Sugar Research Australia

AN ECONOMIC ANALYSIS OF: HOW MUCH N DOES THAT CROP NEED? INCORPORATING CLIMATE FORECASTING TO IMPROVE NITROGEN MANAGEMENT IN THE WET TROPICS

Project 2015/075

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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, 2014).

2 Background

The benefit of using seasonal climate forecasts for decision-making purposes has been demonstrated for such management processes as sugarcane irrigation management, harvesting, milling and marketing sectors of the sugarcane industry. However, there had been scant use of seasonal climate forecasting to assist nitrogen (N) management strategies for the forthcoming season. This is despite seasonal forecasts such as El Niño/Southern Oscillation(ENSO) having been shown to increase gross margins from cereal crops of the order of $10-$20 per hectare.

The annual sugarcane productivity performance across the Wet Tropics region (Tully to Mossman) varies significantly but N fertiliser application rates have remained steady. This suggests that it may not be appropriate to use a set district yield potential to determine N requirements.

A previous Sugar Research Australia (SRA) supported PhD project (STU/073) carried out by Skocaj investigated if N fertiliser requirements could be linked to a seasonal yield potential, as determined by climatic conditions experienced during the growing season. Such a strategy could provide benefits compared to using a constant yield target via SIX EASY STEPS (SES) or the yield of the previous crop (N replacement method). Additional impacts could be delivered from improved prediction of sugarcane yields in the form of, for example, forward selling and factory preparedness planning.

The previous PhD project made a proof of concept contribution towards improving and/or maintaining best practice for N management for sugarcane producers, and showed that, at least in some wet tropics factory areas, N fertiliser rates could potentially be reduced by using seasonal climate forecasts (SCFs) without impacting on sugarcane yield. The results of the project were relevant to some soil types in the two major wet tropics factory areas of Innisfail and Tully. This past research also built capacity for further research, as exemplified by the funding of a further SRA project 2014/024.

Project 2014/024 used a sophisticated hybrid modelling approach that included both statistical methods and seasonal climate forecasting information. Using such models, historical forecasts were made from May in the year before harvest until November in the actual harvest year and the skill of each forecast estimated. Skill levels (predicted versus actual) of forecasts made on the 1st September, 1st January, and 1st March were of most interest as they could theoretically be used respectively as inputs into levels of fertiliser nitrogen applications (1st September), forward selling (1st January) and factory schedules to manage the forthcoming harvest (1st March). Skill levels were assessed as the proportion of year to year variation of yield explained by use of the models (R squared in statistical terms).

Using an optimised random forest regression model, it was possible to produce a yield and crop size forecast for the Tully Mill area yield with moderate skill (cross-validated R squared = 0.689) as early as 1st September. The skill of the model increased for forecasts made later, on 1st September (R squared = 0.75) and 1st March (R squared = 0.83). Even higher skill levels were produced for classification models, again, with increased skill the later the dates.

However, the Project 2014/024 findings could not be used with confidence to lower nitrogen applications as originally hypothesised as it was found that such a strategy would depend on whether the wet season was early or late. Hence, as well as increasing awareness and interest in the potential role of seasonal climate forecasting in nitrogen management, Project 2014/024 led to the new project 2015/075.

3 Project objectives

The overall aim of Project SRA 2015/075 was to improve nitrogen (N) management in sugarcane. Specific objectives of the project were:

1) Use Global Climate Models based seasonal climate forecasts and the APSIM crop model to produce early estimates of yield potential for zones within the Tully mill region;
2) Determine how N requirement, and hence how the N fertiliser application rate, varies according to seasonal climatic conditions and estimates of yield potential for major soil types occurring throughout the Tully region;
3) Identify the benefits of optimal tactical, in-season applications of N fertiliser;
4) Propose options for adoption pathways.

4 Cost of investment for project 2015/075

Estimates of the total investment by the project funders including SRA, the Queensland Department of Environment and Science (DES), and James Cook University (JCU), are provided in Table 1 for this three-year project. It should be noted that contributions from CSIRO and the University of Southern Queensland were also included in the JCU budget column.

