLeaky with a sub-model of the soil-plant interaction runoff and erosion model. Three pesticide were investigated, including glyphosate, chlorothalonil and glufosinate-ammonium. Imidacloprid, Mancozeb and Omethoate were not able to be modelled due to the modes of applications, such as application under bunch covers or directly in the stool. These application modes are not compatible with the existing modelling framework.

Glyphosate, Chlorothalonil and Glufosinate-ammonium were modelled using the following assumptions:

- Roundup (360 g/L glyphosate) – applied with sprayer for inter-row weed control, rate: 5L/ha, four times per year (evenly spaced throughout year), applied to plant and ratoons.
- Basta (200 g/L glufosinate-ammonium) – applied to beds as a spot spray, 1L/ha, six times per year (every two months), applied to plant and ratoons.
- Chlorothalonil (500 g/L chlorothalonil) – applied as an aerial spray, 2.6L/ha 20 times per year (fewer times in winter – every two weeks in summer, every three weeks in winter), applied to plant and ratoons.

3.4.3 Results

Results of modelling glyphosate, chlorothalonil and glufosinate-ammonium for the Dermosol and Ferrosol soils are shown in Table 21. Pesticide loss behaviour was similar for the three pesticides with most pesticide lost in runoff compared to leaching. Of the total lost in runoff, up to 4 per cent was lost in runoff sediments. Runoff in leaching was estimated to be between 10 and 25 per cent of the total lost in runoff.

The highest losses as a percentage of applied pesticides were for glyphosate (approximately 3 per cent), compared to 1 per cent for Chlorothalonil and glufosinate-ammonium. The higher losses can be attributed to the longer half-life assumed for glyphosate (25 days) compared to 9 and 7 days for Chlorothalonil and glufosinate-ammonium respectively. It should be noted that local half-life values were not available and values were sourced from an international pesticides properties database (Lewis *et al*., 2016).

These results indicate that application rate and frequency had the greatest impact on pesticide losses. Therefore the most effective way to reduce losses would be to reduce application rates or frequency of applications.

Both soil types behaved very similarly, while Ferrosol soils showed slightly higher runoff losses, these are scenario specific results and these soils are inherently at risk of higher losses than the Dermosol soils.

Table 21: Pesticide loads lost in runoff and drainage

Soil	Management class	Load lost in runoff water (g/ha)	Load lost in runoff sediment (g/ha)	Total load lost in runoff (g/ha)	Load lost in leaching (g)	% applied lost runoff	% applied lost leaching
Chlorothalonil – 20 applications of 2.6 L/ha @ 500 g/L ~ 26 kg/yr							
Dermosol	B	268.9	0.5	269.4	16.5	1.0%	0.1%
	C	273.6	1.5	275.1	16.4	1.1%	0.1%
	D	283.7	11.1	294.8	16.2	1.1%	0.1%
Ferrosol	B	295.8	0.4	296.2	18.2	1.1%	0.1%
	C	301.0	1.3	302.3	18.0	1.2%	0.1%
	D	312.0	9.0	321.1	17.8	1.2%	0.1%
Glufosinate-ammonia - 6 applications of 1 L/ha @ 200 g/L ~ 1.2 kg/yr							
Dermosol	B	12.2	0.0	12.2	3.6	1.0%	0.3%
	C	12.5	0.0	12.5	3.6	1.0%	0.3%
	D	13.0	0.1	13.1	3.6	1.1%	0.3%
Ferrosol	B	13.4	0.0	13.4	4.0	1.1%	0.3%
	C	13.7	0.0	13.7	3.9	1.1%	0.3%
	D	14.3	0.1	14.4	3.9	1.2%	0.3%
Glyphosate - 4 applications of 5 L/ha @ 360 g/L ~ 7.2 kg/yr							
Dermosol	B	202.6	0.2	202.7	22.5	2.8%	0.3%
	C	206.0	0.6	206.6	22.3	2.9%	0.3%
	D	213.3	4.2	217.6	22.0	3.0%	0.3%
Ferrosol	B	222.8	0.2	223.0	24.8	3.1%	0.3%
	C	226.7	0.5	227.1	24.5	3.2%	0.3%
	D	234.7	3.4	238.1	24.2	3.3%	0.3%

4 Key economic and environmental findings

4.1 Economic results

Improved management practices (table 1) were generally associated with higher farm gross margins per hectare. However, not all management practice improvements had a positive impact on farm gross margin (see Table 22). Farm gross margins were higher for farms on Dermosol soils compared to Ferrosol soils (mainly due to higher irrigation costs in Ferrosols), and larger farms had higher farm gross margins than smaller farms (due to several areas where economies of scale could be realised by larger farms). Due to large investment costs for some management practices, some practice changes resulted in a decrease in farm gross margin. These included crop removal, fallow, tillage (only for Ferrosol), ground cover, nutrient application for several different practice changes.

Comparing the scenarios of farms operating at C level, with individual practices shifted to B, the highest farm gross margins were associated with the scenarios of ‘nutrient rate’, ‘irrigation’ and ‘nutrient application’ at B level.

Comparing the scenarios of farms operating at D level, with individual practices shifted to C, the scenario with ‘nutrient rate’ shifted to C had a significantly higher farm gross margin compared to all other scenarios.

Investment analysis revealed that, in general, adopting improved management practices was profitable for all farm types when investment costs are taken into account, however the profitability of adopting specific practices varied considerably. The highest NPVs were associated with ‘nutrient rate’ and ‘irrigation’ moving from C to B, while nutrient rate was the most profitable change moving from D to C. The most significant decreases in profitability were associated with ‘ground cover’ and ‘nutrient application’ moving from D to C.

4.2 Cost effectiveness results

The findings revealed that collectively changing all modelled practices from D to C, D to B, and C to B had a positive impact on DIN and TSS loss reduction and farm profitability (see Table 22). The majority of the benefit in TSS abatement came from changing practices from D to C, while changing from C to B had a much greater impact on profitability than changing from D to C. Substantial DIN reductions were observed changing from both D to C and C to B.

In terms of individual practices, by far the most effective practice for DIN abatement was ‘nutrient rates’. This held true for changing from D to C and C to B, and on both soil types modelled. Reducing fertiliser rates was also associated with the highest AEB for most farm scenarios.

DIN abatement also resulted from changing from D to C for ‘irrigation’, however the effect was greater for Ferrosol soils compared to Dermosol soils. While not having a significant effect on DIN or TSS, converting to a fully automated irrigation system (changing ‘irrigation’ from C to B) delivered the second highest AEB among the B level practices for Dermosol and Ferrosol soils.

Increasing inter-row and headland ground cover delivered the greatest benefit in sediment reduction. The biggest improvement came from changing from D (spraying or cultivating inter-rows and headlands bare) to C (maintaining at least 60 per cent cover, living or dead). However, this resulted in a negative or break-even AEB for all farm scenarios, as increased costs from slashing were not offset by tangible cost savings.

Improving ‘water control structures’ from D to C also led to significant TSS abatement, and was associated with only a slightly negative AEB, as the investment cost was partially offset by a reduction in machinery repairs and maintenance costs. As previously discussed, the full benefits resulting from improving farm design are likely to be higher than is indicated in this analysis.

Changing ‘crop removal’ and ‘fallow’ from D to C also delivered minor TSS abatement. ‘Crop removal’ had a slightly negative AEB, as the savings in tillage from D level was more than offset by increased labour costs associated with herbicide injection. ‘Fallow’ had a slightly positive AEB due to the savings from reduced herbicide application and tillage.

The pattern of economic benefits and costs associated with management practice change was similar for each farm size. However two key differences were observed: the AEB per hectare for ‘nutrient application’ (moving from C to B, and D to C) increased with farm size as the total investment cost is spread over a greater area; and the AEB associated with moving from C to B for ‘irrigation’ increases slightly with farm size for the same reason.

Table 22: Economic and Water Quality Summary Results

Original practice	New practice	Change in FGM ($/ha)		Economic risk rating	DIN abatement (kg/ha/yr)		TSS abatement (t/ha/yr)		AEB($/ha/yr)	
		Dermosol 40ha	Ferrosol 40ha		Dermosol 40ha	Ferrosol 40ha	Dermosol 40ha	Ferrosol 40ha	Dermosol 40ha	Ferrosol 40ha
All C	All B	1,276	1,541	Low	12.6	14.7	0.3	0.4	1,122	1,367
All D	All C	602	667	Low	18.6	21.8	9.7	12.7	531	535
All D	All B	1,877	2,208	Low	31.2	36.5	10.0	13.1	1,653	1,903
All C	All C, crop removal B	5	5	Low	0.0	0.0	0.1	0.1	5	5
All C	All C, fallow B	-13	-13	Low	0.0	0.0	0.0	0.1	-13	-13
All C	All C, tillage B	6	8	Low	0.0	0.0	0.0	0.0	6	8
All C	All C, ground cover B	0	0	Low	0.0	0.0	0.1	0.1	0	0
All C	All C, water control B	6	6	Medium	0.0	0.0	0.2	0.2	-7	-28
All C	All C, nutrient rate B	691	691	Low	11.6	13.3	0.0	0.0	691	691
All C	All C, nutrient appl. B	85	85	Low	0.6	0.8	0.0	0.0	50	50
All C	All C, irrigation B	496	759	Low	2.5	3.0	0.0	0.0	391	654
All D	All D, crop removal C	-4	-4	Low	0.0	0.0	0.8	1.1	-4	-4
All D	All D, fallow C	18	18	Low	0.0	0.0	0.9	1.3	18	18
All D	All D, tillage C	3	-1	Low	0.0	0.0	0.0	0.1	3	-1
All D	All D, ground cover C	-243	-243	Low	0.0	0.0	8.3	10.8	-243	-243
All D	All D, water control C	11	11	Medium	0.0	0.0	2.1	3.9	-29	-89
All D	All D, nutrient rate C	690	690	Low	16.0	18.8	0.0	0.0	690	690
All D	All D, nutrient appl. C	-121	-121	Low	2.1	2.6	0.0	0.0	-140	-140
All D	All D, irrigation C	240	310	Low	2.9	3.6	0.0	0.0	228	298
All D	All D, crop removal B	1	1	Low	0.0	0.0	0.8	1.2	1	1
All D	All D, fallow B	6	6	Low	0.0	0.0	0.9	1.3	6	6
All D	All D, tillage B	9	7	Low	0.0	0.0	0.0	0.1	9	7
All D	All D, ground cover B	-243	-243	Low	0.0	0.0	8.3	10.8	-243	-243
All D	All D, water control B	15	15	Medium	0.0	0.0	2.1	5.5	-38	-119
All D	All D, nutrient rate B	1,381	1,381	Low	27.2	32.2	0.0	0.0	1,381	1,381
All D	All D, nutrient appl. B	-33	-33	Low	2.1	2.5	0.0	0.0	-88	-88
All D	All D, irrigation B	736	1,069	Low	7.0	8.4	0.0	0.0	619	952

4.3 Pesticide modelling results

The pesticides modelled were glyphosate, chlorothalonil and glufosinate-ammonium for the Dermosol and Ferrosol soils. Pesticide loss behaviour was similar for the three pesticides with most pesticide lost in runoff compared to leaching. Of the total lost in runoff, up to four per cent was lost in runoff sediments. Runoff in leaching was estimated to be between 10 and 25 per cent of total lost in runoff.

These results imply that management of erosion and sediments would not be effective in significantly reducing runoff losses. Given that total runoff cannot be managed, the only effective way to reduce losses would be to reduce application rates or frequency of applications.

Both soil types behaved very similarly, while Ferrosol soils in the case presented show slightly higher runoff losses, these are scenario specific results and these soils are inherently at risk of higher losses than the Dermosol soils.

5 Policy considerations

There are a number of policy options available to government to encourage management practice change, including extension, grants and other incentives and regulation. In theory, practices generating both positive environmental and economic benefits should be encouraged through extension, while practices that provide water quality benefits but come at an economic cost may require some form of incentive or regulation to bring about practice change.

However, the adoption of improved management practices, new technologies and innovations is a complex process that can take many years. Providing funding to support the process is no guarantee that it will occur, even if a practice has been demonstrated to generate positive economic benefits. A number of other factors may limit the uptake of an improved management practice, including its compatibility with a grower's existing farming system, its perceived relative advantage over the current farming system, the perceived level of risk associated with the practice, whether the practice is observable and trialable, and whether the practice aligns with the grower's values.

In addition, for some management practices the degree of uptake of BMP that has already occurred may limit potential additional gains that can be made at the catchment level. For example, according to a survey on management practices (Sing, N.C., 2012) 64 per cent of growers (representing 67 per cent of the area surveyed) applied nitrogen at rates under 300 kilograms per hectare. While the modelling in this report indicates that reducing nitrogen rates should have the greatest potential to reduce DIN in runoff and drainage, the survey results suggest that most of these gains may have already been made.

While this report provides an indication of which management practice improvements deliver the greatest water quality and economic benefits, the above considerations should be taken into account when forming policy prioritisations.

6 Limitations of project findings and areas for future research

6.1 Economic modelling

The farm scenarios modelled in this report, based on three farm sizes and two soil types, were chosen to represent the range of farms in the Innisfail and Tully regions. However, there is a significant amount of variation within each scenario, based on numerous factors such as specific soil type, farm layout, topography, pest pressures, rainfall patterns, grower experience and financial situation, existing infrastructure and farming systems. These can all influence the operating and investment costs faced by each farming business, which can in turn affect the impact of BMP adoption on farm profitability. Further research may be required to explore the extent that these factors may affect the impact of BMP on profitability.

Another avenue for future research is the potential effect of BMP implementation on banana yields to give growers confidence in adoption. Specific BMP changes may be beneficial in terms of yield, such as controlled traffic, permanent beds, improved irrigation, fertiliser practices and improved farm design. However, research to date has been insufficient to include any yield impacts in this analysis. One exception is a recent study, which demonstrates that there is generally no significant difference in yield between C class and B class for N application and inter-row management (Masters *et al*, 2017). In addition, the lack of historical yield data limits our ability to conduct risk analyses.

As previously discussed, improvements to farm design, including water control structures, may lead to numerous cost reductions in a range of areas that are difficult to quantify. Some of these improvements have been examined in the case study component of this project, however further research into this area is still required. Further limitations to the economic modelling are that practice change often occurs progressively over a number of years with the investment analysis not taking this into account and that transaction costs, when adopting BMP, are not accounted for.

6.2 Water quality modelling

When modelling ground cover (relating to 'crop removal', 'fallow', 'tillage' and 'ground cover') for the various management practices to estimate the effect on erosion, we have been quite explicit in fallowing cover estimates provided in the management framework. We recognise that in field management could lead to a wide range of cover outcomes between farms or over time. Further, the model assumes that erosion is primarily a sheet erosion process and does not account fully for rill or gully erosion. Site monitoring data suggests that rill erosion on wheel track areas may disproportionally contribute to erosion even when high levels of grass cover are present between wheel tracks. This is an area where further research into agronomic practices that can maintain higher levels of cover across the full inter-row would be of benefit in reducing erosion.

In modelling the fertiliser application treatments, the effect of application methods (broadcast, banded, fertigation) could not be represented in the modelling. The capacity to include application method is limited by a lack of data on the implication for off-site loss. However, we would suggest that application method will have a have a lower effect on losses compared to the rates of application.

As explained in the modelling methods, while DIN in deep drainage was included in the modelling, the impact of management practice changes on DIN in deep drainage is still poorly understood. We have found in modelling DIN in drainage that the model is sensitive to denitrification losses as the other major pathway of loss for excess nitrogen (difference between fertilisation applied and crop uptake). There has been little work in this area of denitrification losses and further trials would be beneficial.

7 Conclusion

This technical report presents the methodology and findings of the representative economic study examining the economic and water quality implications of Banana BMP adoption. It found that in general, BMP adoption led to reductions in dissolved inorganic nitrogen and total suspended sediment leaving banana farms, while at the same time improving the profitability of farming businesses. However, there was significant variation in the economic impact of individual management practices, with some practices having a negative impact on farm profit.

Reducing fertiliser rates was the single most important driver of DIN abatement on all farms, and delivered substantial economic benefits. This was true for changing ‘nutrient rate’ from D to C, C to B and D to B. On an area basis, the water quality and economic impacts of reduced nutrient rates were the same for all farm sizes and soil types.

Increasing ground cover on inter-rows and headlands was the most important practice in terms of reducing sediment loads in runoff, however this represented a net cost to farming businesses. Changing ‘ground cover’ from D to C resulted in the majority of the water quality benefit, as well as accounting for the negative economic impact. As with ‘nutrient rate’, the water quality and economic impacts per hectare of changing ground cover management were not affected by farm size of soil type.

8 Appendices

8.1 Appendix A – Farm business environment and risk

There are a number of factors that affect the profitability of banana production, including major aspects such as input costs, pest and disease incursion and tropical cyclones. Of particular relevance is the incursion of Panama disease tropical race 4 that has the potential to severely affect production in the Wet Tropics. How these risks are managed can have significant economic implications for growers.

8.1.1 Labour

Labour makes up a large proportion of production costs for most banana growing enterprises. This is due to the heavy labour requirement of banana farms and the price of labour. The labour force is comprised of backpackers, seasonal workers, family and local workers. It is difficult to achieve economies of scale because the variable costs are relatively higher in banana farming, compared to other agricultural industries (e.g. sugar, grains) and increasing farm size proportionally increases labour and other production costs (variable costs) (S Lindsay, pers. comm., 04/11/15).

8.1.2 Diesel

Another key input into banana production is diesel fuel. Due to the crop being perennial, plants across the farm are usually in different production stages to ensure constant supply; hence on-farm activities need to be continuously completed over the year. This requires a large amount of time where vehicles are used in production, such as four-wheel-drive and quad bikes. Over the past 20 years, the price of diesel has had an upward trend in real terms, impacting on the banana industry through increases in supply chain transport costs and farm machinery operating costs (Australian Bureau of Agricultural and Resource Economics and Sciences, 2015). Figure 7 shows the average diesel price paid by Australian farmers, excluding Good and Services Tax (GST) and farm rebates, but including the fuel tax credit subsidy (Australian Taxation Office, 2016).

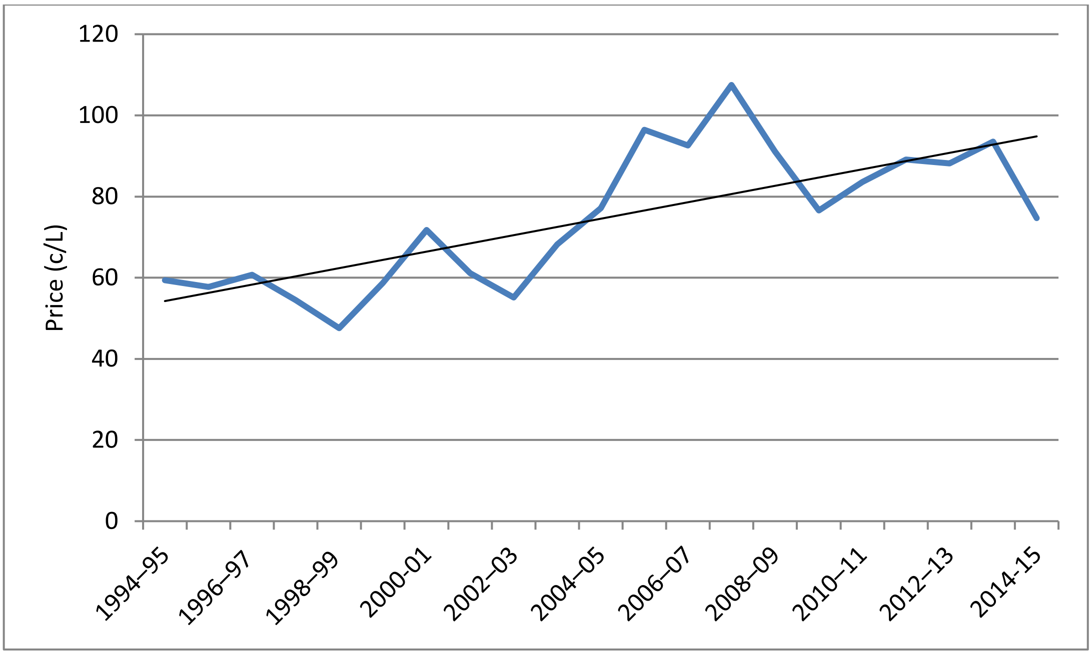

Figure 7: Australian real Diesel price, 1993-94 to 2013-14 (base 2011-12)

Source: Input prices sourced from Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), (2015b). Prices deflated using Consumer Price Index (CPI) measures sourced from: Australian Bureau of Statistics, (2015).

