Understanding the economics of grain cropping management practices and systems for improving water quality run-off in the Great Barrier Reef catchment areas

Reef Plan Action 2.4: Gap Analysis Report

2019

Queensland Government

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Executive Summary

Improving water quality is an important contributor to the resilience and recovery of the Great Barrier Reef (GBR). Agricultural land use in the catchments adjacent to the reef is identified as the dominant land-based contributor of pollutant loads. The Scientific Consensus Statement 2017 suggests that broadacre cropping may provide cost-effective outcomes for improving water quality entering the GBR. The total grain cropping area accounts for 2.9% of land usage within the Great Barrier Reef catchment at approximately 1,200,000 ha, however, historical business financial performance in the industry is poor, averaging between 1-2% return on assets. Therefore, there is a need for improved management practices which increase business profitability as well as provide water quality outcomes.

The Paddock to Reef Water Quality (P2RWQ) risk framework outlines practices that can contribute to better water quality outcomes with respect to soil, nutrient and pesticide management. Overall, there was limited published, publicly available information available with economic information on the management practices recommended in the P2RWQ risk framework. More research is available on the biophysical outcomes of using these practices; however, the scope of this document is limited to a review of economic outcomes. As such, it reports on published economic literature linked to recommended practices in the GBR catchment areas and given the limited economic research, found the following:

- Sediment management:
  - Zero tillage is reported to be more profitable (~30%) than conventional tillage systems, however, reduced tillage appears more profitable than zero tillage.
  - Opportunity cropping historically has not been as profitable as specialist summer cropping. It should be noted that these results are sensitive to the climatic window specified in the modelling and price of opportunistic crops available.
  - Implementing controlled traffic was more profitable when compared to random traffic and was economically optimal when implemented with zero tillage.
  - Use of tillage and controlled traffic is reported by industry data to be well adopted. Therefore, the remaining P2R soil management practices, crop selection and erosion control, are likely to be the primary risks to water quality.
  - There is no published research that includes an economic analysis of a comparison between retaining various levels of stubble cover or no stubble cover.
  - There is no published research that includes an economic analysis of erosion control practices.
- Nutrient management:
  - Research suggests that incorporating high pulse crop frequency into the crop rotation can reduce the nitrogen (N) fertiliser requirements and improve business profitability.
  - No published research was found that includes the economics of matching yield and protein data to formulate soil sampling strategies and N management decisions for crop performance zones.

- Bio-economic modelling suggests that investments in tactical N application is economically optimal in systems which take plant available water capacity (PAWC) and nitrate (NO_3) levels into account.
- No published research was available on the timing of application to minimise potential losses and maximise uptake of N fertiliser.

- Pesticide management:
  - No published studies were available for the management practices as they relate to pesticide management in the GBR catchment areas, therefore, all economic outcomes of these practices remain a gap.

This report identified broad gaps in economic knowledge occurring in all aspects of practices listed under the P2RWQ risk framework for the GBR catchment areas. Much of the information included in the review is dated and may not be applicable under current market conditions. Therefore, the areas for economic validation under Action 2.4 include the following:

- Regionally relevant economic research regarding all practices listed within the P2RWQ risk framework requires updating.
- The development of economic decision support tools to enable farmers to develop customised advice on the adoption of improved management practices.
- Collaboration with project partners to provide economic expertise in research trials to validate the profitability, risk and cost-effectiveness of the adoption of new management practices. Additionally, using specific case studies may help to better understand the economic implications in a commercial setting.
- As many of the management practices are inextricably connected, analysis is required to identify interactions as well as the agronomic and economic performance of individual practices within a whole-of-business systems approach. A whole-of-business systems approach may assist in understanding the combined impact on social, economic and environmental outcomes and resultant adoption levels. The current published economic information available for these management practices provide mostly comparative gross margins, which fails to consider farming system dynamics. For example, nitrogen fixed from a legume crop could save fertiliser costs for subsequent cereal crops which may not be represented by a gross margin. Fixed costs should also be considered where substantive changes need to be made for adoption of a practice or new system.
- Only one of the studies reviewed (Mason, et al., 1995) provided evidence of a whole of business economic analysis for *changing* management practice (i.e. change in business profitability). Other reviewed studies calculated economic outcomes of operating different cropping systems and consequently no inference can be made as to whether changing from a conventional to recommended system is profitable. Therefore, there is a need to determine the whole-of-business impact of the adoption of the management practices in the P2RWQ risk framework, including detailed consideration of the implementation phase on business outcomes.

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1 Introduction

The collective impact of land run-off continues to contribute to the declining health of the Great Barrier Reef (GBR) ecosystems. The Scientific Consensus Statement (SCS) 2017 (Waterhouse, et al., 2017) concludes that nutrients, fine sediments and pesticides pose a water quality risk to the reef, with agriculture recognised as the main source of these water pollutants. The SCS identifies broadacre cropping as an opportunity of short-term cost-effective outcomes.

The Reef 2050 Water Quality Improvement Plan (WQIP) 2017-2022, is a collaborative program between the Australian and Queensland Governments to improve the quality of water entering the Great Barrier Reef. Reef 2050 WQIP aims to reduce the nutrient, fine sediment and pesticide run-off by setting targets to reduce these pollutants for the grazing, sugarcane, banana, grain, and horticulture industries. The 2025 target is for 90% of land to be managed under best management practices in the aforementioned industries.

Action 2.4 of Reef 2050 WQIP aims to "identify and address barriers to change and practice improvement uptake through programs and policy" (Australian and Queensland Governments, 2018). The second deliverable of this action requires the Queensland Government to "conduct economic evaluations to validate the economics of management practices that improve water quality and provide information to landholders as part of the extension program." This report is the initial synthesis review to identify gaps in knowledge of best practices to fulfil the commitments under the action.

1.1 Report objectives

The objective of this report is to provide support to the second deliverable of Action 2.4, as mentioned above. In particular, the information complied in this report aims to:

- Briefly examine the business environment of the grains industry in the GBR catchment.
- Provide a summary of the latest information available on the economic feasibility of management practices that improve water quality run-off from farms for the grains sector.
- Identify information gaps regarding the economic feasibility of priority management practices as well as opportunities for future work to address these gaps.

The information from this report can also assist in prioritisation of investment in the most economically feasible management practices and systems that improve water quality at a regional/catchment scale.

The widespread adoption of best management practices by landholders, identified as delivering improved water quality outcomes, is a key mechanism to improving the health of the GBR ecosystem. For this to occur, management practices must not only address water quality concerns but also maintain or improve farm profitability (Harvey, et al., 2016).

1.2 Report scope and approach

Through Reef 2050 WQIP, significant work has been undertaken to identify the most critical commodity specific practices impacting on water quality, and critical areas needing improvements in management practices. The management practices that affect water quality run-off for grain cropping are outlined in the Paddock to Reef (P2R) Grains Water Quality Risk Framework (Appendix A) and are ranked in terms of their risk to water quality outcomes (Lowest, Low, Moderate and High). This report will review the economic work with respect to those management practices. The geographic area of focus for the report is cropping land within the GBR catchment natural resource management

(NRM) regions (Burdekin, Burnett Mary, Cape York, Fitzroy, Mackay Whitsundays and Wet Tropics,). The scope of the literature reviewed for the report is publicly available research accessible online.

There are studies undertaken that focus only on the biophysical component of the management practices listed within the P2RWQ risk framework which did not contain an economic analysis of the practices modelled and therefore are not included. These studies do provide potential economic implications by reporting yield and/or grain protein differences between management practices. However, as yield and/or grain protein levels contribute only in part to the numerous factors that influence profitability, it consequently can be misleading to assume increases in either one of these would result in an overall increase to profitability without further economic evaluation.

Literature exists that contains information on relevant practices based on trials occurring outside the GBR catchment, particularly the Darling Downs area, which may have principles that are transferrable across regions. However, there is sufficient difference with respect to the Darling Downs and other regions, specifically rainfall variability and soil characteristics, which make extrapolation of these studies problematic and potentially erroneous. As such, these studies were excluded from the review in accordance with its geographic scope.

Given the specificity of the P2RWQ risk framework, the studies reviewed have been merged into three broad categories – soil management, nutrient management and pesticide management. Specific practices analysed by the studies are highlighted in the individual review for each category. These broad categories are also consistent with the reporting format of the Reef Report Cards for grains (Australian and Queensland Governments, 2016a).