TABLE 1: THE COSTS OF THE INVESTMENT IN PROJECT 2015/075 (NOMINAL $)

YEAR ENDED JUNE	SRA	DES	JCU	TOTAL
2016	74,200	74,200	20,339	168,739
2017	94,425	94,425	21,556	210,406
2018	86,876	86,876	21,862	195,614
Total	255,501	255,501	63,757	574,759

4.1 Program Management and Extension Costs

The costs of administration and management of the investment from all parties are assumed to be included in the figures appearing in Table 1.

5 Activities

As a first step in the project a consultative committee was established. The project team then established the data and models required for the project, including a series of climate forecasting models, and previous N response trials.

The APSIM parameters in predicting crop growth were validated to ensure the predictions of the APSIM model compared accurately with actual trial result data. This was achieved by using data from two small plot trials with different nitrogen rates/farming systems carried out in the Tully region from 2003 to 2009 and from 2011 to 2014. New data were incorporated into the modelling routines, giving an improved ability of the model to simulate N response curves in the Tully Region.

Crop productivity zones based on soil type and climate then were identified for the Tully Mill region. Major soil types were grouped according to their water holding capacity and any waterlogging propensity. Both wet and dry years were defined. The organic carbon content of the soil was considered when developing the soil groups. Information from soil surveys and other soil data were used in the soil grouping process. This resulted in soils being classified into five soil groups for wet years and four soil groups for dry years.

Attention then turned to providing estimates of yield potential at the spatial scale of each productivity unit, as well as how such estimates would vary with seasonal conditions. This allowed estimates to be made of optimal N applications (both single and multiple N applications) for both wet and dry years and on high and low yielding crops. Finally, routines were developed for integrating these responses into N guideline tools such as SES and other best management strategies.

6 Outputs

A summary of the principal outputs delivered follows:

- An improved understanding of how climatic conditions influence cane yield potential and crop responsiveness to applied N fertiliser for major soil types in the Wet Tropics.
- A model with the capability to estimate annual yield potential at scales relevant to crop management was pursued so that growers could better manage N fertiliser applications with regard to on an individual climate year forecast.
- However, the complexity was highlighted of delivering refined N management based on management units, essentially embodied in the last two steps of SES and the Cane Water Quality Risk Framework for land management which goes beyond current Best Management Practices (BMPs). This seeks growers to develop a N budget based on their own yield potential and yield zones within blocks for the prevailing/forecast seasonal conditions.
- The project team has now developed an N estimation algorithm (Optim-N App) that fits steps 5 and 6 of the SES framework; the algorithm or tool meshes APSIM with national and international climate forecasting models with expert local knowledge. Sugarcane growers can use the tool to select a soil type, climate zone and their own level of confidence of applying the optimal N rate for their paddock.
- Yield estimation algorithms have been updated. This exercise has been carried out solely to validate the climate zones and the setup of the APSIM modelling approach, not for estimating N directly. The project team cautioned against estimating N directly from yields.
- The N estimation algorithm that uses management, climate and soil information to directly estimate N fertiliser requirements.
- The new modelling framework captures knowledge about a range of soils that represent more than 70% of the Tully sugarcane growing region; however, more research is required to improve components of the N estimation algorithm.
- The identification of soil types and forecasted climate years where tactical changes to N applications can now provide benefits to growers and the environment.
- The project has concluded that climate forecasting is indeed compatible with the SES for those growers and advisers who want to move beyond the initial N guidelines provided in STEP 4 of the SES program. The envisaged system/'app' will allow them to consider and understand the implications of climate forecasts and soil type on their N management strategies and allow adjustments within their personal objectives and risk profiles.
- Significant potential is likely in years when the ENSO signal is strong for a La Nina event - the condition that poses the greatest threat for environmental losses (N run off and denitrification) when crops are small.
- Various media releases (print, radio and TV) were made concerning the project and its accomplishments and findings; these raised awareness and interest in the project and its objectives.

