AN ECONOMIC ANALYSIS OF IMPROVING MANAGEMENT PRACTICES OF LEGUME CROP RESIDUES TO MAXIMISE ECONOMIC AND ENVIRONMENTAL BENEFITS

Project 2015/074

Chief Investigator
Weijin Wang, Principal Scientist, Department of Science, Information Technology and Innovation (DSITI[1])
Queensland (QLD)

Evaluation completed by AgTrans.

1 Introduction

The following impact assessment has been carried out using the guidelines produced by the Council of Research and Development Corporations (CRRDC) (CRRDC, 2018).

2 Background

Breaking the sugarcane monoculture by growing other crops in rotation with sugarcane has proven environmental and productivity benefits (Department of Agiruclture, Fisheries and Forestry, 2014). The 'Sugarcane Yield Decline Joint Venture' (SYDJV) identified grain legume rotation as a key measure for sustainable sugarcane production in 'new farming systems' (Garside, Bell, Robotham, Magarey, & Stirling, 2005).

Growing legumes can reduce the population of sugarcane root pathogens, add extra amounts of nitrogen (N) into soil through biological N fixation, and help conserve soil mineral N in the biomass that could otherwise be lost through leaching, runoff or denitrification (microbial decomposition of nitrate into gases) during the fallow period. The legume biomass at maturity can contain 50-300 kg N per hectare (Garside & Bell, 1999). Therefore, following a legume crop during the fallow period, N fertiliser application to the plant cane can be substantially reduced or even eliminated. For example, the sugarcane nutrient management program, SIX EASY STEPS® (SES), recommends a reduction in fertiliser N application rate by 90 kg/ha for plant cane after a good legume crop (Schroeder, Wood, Moody, Bell, & Garside, 2005).

Unfortunately, large amounts of the legume N can be lost from soil through leaching, runoff or microbial denitrification, particularly during the period before or shortly after cane planting when there is no or limited N demand by the crop. As legume rotation has been increasingly adopted by growers as part of the SYDJV 'new farming system', N losses from legume residues needed to be addressed because:

1) The N losses lead to sugar yield loss, trigger otherwise unnecessary amounts of N fertiliser application and thus compromise farming profitability;
2) The leaching or runoff of legume-derived N exacerbates pollution from farm nutrients to downstream water bodies including the Great Barrier Reef; and
3) Denitrification leads to emissions of nitrous oxide (N2O, a potent greenhouse gas and the predominant ozone-depleting gas in the atmosphere).

Improved legume crop residue management practices were required to minimise N losses and thus maximise the economic and environmental benefits of legume rotation in sugarcane cropping systems. Project 2015/074 was funded to investigate a suite of N-efficient legume residue management strategies through manipulating legume

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[1] *DSITI has been superseded by the Department of Environment and Science (DES) QLD*

N mineralisation (release), capturing excess mineral N, or inhibiting formation of the mobile and vulnerable nitrate N.

3 Project Objectives

The project investigated a suite of novel legume residue and N management strategies aimed at reducing N losses, enhancing N availability to the subsequent sugarcane crop, minimising the amount of supplementary fertiliser application, maintaining sugar yield, and mitigating the impacts of N losses to the environment such as the Great Barrier Reef (GBR).

Specific project objectives were to:

1) Investigate dynamics of soil mineral N and net N mineralisation of different legume residues, including possible biological nitrification inhibition by legume (e.g., peanut) cropping;
2) Quantitatively examine the effects of growing an N catch crop between legume maturity and cane planting on soil mineral N and subsequent N uptake by the following sugarcane;
3) Verify the efficacy of spraying a nitrification inhibitor onto the legume residues before incorporation into soil for N conservation;
4) Assess usefulness and practicality of pre-planting/fertilisation testing of soil mineral N stock, after a long fallow period, as a tool for determining the optimal fertiliser N application rate to maintain sugar yield; and
5) Understand the economic benefits of legume crop rotation and different legume residue management practices.

4 Cost of Investment for Project 2015/074

The project was funded from September 2015 to June 2018. Estimates of the total investment by Sugar Research Australia Ltd (SRA), DES and others for the duration of the project are provided in Table D1. Other contributors included the Department of Agriculture and Fisheries QLD (DAF), Herbert Cane Productivity Services Ltd (HCPSL), and the Burdekin Bowen Integrated Floodplain Management Advisory Committee Inc. (BBIFMAC).