2 Grain cropping within the Great Barrier Reef catchment areas - industry overview

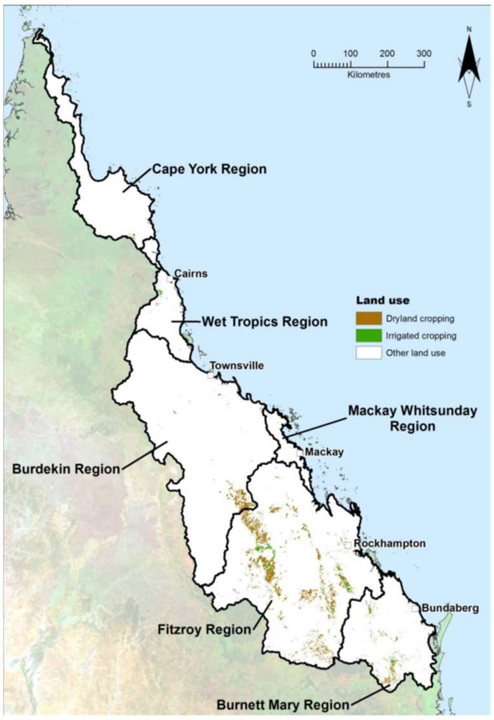
Key Points

- The Fitzroy catchment accounts for 76% of the grain cropping area in the GBR as well as 74% of the gross value of grain production ($291.3million) coming from GBR catchment areas.
- Climate variability is extreme in the grain growing regions of the GBR catchment areas.
- Historical rates of return average 1% (excludes land appreciation value).
- Land value increases were leveraged to raise borrowings, however, it is unclear whether these funds were invested on-farm or utilised elsewhere.
- Cash costs have remained stable over time.

While the focus of this report is to review and identify management practices and systems that deliver critical water quality benefits whilst maintaining grower profitability, it is firstly important to understand the economic environment within which these grain farming businesses operate. An overview of the financial position of the industry identifies possible barriers and constraints that may inhibit farmers moving to improved practices (Harvey, et al., 2016).

Total grain cropping area accounts for 2.9% of land usage within the GBR catchment at approximately 1,200,000 ha for the major cropping catchment areas (Figure 1) (Australian and Queensland Governments, 2016a). The Fitzroy catchment has the largest grain cropping area at 914,000 ha managed by 600 growers. This is 76% of the total GBR cropping area (Australian and Queensland Governments, 2016a). The Burdekin has 44 growers managing 123,000 ha and the Burnett Mary has 280 growers on 80,000 ha (Australian and Queensland Governments, 2016a).

Figure 1 – Great Barrier Reef grain cropping areas



Source: Owens, et al. (2017)

The gross value of broadacre crops in the Fitzroy is $291.3 million, $61.82 million in the Burdekin, $29.21 million in the Burnett Mary, $10.28 million in the Wet Tropics and $0.41 million for the Mackay Whitsunday catchment area (Australian Bureau of Statistics, 2018). Table 1 provides the average production per hectare for each NRM region in 2016-17 financial year (Australian Bureau of Statistics, 2018).

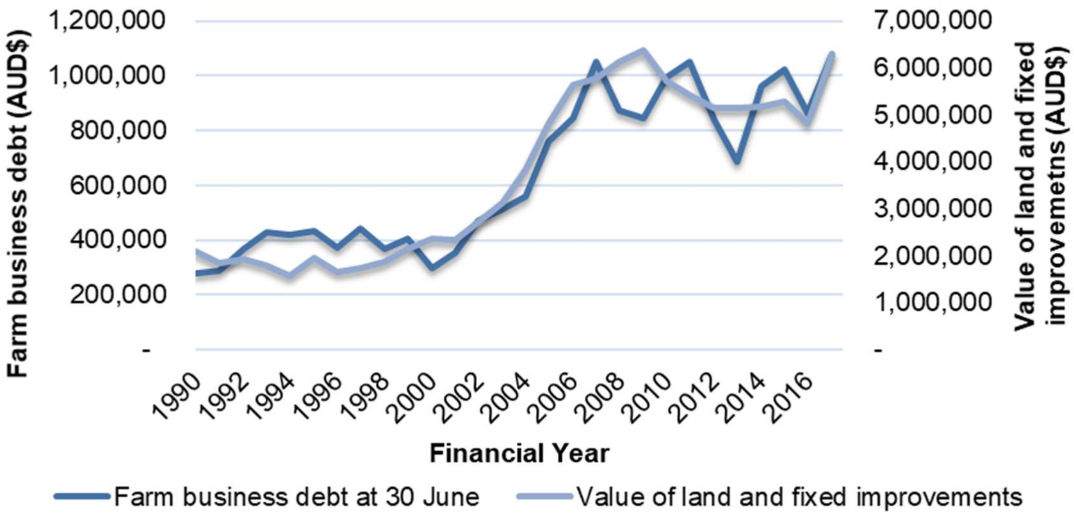
Table 1 – Yield per hectare of NRM region broadacre cereal crops for grain or seed, oilseeds, peanuts and other pulses, 2016-17

	Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Wheat (t/ha)	-	-	1.6	-	2.2	2.9
Oats (t/ha)	-	-	-	-	0.3	0.1
Barley(t/ha)	-	-	2.0	-	2.3	3.0
Sorghum (t/ha)	-	2.6	0.9	-	2.3	2.2
Rice (t/ha)	-	-	3.8	7.5	-	-
Maize (t/ha)	-	8.0	3.3	8.0	4.5	2.1
All other cereals for grain or seed (t/ha)	-	2.7	0.9	-	0.5	4.2
Oilseeds (safflower, soybeans, sunflowers, sesame, linseed) (t/ha)	-	2.4	0.6	1.3	0.3	1.2
Peanuts (t/ha)	-	4.5	-	-	5.9	2.6
Other Pulses (lentils, navy beans, field peas, faba beans, lupins, chickpeas) (t/ha)	-	0.7	1.4	1.2	1.8	1.3

Source: Adapted from Australian Bureau of Statistics (2018)

Data for ABARES region 322 (Australian Bureau of Agricultural and Resource Economics and Sciences, n.d.), which best represents the growing regions in the GBR catchment area, shows a number of trends affecting financial performance of grains businesses. Firstly, business debt increased rapidly in the early to mid-2000's which has been financed through improved land values (Figure 2) (Department of Agriculture and Water Resource Economics and Sciences, 2019). It is possible this debt was used to increase scale through property acquisition, but this is not clear. However, excluding capital appreciation, rate of return on assets has been low over the last 30 years ranging from -2% to 4% (Figure 3). This trend is also evident in business profitability, with 15 of the last 27 years resulting in net losses (Figure 4). Other total cash costs have been relatively stable over time. These trends mean that farmers wishing to re-invest money into the business via management practice change likely need to do so through increased borrowing, as opposed to retained profits.

Figure 2 – Farm business debt vs land value from 1990 to 2017 in real terms

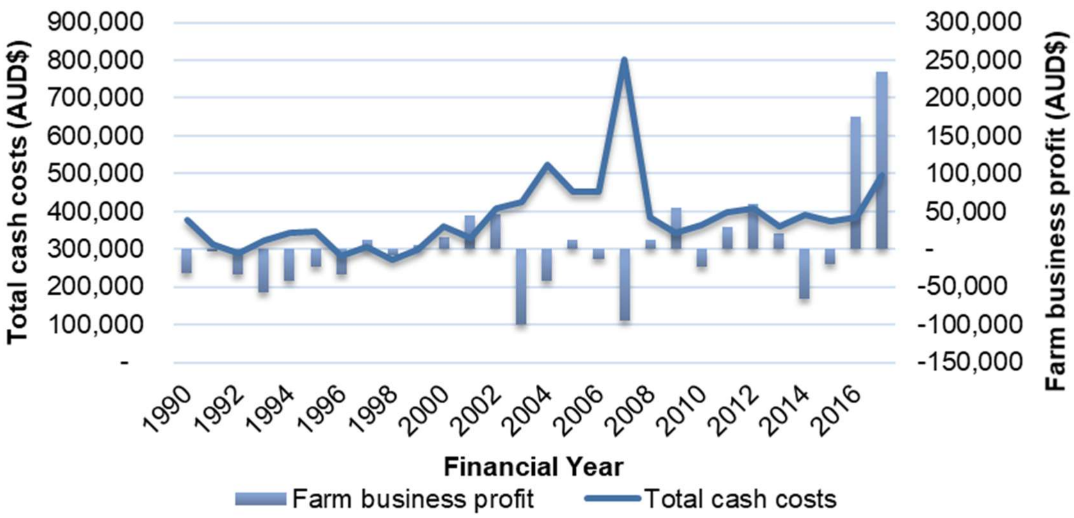


Source: Adapted from Department of Agriculture and Water Resource Economics and Sciences (2019)

Figure 3 – Rate of return excluding capital appreciation from 1990 to 2017 in real terms

Source: Adapted from Department of Agriculture and Water Resource Economics and Sciences (2019)