8.1.3 Fertiliser

Urea fertiliser is the main source of nitrogen used by banana farms. Fertigation often occurs fortnightly in the dry periods, but larger amounts of fertiliser are applied monthly using broadcast applications in the wet periods. Unlike diesel, the trend for the cost of urea in real terms over the past 20 year period appears to be relatively flat (see Figure 8). The real cost of urea is characterised by falling prices up to 2003-04 which is then offset by a significant increase in price occurring in 2007-08 and 2008-09, before falling again in 2011.

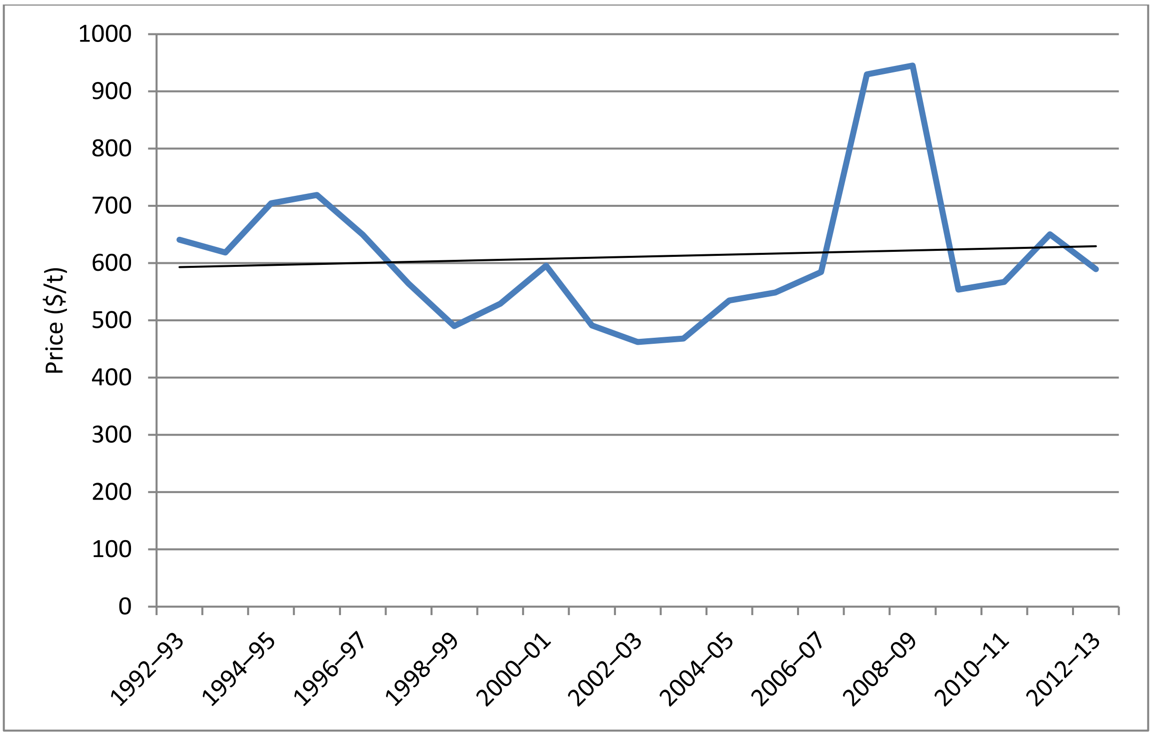

Figure 8: Australian real Urea price ($/t), 1992-93 to 2012-13 (base 2011-12)
Source: Input prices sourced from ABARES, (2015b). Prices deflated using CPI measures sourced from: Australian Bureau of Statistics, (2015).

8.1.4 Pesticide

Pesticides are used as part of an Integrated Pest Management (IPM) program on farm. Pesticides are not deemed a high priority for water quality improvement due to the characteristics of use within the banana production system. This includes occasional use of residual herbicides and the frequently used insecticides and fungicides are generally used in small quantities with a very targeted application method, such as spot spraying (Terrain NRM 2015: 48).

8.1.5 Other Inputs

Irrigation is supplied to the whole banana farm and can be scheduled based on soil properties, crop growth requirements, monitoring of soil moisture and weather forecasts (Department of Agriculture and Fisheries, 2014). Electricity is an important input to banana growing. It is used to power irrigation and other aspects of the farm (e.g. packing shed).

8.1.6 Panama disease tropical race 4

There are a multitude of pests and diseases that hamper banana plantations in north Queensland, such as aphids and spider mites. However, the largest risk is currently Panama Disease (*Fusarium oxysporum* f. sp. Cubense), specifically the Tropical Race 4 strain of the disease, which has the potential to severely impact Cavendish banana production in the Wet Tropics.

Panama disease is easily spread through the movement of infected planting material, by root systems, soil, water and contaminated equipment. Fungal spores can survive in the soil for several decades which makes prevention the most effective control method. Panama Disease has a number of identified Races: 1, 2, Subtropical Race 4 and the most serious threat to the Queensland banana industry, Tropical Race 4, which was initially detected on Cavendish plants in Tully in 2015, with a second detection in mid-2017.

A heavy reliance on one variety of plant exposes the banana industry to potential negative outcomes from disease incursions. The Cavendish cultivar makes up the largest majority of Australian bananas and as such Panama disease tropical race 4 has potential to seriously impact the monoculture industry. Replacing Cavendish as the main variety would constitute a major change to current production systems. However, alternative varieties that have increased tolerance to the disease have unfortunately been found to be less productive in trials to date (Department of Agriculture and Fisheries, 2015).

Several new biosecurity management practices have been adopted in the wake of Panama disease tropical race 4 being detected in Queensland to prevent the spread of the disease (Biosecurity Queensland, 2015). These practices cover nearly all aspects of the farm including: personnel movement, vehicle and machinery movement, wash down facilities, fencing, tools and equipment, water management, waste management, farm-based animal movement, crop production and fruit movement. An on-farm biosecurity Banana Best Management Practices guide has information for preventing the spread of disease (Kukulies, 2017).

8.1.7 Tropical Cyclones

Bananas are a crop grown in the humid lowland tropics, which makes the Wet Tropics an ideal production region. However, as mentioned earlier, extreme weather events during summer months, such as cyclones, can have a huge bearing on banana production. Damage from cyclones can also effect service industries and supply chains, including consumers. From 1906 to 2006 there have been 12 cyclones that have struck the major banana growing area within 50 km of Tully, which on average is a cyclone every eight to nine years (see Figure 9).

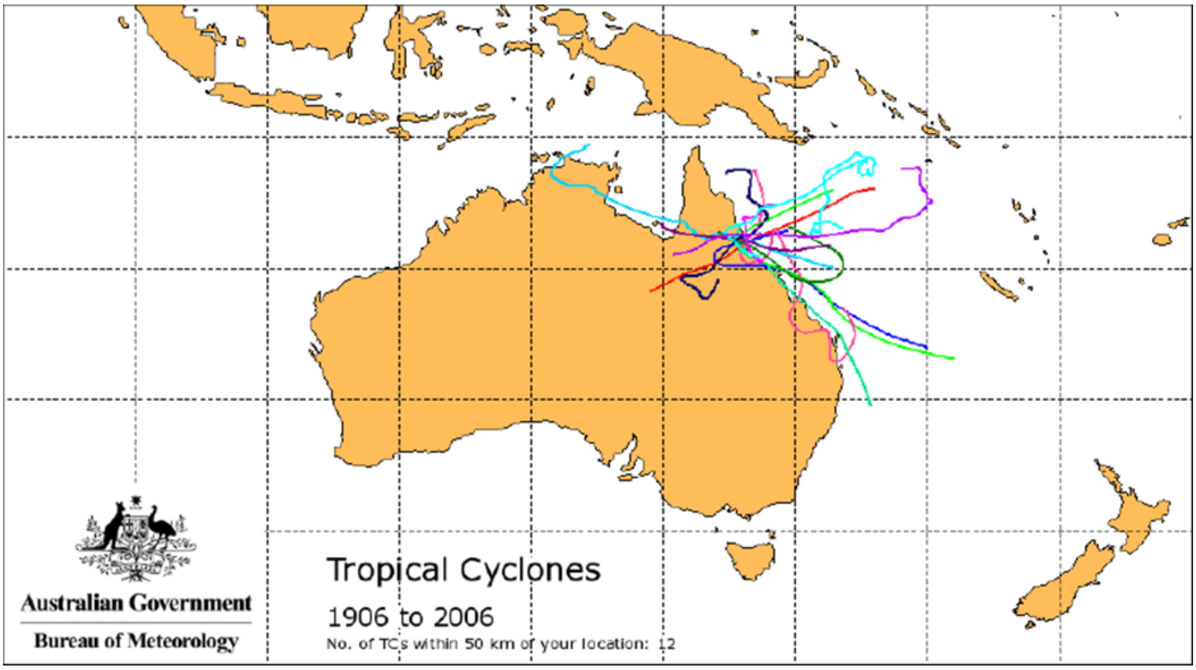

Figure 9: Track Maps for cyclones within 50km of Tully from 1906 to 2006
Source: Australian Government, (2016).

Without any pre-cyclone management practices implemented, considerable periods of undersupply and oversupply will occur in the market. Pre-cyclone management allows for an earlier return to fruit production by partially or completely removing the plant canopy immediately prior to the cyclone, which reduces wind resistance.

Post-cyclone management recommendations include using nurse suckering and replanting crops over a period, rather than all at once, to provide a more even supply of bananas. Economic analysis shows that an average grower implementing post-cyclone management practices after Tropical Cyclone Yasi (2011) would have benefited by a minimum of $9,703 per hectare compared to those who did nothing (Australian Banana Growers Council, 2012).

Apart from cyclones, other extreme weather events that can affect banana production in Queensland include severe storms, storm surges and floods. The Tully and Innisfail regions are renowned for rainfall events that cause heavy erosion, floods and months of saturated soils in the wet season. Bananas are best suited to the humid lowland tropics, therefore these are the best banana production regions in Australia but the severe weather can widely vary production levels.

8.2 Appendix B – Banana Practice framework

Table 19: Banana BMP Environmental Guideline

Practice	Best	Okay	Improve
Soil Structure			
Crop Rotation	Either a volunteer grass fallow or a fallow crop is planted between banana crop cycles.	A weedy fallow grows between banana crop cycles or the block is rotated with another crop.	There is no fallow period between banana crop cycles or bare fallow is left between crop cycles.
Cultivation method and timing - land preparation	The row only is cultivated at the times of year when the risk of erosion is low.	The whole block is cultivated at times of year when the risk of erosion is low.	The whole block is cultivated at any time of year.
Cultivation method and timing - crop destruction	The banana crop is removed by treating with herbicide and plants are left to break down before cultivation.	Practices are implemented to breakdown plants while minimising soil disturbance, for example, using a mulcher or lightly with the discs.	The banana crop is removed by discing green plant material repeatedly.
Which do you use to increase organic matter? Best=6+, Okay=4+, Improve=3 or less. Fallow crops are grown between banana crops, Harvested heads and leaves are left on the row, Products are applied to increase organic matter (such as manures, mulch, compost, mill mud), High nitrogen rates are avoided, Cultivation is reduced, A side-throw slasher or similar is used to put mulch back on the row, Banana waste scraps are spread back onto the rows, Non-competitive companion crops are encouraged around banana plants.			
Soil Erosion			
Ground Cover	Living ground cover is encouraged in areas such as the inter-row space and headlands, excluding major roadways.	Living or dead, at least 60% ground cover is encouraged in areas such as the inter-row space and headlands. This includes mulching banana plant material in the inter-row space. Major roadways are excluded.	Areas such as inter-rows and headlands are sprayed bare.
Which of the practices below do you use to reduce the risk of erosion in plant crops? Best=3+, Okay=2, Improve=1 or less. Planting is confined to low-rainfall times of the year when the risk of erosion is low, Grasses/plants are encouraged as inter-row ground cover in the plant crop, Permanent beds are used, allowing cultivation to be restricted to the row only. If plant blocks are established outside of low-risk rainfall periods, rows are formed early and grass is encouraged as ground cover and only the row or furrow is disturbed at planting.			
Wind Erosion (WA only)	Structures or trees are placed on the southern side of banana blocks to help minimise wind damage and erosion.		No wind breaks of any kind.
Controlling run-off water - slowing water	The farm and blocks have been designed to slow surface water and direct it to an appropriate waterway capable of carrying high velocity water. Blocks are laser-levelled where required to prevent water from collecting in the paddock and creating wet areas.	Most blocks have been designed to slow surface water and direct it to an appropriate waterway, although some corrective work is still required.	Little or no attention is currently given to slowing surface water or directing it to a suitable waterway.
Controlling run-off water - contouring	If the farm has areas under banana production with a gradient of 3% or more, all blocks in these areas have been planted along the contour and designed to include diversion banks and constructed waterways. Advice has been sought for placing these structures correctly. Annual maintenance is carried out to ensure these structures are operating correctly. Blocks are left undeveloped if erosion cannot be managed.	If the farm has areas under banana production with a gradient of 3% or more, most blocks in these areas have been planted along the contour and designed to include diversion banks and constructed waterways. Advice has been sought for placing these structures correctly. Annual maintenance is carried out to ensure these structures are operating correctly. Blocks are left undeveloped if erosion cannot be managed.	The farm has areas under banana production with a gradient of 3% or more, but there are no control structures in place.
Controlling run-off water - silt traps	Silt traps have been designed, constructed and located with expert advice.		Silt traps have been designed, constructed and located without expert advice.
Controlling run-off water - drains	All constructed drains on-farm are vegetated-shallow-spoon drains	Most constructed drains on-farm are vegetated-shallow-spoon drains and any box drains have a batter suited to the soil type, so they do not erode.	Constructed drains on-farm are mostly box drains with straight sides.
Controlling run-off water - roads	All main roadways are either concreted or stabilised with sand or rock. Unless specifically designed the road is not used to direct and carry water. Suitable batters and culverts are used.	Most main roadways are either concreted or stabilised with sand or rock, but some roads still require improvements	Main roadways are not stabilised and water is able to travel along roads that are not designed for this purpose

Controlling run-off water - maintenance	All maintenance of drains, roads and inter-row spaces is carried out during the time of the year when the risk of erosion is low. Maintenance is carried out annually or as required to ensure these structures are working adequately.		Maintenance of drains, roads and inter-row spaces is carried out at any time of the year regardless of rainfall activity or no maintenance is carried out and structures may not be working adequately.
Soil acidity and alkalinity	Soil pH is monitored at least annually and pH amending products are applied as required		Soil pH is not monitored at least annually or pH amending products are applied without testing pH levels
Pesticides			
Integrated pest and disease management	Methods to manage all pests and diseases on-farm include physical (mechanical), biological, cultural and chemical control options. They do not rely only on chemical options.	Methods to manage most pests and diseases on-farm include physical (mechanical), biological, cultural and chemical control options. They do not rely only on chemical options.	Pests and diseases are predominately managed using chemicals and little thought is given to other forms of control.
Monitoring	Pest and disease levels are monitored on a regular and consistent basis by trained staff or service providers. Records are retained and treatments are applied using monitoring information and relevant threshold levels for each pest/disease.	Pest and disease levels are monitored by general observations when doing other activities and control methods applied accordingly.	Spray treatments are applied on a calendar basis or in response to severe outbreaks.
Chemical Rotations	A rotation program is in place to ensure products are applied correctly and rotated according to label instructions, to prevent resistance from developing	Attempts are made to rotate between chemical groups according to label instructions, but there is no rotation program in place.	Chemicals are not rotated to avoid resistance.
Chemical registrations	Key personnel know how to find which products are registered and permitted for use and only these products are used on-farm.	Rely on reseller or consultant advice for product registrations and only registered and permitted products are used on-farm.	Not sure if the products used are registered or permitted for use.
Obtaining chemicals	Chemicals are sourced from an Agsafe-accredited supplier or similar.		Not sure if suppliers are accredited by Agsafe or similar.
Storing chemicals	The chemical storage area is locked and bunded, and is either located in an area where spills will not affect waterways, or measures are in place to ensure potential spills will not affect waterways.		The chemical storage area is not bunded and spills could not be contained.
Handling and applying chemicals	Only appropriately-trained staff handle and apply chemicals. Other staff cannot access or use chemicals.		Measures are not in place that prevent unqualified staff from accessing chemicals.
Disposal of chemicals	Empty chemical drums and unwanted or out-of-date chemicals are disposed of through a DrumMUSTER® or ChemClear® type scheme		Schemes such as DrumMUSTER® or ChemClear® are not used to dispose of empty chemical drums or unwanted or out-of-date chemicals.
Spray Drift chemical treatments	Aerial and ground applications are only made during suitable weather conditions and care is taken to prevent off-target spraying. Vegetative buffer zones are in place around the farm to minimise the risk of drift.	Aerial and ground applications are only made during suitable weather conditions and care is taken to prevent off-target spraying.	Measures are in place to minimise off-target movement of chemicals but improvements are still required.
Maintain and calibrate equipment	Spray equipment is maintained and calibrated regularly to ensure it is working effectively, leaks are avoided and the product is distributed evenly.		Maintenance and calibration of spray equipment could be improved or you need information about calibrating spray equipment.
Banana Integrated Pest and Disease Management			
Nematodes, which of the practices listed below do you use to manage plant-parasitic nematodes? Best=3+, Okay=2+, Improve=1 or less, N/A. Only tissue culture or clean (and dipped) plant material is used, at the end of the crop cycle banana plants are removed with glyphosate to eradicate all living plant material that could harbour plant-parasitic nematodes between crops, A fallow crop identified as a non-host for a particular plant-parasitic nematode is planted in the fallow period, Plant-parasitic nematode levels are monitored using the Root Disease Index (RDI) to determine when economic thresholds are met, N/A.			
Banana weevil borer, Which of the practices listed below do you use to manage banana weevil borer? Best=3+, Okay=2, Improve=1 or less, N/A. Only tissue culture or clean plant material is used, At the end of the crop cycle banana plants are removed using glyphosate to eradicate all living plant material that could harbour banana weevil borer between crops, Banana weevil borer levels are monitored to determine when economic thresholds are met, Desuckering practices that produce broken or cut corm material or excessive stem shatter are avoided, In the subtropics where decay rates are slow the psuedostems are cut in half lengthwise to accelerate the rate of stem decay.			
Spider mites, Which of the practices listed below do you use to manage spider mites? Best=4+, Okay=3, Improve=2 or less, N/A. Using chemicals that disrupt predators is avoided, Spider mite populations are monitored to determine when thresholds are met, Appropriate irrigation management is used to ensure the plants are not water stressed, Excessive applications of nitrogen fertiliser are avoided, Sufficient volume and coverage is applied if spray treatments are used, N/A.			