TABLE D1: THE COSTS OF THE INVESTMENT IN PROJECT 2015/074 (NOMINAL $)

YEAR ENDED JUNE	DES ($)	SRA (EX. DES) ($)	OTHERS ($)	TOTAL ($)
2016	160,476	88,001	92,200	340,677
2017	113,084	62,012	64,972	240,068
2018	185,181	101,549	106,394	393,124
Total	458,741	251,562	263,566	973,869

Sources: (1) Research project agreement (contract) between SRA and the DSITI, (2) Deed effected between DES and SRA (2015-2020).

4.1 Real Investment and Extension Costs

For purposes of the investment analysis, the investment costs of all parties were expressed in 2019/20-dollar terms using the Implicit Price Deflator for Gross Domestic Product (ABS, 2020). No additional costs of extension were included because the project included a range of communication and extension activities. Project findings were communicated to cane growers, consultants, extension officers and researchers through field days and visits, workshops, industry meetings, and publications.

4.2 Program Management and Administration Costs

The cost of managing the investment varied according to the source of funds. Estimates of the cost of administration and management of the investment by SRA and DES were added to the total project costs currently appearing in Table D1. The management cost multipliers used were as follows:

- SRA: 1.10 (based on the project administration costs recognised in the SRA project agreement)
- DES: 1.10

The multipliers are to accommodate the allocation of indirect Research and Development (R&D) expenditure (management and administrative resources) for each organisation across individual projects. This is to ensure the full costs of R&D funding are included as per the CRRDC Guidelines (CRRDC, 2018). The use of multipliers is an accountability item only and does not mean that any of the DES resources granted to SRA are used by SRA to fund project administration or management costs. The DES multiplier applied is to accommodate the resources DES expends in managing the Deed.

Other funding partners included DAF, HCPSL, and BBIFMAC. The management and administration costs for other project partners (‘others’ in Table D1) were assumed to be included already in the contributions appearing in Table D1.

5 Activities

Herbert

- Field trials were conducted in the Herbert region, the Burdekin region, and the Bundaberg region.
- At the Herbert trial site, a sugarcane paddock was divided into four blocks and 48 plots (12 plots per block). Two plots in each block were randomly chosen for bare fallow and the remaining 10 plots were sown with soybean.
- The soybean crop was sprayed out as green manure. Following spray out, 12 treatments were implemented to compare different management strategies in terms of N availability and efficiency, fertiliser N saving, cane and sugar yield, N uptake by cane and profitability.
- Following the soybean crop, a sugarcane crop was planted. Then, based on SES recommendations and allowing for N supplied by the green manure, N fertiliser was applied. The N fertiliser application rate for the cane following soybean cropping was reduced by about 60% (75 kg N/ha) 130 kg N/ha from to 55 kg N/ha compared to the standard SES recommendation.
- The cane crops were mechanically harvested, and sugarcane yield was measured.
- Soil sampling was undertaken from beds at soybean planting, before cane planting, before the high N uptake season, and before post cane harvest.
- Soil extracts were then analysed for mineral N concentrations using colorimetric techniques. Soil moisture contents were also determined.
- Sugarcane biomass samples were taken and analysed for total N content three times throughout the cropping season.
- A field incubation study on mineralisation of soybean residue N also was undertaken.

Burdekin

- At the Burdekin trial site, a paddock was divided into four blocks. Each block then was divided into nine plots.
- Seven plots in each block were randomly selected and planted with soybean, leaving the remaining two plots unplanted as bare fallow.
- The soybean crops were sprayed out as green manure (no grain harvesting) and slashed to prepare for cane planting.
- Nine treatments with contrasting soybean residue and fertiliser N management practices then were used to compare:

  i) bare fallow versus soybean rotation,

ii) heavy tillage versus minimum tillage,

iii) with versus without nitrification inhibitor spray onto the soybean residues before tillage, and

iv) with versus without a N catch crop (mung bean).