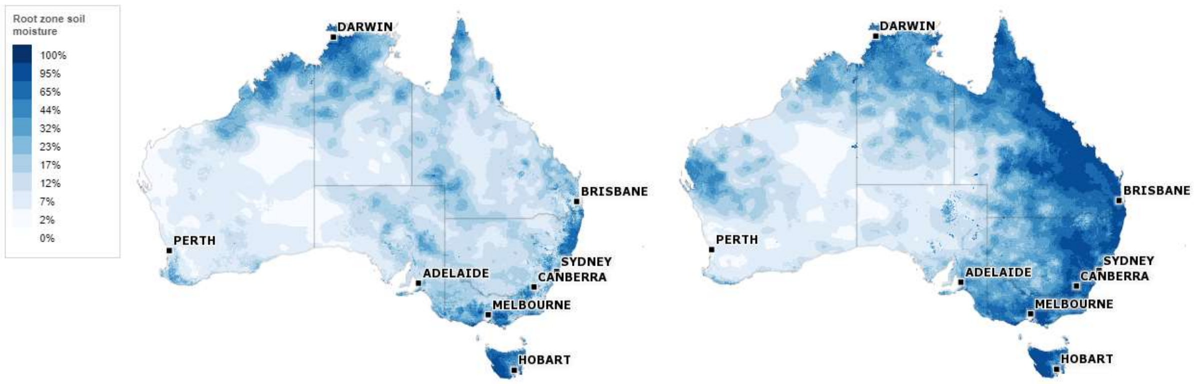
Figure 4 - Total farm cash costs vs farm business profit from 1990 to 2017 in real terms



Source: Adapted from Department of Agriculture and Water Resource Economics and Sciences (2019)

Climate variability is significant in the GBR catchment areas with average annual rainfall varying from about 530 mm in the west, 850 mm in the central regions to approximately 2,000 mm in the northeast ranges near the coast (Bowker, et al., 2008). Rainfall is also extremely variable at any specific location through time with intense rainfall events in the catchments typically generated by monsoonal depressions and tropical cyclones during summer (Bowker, et al., 2008). The extent and effect of climate variability is well demonstrated through available soil moisture indicators. As an example, Figure 5 shows the soil moisture at root zone depths for both 2009 and 2010 seasons. This is indicative of the differences between seasons and the impact on crop potential.

Figure 5 – Root zone soil moisture maps December 2009 (left) and December 2010 (right)



Source: Bureau of Meteorology (2018)

2.1 Current adoption rates of P2RWQ risk framework practices

Key Points

- The Reef Report card shows generally low adoption of recommended management practices in the larger grain growing regions of the GBR catchment, particularly for sediment.

Other sources of adoption information reports:

- Adoption of controlled traffic has improved over the last 4 years from ~40% to ~60%.
- Controlled traffic and minimal tillage practices have a high adoption rate (>60%).
- Reported practice adoption for sediment control (tillage and wheel traffic) is reported at 45% overall, suggesting that the crop selection practice within the P2R risk framework has a low adoption rate.
- Adoption of yield mapping has improved over the last 4 years from 13% to 32%.
- Adoption of variable rate nutrient application is currently 0%.

The current adoption rates for practices recommended under the P2RWQ risk framework are shown in Table 2 (Australian and Queensland Governments, 2016a). These numbers represent the proportion of land being managed under recommended practices for each pollutant across all GBR catchments. The P2R adoption reporting uses a weighting system to determine management practice adoption, of which details are included in the Management practice methods report (Australian and Queensland Governments, 2016b). At the catchment level, while the trend is consistent with sediment practices having the lowest adoption of any pollutant, there are some differences in adoption levels between catchments. For instance, Burnett Mary having a higher level of adoption for sediment and nutrient practices. Furthermore, there are differences in adoption of practices for pollutants (Figure 6). For example, more than half the industry are at moderate risk for soil management whereas in nutrient management the median risk is moderate-low. Adoption levels show little to no change over the reporting period.

Table 2 – Latest adoption rates of management practices reported by Reef Report Card 2016

Pollutant	Proportion managed under best management practice systems (%)					
	Burdekin	Cape York	Burnett Mary	Fitzroy	Mackay-Whitsunday	Overall
Sediment	31	-	80	44	-	45
Nutrients	48	-	65	54	-	54
Pesticides	92	-	76	70	-	73

Source: Adapted from Australian and Queensland Governments (2016a)

Figure 6 – Reef-wide grains water quality risk over time, by pollutant

Soil	Baseline	2014 Report Card	2015 Report Card	2016 Report Card
Lowest Risk	15%	15%	16%	16%
Moderate-Low Risk	29%	29%	29%	29%
Moderate Risk	55%	55%	54%	54%
High Risk	2%	2%	1%	1%
Nutrient				
Lowest Risk	2%	2%	2%	2%
Moderate-Low Risk	52%	52%	53%	53%
Moderate Risk	41%	41%	41%	41%
High Risk	5%	5%	5%	5%
Pesticide				
Lowest Risk	4%	4%	5%	5%
Moderate-Low Risk	68%	68%	68%	68%
Moderate Risk	27%	26%	26%	26%
High Risk	1%	1%	1%	1%

Source: Australian and Queensland Governments (2016a)

The Grains Research and Development Corporation (GRDC) Farm Practices Survey Report 2016 (Umbers, 2017) details some management practice adoption rates in grain-growing regions in Australia. The results for the Queensland Central agro-ecological zone and the relevant management practices to the P2RWQ risk framework can be viewed in Table 3 (soil management practices) and Table 4 (nutrient management practices). There were no pesticide management practices relevant to the framework that were reported on by the survey and therefore are not included. Whilst not every practice under the P2RWQ risk framework was surveyed, the results provide a general indication of which practices are being adopted. The soil management practices which align to the P2R moderate to lowest risk practices show high adoption rates, except for crop selection and erosion control, which were not included in the report. Contour banks, although also excluded, remain the most common method in controlling erosion and have long been implemented in dryland cropping systems of Queensland since the 1930s (Murphy, et al., 2013).

Table 3 – Average percentages (%) of cropped area utilizing different low risk soil management practices in the Queensland Central agro-ecological zone

Management Practice	2008	2011	2014	2016
Zero-tillage (<10% soil disturbance) and no tillage combined (10-30% soil disturbance)	84.8	70.0	69.9	82.7
Controlled Traffic	39.1	48.6	63.8	60.5
Autosteer	69.6	76.1	84.4	84.9
Fallow managed without tillage	-	-	31.8	27.8
Fallow managed only with herbicides	-	-	69.3	53.5
Retained stubble	-	68.3	84.3	-
Retained stubble (intact)	59.0	63.7	57.6	57.9
Cereal crop planted following a pulse crop in previous year	-	27.6	17.8	22.3
Cereal crop planted after long fallow	-	-	18.0	19.8

Source: Adapted from Umbers (2017)

Table 4 – Average percentages (%) of cropped area utilizing different low risk nutrient management practices in the Queensland Central agro-ecological zone

Management Practice	2008	2011	2014	2016
Variable rate fertiliser technology	Not reported	Not reported	3.1	0.0
Yield Mapping	13.0	17.1	34.7	32.7
Break crop planted for nutritional benefits	Not reported	Not reported	14.3	18.9
Fertiliser program informed by soil testing	23.9	37.9	72.0	54.9
In-season soil test	Not reported	Not reported	5.0	8.3
Soil moisture was measured or assessed through the season	Not reported	37.4	45.9	44.8

Source: Adapted from Umbers (2017)

3 Review of economic studies on management practice changes for improved water quality outcomes

This section of the report will review published economic research and information relating to the management practices as identified by the P2R grains water quality framework discussed in section 1.2 above. Two main economic approaches were used in the publications reviewed and are defined below.

A gross margin analysis is gross revenue less all variable growing costs. This method is useful for short-term decisions where other costs are unchanged, such as capital and overheads.

A whole-of-business approach looks at the impact of a change in farming practice across the whole business. This approach can therefore capture changes in other areas of the production system and business that may not be represented in a gross margin analysis. This approach also takes into consideration capital and overhead expenses as well as timeframes of implementation.

The economic analysis method undertaken depends upon the data collected in a study as determined by the objective of the research and design of the study.

Source: Adapted from Harvey, et al. (2016)

The studies reviewed also utilised biophysical methodologies to determine the biological component. The three types of methodologies used in the studies mentioned are defined below.

A trial approach uses physical, real world and replicated data to produce outcomes.

A bio-economic modelling approach uses plant, soil, climate and management modelling, usually Agricultural Production Systems Simulator (APSIM) for cropping. It is a calibrated modelling approach which uses site-specific inputs.

A desktop modelling approach uses broad information based generally on representative information sources.

Source: Adapted from Moravek, et al. (2017)

3.1 Soil management practices

Key Points

- There is limited published research that includes an economic analysis of soil management practices relating to cropping in the GBR catchment area.
- Three studies found on the use of tillage suggest that conservation tillage practices are more profitable than conventional tillage practices.
- A study that had a crop selection component showed that opportunity cropping was not as profitable compared to specialist summer cropping, however, these results are sensitive to the climatic window specified in the modelling and the price of opportunistic crops available at that time.
- The case study examining controlled traffic suggests that implementing controlled traffic was more profitable compared to random traffic and was economically optimal when implemented with zero tillage.