Leaf diseases, Which of the practices listed below do you use to manage yellow Sigatoka? Best=3+, Okay=2, Improve=1 or less, N/A. A deleafing program is followed and infected leaf material removed (the deleafing program removes all inoculum before the peak infection period), Potential sources of infection are removed by eradicating old crops and feral plants, Leaf disease levels are monitored to determine when disease is present, Plant and soil nutritional status is monitored and maintained at desired levels, N/A.			
Which of the practices listed below do you use to manage leaf speckle and leaf rust? Best=3, Okay=2, Improve=1 or less, N/A. A deleafing program is followed and infected leaf material removed, Leaf disease levels are monitored to determine when disease is present, Ground applications are made of the spray treatment to target the organism, N/A.			
Planting material	Only tissue culture or plant material from the farm is used.		Plant material may be sourced from outside of the farm.
Farm quarantine	All vehicles, machinery and personnel are required to be free of soil before entering and leaving the farm. Staff are required to report any unusual plants to management.		Practices need to be improved to achieve the required standard outlined above
Fertiliser and soil additives			
Soil testing pre-plant	100% of blocks are soil tested before planting		Soil testing before planting is infrequent or not done at all.
Soil testing	Soil tests are taken on all blocks more than once a year	Soil tests are taken on all blocks once a year.	Soil tests are taken less than once a year or on fewer than all blocks.
Leaf testing	Paired leaf and soil tests are taken on all blocks at least annually.	Paired leaf and soil tests are taken at indicator sites at least annually or tissue tests taken throughout the year but not paired with soil tests.	Leaf tests are taken less than annually or not at all.
Fertiliser program	The fertiliser program is supported by soil and leaf testing and yield monitoring. The program is revised annually and checked to ensure targets are actually applied.	The fertiliser program is supported by soil and leaf testing and yield monitoring	There is no fertiliser program and/or the rates applied are not based on soil and leaf test results.
Recommended rates	The fertiliser program is based on recommended rates for nitrogen and phosphorus.		The fertiliser program is not based on recommended rates for nitrogen and phosphorus.
Pre-plant pH adjustments and fertiliser applications	If pH adjustments, calcium, magnesium, potassium and phosphorus applications are required pre-plant, they are applied and incorporated into the soil.		If pH adjustments, calcium, magnesium, potassium and phosphorus are required pre-plant, they are applied to the soil surface
Fertiliser application frequency	The aim is to apply fortnightly applications of fertiliser during high growth periods such as summer and potentially reduce this during low growth periods such as winter. Weather conditions may mean that this is not always possible.	The aim is to apply monthly fertiliser applications all year round.	Fertiliser is applied less frequently than monthly
Fertiliser application method	All fertigation or combination of fertigation and banded surface fertiliser applications depending on the weather conditions.	Banded surface fertiliser applications to rows or in non-mechanised production systems the fertiliser is broadcast by hand to entire root zone.	Fertiliser broadcast over rows and inter-row spaces or in non-mechanised production systems the application is more concentrated by placing it primarily at the base of the plant
Calibration and maintenance of fertiliser application equipment	All spreaders are calibrated on a regular basis and fertigation systems are checked regularly for uniformity.		Improvements are required in the current systems and/or regular calibration of spreaders. Fertigation systems are not checked regularly for uniformity.
Storing fertilisers	The fertiliser storage area is located in an area where spills will not affect waterways, or measures are in place to ensure potential spills will not affect waterways. This includes manures, compost and liquid fertilisers.		Spills could not be contained and/or surface water is not diverted away from the site
Fertiliser application records	Records of all fertiliser applications are kept in a manner that allows the user to easily monitor progress and, if required, easily retrieve information such as total nutrients applied to date and soil and tissue test trends (e.g. electronic).	Records of all fertiliser applications are kept although retrieving information would be time-consuming (e.g. hardcopy).	Not all fertiliser applications are recorded.
Water			
Irrigation emitter type	100% under-tree sprinklers or drip and an automated system.	100% under-tree sprinklers or drip and a manual system.	Some overhead irrigation.
Soil Moisture monitoring	Irrigation schedules are based on capacitance probes and weather stations and are fully automated.	Irrigation schedules are based on capacitance probes or tensiometers and use a manual system.	No scheduling equipment is used to develop an irrigation schedule.

Salinity management	Underground water is tested to monitor salinity levels especially after periods of heavy rain. Where possible water sources are combined to reduce salinity levels or irrigation from tidal reaches is only taken at low tide and tests have been taken to ensure this water is safe for use.		Water sources are not tested to monitor salinity levels.
Check irrigation system performance	Water uniformity and distribution is tested and above 90%.	Water uniformity and distribution is tested and above 80% but below 90%.	Water uniformity and distribution is tested and below 80% or not tested and is therefore unknown.
Protect water quality	Applications of fertiliser and pesticides are timed for suitable weather conditions and all run-off water is filtered through grassed headlands or vegetation before reaching waterways.	Applications of fertiliser and pesticides are timed for suitable weather conditions and most run-off water is filtered through grassed headlands or vegetation before reaching waterways.	Applications of fertiliser and pesticides are not timed for suitable weather conditions and/or run-off water is not filtered through grassed headlands or vegetation before reaching waterways.
Packing shed waste water quality	Filtration removes fine particles and larger debris before releasing water into local drains or waterways.	Grates in the shed remove large debris before water is released into local drains or waterways.	There is no filtration of any sort in place and water from the packing shed is disposed of into adjacent drainage lines or waterways.
Biodiversity			
Regional biodiversity priorities	Management is aware of regional biodiversity priorities and how to source this information if required.		Management is not aware of regional biodiversity priorities or how to source this information if required.
Riparian vegetation	Native riparian vegetation is present for 100% of the length of all creeks and rivers.	Native riparian vegetation is present for at least 70% of the length of all creeks and rivers.	Native riparian vegetation is present for less than 70% of the length of all creeks and rivers.
Native vegetation	Stands of native trees are maintained and protected, and additional native vegetation is established through tree plantings.	Stands of native trees are maintained and protected.	Stands of native trees are not maintained and protected.
Native birds and animals	Native birds and animals are identified and their habitats preserved. Farming practices that minimise impact on native wildlife are selected.		Little thought or consideration of native birds and animals.
Feral animals	Feral animals are controlled through suitable methods to minimise their populations and impact on the environment.		Feral animals are not controlled.
Environmental weeds	Weeds on the property are identified and managed according to relevant legislation.		Weeds are not controlled according to relevant legislation.
Disease management	The business has reviewed the major pest and disease threats to their business and a biosecurity plan is in place. Visitors have a designated parking area and all machinery and vehicles are excluded from entering the farm. Only designated farm machinery is used on site. A perimeter fence is in place to prevent unauthorised access.	The business has reviewed the major pest and disease threats to their business and a biosecurity plan is in place. Visitors have a designated parking area and any personnel, machinery or vehicles entering the farm must be free of soil before entry is allowed.	Threats from potential pests and diseases are not considered and there is no set policy for dealing with visitors to the farm. Vehicles and machinery are not forced to be free of soil before entering the farm.
Waste			
General Waste	Products that allow packaging to be minimised, re-used or recycled are used in preference to those that require disposal, where possible. A formal waste plan is in place.	Products that allow packaging to be minimised, re-used or recycled are used in preference to those that require disposal, where possible, but there is no formal waste plan.	Little thought or consideration is given to waste management and no formal waste plan exists.
Banana bunch covers - number of uses	Bunch covers are re-used as many times as possible.		Bunch covers are single use.
Banana bunch covers - disposal method	Recycled or biodegradable bunch covers are used.	Bunch covers are disposed of at the local dump or through a waste contractor	There is no formal disposal method for bunch covers
Banana bunch covers - farm collection	All bunch covers are removed from the paddock and staff are aware that any bags laying around the farm should be collected and returned to an appropriate collection point.		Bunch covers are often left in the paddock or not collected when seen laying around the farm.

Fertiliser bags and containers	All bulk fertiliser bags and containers are stored in a suitable location until collected by the provider.		Fertiliser bags and containers are rarely returned to the provider.
Waste bananas	Waste bananas and stalks are mulched and spread back onto the banana paddock.	Waste bananas are fed to livestock or disposed of away from waterways and not in a single pile.	Waste bananas are dumped in a single pile or where surface water flows directly into waterways and are not managed.
Removing irrigation	All irrigation pipes are removed from the block before cultivating.		No attempt is made to remove irrigation before cultivating.
Disposing of irrigation	If accepted by the local council, irrigation pipes are taken to the designated waste station.	Local council does not currently accept irrigation pipes, so they are stockpiled at the farm until a solution is found.	No formal disposal method exists.
Disposing of string	String is removed from the paddock and stockpiled in an appropriate manner pending waste collection.		String is not removed from the paddock or string is removed from the paddock but no formal disposal method is in place.
Chemical containers and chemical	All chemical containers are triple-rinsed and collected through the DrumMUSTER® scheme. All chemical that is out of date or no longer required is collected through the ChemClear® scheme.		DrumMUSTER® and ChemClear® type schemes are not used.
Disposing of general waste	All waste material that cannot be re-used (e.g. some plastic) is separated from waste that can be recycled (e.g. paper). Waste is either collected by a local waste contractor or taken to the local waste station.	All waste material that cannot be re-used is either collected by a local waste contractor or taken to the local waste station.	There is no waste management plan in place and not all the waste for disposal is taken by a waste contractor or taken to the local waste station.
Air			
Neighbouring properties	Immediate neighbours are known and contactable at short notice. The impacts of business operations have been discussed with the neighbour/s and reasonable practices to minimise disturbance have been adopted.	Reasonable practices to minimise disturbance to neighbouring properties have been adopted.	Neighbouring properties aren't considered when undertaking farming activities.
Odour management	Raw manures, waste bananas and chemicals are stored and applied in a way that minimises their odour potential. The prevailing wind determines where these products are stored and when they are applied, to minimise disturbance to neighbours and staff.		Raw manures, waste bananas and chemicals are stored and applied with little consideration for reducing their odour potential.
Dust management	Disturbance to neighbours and staff is minimised with action taken to reduce the impact of dust from activities such as liming, cultivation and peak traffic periods along dirt roads.		No action is taken to minimise disturbance to neighbours or staff by reducing the impact of dust from activities such as liming, cultivation and peak traffic periods along dirt roads.
Smoke management	The use of fire is minimal and the prevailing wind is considered when burning to reduce disturbance to neighbouring properties and staff.		No action is taken to minimise the impact of smoke on neighbouring properties and staff.
Noise management	The noise level generated from activities has been considered and, where possible, practices have been altered and improved, or measures are in place to reduce the amount of noise produced.		No action is taken to minimise the impact of noise on neighbouring properties and staff.
Artificial light management	Night activities that require lights have been reviewed and all required practices are implemented to minimise disturbance to neighbouring properties and wildlife.		No action is taken to minimise the impact of light on neighbouring properties and wildlife.
Energy			
Machinery	Only machinery with the right capacity for the job is chosen. Machinery that lacks the capacity or has excess capacity is not used.		No consideration is given for the capacity of the machinery.
Machinery - crop destruction	Practices that minimise the number of passes required to remove the banana crop are incorporated. For example, the banana crop is removed by treating with herbicide and plants are left to break down before cultivation.		Little consideration is given to minimising the number of passes required to remove the banana crop. For example the banana crop is removed by cultivating green plant material repeatedly.

Pump	The pump's most efficient operating zone in terms of head pressure and volume of output is understood and adhered to.		The pump's most efficient operating zone in terms of head pressure and volume of output is not understood or adhered to.
Irrigation efficiency	All irrigation is under-tree, rather than overhead, so that less water needs to be pumped.		There is still some overhead irrigation used on farm, which requires more water to be pumped.
Cold Rooms	Cold rooms are well insulated and protected from direct sunlight. All seals are checked on a regular basis to ensure they are not losing air.		Cold room efficiency could be improved through better insulation, protection from direct sunlight or more regular checks for air loss.
Management practices	Where possible, management practices are implemented that reduce the amount of energy used and energy consumption is monitored.		Little consideration given to the business's energy use and consumption is not monitored.
Maintenance	All machinery, cold rooms, pumps and other equipment are serviced following the service book instructions to ensure they are operating efficiently.		Servicing is not always done on time and there are no systems in place to identify when services are due.
Nitrous Oxide	The loss of nitrates to nitrous oxide is minimised by limiting nitrogen fertiliser applications when soils are at field capacity or saturated and by having good drainage in blocks.		There is no awareness of nitrous oxides or how these are formed.
Carbon farming initiative	Management is aware of the types of projects that can be funded under the carbon farming initiative and where to source this information.		Management is unaware of the types of projects that can be funded under the carbon farming initiative or where to source this information
Fuel			
Storage location	Fuel tanks are stored in an area where spills will not affect waterways, or measures are in place to ensure potential spills will not affect waterways. This includes mobile fuel tanks. Bunding is provided on all petrol tanks and diesel tanks	Fuel tanks are stored in an area where spills will not affect waterways, or measures are in place to ensure potential spills will not affect waterways. This includes mobile fuel tanks. Bunding is not in place on all fuel tanks because tank capacity is less than that requiring bunding (minor storage) and a risk assessment has been performed.	Spills from the current fuel tank location could not be contained and prevented from reaching waterways.
Storage and maintenance	Fuel is only stored in tanks specifically designed for this purpose. Tanks are located in easy-to-reach locations, where filling is easy and access to fuel machinery is easy. All tanks are locked when not in use and systems are in place to reduce the chance of accidental spills and leakage.		Fuel is only stored in tanks specifically designed for this purpose. Tank location could be improved to allow improved access or there are no systems in place to reduce the risk of accidental spills and leakage.

Source: King, N., (2008).

8.3 Appendix C – economic and water quality model parameters

Table 23: Management practice descriptions, economic model details and water quality model parameters

Practice	Code	Best (B)			Okay (C)			Improve (D)		
		Description	**Economic model details**	**WQ model parameters**	**Description**	**Economic model details**	**WQ model parameters**	**Description**	**Economic model details**	**WQ model parameters**
Crop removal (Fallow model)	**CR**	Banana crop is killed with herbicide and plants are left to break down in the row area before cultivation.	• Roundup 12.35L/ha (5L/ac) • Labour (injecting): 5hrs/ha (5acres per man per day (10 hr day)) • Offset discs (zonal) x1	Green cover is reduced to 10% but residue cover is maintained at 80% at crop removal period.	Banana crop is removed through mulching and/or light discing which minimises soil disturbance	• Roundup 12.35L/ha (5L/ac) • Labour (injecting): 5hrs/ha (5acres per man per day (10 hr day)) • Offset discs (zonal) x3	Green cover is reduced to 10% but residue cover is maintained at 50% at crop removal period.	Banana crop is removed by being knocked down and repeated disc ploughing	• Chain trees down (2 tractors) • Offset discs (full block) x4	Green and residue cover levels reduced to 10-20% at crop removal period
Fallow management	**F**	Fallow crop is planted between banana crop cycles, or a volunteer grass fallow is maintained between crop cycles.	1 year fallow • Rhodes grass, seed rate: • Spreader	Green cover returns to 50% over fallow period	Weedy fallow grows between banana crop cycles	1 year fallow	Green cover returns to 50% over fallow period	Land is maintained bare between crop cycles, or there is no fallow period between crop cycles	1 year fallow • Roundup 2L/ha x3 • Spray boom • Offset discs (whole block) x1	Green and residue cover levels maintained at 10-20% over fallow period
Tillage – plant crops (Row model)	**T**	Crop planted into permanent beds. Row area only receives minimum tillage necessary for establishment	Dermosol • Offset discs (zonal) x1 • V-blade (clean and shape) x1 Clays • Offset discs (zonal) x2 • Ripper x1 • V-blade (clean and shape) x1	No reduction in green and residue cover at planting	Minimum tillage of whole block area, with row area only subject to more cultivation necessary to establish row profile and plant	• Roundup 2L/ha, applied only to beds (x 60%) • Spray boom Dermosol • Offset discs (whole block) x1 • V-blade (clean and shape) x1 Clays • Offset discs (whole block) x2 • Ripper x1 • V-blade (clean and shape) x1	Green cover maintained but residue cover reduced to 20% at planting	Whole block is cultivated in preparation for planting	Dermosol • Offset discs (whole block) x1 • Ripper x1 • V-blade (bedform) x1 Clays • Offset discs (whole block) x2 • Ripper x1 • V-blade (bedform) x1	Green and residue cover levels maintained at 10-20% at planting
Ground cover (Inter-row model)	**G**	Living ground cover is maintained in the inter-row space and headlands.	• Slashing every 3 weeks	Cover is maintained at 50-60% at all times. Residue cover at 10%.	Living or dead, at least 60% cover is maintained in inter-row space and headlands.	• Slashing every 3 weeks	Green cover is maintained at 40-50% at all times. Residue cover at 20%.	Inter-rows and headlands are sprayed or cultivated bare.	• Roundup 0.8 L/ha + sprayer (3.5 times per year)	Green and residue cover at <10% at all times

Controlling runoff – contouring		For gradient over 3%, All blocks planted on the contour and incorporating diversion banks and constructed waterways	Construction cost (C to B) Dermosol: Small: $1,549, medium: $3,713, large: $8,909; Clays: Small: $3,679, medium: $9,395, large: $23,113.	P factor 0.6	For gradient over 3%, MOST blocks planted on the contour and incorporating diversion banks and constructed waterways	Construction cost (D to C) Dermosol: Small: $4,646, medium: $11,140, large: $26,726; Clays: Small: $11,038, medium: $28,186, large: $69,340.	P factor 0.8	Production areas with gradient of 3% or more, but no control structures in place.		P factor 1.0
Controlling runoff - drains	W	All constructed drains are vegetated shallow spoon drains	Maintenance costs: Sediment traps: $12.35/ha R&M: best practice results in 15% saving to tractor and implement R&M compared to improve practice	P factor 0.6	Most constructed drains are vegetated shallow spoon drains. Any box drains have a batter suited to the soil type to minimise soil erosion.	Maintenance costs: Sediment traps: $9.26/ha R&M: okay practice results in 11% saving to tractor and implement R&M compared to improve practice	P factor 0.8	Constructed drains are mostly box drains with straight sides.		P factor 1.0
Sediment traps		Expert advice informs design, construction and location of sediment traps that are effective across the entire production area.		P factor 0.6	Some sediment trapping structures. Insufficient capacity and/or design issues mean that significant amount of sediment can leave the farm in heavy events.		P factor 0.8	No sediment trapping structures in place.		P factor 1.0
Soil testing		All blocks are soil tested pre-planting. Fertiliser rates for plant crop are adjusted based on soil test results.	Soil test every block pre-plant and then once every six months regardless of crop stage. Soil test cost: $15 per ha	Apply 250 kg N /year	Soil testing before planting is infrequent and/or does not occur on all blocks being planted.	Half the soil test cost of best practice	Apply 350 kg N /year	No soil testing before planting	No soil testing	Apply 450 kg N /year
Matching nutrient supply to crop demand	**NR**	Fertiliser program based on recommended rates for N & P and supported by leaf and soil testing and yield monitoring. Revised annually to ensure targets are achieved.	Bananaphoska 2500 kg (250 kg/N/ha)	Apply 250 kg N /year	N & P fertiliser rates are supported by soil and leaf testing and yield monitoring.	Bananaphoska 3500 kg (350 kg/N/ha)	Apply 350 kg N /year	N & P fertiliser rates are based on historical target rates with infrequent testing and/or no adjustment for yield potential	Bananaphoska 4500 kg (450 kg/N/ha)	Apply 450 kg N /year

Fertiliser application frequency		Aim to apply fortnightly during high growth periods and less frequently during low growth periods.	Apply fortnightly	Apply fortnightly	Monthly fertiliser applications all year around	Apply monthly	Apply monthly	Fertiliser is applied less frequently than monthly.	Every 2 months	Apply monthly
Fertiliser application method	**NA**	All fertigation. Banded surface application if wet weather rules out fertigation.	Fertigation labour (additional to regular irrigation): 3.7 mins/ha per fertigation event Spreader x 6.5 (broadcast every 2 weeks for 3 months during wet season)	Not able to be represented in the model	Banded surface fertiliser application on row area only.	Spreader x 12	Not able to be represented in the model	Fertiliser broadcast over rows and inter-row spaces.	Spreader x 6	Not able to be represented in the model
Irrigation method		All irrigation is automated drip/micro sprinkler system underneath trees	Dermosol: Pumping costs ($/ha/yr): $800 Ferrosol: Pumping costs ($/ha/yr): $1,387	Not able to be represented in the model	All irrigation is drip or micro sprinkler system, manually operated.	Dermosol: Pumping costs ($/ha/yr): $1,333 Ferrosol: Pumping costs ($/ha/yr): $2,080	Not able to be represented in the model	Some overhead irrigation	Dermosol: Pumping costs ($/ha/yr): $1,467 Ferrosol: Pumping costs ($/ha/yr): $2,253	Not able to be represented in the model
Irrigation scheduling	**I**	Irrigation schedules are based on capacitance probes and weather stations and are fully automated.	Dermosol: Labour cost ($/yr): Small $2,349, medium $4,697, large $7,046 Ferrosol: Labour cost ($/yr): Small $2,583, medium $5,167, large $7,750	Irrigated at a SWD of 20mm up to field capacity	Irrigation schedules are based on capacitance probes or tensiometers. Manually operated.	Dermosol: Labour cost ($/yr): Small $4,796, medium $6,523, large $8,250 Ferrosol: Labour cost ($/yr): Small $9,457, medium $12,861, large $16,266	Irrigated at a SWD of 20mm up to field capacity	No soil moisture monitoring tools are used in scheduling irrigation.	Dermosol: Labour cost ($/yr): Small $4,796, medium $6,523, large $8,250 Ferrosol: Labour cost ($/yr): Small $9,457, medium $12,861, large $16,266	Irrigated at a SWD of 20mm up to field capacity

8.4 Appendix D – additional parameter calculations

8.4.1 Diesel price

Table 24: Average diesel prices for Innisfail and Tully, 2012 to 2016

Year	Tully (c/L)	Innisfail (c/L)	Average (c/L)	Net of GST (c/L)	Fuel tax credit (c/L)	Net of fuel tax credit (c/L)
2012	153.1	154.5	153.8	139.8	38.1	101.7
2013	157.8	159.3	158.6	144.1	38.1	106.0
2014	162.6	163.7	163.1	148.3	38.1	110.2
2015	128.3	135.0	131.7	119.7	38.9	80.8
2016	122.6	119.2	120.9	109.9	39.4	70.6
					Average	***93.8***

Sources: Royal Automobile Club of Queensland (RACQ) (2017), Australian Taxation Office (2016)

8.4.2 Banana price

Table 25: Banana production, local value and local price, Wet Tropics, 2010-11 to 2014-15

Year	Local value[10] ($M)	Production (t)	Local price[11] ($/kg)
2010-11	211.0	178,105	1.18
2011-12	360.9	257,949	1.40
2012-13	396.1	299,602	1.32
2013-14	276.3	232,594	1.19
2014-15	380.7	236,638	1.61
		Average	***1.34***

[10] Local value is the value placed on recorded production at the place of production, including indirect taxes. The local value of a commodity is calculated by subtracting total marketing costs from gross value. Marketing costs are the costs of moving the agricultural product from the place of production (i.e. farm) to the market place. These include freight, cost of containers, commission, insurance, storage, handling and other charges necessarily incurred by the producer in delivering commodities to the market place.