- Plant cane then was planted. The soybean crop residues (including roots) contained about 300 kg N/ha. Based on SES, the recommended fertiliser N application rates for the plant cane following bare fallow were 160 kg N/ha. Therefore, no N fertiliser was applied for the treatments with soybean rotation.
- Sugarcane plant sampling was undertaken for each plot three times during the trials.
- Plant samples were processed and measured for fresh and dry matter yield, total N content, and Commercial Cane Sugar (CCS).
- Soil sampling was conducted thirteen times during the experiment, including one before soybean planting, two during the soybean growing season, one between the soybean spray out and cane planting, and nine during the sugarcane cropping season.

Bundaberg

- At the Bundaberg trial site, 36 plots in four blocks were set up in a paddock. Peanut and soybean were sown in dual rows on raised beds.
- The legume crops were sampled in each block at their maximum biomass stages.
- The mature soybean and peanut crops then were harvested for grain and pods. The soybean and peanut crop residues after harvest of grain or pods had a dry matter yield of 7.1 and 6.8 t/ha, containing 281 and 88 kg N/ha, respectively.
- A plant cane crop was subsequently planted and nine treatments were used to compare:

i) bare fallow versus soybean rotation versus peanut rotation,

ii) full tillage versus no-till after the legume crop harvesting,

iii) with versus without spray of nitrification inhibitor onto the legume crop residues before tillage,

iv) with versus without a N-catch crop during late fallow period, and

v) different application rates of fertiliser N (base N + side dressing N) for the subsequent cane crop.

- Based on SES, the recommended fertiliser N application rates for the plant cane following bare fallow were 130 kg N/ha. Therefore, the application rate of N fertiliser for sugarcane following the peanut crop rotation was reduced to 42 kg N/ha. No N fertiliser was applied following the soybean rotation.
- The sugarcane crop was manually harvested. Total biomass was recorded, and CCS determined.
- Soil sampling was conducted on fifteen occasions during the experiment, including one at sowing of the legume crops, three to four during the legume growing season, one to two between the legume crop harvest and cane planting, eight during the sugarcane cropping season, and one after cane harvesting.
- As part of the Bundaberg trial, a study was conducted on the effects of legume crop rotation on the nitrifying microbial community.

Incubation Study

- Separate to, but aligned with, the project’s legume field trials, a laboratory incubation study on N mineralisation of legume residues was undertaken.
- Above ground components of three legume crops were collected from the Herbert and Bundaberg sites.
- Mature soybean samples were collected immediately after grain harvest and consisted of the leaves, stems and empty pods.
- Green manured soybean samples were taken at early pod development and consisted of the leaves, stems and pods.

- Peanut samples were harvested at maturity and consisted of leaves and stems.
- Bulk soil samples also were collected to a depth of 0-10 cm from multiple points at the Herbert, Burdekin and Bundaberg sites.
- Destructive sampling of the incubation treatments was undertaken and net N mineralisation from legume residues was calculated. Carbon mineralisation and N2O flux also were measured.

Economic Analysis

- An economic analysis of the different management scenarios at each site was conducted using the Farm Economic Analysis Tool (FEAT; DAF; https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/sugar/farm-economic-analysis-tool).
- The gross margin per hectare was used to compare the relative profitability of the different management scenarios and calculated as the gross income less all variable costs, not considering fixed costs and capital expenditure.
- The management scenarios used in the study reflected the actual management operations undertaken throughout each experiment, from fallow through to the harvest of the plant cane.

6 Key Outputs

- The project found that growing soybean break crops during the fallow period between two sugarcane cropping cycles could add 70-280 kg N/ha to the cropping systems.
- The amount of soybean biomass N increased with increasing length of growth.
- Therefore, as long as site, weather and operations permit, the project recommended that the cropping season should be extended by sowing early and harvesting or spraying out late.
- About 74-88% of the soybean biomass N derived from biological N fixation and 22-26% from recovery of soil N.
- The N inputs from soybean residues significantly reduced or eliminated N fertiliser application, thus saving on fertiliser cost by $75-215/ha.
- There also was evidence that substantial amounts of mineral N (predominantly NO3) in bare soil accumulated during the fallow period were lost following rainfall.
- Growing legume crops significantly decreased accumulation of mineral N in soil due to plant N uptake. Thus, legume crop rotation provided an effective means to retain soil mineral N in plant biomass.
- In addition, DNA analysis indicated that abundances of soil microbes were significantly higher in soybean or peanut cropping soil than in bare fallow soil at the maximum biomass stage. However, abundances of nitrifying archaea and bacteria and the amoA gene that encodes the enzyme responsible for the first step of nitrification were significantly lower in the legume cropping soil than the bare soil.
- The project recommended that further research be conducted to assess long-term effects of legume cropping on soil microbial community and nitrification under field conditions.
- With grain or pod harvest for legume break crops, findings indicated that mature soybean crop residues contained three times more N (280 kg N/ha) than peanut residues (88 kg N/ha) at Bundaberg.
- However, farming profit was markedly higher for growing peanut than soybean thanks to higher market values of peanut pods. Nonetheless, if circumstances do not allow the legume crops to grow to maturity (taking approximately 5 months for soybean and 6 months for peanut), soybean was determined to be a better green manure crop because of its greater N benefit.
- The incubation study demonstrated that rapid N release from soybean residues occurred in the first 2-3 months.
- About 73% and 43% of the total residue N was released from the crop residues within two months after incorporation into soil and placement on the soil surface, respectively.
- Therefore, the project concluded that N-efficient management of legume residues is critical during the early months after harvest or spray out of the legume crops.