Four studies were reviewed that examined the economics of using one or more of the soil management practices listed in the P2RWQ risk framework. Table 5 summarises the key points of each study.

Table 5 - Summary of studies reviewed for soil management practices

Year Author	Region	Publication type	Practice	Economic method	Biophysical method
(Radford, et al., 1995)	Fitzroy	Journal Article	Use of tillage	Gross margin analysis	Trial
(Bell, 2014)	Burnett Mary and Cape York	Report	Use of tillage	Whole-of-business	Trial
(Mason, et al., 1995)	Burnett Mary	Conference Proceedings	Use of tillage and controlled traffic farming	Whole-of-business	Desktop modelling
(Chudleigh, et al., 2001)	Fitzroy	Conference Proceedings	Crop selection	Whole-of-business	Bio-economic modelling

Radford, et al. (1995) conducted a trial comparing four tillage treatments for sorghum and wheat crops over 10 years at Biloela in Central Queensland. The tillage practices compared traditional (average four tillage operations a year), stubble mulch, reduced (averaged half of the traditional tillage operations), and no tillage (zero tillage) as well as response to fertiliser treatments (N, N + S, and N + S + Zn) in the final four years. The focus was on the biophysical results rather than economic analysis, but gross margins were provided for the wheat crops from the years 1989 to 1992 (Figure 7). The results found that without soil ameliorants, stubble mulch produced the highest gross margin and no tillage produced the lowest. With the soil ameliorants, the profitability of no tillage increased by 38% but was still not as profitable as reduced tillage or stubble mulch. Traditional tillage generally produced the lowest gross margin. Given yield differences were not significant across some years and crops, it is likely that reduced tillage costs had more influence on the economic results. With no detailed information presented on gross margins, the main influence (i.e. machinery costs, fertiliser costs or increased/decreased yields) affecting these results remains unclear.

Figure 7 - Total gross margin ($/ha) results from 1989 to 1992 for four wheat crops from the Biloela trial

Tillage treatment	Unfertilised	N	N + S	N + S + Zn
Traditional	1078	1013	1154	865
Stubble mulch	1289	1515	1373	1435
Reduced	1192	1445	1430	1445
No tillage	1027	1312	1405	1420

Source: Radford, et al. (1995)

Bell (2014) led Project DAQ00063 'Viable and Sustainable Farming Systems on Ferrosols' which conducted on-farm trials in the inland Burnett and Atherton Tableland to examine the effect of strip tillage on water and nutrient use on a peanut and maize rotation. The project suggests that changing to strip tillage improved water use efficiency and reduced fixed and variable costs in the inland Burnett trials. The practice change also doubled the average operating returns to approximately $200/ha and increased return on assets to 4%, up from 2.4% with conventional tillage. However, the project found that adoption of a strip tillage system without a high value peanut crop in the rotation did not improve profitability and on occasion produced a negative result. The minimum tillage demonstrations in the Atherton Tablelands were discontinued after two years due to negative perceptions around inflexibility of the management practice. It was not reported on which aspects of the management practice were considered inflexible or why. Further investigation may improve insights on the non-adoption of minimum tillage practices, but it is possible this was the result of an increase in the use of mechanical weed control arising from herbicide resistant weeds.

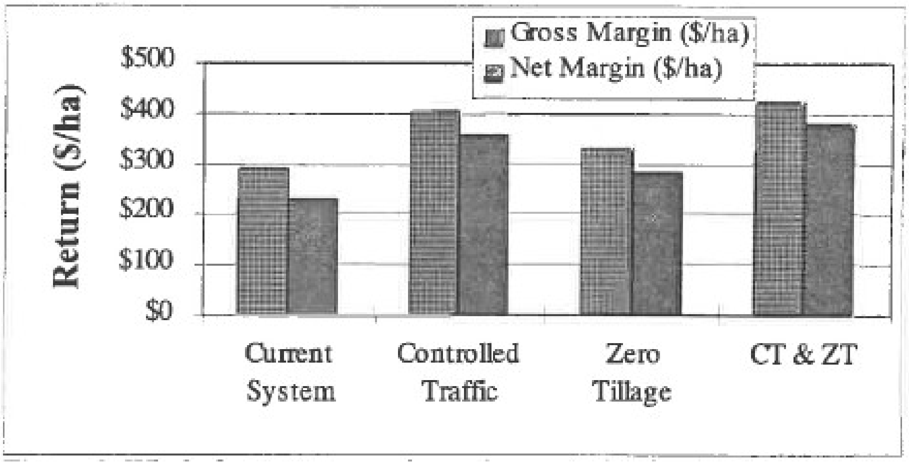
Mason, et al. (1995) modelled the costs, labour requirements and profitability of implementing a controlled traffic system on a case study property in the south Burnett region. The property has up to approximately half of the crops planted per year under zero tillage conditions. The crops are summer dominated with opportunity plantings of winter crops. The typical crops planted are maize, soybeans, sorghum, millet and wheat. The tillage system and crop selection were determined with the aim to maximize profits on soils with lower erosion potential. The following three conservative farming system scenarios were examined:

1. The current system with controlled traffic;
2. A complete zero tillage system; and
3. A combination system of controlled traffic and complete zero tillage.

In the first scenario, there were minimal modifications made to the system with the exception of controlled traffic. It was assumed that fuel consumption would be reduced by 30% due to the implementation of permanent wheel tracks and that there would be a 40% increase in yields for the worst seasons, 10% in the most likely seasons and no yield change in the better seasons. To account for higher nutrient removal from increased yields, fertiliser rates were increased. For the second scenario of a complete zero tillage system, the only operations retained from the current system were planting, slashing and boom-spraying. For the most likely seasons there were assumed to be no change in yield, a 10% increase in the worst seasons and a decline of 10% in the best seasons with a move to zero tillage. The third scenario was a combination of the first and second scenarios, with a 40% yield increase in the worst seasons, 10% increase in the most likely seasons and no change in the best seasons.

The costs for each system were calculated with controlled traffic decreasing variable costs due to less tillage operations. However, the systems with zero tillage increased the variable costs due to an increase in the crop grown as well as higher chemical weed control compared to mechanical weed control. Regardless of these increased costs, the controlled traffic and zero tillage system achieved the highest net margin (Figure 8) reflecting the gross margin less fixed machinery costs.

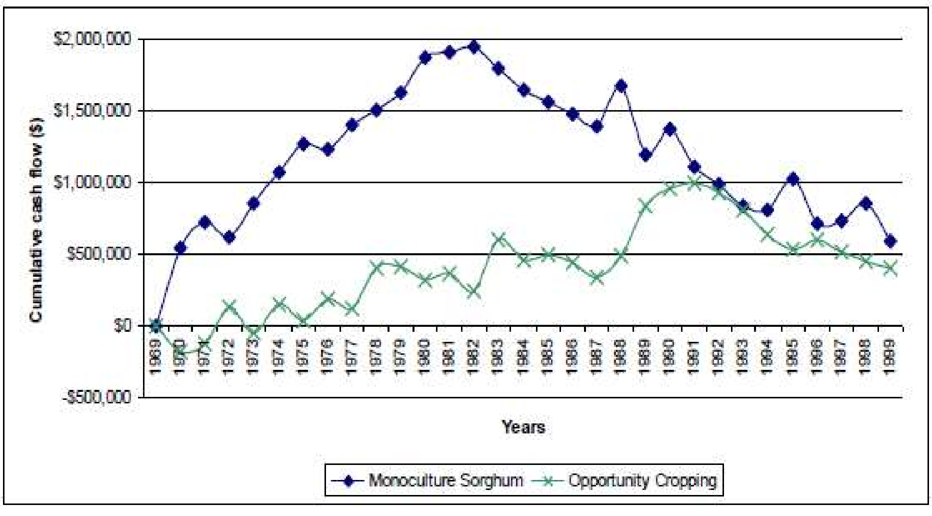
Figure 8 – Modelled whole business gross and net margins for tillage scenarios based on a representative property in the Burnett-Mary Catchment



Source: Mason, et al. (1995)

Chudleigh, et al. (2001) examined alternative farming systems of monoculture sorghum or opportunity cropping (either sorghum or wheat) using APSIM in the Capella district over 30 years. Opportunity cropping was only modelled in years with sufficient PAWC. The systems profitability was largely a function of climatic conditions. Due to summer-dominated rainfall for the district, the monoculture sorghum outperformed the opportunity cropping system (Figure 9 –Figure 9). Prior to 1990, higher than average winter rainfall and lower than average summer rainfall resulted in similar financial positions for both systems. From 1990 to 1999, dry years resulted in profitability declines in both systems. Although opportunity cropping produced reasonable economic results, a winter crop can potentially prevent planting a more reliable crop in a summer dominated rainfall system. This would likely reduce longer-term profitability.