[11] Local price is derived by dividing local value by production.

8.5 Appendix E – additional results

8.5.1 Farm gross margin charts

Figure 10 compares the farm gross margins for farms on Dermosol soils operating at D, C and B management practice levels. As the chart shows, the farm gross margin differences between farm sizes remain largely consistent across management practice scenarios, caused mainly by savings achieved by larger farms in their contract labour rates, packing shed costs and irrigation labour costs.

The increase in farm gross margins between C and B levels were primarily driven by fertiliser savings, and reduced labour costs resulting from automatic irrigation. Savings were also made by adopting fertigation, with minor savings from lower pre-plant tillage operations, cost savings in crop removal and lower machinery repairs and maintenance costs associated with improved drainage.

The improvement from D to C practices was again driven mainly by fertiliser savings, but partly offset by increased costs from increasing the frequency of fertiliser applications and replacing herbicide applications with slashing for inter-row weed management (‘ground cover’).

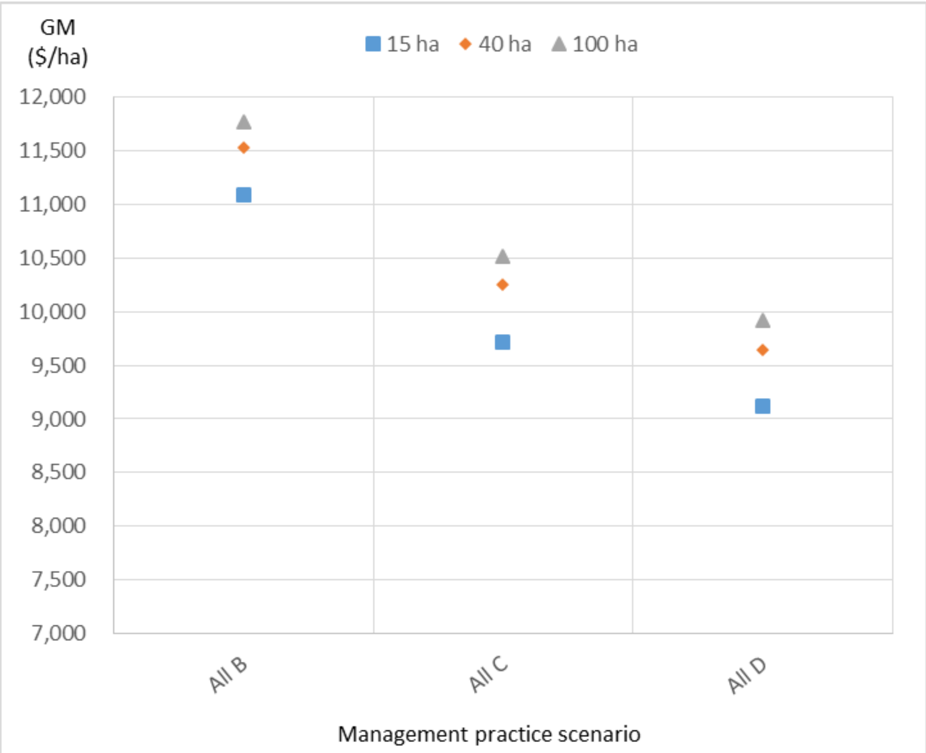

Figure 10: Farm gross margin results, all B, C, and D, Dermosol soils

Figure 11 shows the farm gross margins of farms operating at C level, with individual practice groups shifted to B. The chart highlights the relative benefits of ‘nutrient rate’, ‘irrigation’ and ‘nutrient application’ savings compared to all other management practice changes. ‘Fallow’ was the only management practice to result in a decrease in farm gross margin (by $13 per hectare), due to the costs associated with planting Rhodes grass.

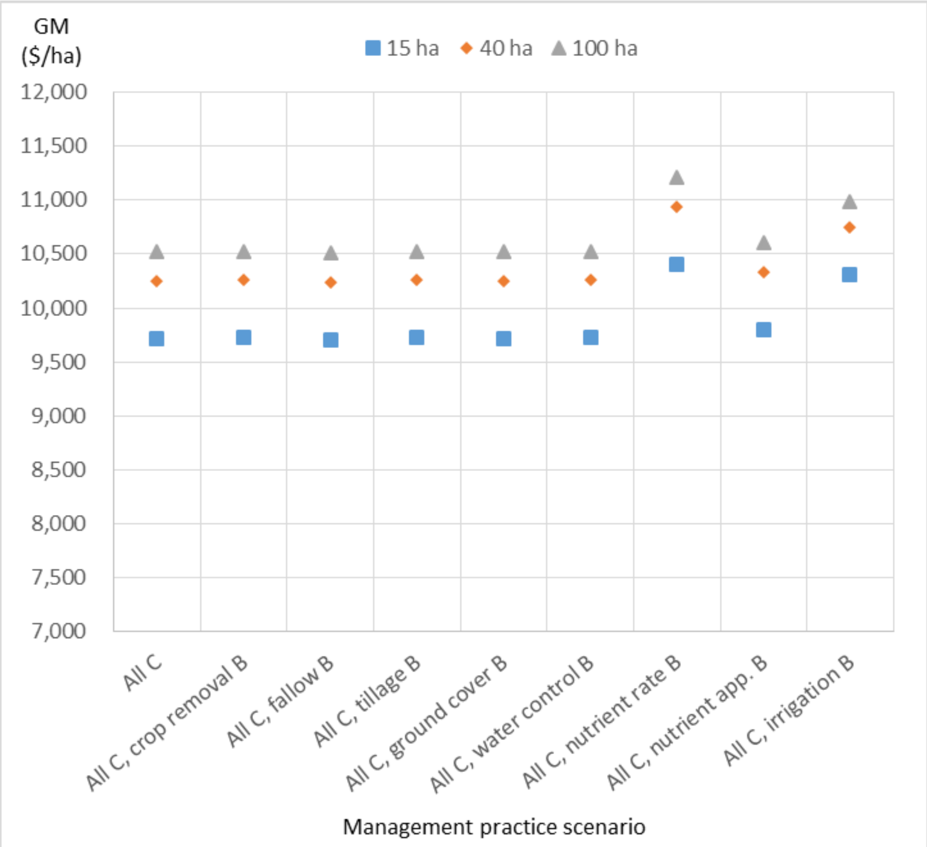

Figure 11: Farm gross margin results, changing practice groups from C to B, Dermosol soils

Similarly, Figure 12 shows the farm gross margins of farms operating at D level, with individual practice groups shifted to C. ‘Nutrient rate’ again provided the greatest improvement in farm gross margin, with minor improvements in ‘fallow’, due to removing herbicide and tillage operations, and ‘water control structures’, due to machinery repairs and maintenance savings resulting from improved drainage. Decreases in farm gross margins resulted from ‘ground cover’, due to increased costs associated with slashing, and ‘nutrient application’ due to the increased frequency of fertiliser application (from two months to one month).

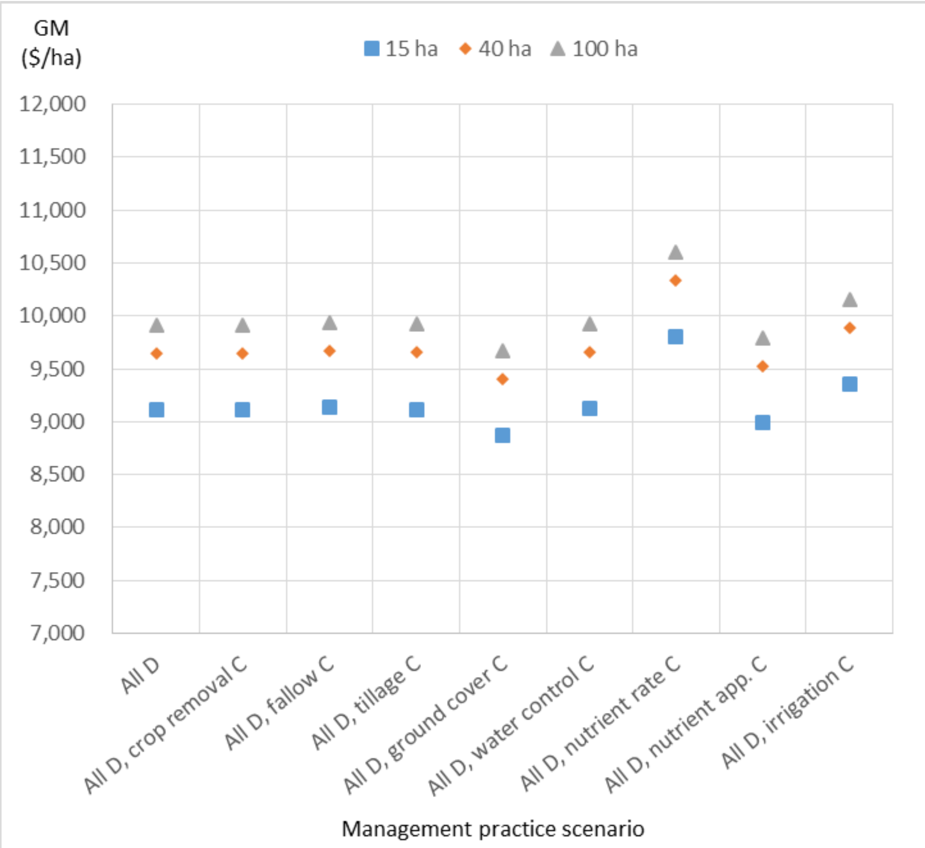

Figure 12: Farm gross margin results, changing practice groups from D to C, Dermosol soils

Figure 13 shows the farm gross margin results for operating at D level, with individual practice groups at B level. The highest farm gross margin was associated with ‘nutrient rate’, demonstrating the decrease in costs from reducing nutrient rates from D to B levels, followed by ‘irrigation’, which mainly reflected the benefits associated with introducing irrigation automation.

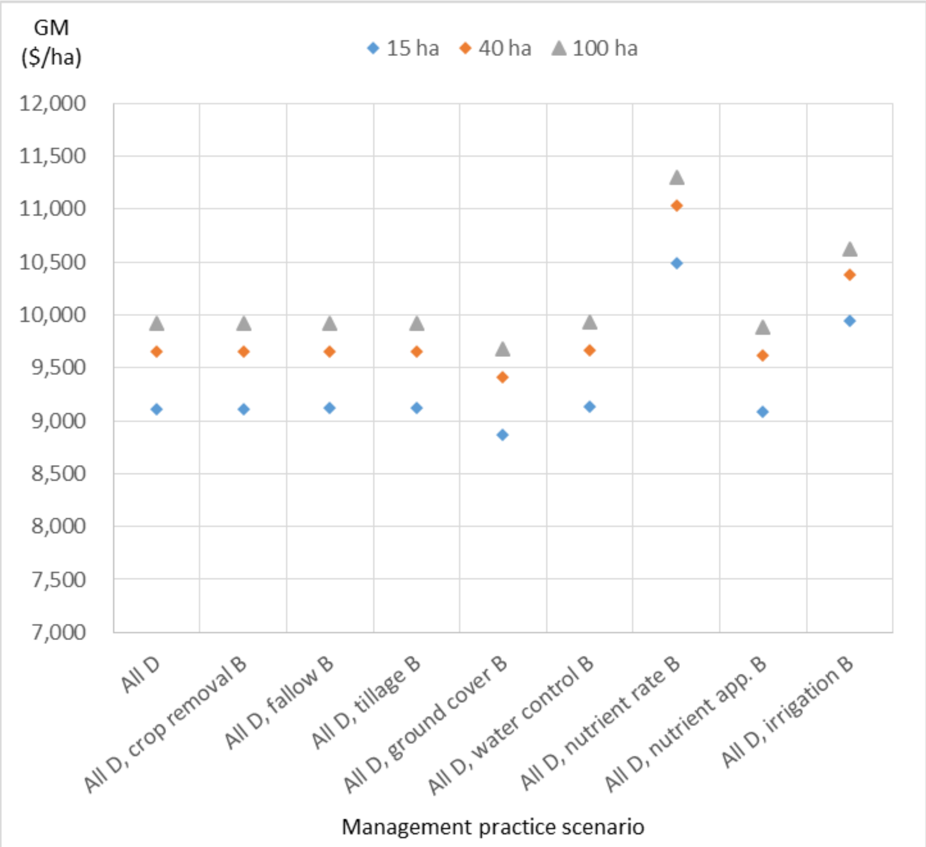

Figure 13: Farm gross margin results, changing practice groups from D to B, Dermosol soils

As previously mentioned, the relative impact of practice change on the farm gross margins of farms with Ferrosol soils was very similar to Dermosol soils (Figure 14 to Figure 17).

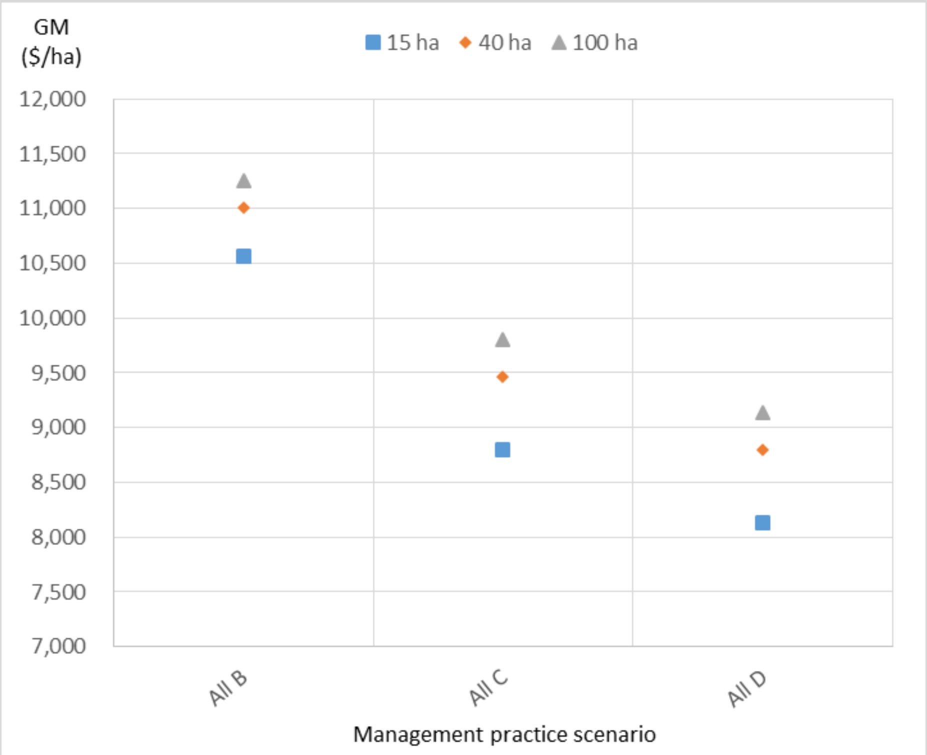

Figure 14: Farm gross margin results, all B, C, and D, Ferrosol soils

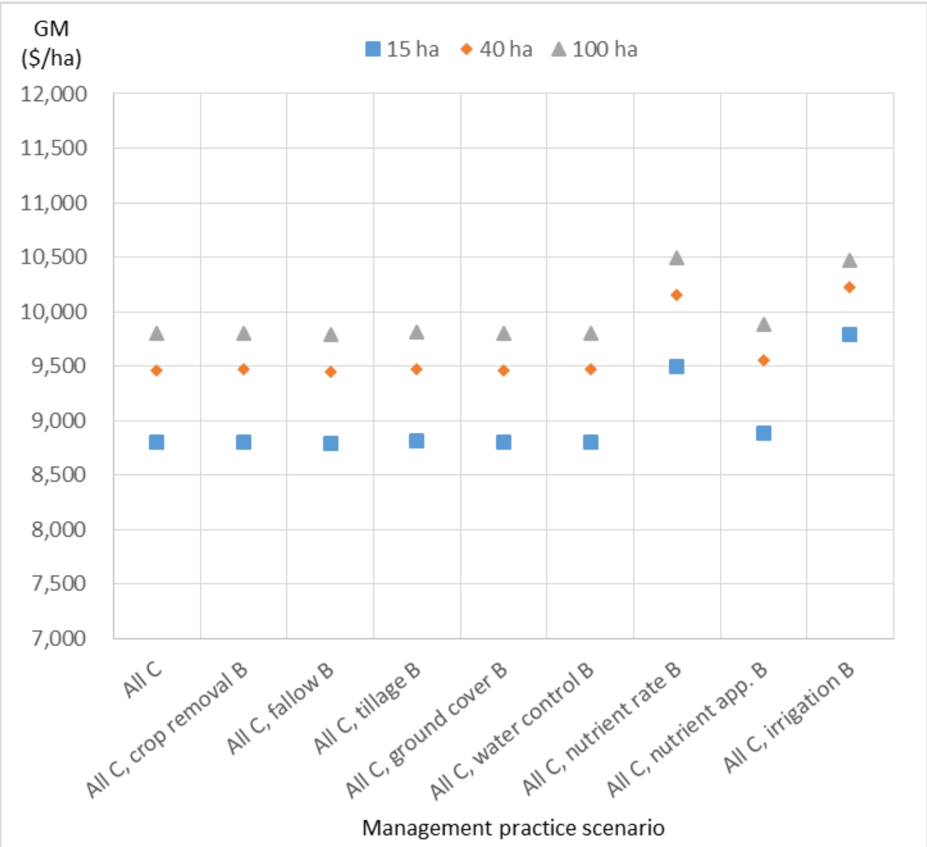

Figure 15: Farm gross margin results, changing practice groups from C to B, Ferrosol soils

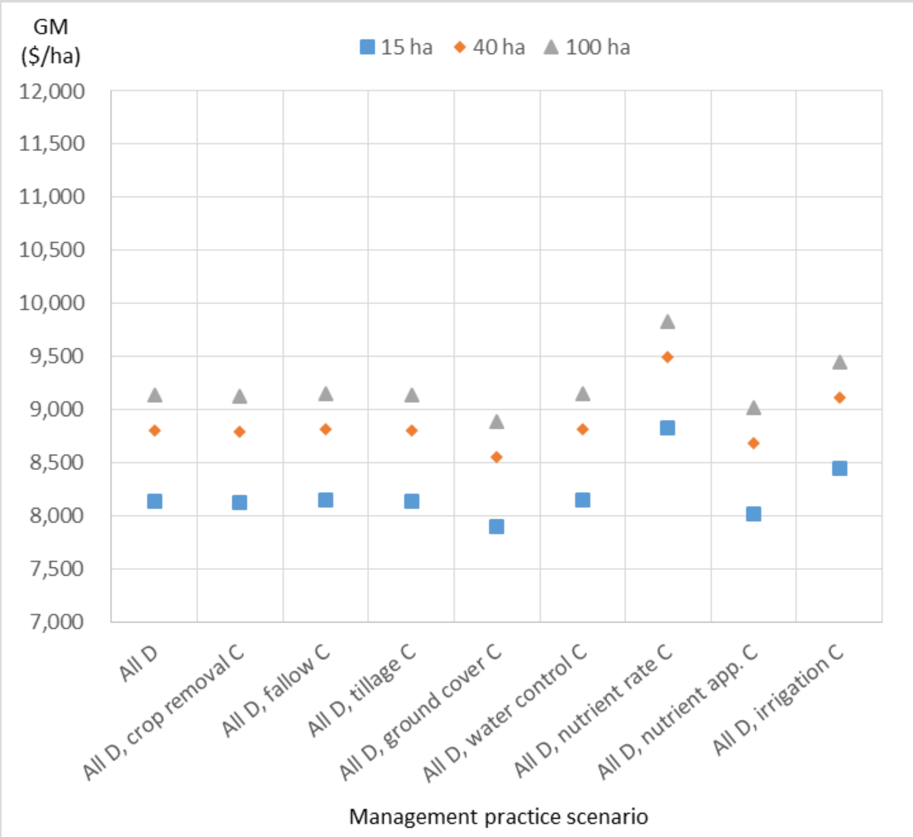

Figure 16: Farm gross margin results, changing practice groups from D to C, Ferrosol soils