7 Outcomes

A summary of the important outcomes of the project follows:

- Potential for improved advice by advisers and decision making by sugarcane growers to make more informed decisions on the amount of N required and the frequency of N applications.
- Potential contribution by the industry to a reduction in environmental losses of N, greater nitrogen-use efficiency and improved water quality to deliver increased environmental sustainability.
- More accurate and early estimates of yield potential will benefit other aspects of the sugarcane production system including the milling and marketing sectors.
- The methodology developed in this proposal is transportable to other regions.
- The project's outputs will be suited to other mill areas in the Wet Tropics which experience similar climate, soil and management systems as those considered in this study. This would include the super wet belt which extends from Tully to Fishery Falls.
- Awareness of the its potential and relevance has been raised by the project's communication activities.
- Project outputs are of interest to government bodies, environmentalists and researchers addressing other issues such as water quality and climate change scenario analysis.
- The SES committee has recommended that the research in this project be extended to other regions.
- At the completion of SRA 2015/075, Optim-N was still only a prototype decision support tool applicable in the Tully Mill area. Experience with, and validation of, the tool was required to develop it into a widely accepted and useful decision aid by sugarcane growers.

8 Impacts

The principal impact of SRA Project 2015/075 has been its contribution to the development of future N fertiliser strategies to incorporate seasonal climate forecasting into decision making in the sugarcane industry. The project has raised awareness of approaches for increasing potential industry profitability and reducing environmental impacts from planning ahead based on soil type and forecasts of the forthcoming climate in the Tully Mill area.

If operational models are applied by industry, there could be significant positive impacts in profitability of sugarcane growers in terms of management of N in some years (e.g. N cost savings in some years or increases in sugarcane yields with increased N applications in other years).

Some strategies (reduced N applications in wet years or split applications) may also reduce the extent of off-site nutrient export from sugarcane farms in the Wet Tropics and so contribute to meeting Great Barrier Reef water quality targets.

In addition, seasonal climate and sugarcane yield forecasts together can be used in;

- forward selling decisions
- factory management planning for the forthcoming crushing season such as labour supply organisation and start-up dates.

A summary of the principal types of potential impacts associated with the outcomes of the project is shown in Table 2.

TABLE 2: CATEGORIES OF PRINCIPAL POTENTIAL IMPACTS FROM THE INVESTMENT

ECONOMIC • Potential contribution to future N fertiliser savings by some growers from more accurate predictions of forthcoming sugarcane yields dependent on climate and soil types. • Potential contribution to enhanced sugarcane yields by varying N application strategies in some years. • Potential contribution to future improved forward selling strategies by growers and improved preparedness and forward planning by the Tully Mill from improved knowledge of the size of the forthcoming crop.
ENVIRONMENTAL

• Contribution to reduced rates of N fertilisers in wet years with associated reduced export off-farm via runoff and leaching.
SOCIAL Contribution to increased future rural community well-being due to higher average future net farm income of sugarcane growers, reduced income variability for growers, and improved factory profitability.

8.1 Public versus private impacts

The key potential impacts will include both private and public. The future private impacts potentially will accrue primarily to growers and potentially, the Tully Mill. Public impacts potentially will include the environmental impacts and spillover regional impacts from the private sector profitability gains.

8.2 Distribution of impacts along the supply chain

Potential future impacts associated with this project will most likely accrue to sugarcane producers, some associated service industries, and the Tully Mill.

8.3 Impacts on other primary industries

There are not likely to be any direct impacts to other agricultural industries from the investment.

8.4 Match with national, state and SRA priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 3. The investment contributes primarily to Rural RD&E Priority 1 and Priority 3 and to Science and Research Priority 1 and 2, and potentially Priority 7.

TABLE 3: AUSTRALIAN GOVERNMENT RESEARCH PRIORITIES

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

Sources: DAWR (2015) and OCS (2016)

8.5 SRA Key Focus Areas

SRA's key focus areas are presented in Table 4. Project 2015/075 addressed KFAs 2, 4, and 5.

TABLE 4: SRA STRATEGIC FOCUS AREAS AND DESIRED OUTCOMES

KEY FOCUS AREA (KFA)	OUTCOMES
1) Optimally adapted varieties, plant breeding and release	Increased sugarcane yield and commercial cane sugar (CCS)
2) Soil health, nutrient management and environmental sustainability	Better soil health, reduced nutrient losses and improved water quality
3) Pest, disease and weed management	Reduced or avoided yield losses and/or added input costs

4) Farming systems and harvesting	Improved farm input-output efficiencies and profitability
5) Milling efficiency and technology	Optimised production, improved capital u4lisa4on and waste minimisation
6) Product diversification and value adding	Diversified revenue streams and product innovation
7) Knowledge and technology transfer and adoption	Accelerated adoption of new technology and practice change
8) Collaboration and capability development	Enhanced industry and research capability and capacity
9) Organisational effectiveness	Increased investor satisfaction and returns on investment

Source: SRA Strategic Plan (2018)

9 Valuation of impacts

9.1 Impacts valued

The project has increased awareness, understanding, and knowledge of seasonal forecasts and their use in sugarcane N management in the Tully Mill area. Additionally, the project has raised the awareness of risk management possibilities associated with N use dependent on different soil types and seasonal climate forecasts.

