

Innovative economic levers: a system for underwriting risk of practice change in cane-farming

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ACRONYMS

APSIM	Agricultural Production systems SIMulator
BD	Bulk Density
BOM	Bureau of Meteorology
DIN	Dissolved Inorganic Nitrogen
DUL	Drained upper limit
FOM	Fresh organic matter
GBR	Great Barrier Reef
NESP	National Environmental Science Program
OC	Organic Carbon
PTF	Pedotransfer functions
RGP	Reduced Growth Phenomenon
TWQ	Tropical Water Quality

ABBREVIATIONS

CO₂	Carbon dioxide
kg N ha⁻¹	Kilograms of Nitrogen per hectare
Ks	Saturated hydraulic conductivity
N	Nitrogen
N₂	dinitrogen
N₂O	nitrous oxide
NO₃-N	nitrate-nitrogen
t yr⁻¹	tonnes (of cane) per hectare

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Finally, we would like to acknowledge the advice of Burn Ashburner and Matt Kealey of Australian Canegrowers. They were instrumental with introducing us to Willis Towers Watson, supported our modelling (which led us to believe a simulation-based parametric product may be acceptable to farmers), and pointed out concerns the sugarcane industry may have with various aspects of the N insurance concept. We hope the industry will one day benefit from a commercial product based on this research. This research was funded by the Australian Government’s National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub.

EXECUTIVE SUMMARY

Discharge of dissolved inorganic nitrogen (DIN) from sugarcane farms is a major threat to the Great Barrier Reef (GBR). The export of DIN from sugarcane farms is related to the application of nitrogen (N) fertiliser in excess of the amount taken up by crops. Applying nitrogen fertiliser in excess of crop needs is a rational response by farmers growing high value crops, including sugarcane, to minimise the risk of crop growth and yield being limited by availability of N. Insurance is an instrument commonly used to mitigate risk, and this project examined whether insurance could be an enduring instrument, that does not depend on public funding, to help farmers manage risk leading to them reducing N applications. The opportunity for insurance exists because, most farmers over-estimate the risk of yield loss compared with the real risk, and the money saved by the farmer on reduced N fertiliser effectively subsidises the premiums. Further, N fertiliser management of sugarcane crops is regulated in GBR catchments creating further incentive for some sugarcane farmers to reduce N fertiliser application rates and explore new risk-management strategies.

We surveyed existing crop insurance products, through both a literature review and interviewing insurance companies, to gauge their suitability for the problem of insuring against the loss of yield from reducing N fertiliser applications and determine the requirements of a successful crop insurance product. Products existed for specific perils to crops (e.g. hail, or fire), adverse weather (e.g. inadequate rain), low crop yields and low farm income. However, none of these were suitable for N insurance. So, we needed to design an original product. Broadly, there are three elements needed to create an insurance product. You need to:

1. Quantify the risk of loss, for this project the size and frequency of cane yield lost due to N reduction. This activity is central to determining the price of an insurance product.
2. Develop a technique for assessing the size and value of a loss, if any.
3. Estimate the variability in total losses, and thus claims payed out. This information is necessary for insurance companies to assess the likelihood of large, infrequent total claims, which are a potential risk to their business.

The methods used to solve these problems have a strong influence on the type of product offered. The product needs to be developed to minimise a range of perils associated with insurance, which affects the attractiveness and/or viability to both customers and insurance companies.

We explored using empirical data to both assess risk of loss and determine the size and value of a loss. Using this approach would have allowed us to create an indemnity product (e.g. traditional hail insurance). However, there was insufficient empirical data to provide a widespread and robust assessment of risk of loss. Likewise, using empirical data to determine the size of a loss would add substantial complexity to a product and be impractical. Thus, creating a product on empirical data would very likely result in one that was unacceptable to both farmers and insurance companies.

An alternative is to use crop modelling to assess the risk of yield loss and find some index relating weather to the loss suffered. This results in a parametric insurance product. Parametric products are increasingly common in crop insurance because they overcome many of the

perils associated with indemnity products for crops. Relationships between weather and sugarcane response to N fertiliser are complex, so a simple index (e.g. rainfall above or below a threshold) will not be accurate. However, the Australian sugarcane industry has access to world-leading capability for simulating sugarcane growth and yield as influenced of N fertiliser applications. Thus, we developed simulation-based methods to both assess risk of loss and size of a loss, we termed the latter a *Weather Derivative Index*.

The result was a prototype product for insuring the risk to yield from reduced N rates. This is a world-first – there is no other insurance product like it. Sugarcane farmers, Canegrowers and insurance companies collaborated in the development of this prototype product. Indicative pricing shows that there are indeed many situations where premiums are less than money saved on fertiliser. We have tested the product with farmers via participatory rural appraisal processes, with positive responses including comments from farmers like “it’s the only way to get N rates down...” International crop insurance companies think the prototype product is conceptually sound and could potentially be developed to commercial reality.