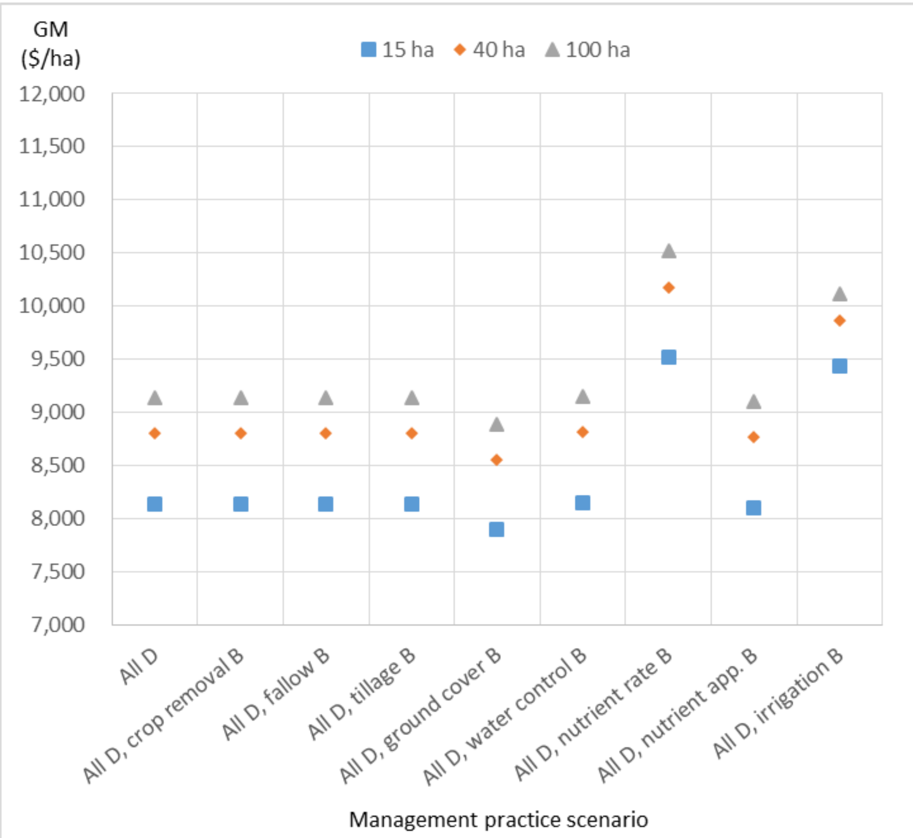

Figure 17: Farm gross margin results, changing practice groups from D to B, Ferrosol soils

8.5.2 Investment analysis tables

Table 26: Investment analysis, 15 hectare farm, Dermosol soil

Original practice	New practice	CAPEX ($/ha)	Change in FGM ($/ha)	Net present value ($/ha)	Payback period	Break even CAPEX ($/ha)
All C	All B	1,703	1,377	7,965	2	9,668
All D	All C	770	602	3,456	2	4,226
All D	All B	2,474	1,978	11,421	2	13,894
All C	All C, except crop removal is B	0	5	35	-	35
All C	All C, except fallow is B	0	-13	-88	-	N.A.
All C	All C, except tillage is B	0	6	42	-	42
All C	All C, except ground cover is B	0	0	0	-	0
All C	All C, except water control structures is B	103	6	-62	>10	41
All C	All C, except nutrient rate is B	0	691	4,852	-	4,852
All C	All C, except nutrient application is B	667	85	-67	>10	599
All C	All C, except irrigation is B	933	597	3,260	2	4,193
All D	All D, except crop removal is C	0	-4	-31	-	N.A.
All D	All D, except fallow is C	0	18	129	-	129
All D	All D, except tillage is C	0	3	22	-	22
All D	All D, except ground cover is C	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is C	310	11	-232	>10	77
All D	All D, except nutrient rate is C	0	690	4,848	-	4,848
All D	All D, except nutrient application is C	367	-121	-1,214	>10	N.A.
All D	All D, except irrigation is C	94	240	1,592	1	1,686
All D	All D, except crop removal is B	0	1	6	-	6
All D	All D, except fallow is B	0	6	41	-	41
All D	All D, except tillage is B	0	9	64	-	64
All D	All D, except ground cover is B	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is B	413	15	-310	>10	103
All D	All D, except nutrient rate is B	0	1,381	9,701	-	9,701
All D	All D, except nutrient application is B	1,033	-33	-1,263	>10	N.A.
All D	All D, except irrigation is B	1,027	837	4,852	2	5,879

Table 27: Investment analysis, 100 hectare farm, Dermosol soil

Original practice	New practice	CAPEX ($/ha)	Change in FGM ($/ha)	Net present value ($/ha)	Payback period	Break even CAPEX ($/ha)
All C	All B	484	1,247	8,272	1	8,756
All D	All C	406	602	3,820	1	4,226
All D	All B	890	1,848	12,092	1	12,982
All C	All C, except crop removal is B	0	5	35	-	35
All C	All C, except fallow is B	0	-13	-88	-	N.A.
All C	All C, except tillage is B	0	6	42	-	42
All C	All C, except ground cover is B	0	0	0	-	0
All C	All C, except water control structures is B	89	6	-48	>10	41
All C	All C, except nutrient rate is B	0	691	4,852	-	4,852
All C	All C, except nutrient application is B	100	85	499	2	599
All C	All C, except irrigation is B	295	467	2,988	1	3,283
All D	All D, except crop removal is C	0	-4	-31	-	N.A.
All D	All D, except fallow is C	0	18	129	-	129
All D	All D, except tillage is C	0	3	22	-	22
All D	All D, except ground cover is C	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is C	267	11	-190	>10	77
All D	All D, except nutrient rate is C	0	690	4,848	-	4,848
All D	All D, except nutrient application is C	55	-121	-902	>10	N.A.
All D	All D, except irrigation is C	83	240	1,602	1	1,686
All D	All D, except crop removal is B	0	1	6	-	6
All D	All D, except fallow is B	0	6	41	-	41
All D	All D, except tillage is B	0	9	64	-	64
All D	All D, except ground cover is B	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is B	356	15	-253	>10	103
All D	All D, except nutrient rate is B	0	1,381	9,701	-	9,701
All D	All D, except nutrient application is B	155	-33	-385	>10	N.A.
All D	All D, except irrigation is B	378	707	4,591	1	4,969

Table 28: Investment analysis, 15 hectare farm, Ferrosol soil

Original practice	New practice	CAPEX ($/ha)	Change in FGM ($/ha)	Net present value ($/ha)	Payback period	Break even CAPEX ($/ha)
All C	All B	1,845	1,769	10,580	2	12,426
All D	All C	1,196	667	3,489	2	4,686
All D	All B	3,042	2,436	14,070	2	17,111
All C	All C, except crop removal is B	0	5	35	-	35
All C	All C, except fallow is B	0	-13	-88	-	N.A.
All C	All C, except tillage is B	0	8	59	-	59
All C	All C, except ground cover is B	0	0	0	-	0
All C	All C, except water control structures is B	245	6	-204	>10	42
All C	All C, except nutrient rate is B	0	691	4,852	-	4,852
All C	All C, except nutrient application is B	667	85	-67	>10	599
All C	All C, except irrigation is B	933	987	5,999	2	6,933
All D	All D, except crop removal is C	0	-4	-31	-	N.A.
All D	All D, except fallow is C	0	18	129	-	129
All D	All D, except tillage is C	0	-1	-9	-	N.A.
All D	All D, except ground cover is C	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is C	736	11	-657	>10	79
All D	All D, except nutrient rate is C	0	690	4,848	-	4,848
All D	All D, except nutrient application is C	367	-121	-1,214	>10	N.A.
All D	All D, except irrigation is C	94	310	2,080	1	2,174
All D	All D, except crop removal is B	0	1	6	-	6
All D	All D, except fallow is B	0	6	41	-	41
All D	All D, except tillage is B	0	7	52	-	52
All D	All D, except ground cover is B	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is B	981	15	-876	>10	105
All D	All D, except nutrient rate is B	0	1,381	9,701	-	9,701
All D	All D, except nutrient application is B	1,033	-33	-1,263	>10	N.A.
All D	All D, except irrigation is B	1,027	1,297	8,079	1	9,107

Table 29: Investment analysis, 100 hectare farm, Ferrosol soil

Original practice	New practice	CAPEX ($/ha)	Change in FGM ($/ha)	Net present value ($/ha)	Payback period	Break even CAPEX ($/ha)
All C	All B	626	1,450	9,555	1	10,181
All D	All C	832	667	3,854	2	4,686
All D	All B	1,458	2,117	13,409	1	14,867
All C	All C, except crop removal is B	0	5	35	-	35
All C	All C, except fallow is B	0	-13	-88	-	N.A.
All C	All C, except tillage is B	0	8	59	-	59
All C	All C, except ground cover is B	0	0	0	-	0
All C	All C, except water control structures is B	231	6	-189	>10	42
All C	All C, except nutrient rate is B	0	691	4,852	-	4,852
All C	All C, except nutrient application is B	100	85	499	2	599
All C	All C, except irrigation is B	295	667	4,392	1	4,687
All D	All D, except crop removal is C	0	-4	-31	-	N.A.
All D	All D, except fallow is C	0	18	129	-	129
All D	All D, except tillage is C	0	-1	-9	-	N.A.
All D	All D, except ground cover is C	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is C	693	11	-615	>10	79
All D	All D, except nutrient rate is C	0	690	4,848	-	4,848
All D	All D, except nutrient application is C	55	-121	-902	>10	N.A.
All D	All D, except irrigation is C	83	310	2,091	1	2,174
All D	All D, except crop removal is B	0	1	6	-	6
All D	All D, except fallow is B	0	6	41	-	41
All D	All D, except tillage is B	0	7	52	-	52
All D	All D, except ground cover is B	0	-243	-1,705	-	N.A.
All D	All D, except water control structures is B	925	15	-819	>10	105
All D	All D, except nutrient rate is B	0	1,381	9,701	-	9,701
All D	All D, except nutrient application is B	155	-33	-385	>10	N.A.
All D	All D, except irrigation is B	378	977	6,482	1	6,861

8.5.3 Cost effectiveness tables and charts

Table 30: Cost effectiveness, 15 hectare farm, Dermosol soil

Original practice	New practice	DIN abatement (kg/ha/yr)	TSS abatement (t/ha/yr)	AEB ($/ha/yr)
All C	All B	12.6	0.3	1,134
All D	All C	18.6	9.7	492
All D	All B	31.2	10.0	1,626
All C	All C, except crop removal is B	0.0	0.1	5
All C	All C, except fallow is B	0.0	0.0	-13
All C	All C, except tillage is B	0.0	0.0	6
All C	All C, except ground cover is B	0.0	0.1	0
All C	All C, except water control structures is B	0.0	0.2	-9
All C	All C, except nutrient rate is B	11.6	0.0	691
All C	All C, except nutrient application is B	0.6	0.0	-10
All C	All C, except irrigation is B	2.5	0.0	464
All D	All D, except crop removal is C	0.0	0.8	-4
All D	All D, except fallow is C	0.0	0.9	18
All D	All D, except tillage is C	0.0	0.0	3
All D	All D, except ground cover is C	0.0	8.3	-243
All D	All D, except water control structures is C	0.0	2.1	-33
All D	All D, except nutrient rate is C	16.0	0.0	690
All D	All D, except nutrient application is C	2.1	0.0	-173
All D	All D, except irrigation is C	2.9	0.0	227
All D	All D, except crop removal is B	0.0	0.8	1
All D	All D, except fallow is B	0.0	0.9	6
All D	All D, except tillage is B	0.0	0.0	9
All D	All D, except ground cover is B	0.0	8.3	-243
All D	All D, except water control structures is B	0.0	2.1	-44
All D	All D, except nutrient rate is B	27.2	0.0	1,381
All D	All D, except nutrient application is B	2.1	0.0	-180
All D	All D, except irrigation is B	7.0	0.0	691

Table 31: Cost effectiveness, 100 hectare farm, Dermosol soil

Original practice	New practice	DIN abatement (kg/ha/yr)	TSS abatement (t/ha/yr)	AEB ($/ha/yr)
All C	All B	12.6	0.3	1,178
All D	All C	18.6	9.7	544
All D	All B	31.2	10.0	1,722
All C	All C, except crop removal is B	0.0	0.1	5
All C	All C, except fallow is B	0.0	0.0	-13
All C	All C, except tillage is B	0.0	0.0	6
All C	All C, except ground cover is B	0.0	0.1	0
All C	All C, except water control structures is B	0.0	0.2	-7
All C	All C, except nutrient rate is B	11.6	0.0	691
All C	All C, except nutrient application is B	0.6	0.0	71
All C	All C, except irrigation is B	2.5	0.0	425
All D	All D, except crop removal is C	0.0	0.8	-4
All D	All D, except fallow is C	0.0	0.9	18
All D	All D, except tillage is C	0.0	0.0	3
All D	All D, except ground cover is C	0.0	8.3	-243
All D	All D, except water control structures is C	0.0	2.1	-27
All D	All D, except nutrient rate is C	16.0	0.0	690
All D	All D, except nutrient application is C	2.1	0.0	-128
All D	All D, except irrigation is C	2.9	0.0	228
All D	All D, except crop removal is B	0.0	0.8	1
All D	All D, except fallow is B	0.0	0.9	6
All D	All D, except tillage is B	0.0	0.0	9
All D	All D, except ground cover is B	0.0	8.3	-243
All D	All D, except water control structures is B	0.0	2.1	-36
All D	All D, except nutrient rate is B	27.2	0.0	1,381
All D	All D, except nutrient application is B	2.1	0.0	-55
All D	All D, except irrigation is B	7.0	0.0	654

Table 32: Cost effectiveness, 15 hectare farm, Ferrosol soil

Original practice	New practice	DIN abatement (kg/ha/yr)	TSS abatement (t/ha/yr)	AEB ($/ha/yr)
All C	All B	14.7	0.4	1,506
All D	All C	21.8	12.7	497
All D	All B	36.5	13.1	2,003
All C	All C, except crop removal is B	0.0	0.1	5
All C	All C, except fallow is B	0.0	0.1	-13
All C	All C, except tillage is B	0.0	0.0	8
All C	All C, except ground cover is B	0.0	0.1	0
All C	All C, except water control structures is B	0.0	0.2	-29
All C	All C, except nutrient rate is B	13.3	0.0	691
All C	All C, except nutrient application is B	0.8	0.0	-10
All C	All C, except irrigation is B	3.0	0.0	854
All D	All D, except crop removal is C	0.0	1.1	-4
All D	All D, except fallow is C	0.0	1.3	18
All D	All D, except tillage is C	0.0	0.1	-1
All D	All D, except ground cover is C	0.0	10.8	-243
All D	All D, except water control structures is C	0.0	3.9	-94
All D	All D, except nutrient rate is C	18.8	0.0	690
All D	All D, except nutrient application is C	2.6	0.0	-173
All D	All D, except irrigation is C	3.6	0.0	296
All D	All D, except crop removal is B	0.0	1.2	1
All D	All D, except fallow is B	0.0	1.3	6
All D	All D, except tillage is B	0.0	0.1	7
All D	All D, except ground cover is B	0.0	10.8	-243
All D	All D, except water control structures is B	0.0	5.5	-125
All D	All D, except nutrient rate is B	32.2	0.0	1,381
All D	All D, except nutrient application is B	2.5	0.0	-180
All D	All D, except irrigation is B	8.4	0.0	1,150

Table 33: Cost effectiveness, 100 hectare farm, Ferrosol soil

Original practice	New practice	DIN abatement (kg/ha/yr)	TSS abatement (t/ha/yr)	AEB ($/ha/yr)
All C	All B	14.7	0.4	1,360
All D	All C	21.8	12.7	549
All D	All B	36.5	13.1	1,909
All C	All C, except crop removal is B	0.0	0.1	5
All C	All C, except fallow is B	0.0	0.1	-13
All C	All C, except tillage is B	0.0	0.0	8
All C	All C, except ground cover is B	0.0	0.1	0
All C	All C, except water control structures is B	0.0	0.2	-27
All C	All C, except nutrient rate is B	13.3	0.0	691
All C	All C, except nutrient application is B	0.8	0.0	71
All C	All C, except irrigation is B	3.0	0.0	625
All D	All D, except crop removal is C	0.0	1.1	-4
All D	All D, except fallow is C	0.0	1.3	18
All D	All D, except tillage is C	0.0	0.1	-1
All D	All D, except ground cover is C	0.0	10.8	-243
All D	All D, except water control structures is C	0.0	3.9	-88
All D	All D, except nutrient rate is C	18.8	0.0	690
All D	All D, except nutrient application is C	2.6	0.0	-128
All D	All D, except irrigation is C	3.6	0.0	298
All D	All D, except crop removal is B	0.0	1.2	1
All D	All D, except fallow is B	0.0	1.3	6
All D	All D, except tillage is B	0.0	0.1	7
All D	All D, except ground cover is B	0.0	10.8	-243
All D	All D, except water control structures is B	0.0	5.5	-117
All D	All D, except nutrient rate is B	32.2	0.0	1,381
All D	All D, except nutrient application is B	2.5	0.0	-55
All D	All D, except irrigation is B	8.4	0.0	923

The following charts present the above analysis in ‘cost-effectiveness planes’, with the economic benefit plotted on the vertical axis and the water quality benefit on the horizontal axis (DIN and TSS abatement are presented in separate charts). The cost-effectiveness planes provide a visual display of the outcomes, whereby management practice changes that provide both water quality and economic benefits fall in the area above the horizontal axis, while those that represent a trade-off between water quality benefit and economic cost fall below the axis. Practices that resulted in little or no DIN or TSS abatement fall on or near the vertical axis.