- However, the project also found that 45-65% of the initial soil nitrate (generally the major form of mineral N) was immobilised into non-exchangeable soil N pools 302 days after incorporation of legume residues, compared to 7-24% in the control without legume residues.
- Only 23% of the peanut residue N and 27-35% of soybean residue N (depending on C:N ratios) were found in the soil mineral N pool after 302 days of incubation.
- The project team suggested that the incubation study findings will have implications for estimating plant-available N from the legume residues, and that care should be taken to avoid overestimation of N supply from the legume residues.
- Results from the laboratory incubation, field incubation and field soil sampling consistently indicated that leaving legume residues on the soil surface by practising no-till could slow down N mineralisation compared to incorporating crop residues into soil with tillage.
- Therefore, the project concluded that, if sugarcane is not planted for a prolonged period and high rainfall is expected after legume crop harvest or spray out, no-till provides an effective management strategy to slow down N mineralisation thus reduce the risk of soil mineral N loss.
- In cases where cane was planted shortly after the legume cropping, tillage was found to improve N supply to the cane crop and thus may benefit crop growth. The project team noted that selection of tillage method would need to consider seasonal conditions, time and practicality.
- Results showed that spraying nitrification inhibitor onto legume residues before tillage could slow down conversion of ammonium to nitrate for at least 10-30 days. However, this did not result in significant improvement of cane or sugar yield and crop N uptake.
- Allowing volunteer soybean to re-grow after grain harvest as N-catch crops was found to significantly decreased mineral N accumulation in the soil profile and thus could potentially reduce the risk of N loss. This technique also resulted in a non-significant increase in sugar yield by 2 t/ha.
- Growing mungbean during the early months of sugarcane cropping season at the Burdekin site did not have any benefits to the cane growth and productivity. Therefore, the project concluded that efficacy of N-catch crops may depend on the length of time between legume crop harvest/spray out and cane planting, species of the N-catch crops, N mineralisation from soil and previous legume crop residues as well as site and weather conditions.
- Further, if sugarcane cannot be planted for a prolonged period during a high rainfall season, allowing the volunteer legume crop to grow or delaying spray out of the legume crop for green manure could potentially minimise the risk of N loss.
- Based on existing knowledge, previous research and findings in project 2015/074, a decision-tree was produced to assist growers with selection of fallow and legume crop residue management practices.
- Findings of the project were presented to over 190 growers and other industry stakeholders at field demonstrations, industry meetings, BBIFMAC bimonthly general meetings, and the Burdekin Cane Extension Group.

7 Outcomes

- The project team involved researchers, consultants, farmers, representatives from QLD government departments (DES and DAF), BBIFMAC and HCPSL
- Through close collaboration, the project team was able to communicate the tested techniques and knowledge on sustainable management of legume residues to cane growers, consultants, extension officers and researchers through field days and visits, workshops, industry meetings, and publications.
- The project has led to adoption of improved legume residue management practices by Australian sugarcane growers, particularly in the Herbert, Burdekin and Bundaberg regions.
- Adoption of the new and improved residue management techniques may reduce N fertiliser input by between 50 to 100 kg N/ha and increase net farm profits.
- The project team estimated that, assuming legume rotation could replace 100 kg fertiliser N/ha, fertiliser costs would be reduced by approximately $108/ha. Then, if 12% of Australian sugarcane cropping areas adopted

legume rotation each year, this could save fertiliser N inputs for the industry by approximately $5.8 million /year (based on a total crop area of 450,000 ha).