The two impacts tentatively valued in this evaluation include:

- IMPACT 1: The N cost-savings in reducing N fertiliser applications in some Tully area soil types when a wet year is predicted from seasonal climate forecasts.
- IMPACT 2: The sugarcane yield increases for some Tully area soil types in less wet years from increased N usage.

A summary of the key assumptions made is shown in Table 5. The adoption levels assumed are conservative at this stage as further testing and validation of the model is required before any widespread adoption will be attained.

TABLE 5: ASSUMPTIONS FOR ESTIMATING BENEFITS FROM IMPROVED NITROGEN MANAGEMENT DUE TO PROJECT 2015/075

VARIABLE	ASSUMPTION	SOURCE/COMMENT
GENERAL ASSUMPTIONS		
Applicable crop region	Tully Mill supply region	Agtrans Research
Total sugarcane area (ha)	29,000 ha	Average annual sugarcane area harvested in 2015 and 2016 (Canegrowers Annual Report 2016/17)
Area with applicable soils	70% of total sugarcane area	Project 2015/075 Final Report
Frequency of wet years	20%	Agtrans Research after discussions with Danielle Skocaj in 2015
Average nitrogen applications in Wet Tropics (kg/ha)	160 kg per ha	Agtrans Research
Value of nitrogen ($ per kg)	$1.23 per kg N	Based on urea price of $565 per tonne on farm
Average sugarcane yield	80 tonnes /ha	Agtrans Research
Marginal value of additional sugarcane after harvesting costs and transport	$25 per tonne	

AVERAGE NITROGEN USAGE IN TULLY MILL AREA (WITHOUT PROJECT)		
Average nitrogen usage in Tully Mill area in all years	160 kg per ha	Agtrans Research
IMPACT 1: AVERAGE NITROGEN USAGE IN TULLY MILL AREA IN WET YEARS (WITH PROJECT)		
Proportion of years when wet years predicted	20%	Agtrans Research
Estimated average nitrogen usage if wet years predicted	120 kg per ha	
Maximum proportion of Tully Mill area adopting the lower nitrogen application in wet years	20%	
Adoption profile	5% of area adopting in 2021, rising linearly to 20% in 2024	
ATTRIBUTION AND RISK FACTORS FOR IMPACT 1		
Attribution to 2015/075	58%	Agtrans Research; based on relative investments in 2015/075 and earlier contributing projects: STU 073: $373,974 2014/024: $49,000 2015/075: $574,759 Total: $997,733
Probability of outcome (usage/adoption)	50%	Agtrans Research
Probability of impact given usage	100%	
IMPACT 2: AVERAGE NITROGEN USAGE IN DRY/NORMAL YEARS (WITH PROJECT)		
Proportion of years when non-wet years predicted	80%; based on 20% wet years as above	Agtrans Research
Estimated average nitrogen usage if dry/normal years predicted	200 kg per ha	
Sugarcane yield increase from higher nitrogen usage	5%	
Maximum proportion of Tully Mill area adopting higher nitrogen usage in dry/normal years	40%	
Adoption profile	10% of area adopting in 2021, rising linearly to 40% in 2024	
ATTRIBUTION AND RISK FACTORS FOR IMPACT 2		
Attribution to 2015/075	58%	Agtrans Research; based on relative investments in 2015/075 and earlier contributing projects: STU 073: $373,974 2014/024: $49,000 2015/075: $574,759 Total: $997,733

Probability of outcome (usage)	75%	Agtrans Research
Probability of impact given usage	90%	

9.2 Impacts and potential impacts identified but not valued

The potential impacts identified but not valued include:

- More informed forward sugar selling strategies by some sugar owners
- Improved preparedness and forward planning by the Tully Mill from improved knowledge of the size of the forthcoming crop.
- Environmental benefits in wet years with associated reduced nutrient export off-farm via runoff and leaching.
- Benefits to rural community well-being from spinoffs from higher average net farm income of sugarcane growers, reduced income variability of growers, and improved factory profitability.