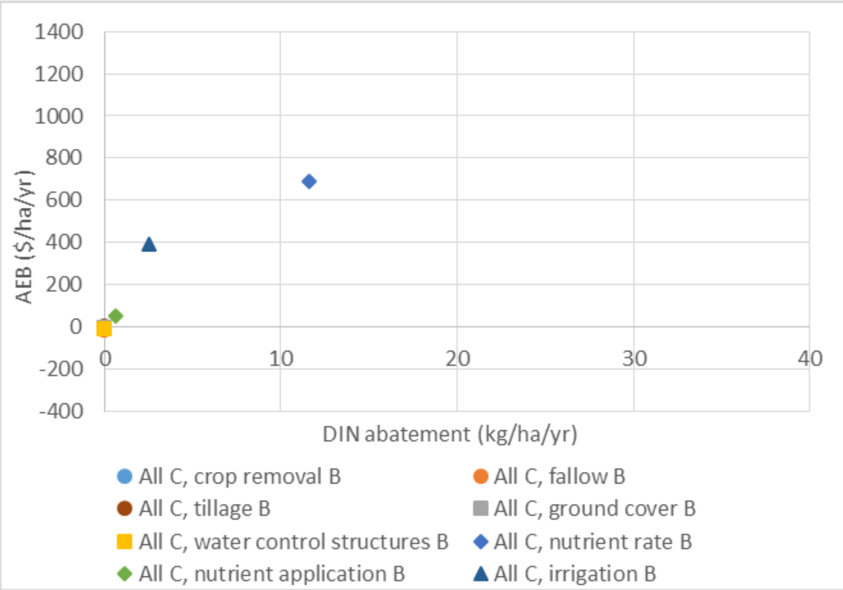

Figure 18: DIN abatement cost effectiveness: changing practice groups from C to B (40 ha farm, Dermosol soil)

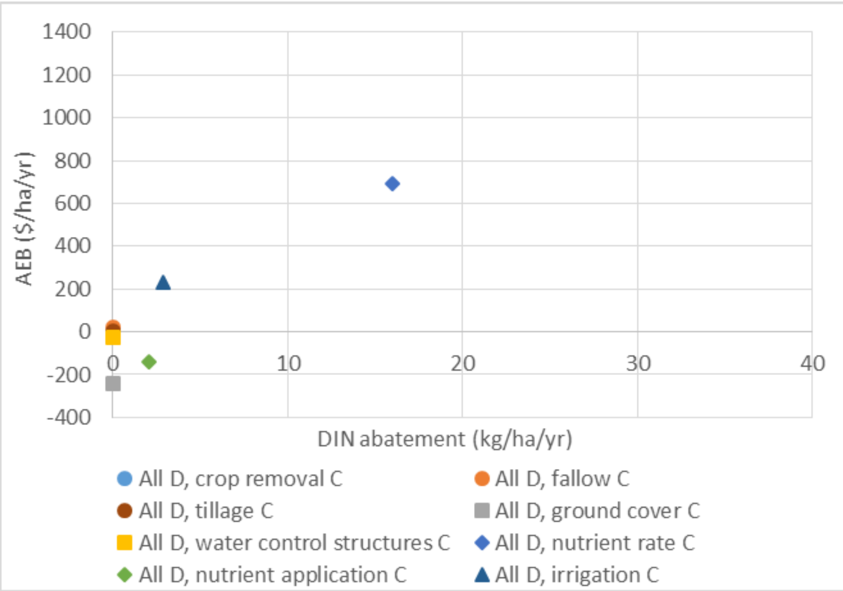

Figure 19: DIN abatement cost effectiveness: changing practice groups from D to C (40 ha farm, Dermosol soil)

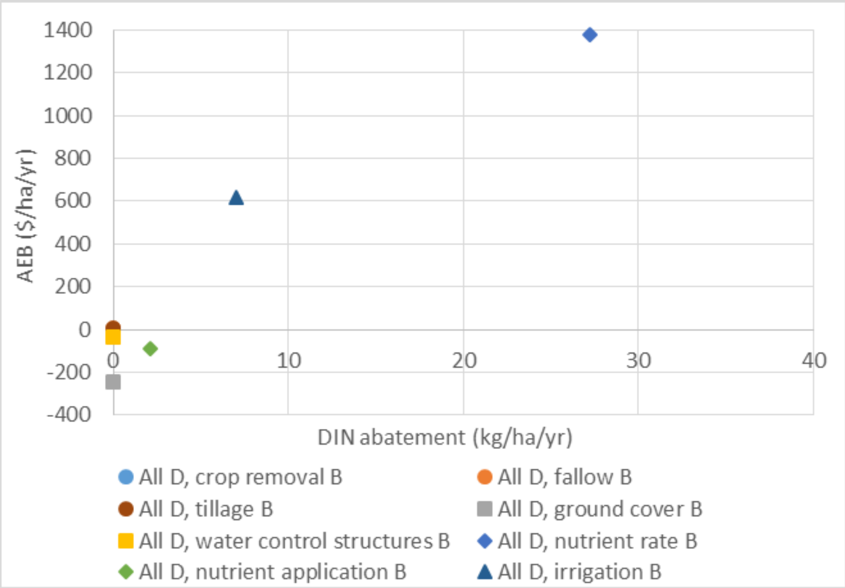

Figure 20: DIN abatement cost effectiveness: changing practice groups from D to B (40 ha farm, Dermosol soil)

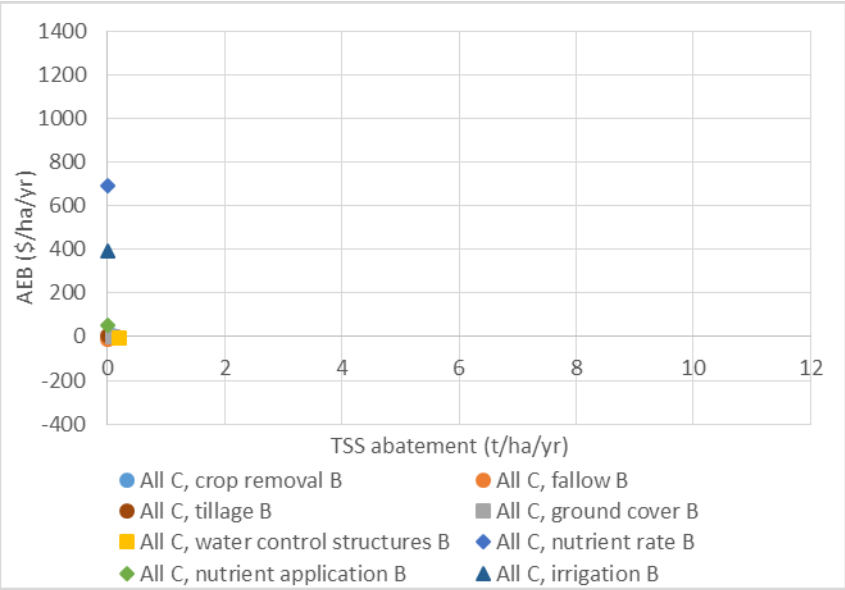

Figure 21: TSS abatement cost effectiveness: changing practice groups from C to B (40 ha farm, Dermosol soil)

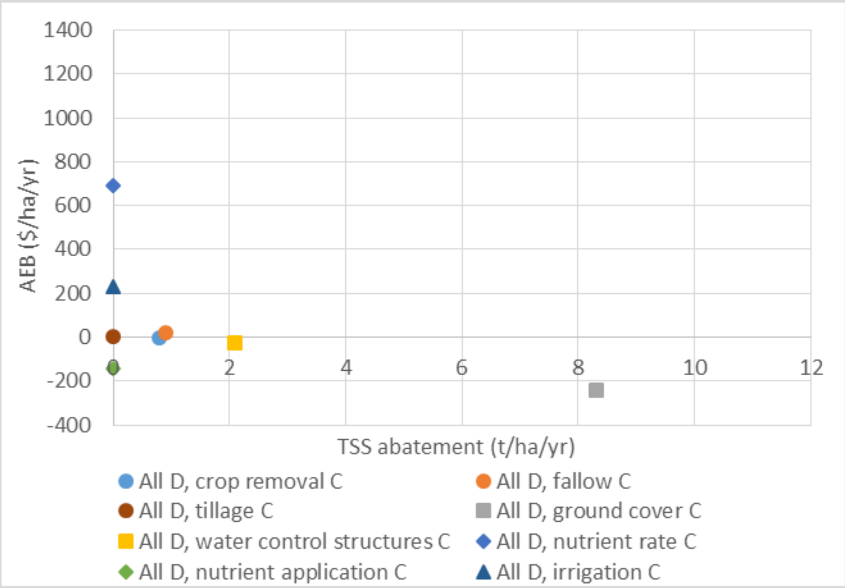

Figure 22: TSS abatement cost effectiveness: changing practice groups from D to C (40 ha farm, Dermosol soil

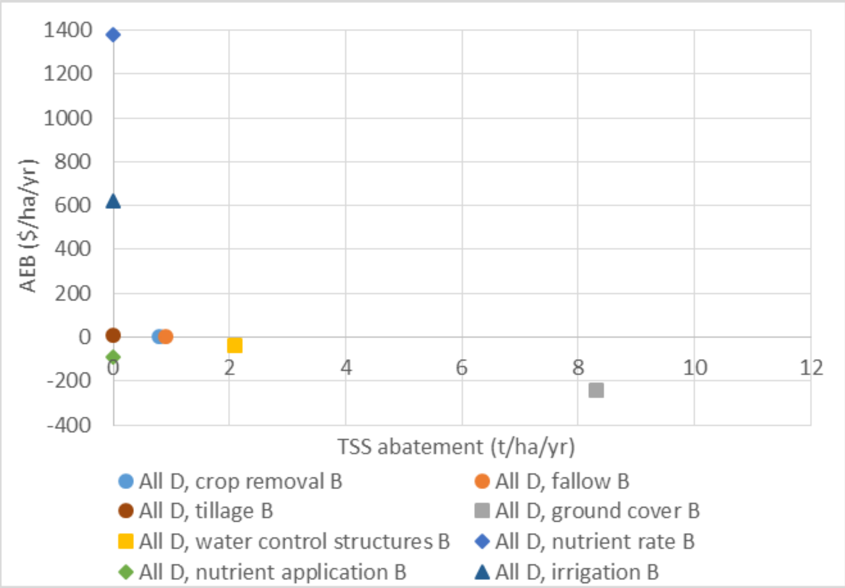

Figure 23: TSS abatement cost effectiveness: changing practice groups from D to B (40 ha farm, Dermosol soil

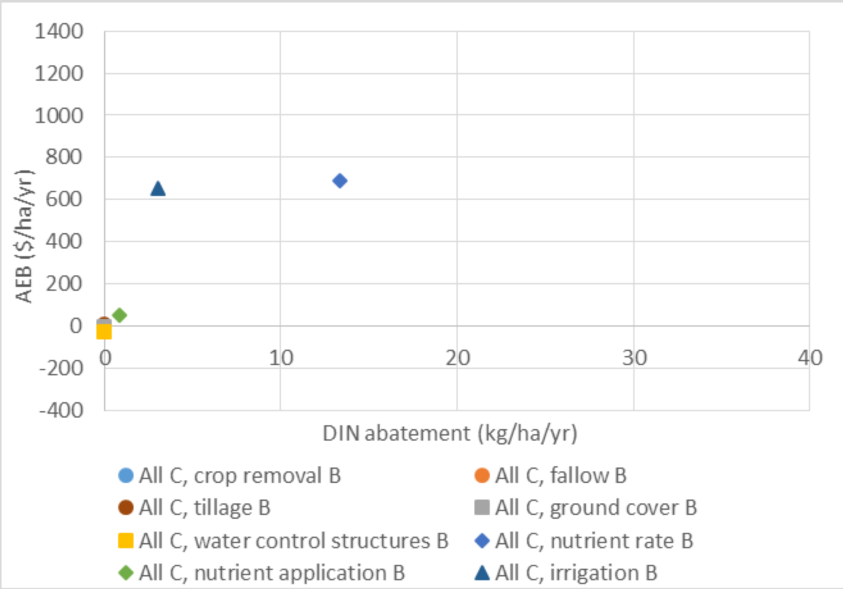

Figure 24: DIN abatement cost effectiveness: changing practice groups from C to B (40 ha farm, Ferrosol soil

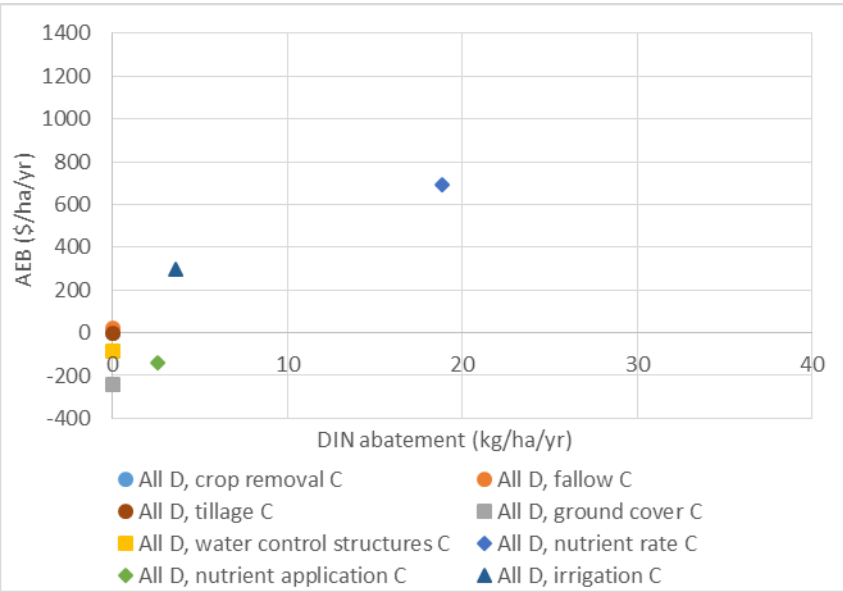

Figure 25: DIN abatement cost effectiveness: changing practice groups from D to C (40 ha farm, Ferrosol soil

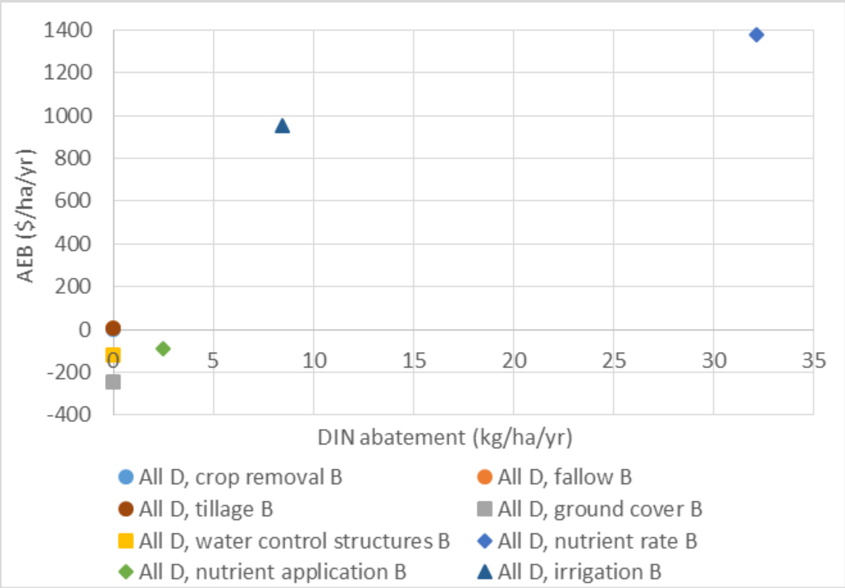

Figure 26: DIN abatement cost effectiveness: changing practice groups from D to B (40 ha farm, Ferrosol soil

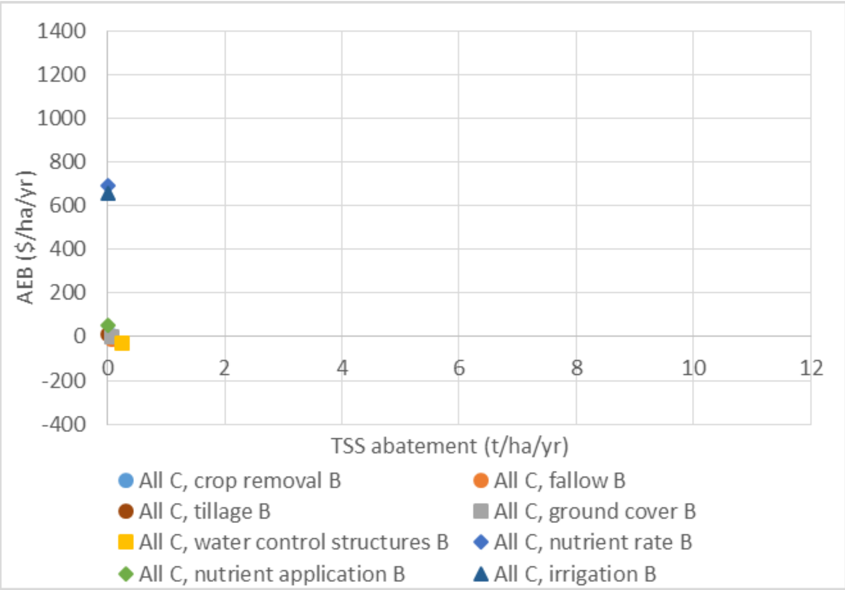

Figure 27: TSS abatement cost effectiveness: changing practice groups from C to B (40 ha farm, Ferrosol soil

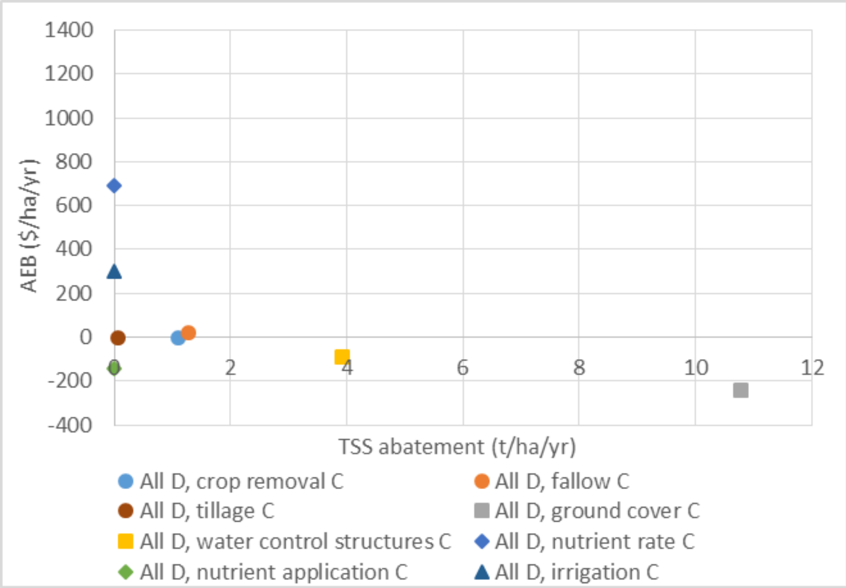

Figure 28: TSS abatement cost effectiveness: changing practice groups from D to C (40 ha farm, Ferrosol soil

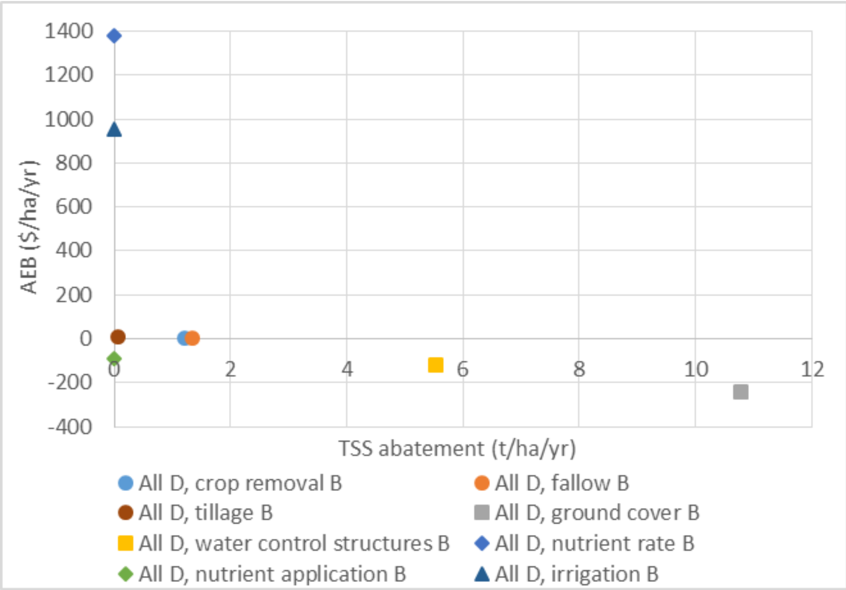

Figure 29: TSS abatement cost effectiveness: changing practice groups from D to B (40 ha farm, Ferrosol soil

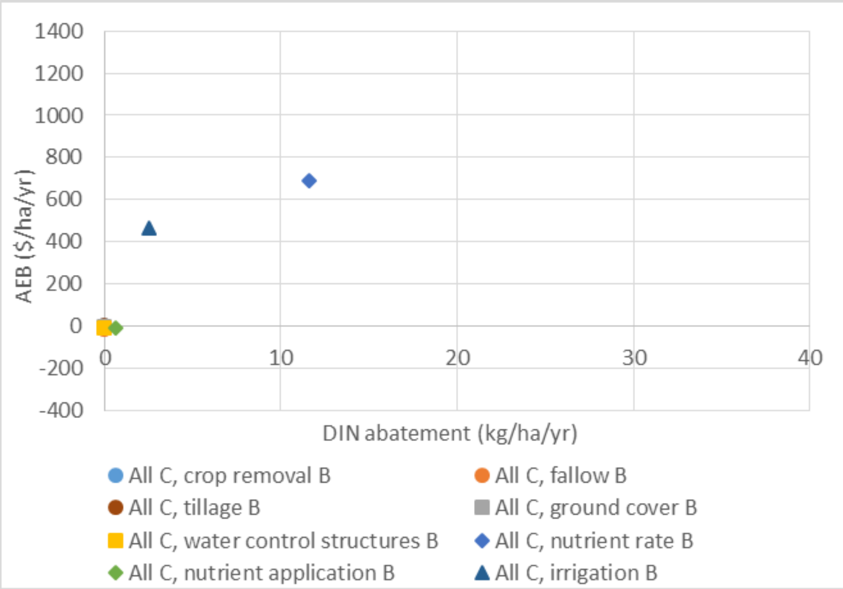

Figure 30: DIN abatement cost effectiveness: changing practice groups from C to B (15 ha farm, Dermosol soil)