Figure 9 – Cumulative cash flows for the modelled systems



Source: Chudleigh, et al. (2001)

3.2 Nutrient management practices

Key Points

- There is limited published research that includes an economic analysis of nutrient management practices relating to cropping in the GBR catchment area.
- Bio-economic modelling indicates that determining N application rates based upon both rather than individual PAWC or $N0_3$ levels is economically optimal.
- Research suggests that incorporating high pulse crop frequency into the crop rotation can reduce the N fertiliser requirements and improve business profitability.

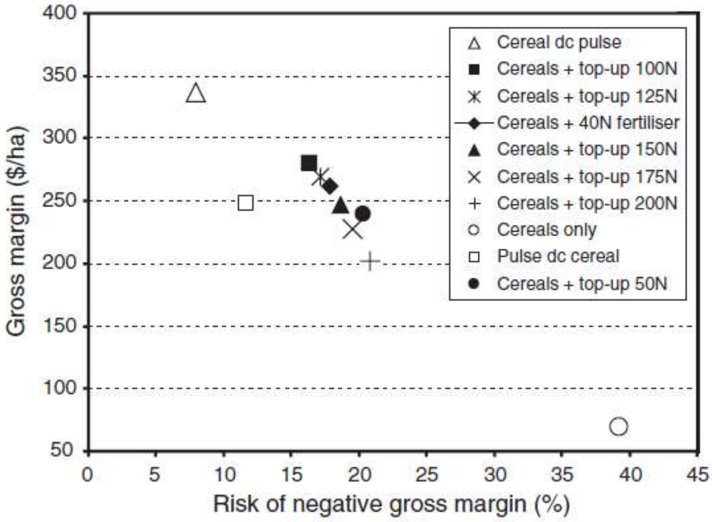
Four studies were reviewed that examined the economics of using one or more of the nutrient management practices listed in the Grains Water Quality Risk Framework. Table 6 summarises the key points of each study reviewed.

Table 6 - Summary of studies reviewed for nutrient management practices

Year Author	Region	Publication type	Practice	Economic method	Biophysical method
(Cox, et al., 2010)	Fitzroy	Journal Article	Determining nitrogen requirements	Gross margin analysis	Trial & bio-economic modelling
(Cox & Chudleigh, 2001)	Fitzroy	Conference proceedings	Determining nitrogen requirements and Influence of stored soil moisture on yield and N fertiliser decisions	Whole-of-business	Bio-economic modelling
(Aisthorpe & McCosker, 2018)	Fitzroy	Report	Determining nitrogen requirements	Whole-of-business	Trial
(Chudleigh, et al., 2001)	Fitzroy	Conference proceedings	Determining nitrogen requirements and Influence of stored soil moisture on yield and N fertiliser decisions	Whole-of-business	Bio-economic modelling

Cox, et al. (2010) conducted three replications of three different rotations at Jambin in Central Queensland over four years as well as simulation modelling over 99 years with APSIM to determine whether incorporating a pulse crop into a cereal rotation would reduce the N fertiliser requirement (provided low soil water did not compromise the yield potential of the pulse crop). The rotations consisted of cereals-only (sorghum and wheat were opportunity planted in rotation), cereal double-cropped pulse (cereals were planted after a fallow followed by a pulse crop), and pulse double-cropped cereal (pulses were planted after a fallow followed by a cereal crop). The gross margins of tactical N strategies as well as topping N levels up to 50, 100, 125, 175 and 200 kg N/ha were modelled. The most profitable tactical N strategy was 100 kg N/ha whilst increasing N levels above this resulted in negative returns and increased risk due to diminishing yield improvements. The results also indicated that the highest gross margin was the cereal double-cropped pulse with the lowest downside risk. Cereals-only was the least profitable as well as having the highest downside risk (Figure 10).

Figure 10 - Modelled long-term gross margins and percent of crops with negative gross margins over 99 years. Open symbols represent field results from Jambin with closed symbols representing modelled tactical N strategies



Source: Cox, et al. (2010)

Cox & Chudleigh (2001) examined different cropping system scenarios with whole business economics on two example farms for wheat and sorghum crops in the Central Queensland region utilising the APSIM modelling tool. The example farms were characteristic of the Dawson Callide and Central Highlands districts with farms modelled at Biloela and Capella respectively. A monoculture of each crop as well as an opportunity cropped system of both crops under no-till with three levels of soil fertility (low, medium and high), four nitrogen rates (0, 50, 100 kg N/ha and tactical application) and different plant available water capacity levels (100mm & 158mm for Biloela and 90mm, 120mm & 150mm for Capella) were simulated. The modelled results showed that matching soil water and NO_3-N through tactical N rate application would more likely provide the highest economic return. It was not economical for any cropping system to apply N on soils with high N fertility, regardless of high or low the PAWC. Additionally, in all scenarios low PAWC reduced potential profiability regardless of inherent soil fertility.

Aisthorpe & McCosker (2018) began an ongoing project in 2015 that is examining the performance of six different farming systems at Emerald in Central Queensland over 5-10 years. The details of each system can be viewed in Table 7.

Table 7 - Treatment details

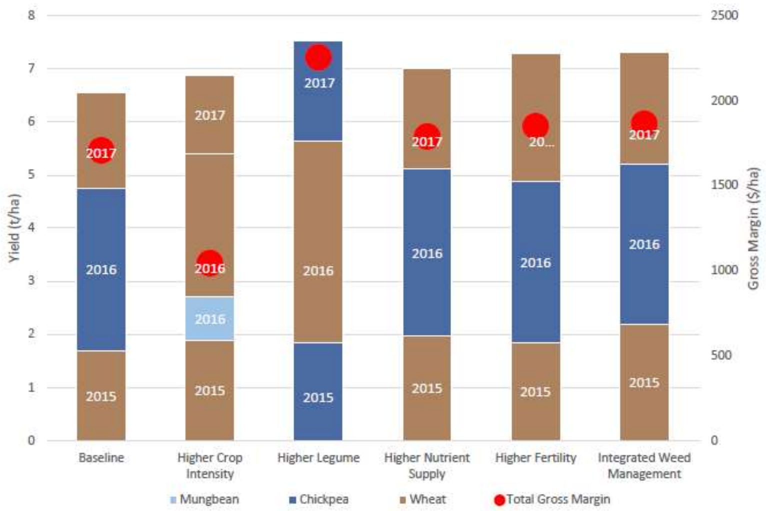
Treatment Number	Treatment Name	Practices	Crop Selection
1	Baseline	• Zero tillage • 1 crop per year • Fertiliser rate matched to support 50 percentile yield potential relative to PAW at sowing	Wheat, chickpea, sorghum
2	Higher Legume	• Increased pulse cropping frequency	Wheat, chickpea (chickpeas are not double cropped), sorghum, mungbean, new legume crops

3	Higher crop intensity	• Increased cropping intensity to 1.5 crops per year	Wheat, chickpea, sorghum, mungbean, forage crops/legumes
4	Higher nutrient supply	• Fertiliser rate matched to support 90 percentile yield potential relative to PAW at sowing	Same as 'baseline' system
5	Higher soil fertility	• Same treatment as 'high nutrient supply' system but 20t/ha manure applied in 2015 and an additional 40t/ha applied in 2016	Same as 'high nutrient supply' system
6	Integrated weed management (IWM)	• Practices that reduced usage of traditional knockdown herbicides: residual and contact herbicides, tillage with full disturbance planting, crop choice, narrow rows, high plant population and other emerging technologies	Wheat, chickpea, sorghum, mungbean

Source: Adapted from Aisthorpe & McCosker (2018).

The results show that the higher legume system produced the highest cumulative grain yield and provided the highest total gross margin per hectare at long term prices (Figure 11). Each system also removed more N from the system than what was applied, except for the higher legume system which increased the amount of available N through nitrogen fixation. One of the limitations of the trial was that it was conducted during periods of drought and it is possible results might be different during wetter years.