10 Results

All past costs and benefits were expressed in 2018/19-dollar terms using the Implicit Price Deflator for GDP. All benefits after 2018/19 were expressed in 2018/19-dollar terms. All costs and benefits were discounted to 2018/19 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 and the SRA investment in Tables 6 and 7.

TABLE 6: INVESTMENT CRITERIA FOR TOTAL INVESTMENT AND TOTAL BENEFITS (DISCOUNT RATE 5%)

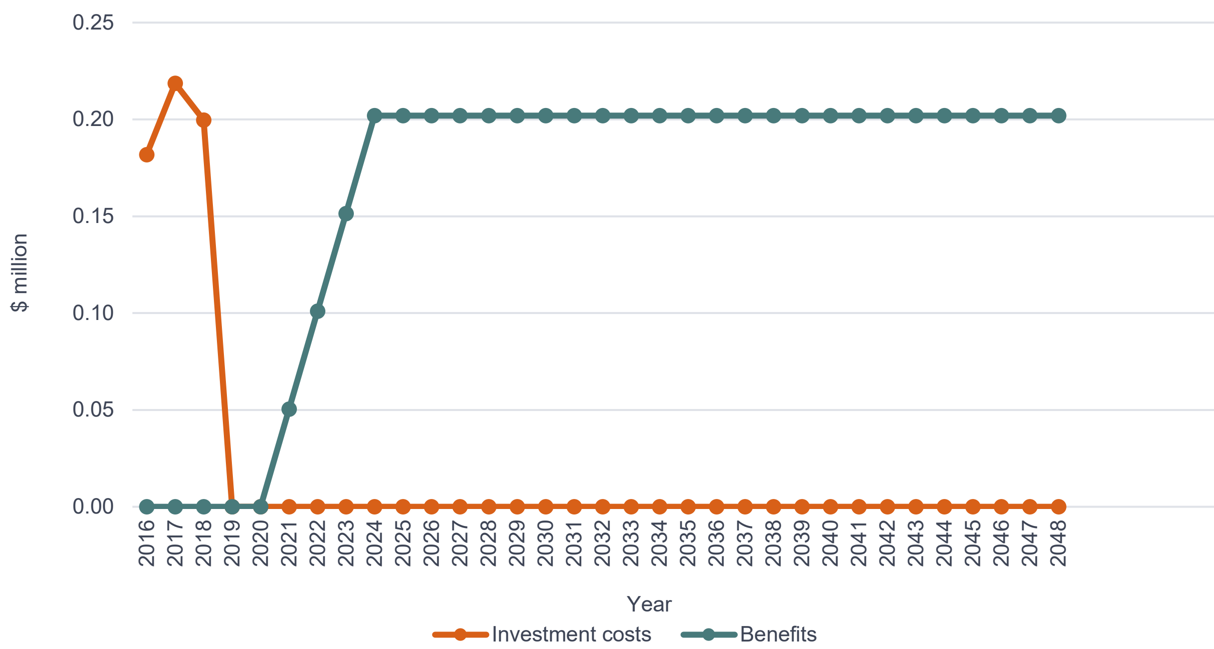
INVESTMENT CRITERIA	YEARS FROM LAST YEAR OF INVESTMENT						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	0.26	0.98	1.54	1.98	2.33	2.60
Present value of costs ($m)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Net present value ($m)	-0.66	-0.40	0.32	0.88	1.32	1.67	1.94
Benefit–cost ratio	0.00	0.39	1.48	2.33	3.00	3.52	3.93
Internal rate of return (%)	negative	negative	10.4	14.6	16.0	16.5	16.7
Modified internal rate of return (%)	negative	negative	9.7	11.5	11.3	10.7	10.1

TABLE 7: INVESTMENT CRITERIA FOR SRA INVESTMENT AND SRA BENEFITS (DISCOUNT RATE 5%)

INVESTMENT CRITERIA	YEARS FROM LAST YEAR OF INVESTMENT						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	0.11	0.43	0.68	0.88	1.03	1.16
Present value of costs ($m)	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Net present value ($m)	-0.29	-0.18	0.14	0.39	0.59	0.74	0.86
Benefit–cost ratio	0.00	0.39	1.48	2.33	3.00	3.52	3.93
Internal rate of return (%)	negative	negative	10.3	14.6	16.0	16.5	16.7
Modified internal rate of return (%)	negative	negative	9.7	11.5	11.3	10.7	10.1

The annual cash flow of undiscounted benefits and costs for the total investment are shown in Figure 1.