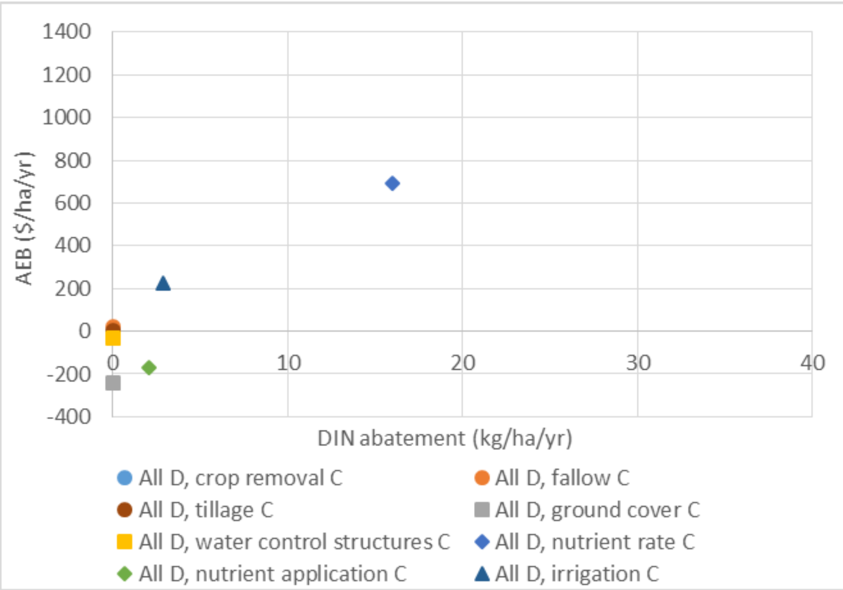

Figure 31: DIN abatement cost effectiveness: changing practice groups from D to C (15 ha farm, Dermosol soil)

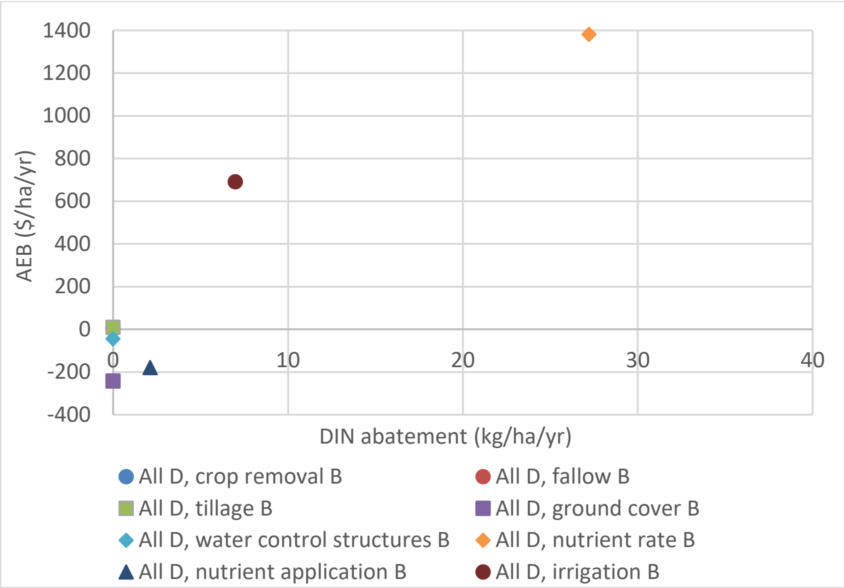

Figure 32: DIN abatement cost effectiveness: changing practice groups from D to B (15 ha farm, Dermosol soil)

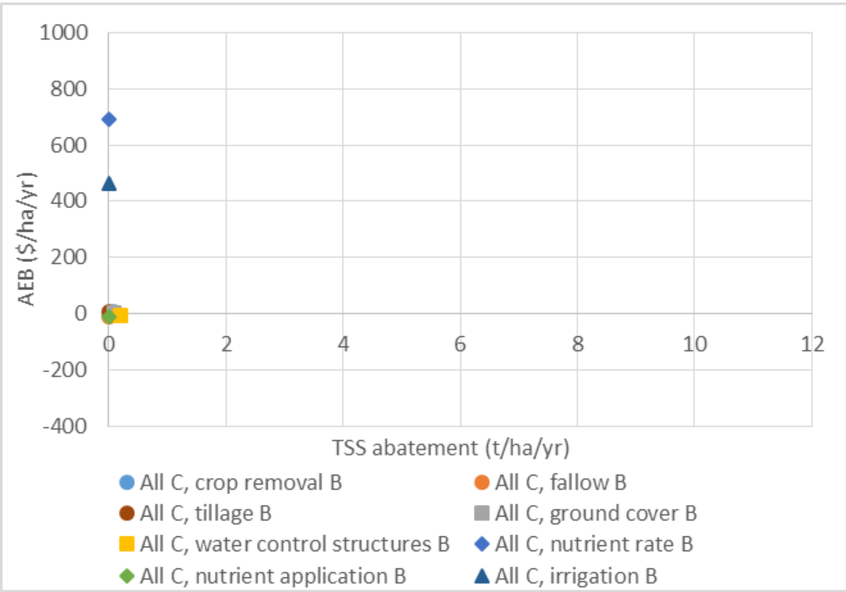

Figure 33: TSS abatement cost effectiveness: changing practice groups from C to B (15 ha farm, Dermosol soil)

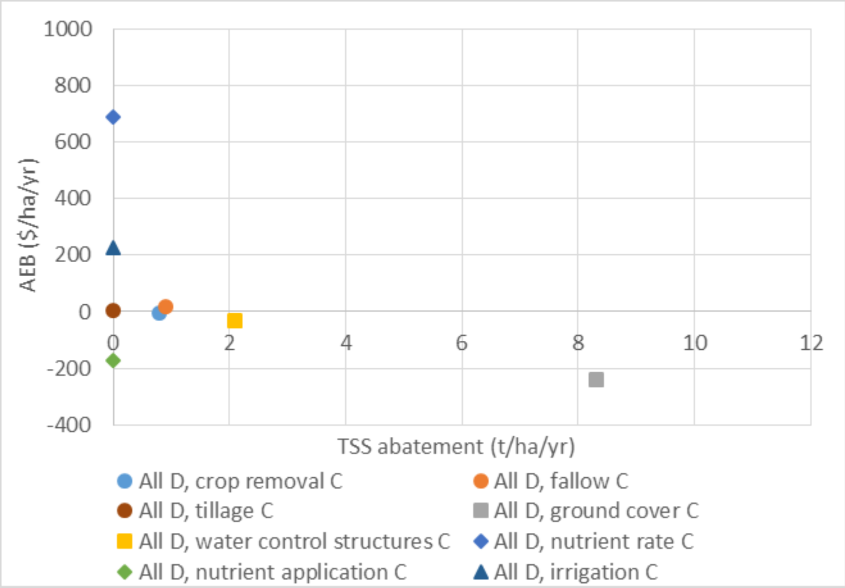

Figure 34: TSS abatement cost effectiveness: changing practice groups from D to C (15 ha farm, Dermosol soil

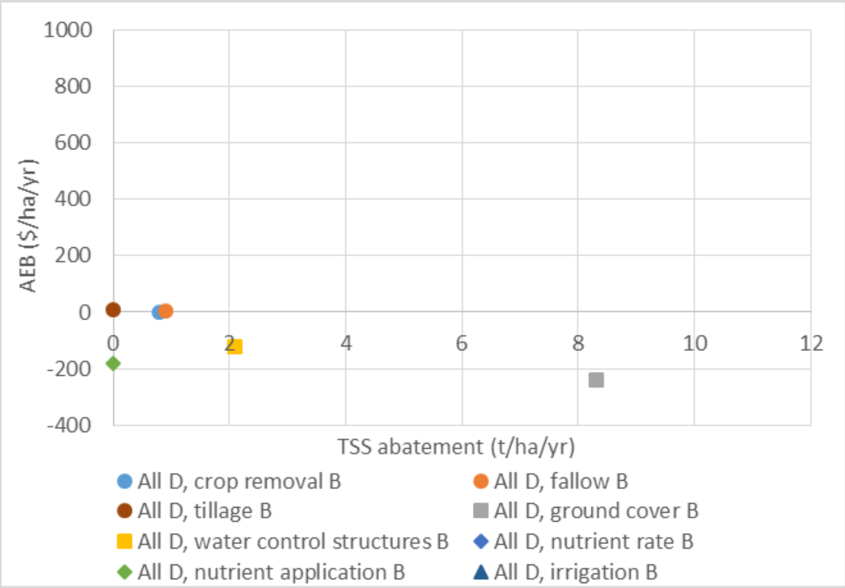

Figure 35: TSS abatement cost effectiveness: changing practice groups from D to B (15 ha farm, Dermosol soil

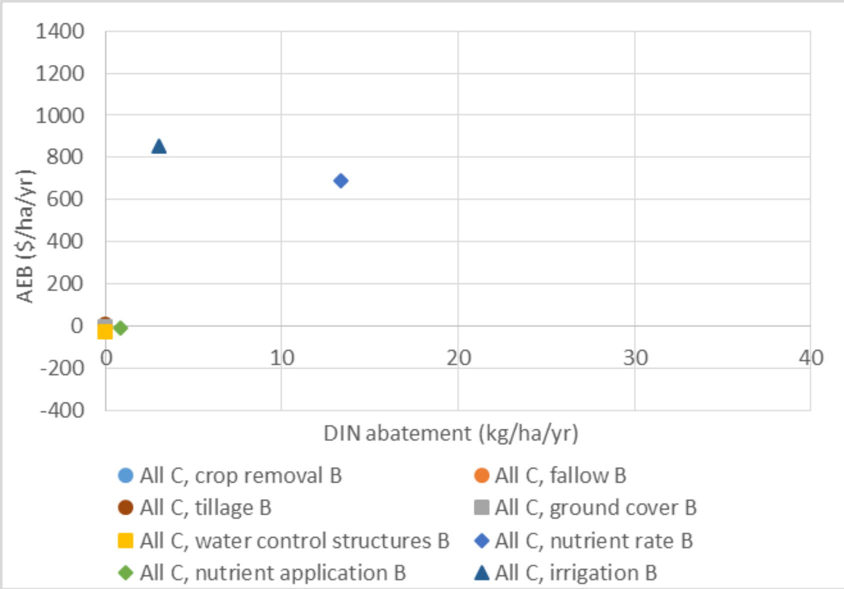

Figure 36: DIN abatement cost effectiveness: changing practice groups from C to B (15 ha farm, Ferrosol soil

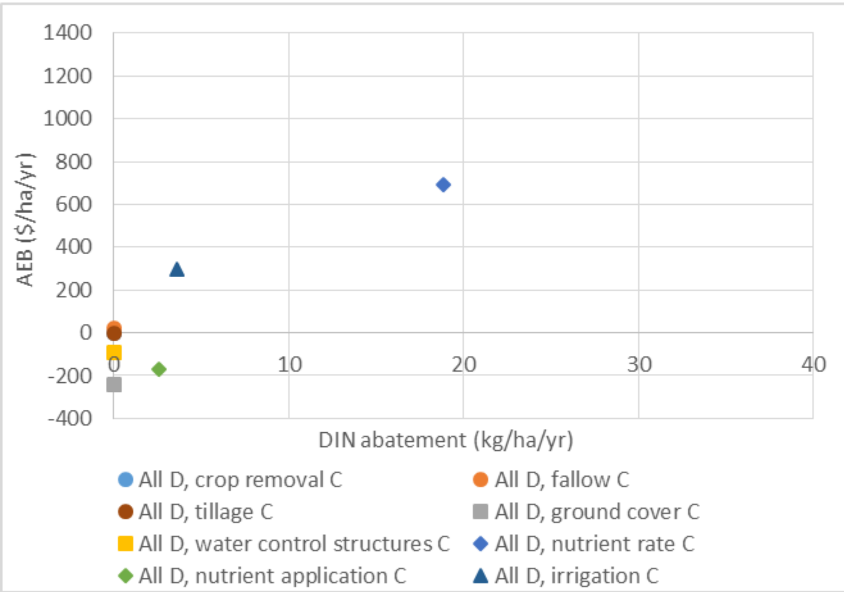

Figure 37: DIN abatement cost effectiveness: changing practice groups from D to C (15 ha farm, Ferrosol soil

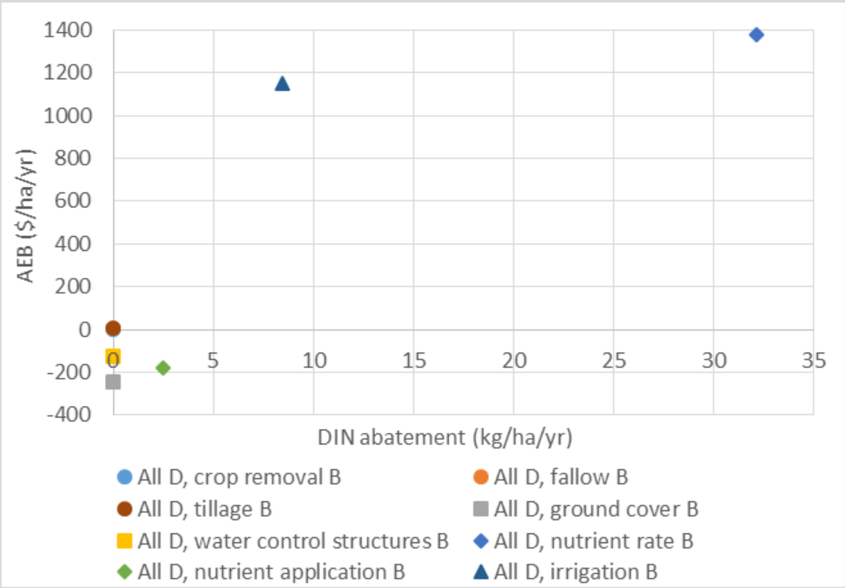

Figure 38: DIN abatement cost effectiveness: changing practice groups from D to B (15 ha farm, Ferrosol soil

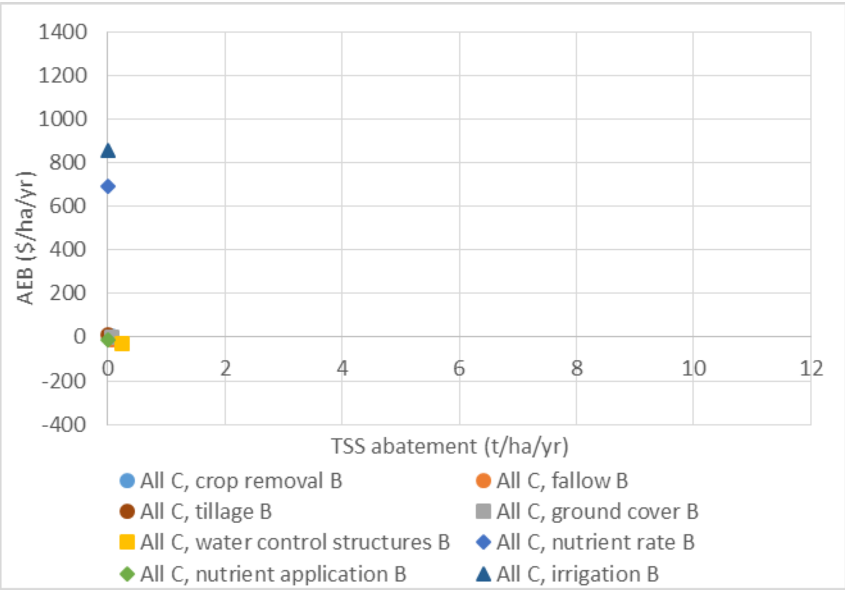

Figure 39: TSS abatement cost effectiveness: changing practice groups from C to B (15 ha farm, Ferrosol soil

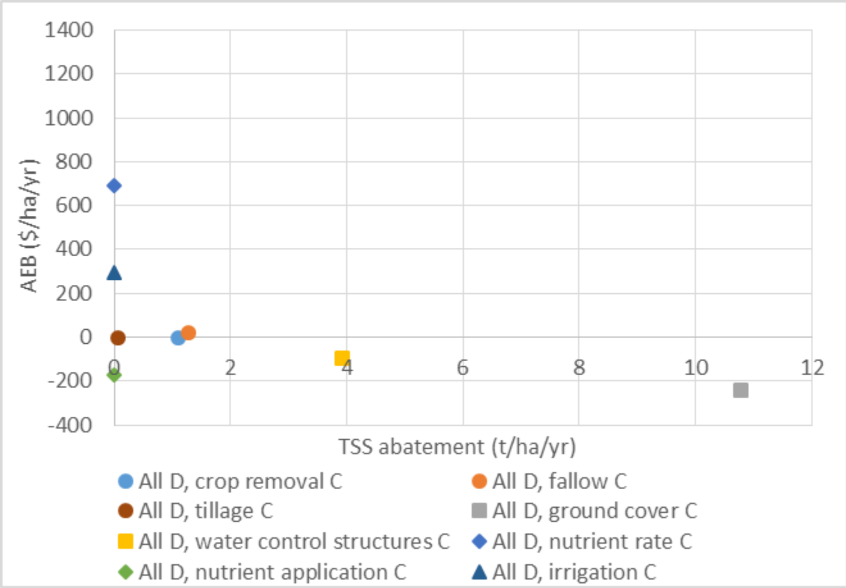

Figure 40: TSS abatement cost effectiveness: changing practice groups from D to C (15 ha farm, Ferrosol soil

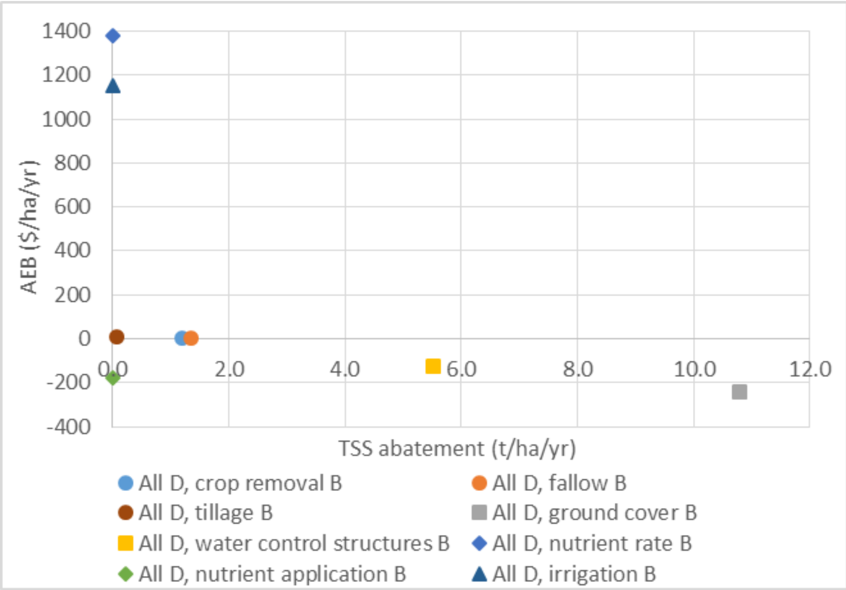

Figure 41: TSS abatement cost effectiveness: changing practice groups from D to B (15 ha farm, Ferrosol soil