- It is expected that the new residue management strategies identified in project 2015/074 will contribute to more rapid adoption of legume crop rotations and speed the industry's progress towards this potential (?).

8 Impacts

Project 2015/074 has led to improved management of break crop legume residues. Such practice changes are likely to have resulted in increased profitability for some Australian sugarcane growers because of increased NUE driven by reduced N fertiliser (with maintained productivity) for growers implementing legume break crops as part of their standard crop rotation.

A summary of the principal types of likely impacts associated with the outcomes of the project is shown in Table D2.

TABLE D2: CATEGORIES OF PRINCIPAL POTENTIAL IMPACTS FROM THE INVESTMENT

ECONOMIC
• Increased productivity/profitability from increased NUE driven by reduced N fertiliser use by growers implementing improved legume residue management practices.
ENVIRONMENTAL
• A reduction in export of nitrogen to off-farm environments (including the GBR) through reduced use of N fertiliser and reduced N leaching and denitrification.
SOCIAL
• Spillover impacts to regional communities from increased sugarcane industry net incomes. • Maintained social licence to operate for some sugarcane producers from improved N fertiliser management.

8.1 Public versus Private Impacts

The key potential impacts will be private, initially delivered to some sugarcane growers that implement practice change to improve legume residue management.

Public impacts are likely to be in the form of environmental benefits from a potential net reduction in the level of N entering off-farm environments (including the GBR catchment) and from regional spillovers from increased grower net incomes.

8.2 Distribution of Impacts along the Supply Chain

The project is likely to have contributed to direct private productivity/profitability impacts for Australian sugarcane producers through improved NUE driven largely by reduced N fertiliser use/N savings. Secondary productivity/profitability impacts may accrue to the Australian sugarcane milling sector if, in the future, improved NUE on-farm results in increased sugarcane yields and therefore increased cane processing.

8.3 Impacts on other Primary Industries

There are not likely to be any direct impacts to other agricultural industries from the investment. However, it is possible that scientific knowledge sharing through research and industry networks may create some spillover impacts to other cropping industries that use legume break crocks to improve N fertiliser management.

8.4 Impacts Overseas

No direct overseas impacts were identified.

8.5 Match with National, State and SRA Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table D3. The Project 2015/074 investment has potentially contributed to Rural RD&E Priority 3, with some minor contribution to Priority 4, and to Science and Research Priorities 1.

TABLE D3: AUSTRALIAN GOVERNMENT RESEARCH PRIORITIES

AUSTRALIAN GOVERNMENT	
RURAL RD&E PRIORITIES (EST. 2015)	**SCIENCE AND RESEARCH PRIORITIES (EST. 2015)**
1) Advanced technology	5) Food
2) Biosecurity	6) Soil and Water
3) Soil, water and managing natural resources	7) Transport
4) Adoption of R&D	8) Cybersecurity
	9) Energy and Resources
	10) Manufacturing
	11) Environmental Change
	12) Health

Sources: DAWE (2019) and Department of Industry, Science, Energy and Resources (2015)

9 SRA Research Priorities

SRA's key focus areas are presented in Table D4. Project 2015/074 directly addressed KFA 2, but also, at least in part, addressed KFAs 4 and 7.

TABLE D4: SRA STRATEGIC FOCUS AREAS AND DESIRED OUTCOMES

KEY FOCUS AREA (KFA)	OUTCOMES
13) Optimally adapted varieties, plant breeding and release	Increased sugarcane yield and commercial cane sugar (CCS)
14) Soil health, nutrient management and environmental sustainability	Better soil health, reduced nutrient losses and improved water quality
15) Pest, disease and weed management	Reduced or avoided yield losses and/or added input costs
16) Farming systems and harvesting	Improved farm input-output efficiencies and profitability
17) Milling efficiency and technology	Optimised production, improved capital utilisation and waste minimisation
18) Product diversification and value adding	Diversified revenue streams and product innovation
19) Knowledge and technology transfer and adoption	Accelerated adoption of new technology and practice change
20) Collaboration and capability development	Enhanced industry and research capability and capacity
21) Organisational effectiveness	Increased investor satisfaction and returns on investment

Source: SRA Strategic Plan (2018)

10 Valuation of Impacts

10.1 Impacts Valued

Of the impacts identified in Table D2, one impact was valued in monetary terms:

- Increased profitability from increased NUE driven by reduced N fertiliser use by growers implementing improved legume residue management practices.