Figure 11 - Cumulative total gross margins and grain yields at the conclusion of the 2017 winter system



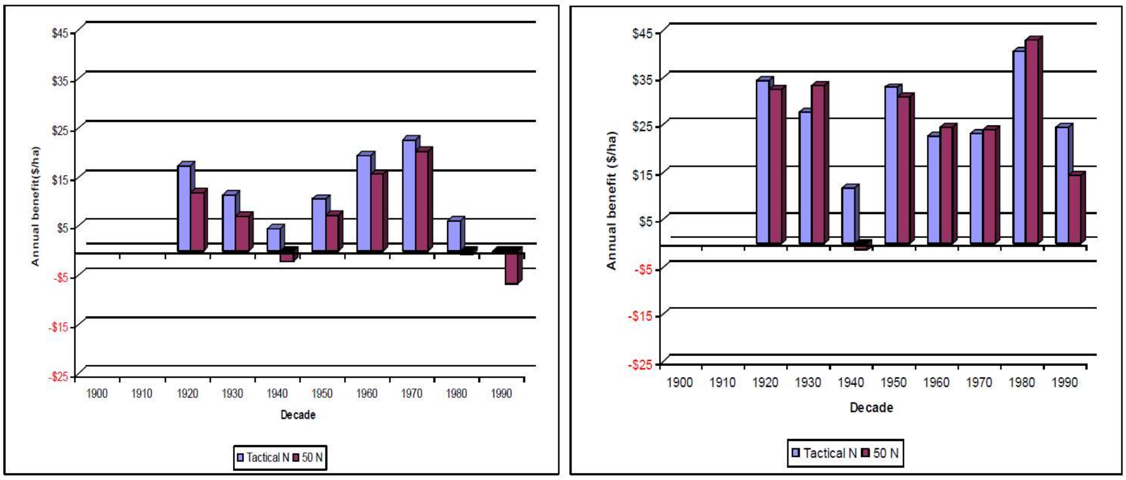
Source: Aisthorpe & McCosker (2018)

Chudleigh, et al. (2001) conducted bio-economic modelling using APSIM to simulate and evaluate the sustainability and profitability of a range of different farming systems for the Sustainable Farming Systems for Central Queensland (DAQ382) project. Multiple outputs were examined for determining nitrogen requirements, application techniques and the the influence of PAWC on nitrogen fertiliser decisions with an economic analysis. Some of these outputs were as follows:

- Modelling the effect of varying soil PAWC – this scenario was used to determine the optimal fertiliser rate and application technique based on varying levels of PAWC for the Capella district over 8 different 30 year climate periods. PAWC of 90mm, 120mm and 150mm with fixed rates of 0, 50 or 100 kg N/ha per crop were modelled as well as a tactical application method where technology was used to apply N based on PAWC. While it appears that gross margins are slightly improved through tactical applications (approximately $15/ha increase in GM vs applying a flat rate of fertiliser), this marginal increase in gross margin is not able to offset the investment costs of setting up a system capable of applying tactical N. The authors state that "it appears uneconomic to invest in technology to apply optimal fertiliser rates to each soil PAWC…". However, the paper does not outline the investment costs used in the analysis, time period of the analysis or major assumptions used for the analysis.

- Modelling tactical N fertiliser application - this scenario involved determining the profitability of tactical N fertiliser application based on soil NO_3 and water levels versus a set N application rate. It was also modelled on the Capella district with an average PAWC and medium nitrogen soil. The tactical N and set 50kg N/ha was applied to both a monoculture sorghum and opportunity cropping system of wheat and sorghum. The results suggest that there is not much of an economic difference in applying fertiliser tactically against a fixed amount at planting (Figure 12).

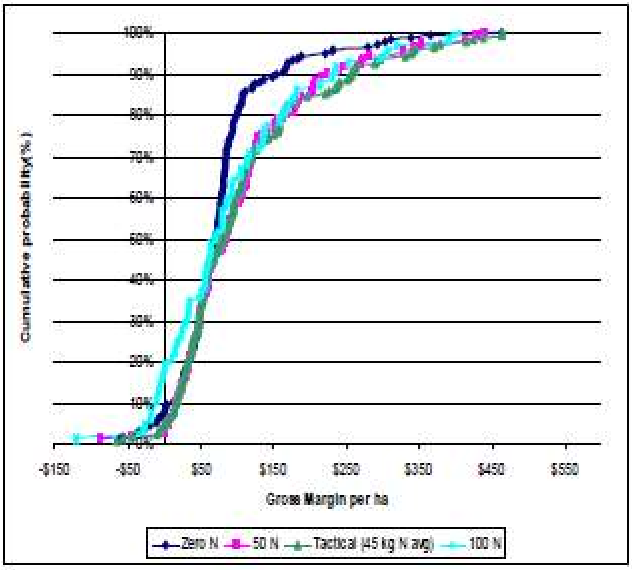
Figure 12 - Annual benefits per hectare of applying N fertiliser to monoculture sorghum (left) or opportunity cropping of wheat and sorghum (right)



Source: Chudleigh, et al. (2001)

- Modelling the application of N fertiliser to wheat - this scenario investigated the profitability and risk outcomes of applying different fertiliser rates to wheat, either at 0, 50, 100 kg N/ha and tactical N – which averaged at 45 kg N/ha. The results found that the probability of gross margin returns did not appear to be any different at the average return, nor across the risk distribution, for any of the fertilised treatments (Figure 13). While the study did not conduct an investment analysis, given there was no benefit to recoup any potential investment required to adopt variable rate technology, it would not be possible for a profitable investment.

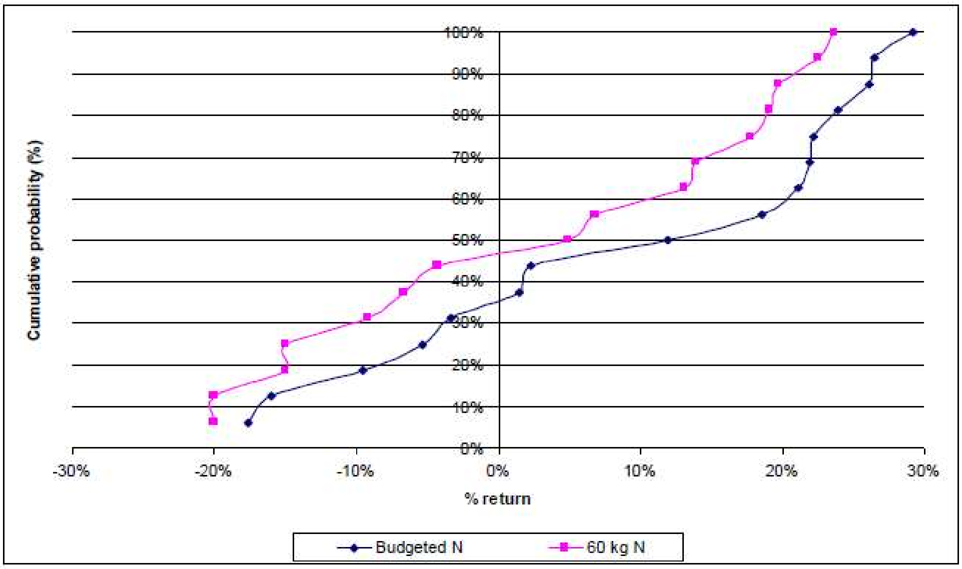
Figure 13 – Modelled distribution of business returns on an annual basis for set and tactical fertiliser treatments



Source: (Chudleigh, et al. (2001)

- Modelling the response to N fertiliser - this scenario was based on a 4.5 year trial at the site "Moonggoo", which compared applying tactical (budgeted) N rates (ranging between 30 – 40 kg N/ha) against a fixed rate of 60 kg N/ha. The tactical rate was calculated using both soil moisture and soil nitrates. The results of the trial were used to calibrate APSIM to determine whether it was more profitable and to understand the risks in applying the different treatments. The results showed that applying tactical N rates achieved higher returns, both on average and across the entire distribution of returns when compared to fixed rates (Figure 14).

Figure 14 – Modelling of distributed return on investment earned by each crop with different fertiliser treatments based on the Moonggoo trial



Source: (Cox & Chudleigh (2001)

3.3 Pesticide management practices

Key Points

- There were no published economic studies found relating to practices in pesticide management for the GBR catchment area.

The review found no GBR catchment area literature that contained an economic analysis of using pesticide management practices listed under the P2R water quality risk framework. Pesticide, herbicide and insecticide use for crop protection is widely adopted by agriculture worldwide. Investigations into crop protection use on broadacre crops has contributed over 54% of the value of gross value of agricultural product, demonstrating their importance in reducing risk (Deloitte Access Economics, 2018). However, the report notes that it was not a cost-benefit analysis of use versus non-use of crop protection products. Furthermore, that there was limited global research available on the economic contribution of crop protection products.

Outside of the GBR catchment, Bennett & Pannell (1998) modelled an economic analysis in Western Australia for the variable rate application technology named Weed Activated Spray Process (WASP). The results indicated that there was little economic benefit derived from the technology. This was due to the area of crop either requiring too high a level of spray, which was not significantly different to using a conventional sprayer, or that the area was too small proving almost no difference against not spraying. Approximately 15% of modelled scenarios did show that WASP could be profitable in terms of gross margins, however, the investment cost of the technology outweighed any net positive benefit at the time of the study. It should be noted that the results from this study are dated and further investigation would be necessary under current market conditions for relevant economic validation of variable rate application technology.

The lack of available research is consistent with a synthesis review on pesticides and herbicide use as part of an integrated pest management plan that stated *"There were no examples found of the economic impacts (either positive or negative) to a grower of applying an integrated pest and weed management plan"* (Department of Agriculture, Fisheries and Forestry, 2014). The review contains a list of case studies conducted in sugarcane growing regions that reported on biophysical aspects (predominately water quality run-off) in adopting certain herbicide and pesticide management practices, however, the applicability of those case studies, given the high rainfall areas they were conducted in, are outside the scope of this review.