What magnitude of fertiliser reductions might N insurance facilitate? We estimate that wide uptake of a successful product could result in a reduction in DIN discharge of $\sim 1,000 \text{ t yr}^{-1}$. Achieving this environmental outcome, without the need for ongoing public funding would be a big “win” for the GBR and a likely no regrets outcome for farmers.

What is needed to transform the prototype into commercial reality? While international insurance companies think the prototype is conceptually sound, they still have many questions around the cost of administering and developing the product (i.e. the price) and the demand for this insurance. Due to the novelty of this product, there is no prior experience on which to estimate its likely uptake. Being a new and conceptually complex concept, it will also require considerable education and trust-building amongst farmers and their advisors to stimulate demand. Proving that the product is efficient to administer and deliver, and building trust among farmers will be critical steps in moving the prototype to commercial reality.

Will it be attractive for insurance companies to invest in establishing the commercial viability of an N insurance product for the GBR? There are many barriers to establishing new agricultural parametric insurance products, including unknown demand and high setup costs. Further, if a new product is successful, it may be easily replicated by other companies making it hard for the originator to recoup costs. Compounding these problems is the small potential revenue, by global standards, of sugarcane N insurance in GBR catchments. Thus, while insurance is potentially a very useful tool for helping reduce N rates and protect the GBR there are substantial barriers to companies creating the product by themselves.

In conclusion, we have shown that insuring against the risk of sugarcane yield loss with reduced N fertiliser applications is technically feasible. Further, we have shown that it can be implemented in a way that overcomes many of the problems that have plagued traditional crop insurance. If widely adopted, it could facilitate substantial reductions in DIN discharged from GBR catchments. However, establishing commercial viability of this prototype product will require considerable effort to build understanding of, and trust in the product amongst farmers. Likewise, efforts will be needed to facilitate potential insurers and re-insurers understanding and assessing the commercial viability of this new product. Without these next steps the

opportunity to create an enduring market-based risk management tool that supports cane farmer behaviour change and water quality improvement will be lost.

1. INTRODUCTION

The health of the Great Barrier Reef (GBR) is under pressure from discharge of dissolved inorganic nitrogen (DIN). The main source of DIN is nitrogen (N) fertilisers applied to sugarcane cropping, with DIN discharges correlated to N fertiliser application rates at all scales, from the field to the basin (Brodie et al., 2013; Waterhouse et al., 2017). Thus, the primary and most well proven path to reducing DIN impacts on the GBR is to have farmers reduce N fertiliser application rates to sugarcane crops (Thorburn and Wilkinson, 2013); currently other approaches are secondary to this goal.

The Queensland and Australian governments have recognised the need for farmers to reduce N fertiliser applications to sugarcane crops and since 2008 have put in place two broad-scale activities to effect that change (Kroon et al 2016): (1) regulation of N application rates to be at least equal to industry support recommendations (The State of Queensland 2019), and (2) providing grants to facilitate voluntary adoption of improved practice. However, after more than 10 years of these measures many farmers still apply N fertiliser at above-regulated rates, as shown by successive Report Cards (Australian and Queensland Governments 2019). This lack of success is, perhaps, not unexpected. Compliance with regulations to control distributed source pollution is difficult and expensive to enforce (Kroon et al 2016). Further, regulations represent a “minimum standard” and rates will need to be reduced below those in order to achieve water quality targets (Brodie et al., 2013; Waterhouse et al., 2017). Internationally, the history of success with voluntary reductions of N fertiliser rates is poor (Kroon et al 2014) so the lack of success in Australia comes as no surprise.

When seeking to effect change in farmers’ behaviour it is useful to consider the motives for their behaviour. Sugarcane farmers over-apply N fertiliser because they fear losing profits: the reduction in profits (through reduced yield) from under-application of N is much greater than reduction in profits (through unnecessary expenditure on fertiliser) from over-application (Pannell 2017). Addressing this fear is key to facilitating farmers reducing N applications. Demonstration trials that prove less N can achieve similar yields have been shown to help sugarcane farmers overcome their fear (Connellan et al 2017). However, these trials are expensive, and their residual effectiveness has not been tested; that is do farmers revert to previous N rates some years after the trials? This question is relevant because there are two important considerations in the adoption of an agricultural practice: is it easy to try, and does it give a relative advantage compared to the alternative (Pannell et al 2006). Demonstration trials may facilitate farmers trying lowering N rates during the time of the trials but do little to address the fear that lower rates provide an advantage (i.e. increased profits) in the longer-term. The GBR requires enduring instruments to address farmers’ fear of risk.