This impact was valued for the particular regions where the project findings were most relevant, that is, the Herbert, Burdekin, and Bundaberg regions. It is possible that additional benefits may be delivered if improved legume residue practices are adopted by other Australian sugarcane growing regions in the future.

10.2 Other Potential Impacts Identified but not Valued

The other impacts of identified in Table D2 were not valued for the following reasons:

1) A reduction in export of nitrogen to off-farm environments (including the GBR) was not valued due to the difficulty of quantifying the reduction and uncertainty about the value of such reductions for improving GBR health.
2) Spillover impacts to regional communities from increased sugarcane industry net incomes was not valued due to the range and diversity of geographic locations involved.
3) Maintenance of some Australian sugarcane producer’s social licence to operate through improved N management was not valued because of the difficulty of identifying clear linkages between the likely project outcomes and community views and/or government policy.

10.3 Counterfactual

The counterfactual assumed is that the industry changes that are anticipated would not have taken place without the funding of this project.

10.4 Summary of Assumptions for Impact Valuation

A summary of the key assumptions made is shown in Table D5.

TABLE D5: SUMMARY OF ASSUMPTIONS FOR VALUING INVESTMENT IN PROJECT 2015/074

VARIABLE	ASSUMPTION	SOURCE
GENERAL		
Estimated applicable sugarcane area (Herbert, Burdekin and Bundaberg regions)	142,878 ha	Average of past three years (2017 to 2019) (Canegrowers Annual Report 2018, 2019 and 2020)
BENEFIT 1: ESTIMATES OF N COST SAVINGS THROUGH IMPROVED LEGUME RESIDUE MANAGEMENT		
Current average annual N usage	160 kg/ha	Analyst estimate – based on SES N usage recommendations for the Herbert, Burdekin and Bundaberg regions reported in the 2015/074 final report
Estimated proportion of the Herbert, Burdekin and Bundaberg regions currently implementing legume break crops	3.5%(a)	Barry Salter, pers. comm., 2020
Proportion of legume break crop area implementing improved residue management because of project 2015/074	70%	Analyst estimate – based on evidence of significant N savings resulting from improved legume residue management generated by project 2015/074 (described in the 2015/074 final report – see Outcome section above)

Potential N savings made for applicable sites	50kg N/ha	Analyst estimated – based conservatively on project 2015/074 findings that adoption of new and improved residue management techniques may reduce N fertiliser input by between 50 to 100 kg N/ha
Farm gate value of elemental N	$1.23 per kg	Based on urea price of $565 per tonne @46% N
Year of first adoption due to project	2019	Analyst estimate – based on year after publication of project 2015/074 results
Year of maximum adoption	2023	
RISK FACTORS		
Probability of Output	100%	Analyst estimate – based on successful completion of project 2015/074
Probability of Outcome (Usage)	80%	Analyst estimate - refers to the probability that the adoption rate estimated above will eventuate
Probability of Impact (given usage)	90%	Analyst estimate - refers to the probability that the N reduction (and associated savings) occur
ATTRIBUTION		
Attribution to SRA Project 2015/074	100%	Analyst assumption

(a) There is about 377,000 ha of sugarcane in an average year based on the 2017 and 2018 years (Canegrowers Annual Report, 2018/19). If it is assumed that 60,000 ha of plant cane exists in any one season, that 75% of plant cane comes from a fallow, and 30% of the fallow area comes from a legume break crop, the estimated annual percentage of the total sugarcane area that is planted to a legume break crop would be about 13,500 ha or about 3.5% of the total area of sugarcane in any one year (13,500/377,000).

10.5 Results

All past costs and benefits were expressed in 2019/20-dollar terms using the Implicit Price Deflator for Gross Domestic Product (Australian Bureau of Statistics, 2020). All benefits after 2019/20 were expressed in 2019/20-dollar terms. All costs and benefits were discounted to 2019/20 using a discount rate of 5%. A Re-investment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. All analyses ran for a period of 30 years after the last year of investment (2017/18).