4 Key findings, information gaps and potential future work

The key findings and information gaps identified in economic research for each priority management categories as well as areas for future economic work are listed in the following sub-sections.

4.1 Soil management practices

The key findings and major economic information gap/s identified by the review regarding these management practices were:

- Zero tillage is reported to be more profitable (~30%) than conventional tillage systems, however, reduced tillage appears more profitable than zero tillage.
- Opportunity cropping historically has not been as profitable as specialist summer cropping. It should be noted that these results are sensitive to the climatic window specified in the modelling and price of opportunistic crops available.
- Implementing controlled traffic was more profitable when compared to random traffic and was economically optimal when implemented with zero tillage.
- Use of tillage and controlled traffic is reported by industry data to be well adopted. Therefore, the remaining P2R soil management practices, crop selection and erosion control, are likely to be the primary risks to water quality.
- There is no published research that includes an economic analysis of a comparison between retaining various levels of stubble cover or no stubble cover.
- There is no published research that includes an economic analysis of erosion control practices.

4.2 Nutrient management practices

The key findings and major economic information gap/s identified by the review regarding these management practices were:

- Research suggests that incorporating high pulse crop frequency into the crop rotation can reduce the N fertiliser requirements and improve business profitability.
- No published research was found that includes the economics of matching yield and protein data to formulate soil sampling strategies and N management decisions for crop performance zones.
- Bio-economic modelling suggests that investments in tactical N application is economically optimal in systems which take PAWC and NO_3 levels into account.
- No published research was available on the timing of application to minimise potential losses and maximise uptake of N fertiliser.

4.3 Pesticide management practices

The key findings and major economic information gap/s identified by the review regarding these management practices were:

- No published studies were available for the management practices as they relate to pesticide management in the GBR catchment areas, therefore, all economic outcomes of these practices remain a gap.

4.4 Future work

As identified, there are broad gaps in economic knowledge occurring in all aspects of practices listed under the P2RWQ risk framework for the GBR catchment areas. Much of the information included in the review is dated and may not be applicable under current market conditions. Furthermore, based on data pertaining to current adoption levels in the Reef Report Card 2016, soil and nutrient management practices have the lowest adoption at 45% and 54% respectively, when compared to 73% for pesticide management. Therefore, further examination into soil and nutrient management practices should be an immediate priority. The areas for economic validation under Action 2.4 include the following:

- Regionally relevant economic research regarding all practices listed within the P2RWQ risk framework requires updating.
- The development of economic decision support tools to enable farmers to develop customised advice on the adoption of improved management practices.
- Collaboration with project partners to provide economic expertise in research trials to validate the profitability, risk and cost-effectiveness of the adoption of new management practices. Additionally, using specific case studies may help to better understand the economic implications in a commercial setting.
- As many of the management practices are inextricably connected, analysis is required to identify interactions as well as the agronomic and economic performance of individual practices within a whole-of-business systems approach. A whole-of-business systems approach may assist in understanding the combined impact on social, economic and environmental outcomes and resultant adoption levels. The current published economic information available for these management practices provide mostly comparative gross margins, which fails to consider farming system dynamics. For example, nitrogen fixed from a legume crop could save fertiliser costs for subsequent cereal crops which may not be represented by a gross margin. Fixed costs should also be considered where substantive changes need to be made for adoption of a practice or new system.
- Only one of the studies reviewed (Mason, et al., 1995) provided evidence of a whole of business economic analysis for *changing* management practice (i.e. change in business profitability). Other reviewed studies calculated economic outcomes of operating different cropping systems and consequently no inference can be made as to whether changing from a conventional to recommended system is profitable. Therefore, there is a need to determine the whole-of-business impact of the adoption of the management practices in the P2RWQ risk framework, including detailed consideration of the implementation phase on business outcomes.

5 References

Aisthorpe, D. & McCosker, E., 2018. *Northern Farming Systems - Emerald regional site.* Queensland grains research 2017-18, Department of Agriculture and Fisheries: State of Queensland.

Australian and Queensland Governments, 2016a. *Great Barrier Reef Report Card 2016,* Brisbane: State of Queensland.

Australian and Queensland Governments, 2016b. *Great Barrier Reef Report Card 2016: Management practice methods,* Brisbane: State of Queensland.

Australian and Queensland Governments, 2018. *Reef 2050 Water Quality Improvement Plan 2017-2022,* Brisbane: State of Queensland.

Australian Bureau of Agricultural and Resource Economics and Sciences, n.d. *Australian broadacre zones and regions.* [Online]
Available at: http://apps.agriculture.gov.au/agsurf/regions.html
[Accessed 24 June 2019].

Australian Bureau of Statistics, 2018. *Agricultural Commodities, Australia, 2016-17, cat. no. 7121.* [Online]
Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/7121.0
[Accessed 14 February 2019].

Australian Bureau of Statistics, 2018. *Value of agricultural commodities produced, Australia, 2016-17, cat. no. 7503.* [Online]
Available at: https://www.abs.gov.au/ausstats/abs@.nsf/mf/7503.0
[Accessed 14 February 2019].

Barson, M., Mewett, J. & Paplinska, J., 2012. *Land management practice trends in Australia's broadacre cropping industries. Caring for our Country Sustainable Practices fact sheet 3,* Canberra: Commonwealth of Australia.

Bell, M., 2014. *Viable and sustainable farming systems on Ferrosols,* Canberra: Grains Research and Development Corporation (GRDC).

Bennett, A. L. & Pannell, D. J., 1998. Economic evaluation of a weed-activated sprayer for herbicide application to patchy weed populations. *The Australian Journal of Agricultural and Resource Economics,* 42(4), pp. 389-408.

Bowker, M. A. et al., 2008. Prioritizing Conservation Effort through the Use of Biological Soil Crusts as Ecosystem Function Indicators in an Arid Region. *Conservation Biology,* 22(6), pp. 1533-1543.

Bureau of Meteorology, 2018. *Australian Landscape Water Balance.* [Online]
Available at: http://www.bom.gov.au/water/landscape/#/sm/Actual/month/-29.93/133.13/3/Point////2009/12/31/
[Accessed 18 February 2019].

Chudleigh, F., Cox, H. & Chapman, V., 2001. *Modelling profitable and sustainable farming systems in Central Queenlsand.* Canberra, Australian Agricultural and Resources Economics Society.

Cox, H. W. & Chudleigh, F. C., 2001. *Modelling strategic nitrogen fertiliser decisions for Central Queensland farming systems.* Hobart, The Australian Society of Agronomy.

Cox, H. W., Kelly, R. M. & Strong, W. M., 2010. Pulse crops in rotation with cereals can be a profitable alternative to nitrogen fertiliser in central Queensland. *Crop & Pasture Science,* 61(9), pp. 752-762.

Davies, S. et al., 2017. *Developing a controlled traffic (tramline) farming system.* [Online]
Available at: https://www.agric.wa.gov.au/soil-compaction/developing-controlled-traffic-tramline-farming-system
[Accessed 2 July 2019].

Deloitte Access Economics, 2018. *Economic activity attributable to crop protection products,* s.l.: Deloitte Access Economics.

Department of Agriculture and Water Resource Economics and Sciences, 2019. *AGSURF data - Australian Bureau of Agriculture and Resources.* [Online]
Available at: http://apps.daff.gov.au/agsurf/
[Accessed 18 February 2019].

Department of Agriculture, Fisheries and Forestry, 2014. *Pesticide use as a part of an integrated pest management plan,* Brisbane: State of Queensland.

Grains Research & Development Corporation (GRDC), 2009. *Water Use Efficiency Fact Sheet.* [Online]
Available at: https://grdc.com.au/__data/assets/pdf_file/0028/207667/water-use-efficiency-southwest.pdf.pdf
[Accessed July 2 2019].

Harvey, S., Poggio, M., Thompson, M. & Holligan, E., 2016. *Understanding the economics of improved management practices and systems on sugarcane farms,* Brisbane: State of Queensland.

Leskovar, D., Othman, Y. & Dong, X., 2016. Strip tillage improves soil biological activity, fruit yield and sugar content of triploid watermelon. *Soil and Tillage Research,* Volume 163, pp. 266-273.

Mason, R. M., Page, J. R., Tullberg, J. N. & Buttsworth, P. K., 1995. *The Economics of Controlled Taffic: South Burnett Case Study.* Rockhampton, National Controlled Traffic Conference.

Moravek, T. et al., 2017. *Understanding the economics of grazing management practices and systems for improving water quality run-off from grazing lands in the Burdekin and Fitzroy Catchments,* Brisbane: State of Queensland.

Murphy, T., Dougall, C. & Carroll, C., 2013. Runoff water quality from dryland cropping on Vertisols in Central Queensland, Australia. *Agriculture, Ecosystems & Environment,* Volume 180, pp. 21-28.