FIGURE 1: ANNUAL CASH FLOW OF UNDISCOUNTED BENEFITS AND COSTS



10.1 Source of benefits

The relative contributions of the two sources of benefits are provided in Table 8. Given the assumptions made, the application of higher N in selected seasons and soil types generated significant benefits compared to N cost savings in expected wet seasons.

SOURCE OF BENEFIT	CONTRIBUTION TO PVB ($M)	CONTRIBUTION TO PVB (%)
Nitrogen cost savings	0.15	5.7
Increased sugarcane yields	2.45	94.3
Total	2.60	100.0

10.2 Sensitivity analyses

Sensitivity analyses were carried out for several variables and results are reported in Tables 9 to 10. All sensitivity analyses were performed on the total investment only using a 5% discount rate (with the exception of Table 9) with benefits taken over the 30-year period. All other parameters were held at their base values.

Table 9 shows there is a moderate sensitivity to the discount rate, largely due to the long period of time over which the benefits are delivered.

TABLE 9: SENSITIVITY TO DISCOUNT RATE (TOTAL INVESTMENT, 30 YEARS)

CRITERION	DISCOUNT RATE		
	0%	BASE (5%)	10%
Present value of benefits ($m)	5.35	2.60	1.47
Present value of costs ($m)	0.60	0.66	0.73
Net present value ($m)	4.75	1.94	0.75
Benefit-cost ratio	8.92	3.93	2.03

Table 10 provides a sensitivity analysis for the assumption regarding the yield gain from applying more nitrogen in years predicted not to be wet. Results show that the investment criteria are quite sensitive to the yield gain assumed.

TABLE 10: SENSITIVITY TO RISK ASSUMPTIONS ASSOCIATED WITH THE YIELD GAIN ASSUMED FROM INCREASED N APPLIED IN YEARS NOT PREDICTED TO BE OVERLY WET (TOTAL INVESTMENT, 5% DISCOUNT RATE, 30 YEARS)

CRITERION	YIELD GAIN ASSUMED FROM ADDITIONAL 20 KG N/HA		
	2.5%	5%	7.5%
Present value of benefits ($m)	0.97	2.60	4.22
Present value of costs ($m)	0.66	0.66	0.66
Net present value ($m)	0.31	1.94	3.56
Benefit-cost ratio	1.47	3.93	6.39

11 Conclusions

The investment in this project has built on earlier SRA investments in management of N fertiliser strategies in the Wet Tropics, using seasonal climate forecasting. The project has added soil type and climate zones as further influencing variables and has built an algorithm (Optim-N app) that integrates APSIM with the seasonal climate forecasting models and other local knowledge to estimate N fertiliser requirements. The algorithm enhances Steps 5 and 6 of the SES N management aid.

As with all prototypes, further testing and validation of the model is required before any widespread applications will be evident, the current preliminary economic assessment indicates that considerable benefits may be delivered in future. The associated uncertainties in the current assessment have been accommodated by conservative base adoption and impact assumptions as well as the inclusion of risk factors for outcomes and impacts for each impact valued.

Given the assumptions made and recognising earlier investment in N management and seasonal climate forecasting, the investment criteria are positive. The total investment in the project of $0.66m (present value of investment costs) was estimated to deliver an expected present value of benefits of $2.6m, an expected net present value estimated at $1.94 million and an expected benefit-cost ratio of 3.93 to 1. All investment criteria were estimated using a discount rate of 5% and with benefits estimated over 30 years from the final year of investment. The internal rate of return was estimated at 16.7% and the modified internal rate of return at 10.1%.

12 Acknowledgments

Yvette Everingham, James Cook University

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