The investment criteria are reported for the total investment, the SRA investment, and the DES investment in Table D6, Table D7 and Table D8.

TABLE D6: INVESTMENT CRITERIA FOR TOTAL INVESTMENT (DISCOUNT RATE 5%)

INVESTMENT CRITERIA	YEARS FROM LAST YEAR OF INVESTMENT						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	0.43	1.01	1.46	1.82	2.10	2.32
Present value of costs ($m)	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Net present value ($m	-1.30	-0.87	-0.29	0.16	0.52	0.80	1.01
Benefit-cost ratio	0.00	0.33	0.77	1.12	1.40	1.61	1.78
Internal rate of return (IRR) (%)	negative	negative	1.32	6.35	8.33	9.26	9.73
Modified IRR (%)	negative	negative	1.70	5.94	6.97	7.20	7.18

TABLE D7: INVESTMENT CRITERIA FOR SRA INVESTMENT (DISCOUNT RATE 5%)

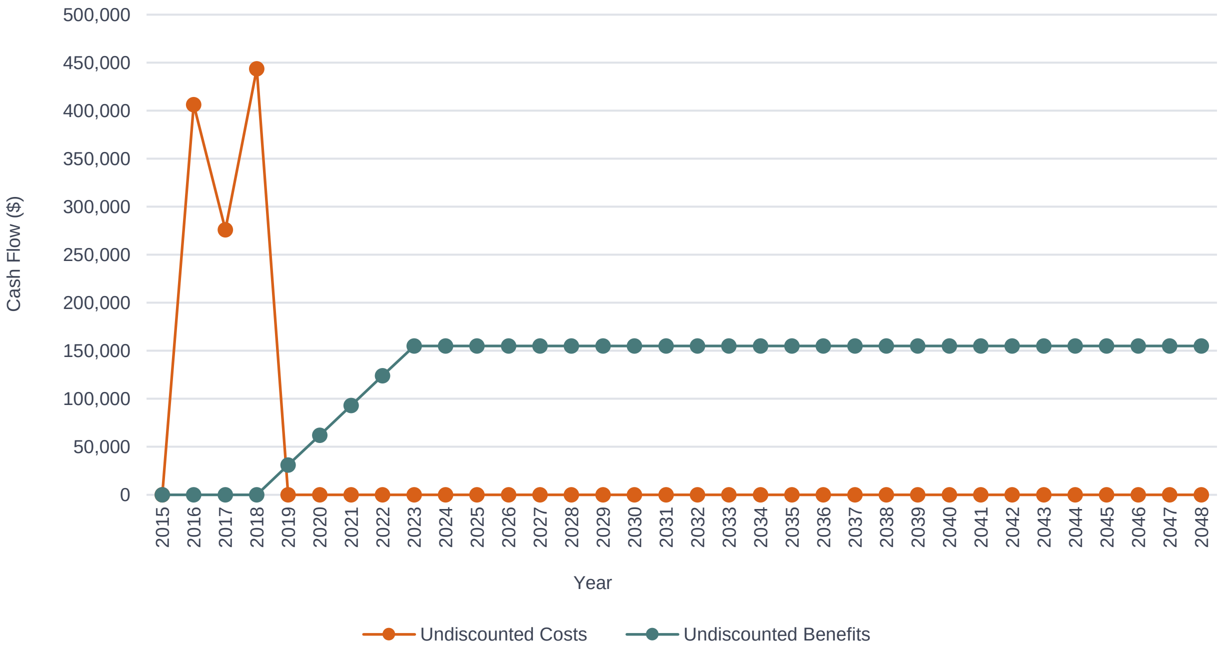
INVESTMENT CRITERIA	YEARS FROM LAST YEAR OF INVESTMENT						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	0.11	0.27	0.39	0.48	0.56	0.61
Present value of costs ($m)	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Net present value ($m)	-0.35	-0.23	-0.08	0.04	0.14	0.21	0.27
Benefit-cost ratio	0.00	0.33	0.77	1.12	1.40	1.61	1.78
Internal rate of return (IRR) (%)	negative	negative	1.32	6.32	8.32	9.26	9.72
Modified IRR (%)	negative	negative	1.70	5.94	6.97	7.20	7.18

TABLE D8: INVESTMENT CRITERIA FOR DES INVESTMENT (DISCOUNT RATE 5%)