Owens, J., Silburn, M. & Shaw, M., 2017. *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Grains Cropping Modelling, Technical Report, Great Barrier Reef Report Card 2014 and 2015,* Brisbane: The State of Queensland. Unpublished.

Queensland Government, 2019. *Grains Water Quality Risk Framework 2017-2022.* [Online]
Available at: https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/management-practices
[Accessed 28 August 2019].

Radford, B. J., Key, A. J., Robertson, L. N. & Thomas, G. A., 1995. Conservation tillage increases soil water storage, soil animal populations, grain yield, and response to fertiliser in the semi-arid subtropics. *Australian Journal of Experimental Agriculture,* 35(2), pp. 223-232.

Umbers, A., 2017. *GRDC Farm Practices Survey Report 2016,* Canberra: Grains Research & Development Corporation (GRDC).

Waterhouse, J. et al., 2017. *2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition,* Brisbane: The State of Queensland.

Appendix A Paddock to Reef grains water quality risk framework

Soil management (weighting)	**Relative water quality risk**				
	Lowest risk (A) Innovative	**Moderate – Low risk (B)** Best practice	**Moderate risk (C)** Minimum standard	**High risk (D)** **Superseded**	**Not applicable**
Use of tillage (30%)	As for best practice AND Strategy to control certain difficult to control weeds may involve occasional zonal or 'patch' tillage. Fertiliser is applied using zero-till machinery.	Crops are planted into standing stubble from the previous crop/s. Tillage is only used when required to deal with severe compaction, nutrient stratification, or as part of a strategy to manage certain difficult weeds. Fertiliser is applied using zero-till machinery.	Efforts are made to maintain stubble cover during fallows. Stubble usually needs to be cultivated to allowed for planting and/or fertiliser is applied using full disturbance implements.	Tillage is frequently used for weed control and/or managing stubble.	
Crop selection (30%)	Maintaining >30% stubble cover is high priority when choosing crops. Successive low-stubble crops are avoided. Back to back pulse crops will not occur. Grain crops may be planted into marginal soil moisture for the purpose of increasing ground cover.	Maintaining >30% stubble cover is high priority when choosing crops. Successive low stubble crops are rare. Back to back pulse crops are avoided.	Crop rotation based on planting opportunities and gross margin, with little or no consideration of stubble cover. Back to back pulse crops may be grown if commodity prices are high.		

Soil management (weighting)	Relative water quality risk				
	Lowest risk (A) Innovative	**Moderate – Low risk (B)** Best practice	**Moderate risk (C)** Minimum standard	**High risk (D)** **Superseded**	**Not applicable**
Wheel traffic (20%)	A controlled traffic system is in place with all tractors and implements, headers and mobile grain bins operating on the same set of wheel tracks. All machines operate under GPS guidance of at least 4cm pass to pass accuracy.	A controlled traffic system is in place with all tractors and implements, headers and mobile grain bins operating on the same set of wheel tracks. Spraying and planting occurs under machine guidance of at least 10cm pass to pass accuracy.	All farm equipment except headers and mobile grain bins operates on the same wheel spacing and consistent implement width.	Farming equipment has different widths and wheel spacing.	
Erosion control (20%)	Contour and diversion banks are present and regularly maintained. The placement and design of banks is informed by a skilled third party. Secondary forms of sediment control (such as sediment traps) are in place.	Contour and diversion banks are present and regularly maintained. The placement and design of banks is informed by a skilled third party.	Contour and diversion banks are present and regularly maintained.	Contour and diversion banks not present or not maintained in functional state.	All farmed land has a slope lower than 1%.

Nutrient management (weighting)	**Relative water quality risk**				
	Lowest risk (A) Innovative	**Moderate – Low risk (B)** Best practice	**Moderate risk (C)** Minimum standard	**High risk (D)** **Superseded**	**Not applicable**
Determining nitrogen requirements (40%)	Yield mapping data informs precise variable fertiliser rate control for specific management zones. Pulse crops are regularly included in the crop rotation to reduce need for N fertiliser.	Yield and protein data is matched to crop performance zones to formulate soil sampling strategies and N management decisions for individual zones. Pulse crops are regularly included in the crop rotation to reduce need for N fertiliser.	Regular soil analysis, in conjunction with yield/protein information, is used to make N management decisions.	Fertiliser N rates are based on historical rates or rules of thumb for particular crops.	Do not use nitrogen fertiliser.
Influence of stored soil moisture on yield and N fertiliser decisions (40%)	Stored soil moisture is monitored throughout the fallow and decision support tools are used to indicate yield potential when selecting fertiliser application rates.	Stored soil moisture is monitored throughout the fallow and informs decisions on yield potential and appropriate fertiliser rates.		Stored soil moisture is not considered when selecting fertiliser application rates.	Do not use nitrogen fertiliser.
Application timing to minimise potential losses and maximise uptake of N fertiliser (20%)	N fertiliser is applied early in a fallow to minimise probability of losses. Fertiliser may be applied as split applications (e.g. during the fallow, at planting and/or in crop).	N fertiliser is applied early in a fallow to minimise probability of losses.	Normal practice is that N fertiliser is only applied late in the fallow and/or when there is a full soil moisture profile.		

Pesticide management (weighting)	Relative water quality risk				
	Lowest risk (A)	**Moderate – Low risk (B)**	**Moderate risk (C)**	**High risk (D)**	**Not applicable**
	Innovative	Best practice	Minimum standard	**Superseded**	
Targeting herbicide application (30%)	Bandspray residual herbicides, and/or target specific zones within paddocks rather than apply to 100% of the paddock.		Knockdown and residual herbicides are usually applied through conventional boomspray with 100% paddock coverage.		Rarely use herbicides. Usually rely on tillage or livestock for weed control.
Use of residual herbicides (40%)	Residual herbicide use is confined to paddocks, parts of paddocks and seasons when weed pressure is high. Application of multiple below-label rates of residual herbicides through the year is preferred to full label rates.		The same residual herbicide program (fallow and incrop, pre- and post-emergent) is used in each paddock every year, in response to possible or anticipated weed pressure. High-risk products are usually applied once per season and prior to commencement of the wet season.		Rarely use residual herbicides.
Efficient herbicide application (15%)	Boomspray operates under machine guidance of at least 10cm pass to pass accuracy in a controlled traffic system. Boom has automated section and individual nozzle controls to further minimise overlap.	Boomspray operates under machine guidance of at least 10cm pass to pass accuracy in a controlled traffic system. Boom has automated section control to further minimise overlap.	Boomspray operates in a controlled traffic system to minimise overlap.	Boomspray does not operate in a controlled traffic system or with GPS guidance.	Rarely use herbicides. Usually rely on tillage or livestock for weed control.
Pesticide selection (15%)	Herbicide choice is informed by assessment of weed control efficacy AND environmental risk, with lower toxicity products selected wherever feasible. Product choice considers rate, relative toxicity, product half-life, solubility, soil adsorption properties and their interaction with the soils on the farm.		Pesticide product choice is based on efficacy and cost effectiveness of control.		

Abbreviations

ABARES	Australian Bureau of Agriculture, Resource Economics and Science
ABS	Australian Bureau of Statistics
APSIM	Agricultural Production Systems Simulator
GBR	Great Barrier Reef
N	Nitrogen
$N0_3$	Nitrate
NRM	Natural resource management
P2R	Paddock to Reef
P2RWQ	Paddock to Reef Water Quality
PAWC	Plant Available Water Capacity
S	Sulphur
SCS	Scientific Consensus Statement
WQIP	Water Quality Improvement Plan
Zn	Zinc

Glossary of terms

Broadacre cropping	Cropping production systems on an extensive scale. Includes crops such as cereals, oilseeds, legumes, sugarcane, lupins, cotton, hops, hay and silage (Barson, et al., 2012).
Controlled traffic	A farming system built on permanent wheel tracks to separate traffic lanes from the crop zone (Davies, et al., 2017).
Conventional tillage	A farming system involving multiple tillage passes with >30% soil disturbance and low soil cover (Umbers, 2017). Also known as traditional tillage.
Minimum tillage	A term for soil conservation farming systems that aims to minimise soil disturbance. It includes practices such as zero tillage, no tillage and strip tillage. Soil cover is maintained through retained crop residues (Umbers, 2017). Also known as conservational tillage.
No till	A minimum tillage practice with minimal (10-30%) soil disturbance (Umbers, 2017).
Plant available water capacity	The maximum amount of water stored in the soil that is available to a growing crop (Chudleigh, et al., 2001).
Strip tillage	A minimum tillage practice that only disturbs the seedbed in a strip (Leskovar, et al., 2016).
Water use efficiency	A measure of a crop's capacity to convert water into plant biomass or grain (GRDC, 2009).
Zero tillage	A minimum tillage practice with <10% soil disturbance (Umbers, 2017).