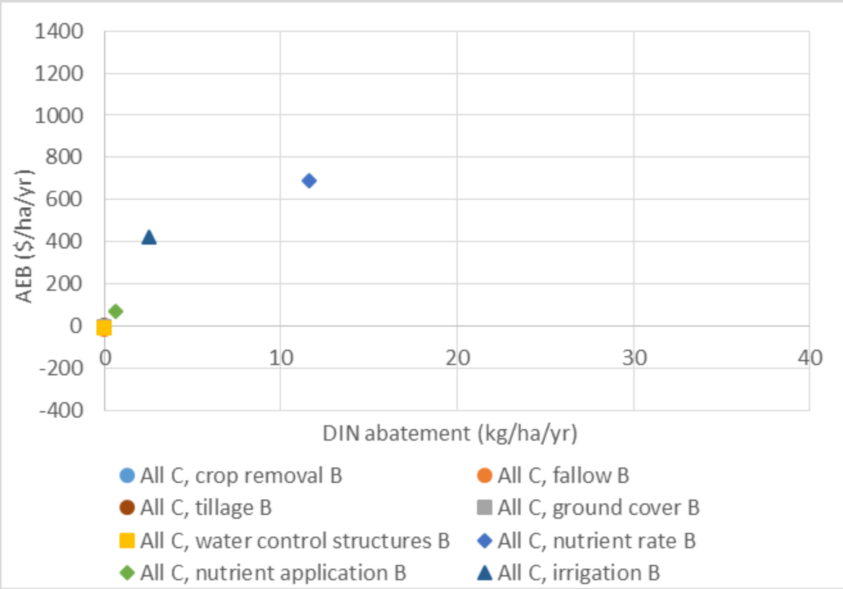

Figure 42: DIN abatement cost effectiveness: changing practice groups from C to B (100 ha farm, Dermosol soil)

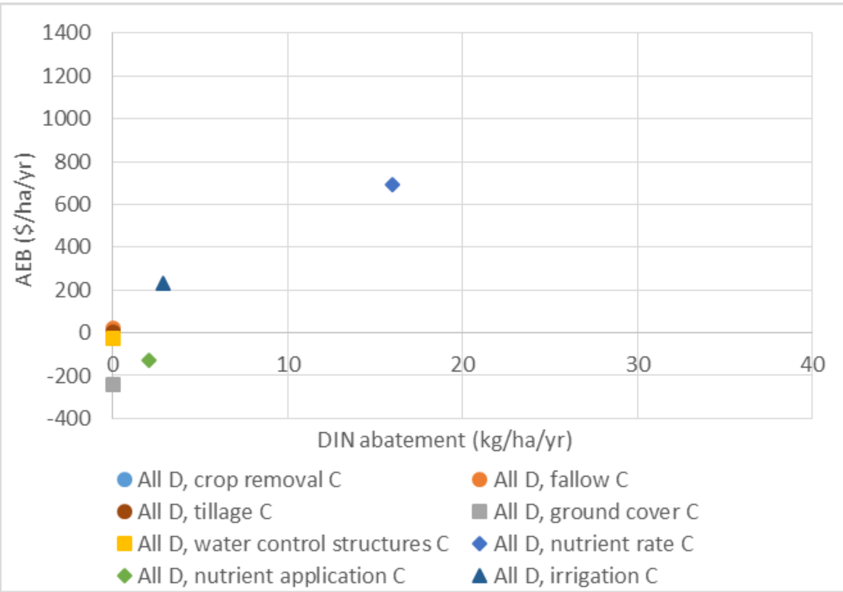

Figure 43: DIN abatement cost effectiveness: changing practice groups from D to C (100 ha farm, Dermosol soil)

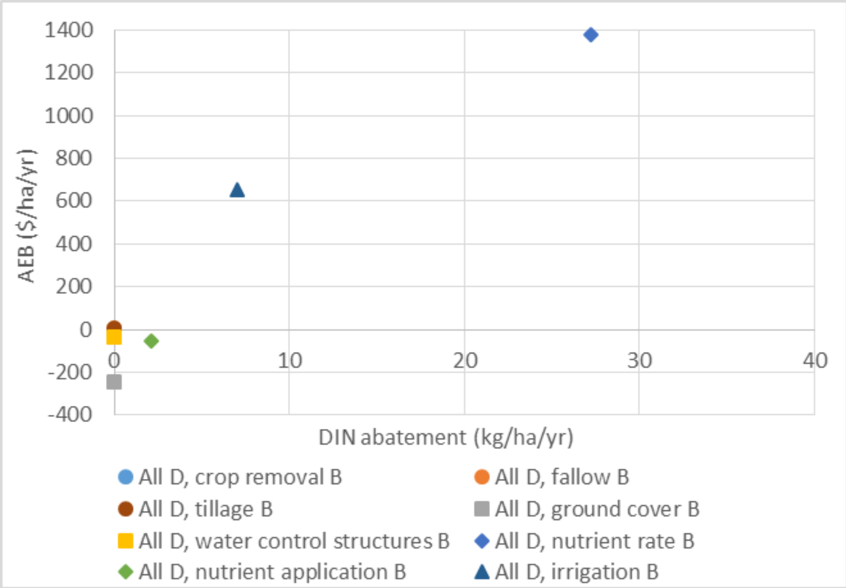

Figure 44: DIN abatement cost effectiveness: changing practice groups from D to B (100 ha farm, Dermosol soil)

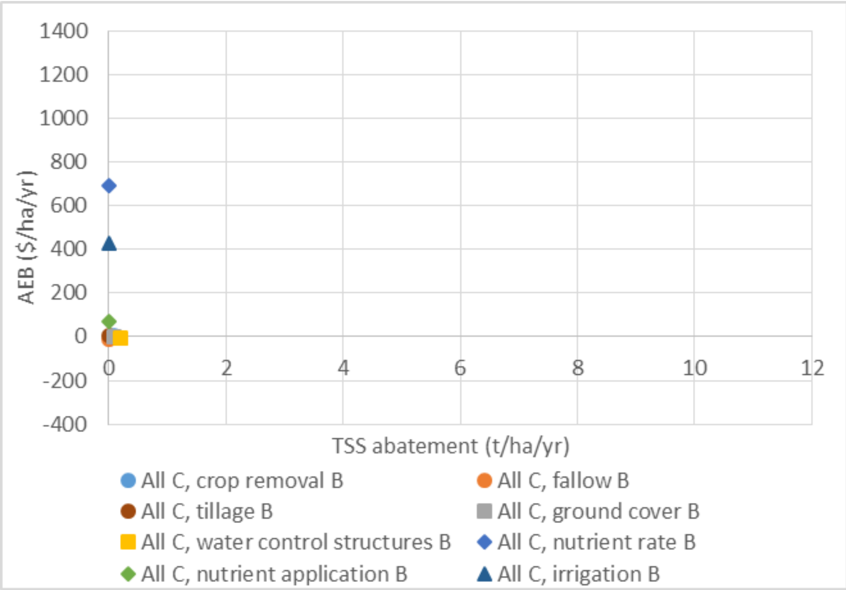

Figure 45: TSS abatement cost effectiveness: changing practice groups from C to B (100 ha farm, Dermosol soil)

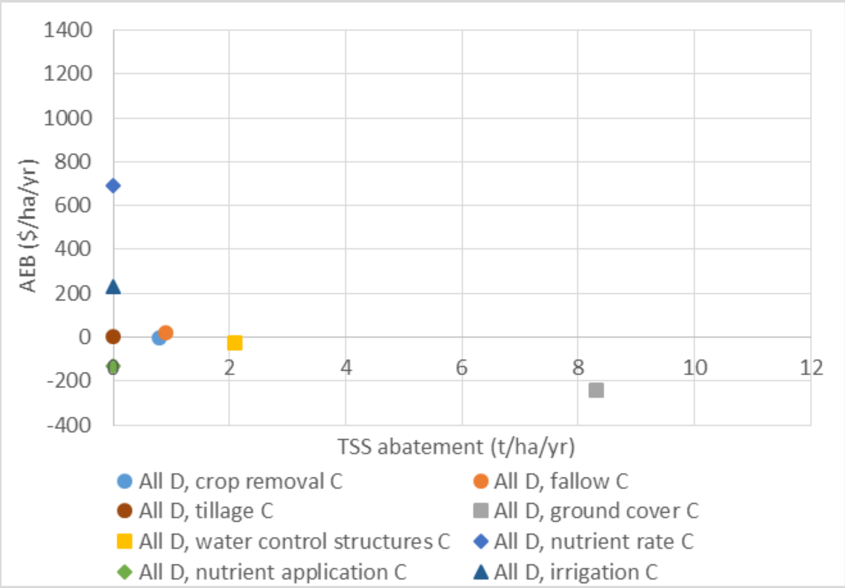

Figure 46: TSS abatement cost effectiveness: changing practice groups from D to C (100 ha farm, Dermosol soil

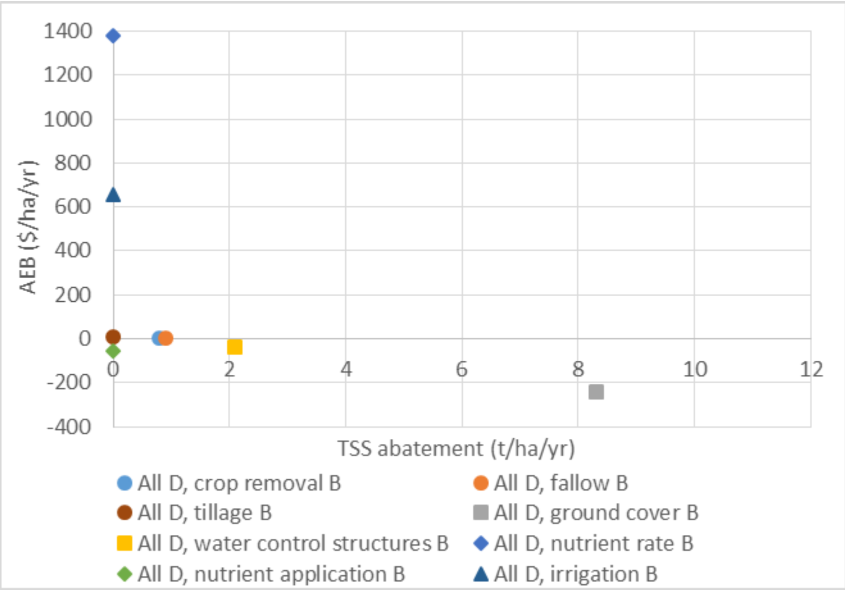

Figure 47: TSS abatement cost effectiveness: changing practice groups from D to B (100 ha farm, Dermosol soil

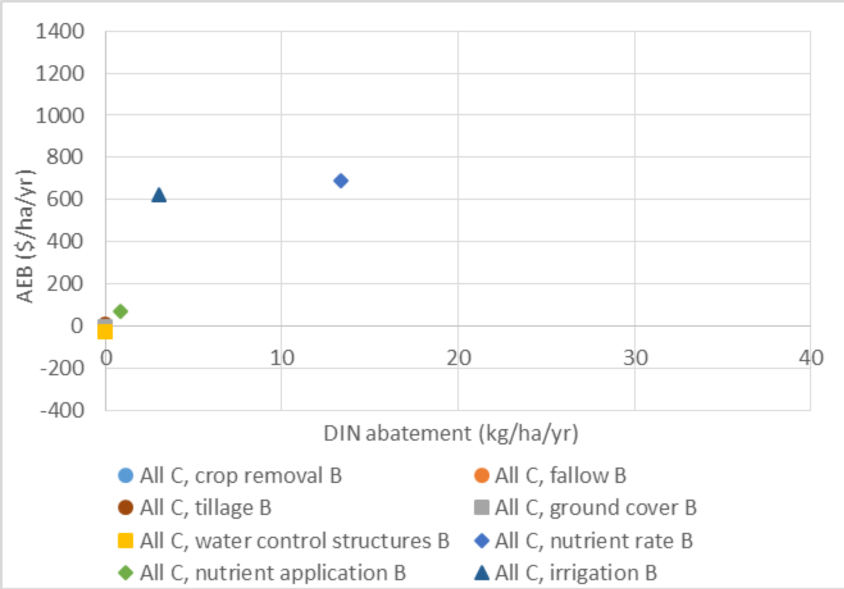

Figure 48: DIN abatement cost effectiveness: changing practice groups from C to B (100 ha farm, Ferrosol soil

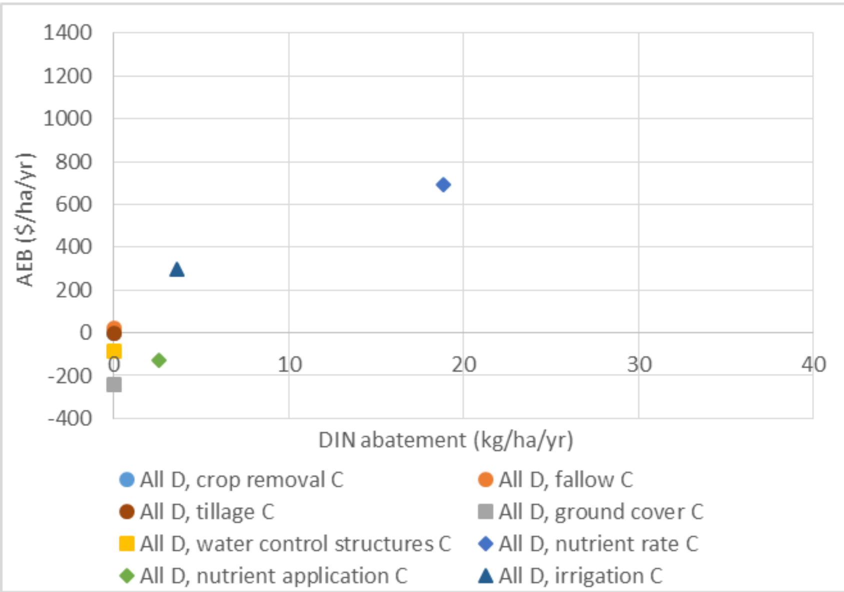

Figure 49: DIN abatement cost effectiveness: changing practice groups from D to C (100 ha farm, Ferrosol soil

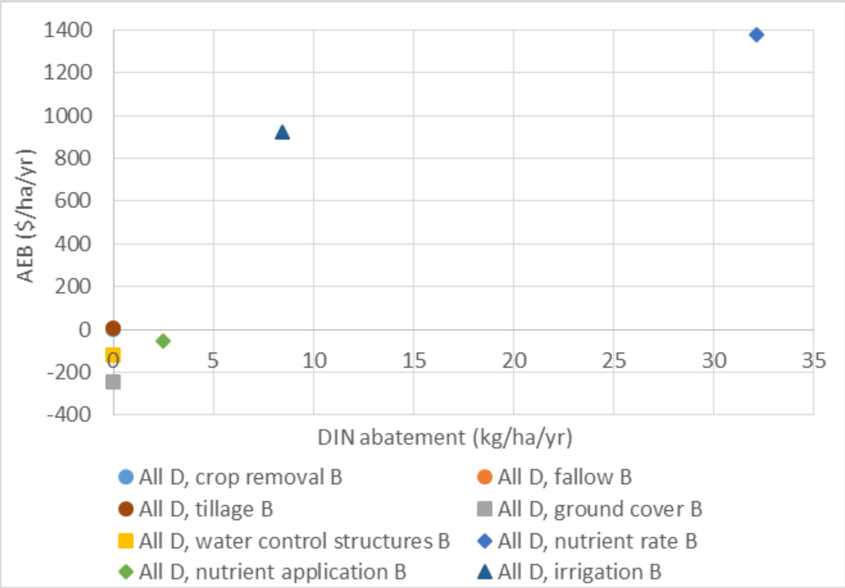

Figure 50: DIN abatement cost effectiveness: changing practice groups from D to B (100 ha farm, Ferrosol soil

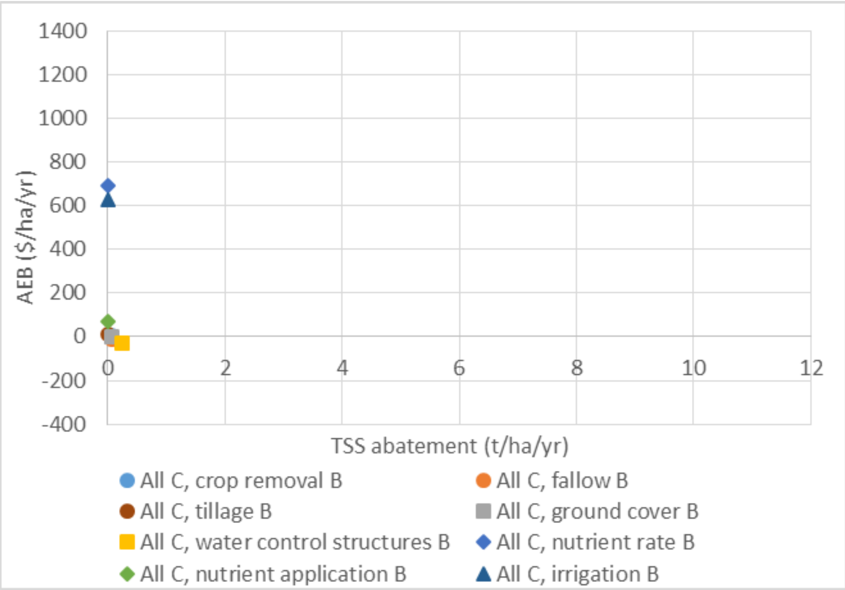

Figure 51: TSS abatement cost effectiveness: changing practice groups from C to B (100 ha farm, Ferrosol soil)

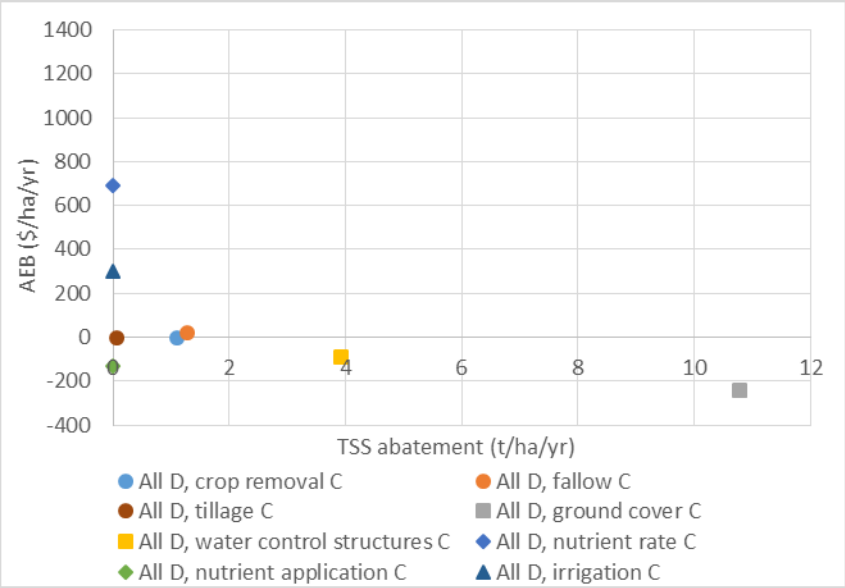

Figure 52: TSS abatement cost effectiveness: changing practice groups from D to C (100 ha farm, Ferrosol soil)

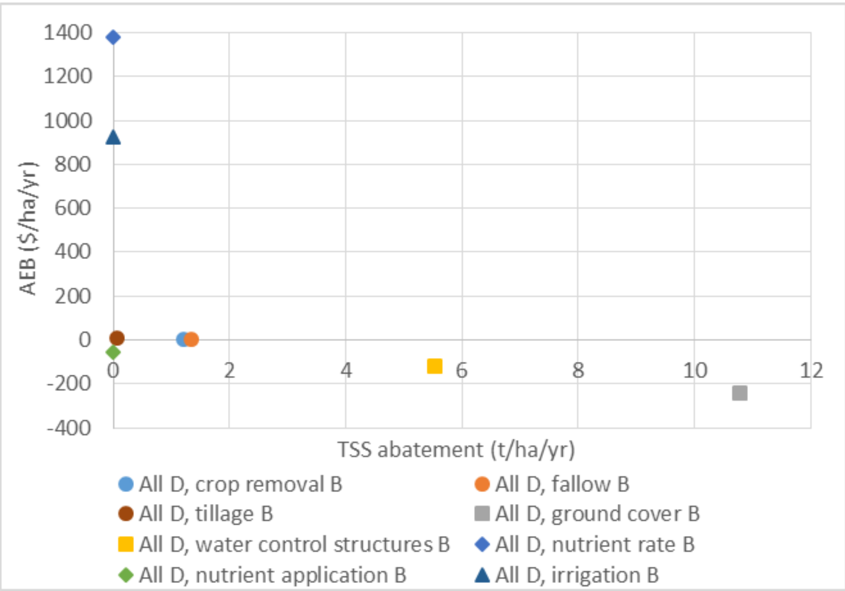

Figure 53: TSS abatement cost effectiveness: changing practice groups from D to B (100 ha farm, Ferrosol soil

9 References

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