INVESTMENT CRITERIA	YEARS FROM LAST YEAR OF INVESTMENT						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	0.21	0.49	0.71	0.88	1.01	1.12
Present value of costs ($m)	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Net present value ($m)	-0.63	-0.42	-0.14	0.08	0.25	0.38	0.49
Benefit-cost ratio	0.00	0.33	0.77	1.12	1.40	1.61	1.78
Internal rate of return (IRR) (%)	negative	negative	1.32	6.35	8.32	9.26	9.72
Modified IRR (%)	negative	negative	1.70	5.94	6.97	7.20	7.18

The annual cash flow of undiscounted benefits and costs for the total investment are shown in Figure D1.

FIGURE D1: ANNUAL CASH FLOW OF UNDISCOUNTED BENEFITS AND COSTS



10.6 Sensitivity Analyses

Sensitivity analyses were carried out for two variables and results are reported in Table D9 and Table D10. The sensitivity analyses were performed on the total investment using a 5% discount rate (with the exception of Table D9) with benefits taken over the 30-year period. All other parameters were held at their base values.

Table D9 shows there is a moderate sensitivity to the discount rate. This was because the benefit cash flows occur into the future and therefore were subjected to relatively more significant discount factors.

TABLE D9: SENSITIVITY TO DISCOUNT RATE (TOTAL INVESTMENT, 30 YEARS)

CRITERION	DISCOUNT RATE		
	0%	BASE (5%)	10%
Present value of benefits ($m)	4.34	2.32	1.46
Present value of costs ($m)	1.13	1.30	1.50
Net present value ($m)	3.21	1.01	-0.04
Benefit-cost ratio	3.85	1.78	0.97

Table D10 provides an optimistic/pessimistic sensitivity of the investment criteria to the (1) the assumed area adopting legume residue management changes, and (2) the N savings achieved as a result of such changes.

Table D10 shows that the investment criteria are moderately sensitive to the key assumptions associated with the applicable adoption area and N savings.

TABLE D10: OPTIMISTIC/PESSIMISTIC SENSITIVITY TO AREA OF ADOPTION AND N SAVINGS (TOTAL INVESTMENT, 5% DISCOUNT RATE, 30 YEARS)

CRITERION	AREA OF ADOPTION AND N SAVINGS		
	PESSIMISTIC 50%, 25 KG N/HA (HALF BASE)	BASE ADOPTION = 70% N SAVING = 50 KG N/HA	OPTIMISTIC 90%, 100 KG N/HA
Present value of benefits ($m)	0.83	2.32	5.96
Present value of costs ($m)	1.30	1.30	1.30
Net present value ($m)	-0.48	1.01	4.65
Benefit-cost ratio	0.64	1.78	4.57

11 Conclusions

The project is likely to have contributed to direct private productivity/profitability impacts for Australian sugarcane producers through improved NUE driven largely by reduced N fertiliser use/N savings. Secondary productivity/profitability impacts may accrue to the Australian sugarcane milling sector if, in the future, improved NUE on-farm results in increased sugarcane yields and therefore increased cane processing.

Given the assumptions made, the investment criteria estimated for total investment in the project of $1.30 million (present value of costs) were positive with an expected present value of benefits of $2.32 million, an expected net present value estimated at $1.01 million and an expected benefit-cost ratio of 1.78 to 1. The internal rate of return was estimated at 9.7% and the modified internal rate of return at 7.2%.

For the SRA investment, the investment of $0.35 million provided an expected net present value estimate of $0.61 million and an expected benefit-cost ratio of 1.78 to 1, with rates of return similar to those for the total investment.

For the DES investment, the investment of $0.63 million gave an expected net present value of $1.12 million and an expected benefit-cost ratio and rates of return similar to those for the total investment.

All investment criteria were estimated using a discount rate of 5% and with benefits estimated over 30 years from the final year of investment (2017/18).

The quantitative analysis relied on assumptions regarding future adoption and impact of improved management of break crop legume residue management in the Herbert, Burdekin and Bundaberg sugarcane growing regions. While best bet estimates for adoption and impacts have been made, no specific adoption and/or impact data were available at the time of evaluation. Further, a number of impacts of the project investment that were identified were not valued in monetary terms. Hence, the investment criteria estimated are likely to be an underestimate of the true performance of the investment in project 2015/074.

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