Market based approaches have the potential to help alleviate farmers’ fear because they could provide farmers with a source of income to offset the possible losses in profits from reducing N fertiliser rates. One approach trialled, “reverse auctions” (Reef Trust N Tenders, <https://www.environment.gov.au/marine/gbr/reef-trust/repeated-reverse-auctions>) helped to de-risk farmers’ changes in N fertiliser management by having the Government “purchase” reduced N fertiliser rates over a period of time (e.g. 3 years). However, de-risking through the provision of public funds, whether through reverse auctions or other means, is not attractive in the long-term. The success of Reef Trust N Tenders with innovative farmers has led to the

development of a similar commercial scheme, the Reef Credit Scheme (<https://www.reefcredit.org/>). While this scheme looks promising, the number of reef credits “sellers” (i.e. innovative farmers) may be small and the number of purchasers unknown (especially in the long term). There is a need for additional approaches.

An alternative market-based approach may be for farmers to insure against the risk of yield loss. The opportunity for insurance exists for two reasons: (1) Most farmers over-estimate the risk of yield loss compared with the real risk (as evidenced by the need for regulation to curtail above-recommended applications), so an insurance product developed on the real risk could be priced attractively. (2) The money saved by the farmer on reduced N fertiliser effectively subsidises the premiums. Further, N fertiliser management of sugarcane crops is regulated (The State of Queensland 2019), creating further incentive for some sugarcane farmers to reduce N fertiliser application rates and explore new risk-management strategies. While insurance of agricultural production has been in existence for centuries (Makki 2002, Smith and Glauber 2012) existing products focus on weather related risks on production, i.e. potential reduction in yields under given weather conditions. These approaches are not directly applicable to N insurance because of the added complexity of the crop’s response to N fertiliser, a response that can be quite different affected by weather than yield alone (e.g. a weather event results in lower yield, but the yield is the same at two different N fertiliser rates and there is no yield loss due to N). Thus, a new approach is needed if potential risks to yields from reduced N fertiliser are to be mitigated through insurance.

There are multiple design elements that must be addressed in creating a crop insurance product that considers the above issues. Of critical importance is the structure of the product. Common crop insurance products are specified peril, that is indemnifying farmers against specific events (e.g. fire insurance in sugarcane, or hail insurance in broad acre crops). Yield (or income) is often protected through multi-peril insurance, where the loss (e.g. reduced yield) can arise from a number of different causes. Historically, most agricultural insurance is indemnity-based contracts, where products are based on actual, verifiable losses (Linnerooth-Bayer et al 2019). These products possess some well-known structural problems (or risks) and are costly (Makki 2002). A more efficient approach is parametric insurance, where the product is based on the value of a specified “index” (e.g. rainfall) that is reliably measurable and objectively observable by a third party, and thus not subject to the influence of either party in the contract (Miranda and Farrin 2012). Over the past decade parametric products have become common in agriculture because they are operational simple and overcome many of the risks associated with an indemnity approach to crop insurance (Hazell and Hess 2017). Finally, any new product must be understood and accepted by stakeholders (Hazell and Hess 2017), be they purchasers (i.e. farmers) or suppliers (i.e. insurance companies).

This report describes the development of a prototype product for sugarcane farmers to insure against the risk of yield loss due to the reduction in N fertiliser application rates. The product developed is focused on application to The Wet Tropics region in Far North Queensland (primarily from Tully to Cairns), a region where DIN discharges cause high risk to the GBR (Waterhouse et al., 2017). The report is divided into 7 sections. In section 2 we review the multiple design elements that must be addressed in creating a crop insurance product. Important elements, addressed in subsequent sections are:

- Quantifying the risk of yield loss,
- Assessing the loss (if any)
- Systemic risk (i.e. the likelihood of correlated losses)

We then describe our interactions with important stakeholders: farmers, farming institutions and insurance companies. Finally, we describe the steps needed to transform the product from a prototype to commercial reality. If that transformation proves possible, the insurance product described here provides the potential for a “world first”, a non-publicly funded risk management tool that can facilitate enduring reductions in DIN discharged to the GBR. Thus, there could be virtually no public cost to the abatement resulting from this approach.

2. REVIEW OF CROP INSURANCE

2.1 Introduction

Crop insurance has existed in various forms for centuries (Makki 2002, Smith and Glauber 2012). In Australia, there are a range of indemnity and parametric insurance products that are or have been available for broadacre crops as well as a long history of named-peril products (Hatt et al 2012, Grain Growers 2018). The indemnity or parametric products may serve as a framework for developing a product for insuring risk to production from reduced N fertiliser applications in sugarcane farming. However, there are a number of potential barriers to both the development and long-term viability of insurance products. Thus, the creation of an insurance product for yield risk associated with reducing N fertiliser in sugarcane requires good understanding of crop insurance, encompassing both the existing products and the attributes of successful products.

Here we: (1) review agricultural crop insurance products available in Australia in recent times, (2) review the issues associated with the development and long-term viability of an insurance product for N practice change in sugarcane farming, and (3) summarise the implications of these points for insuring production risk from reduced N fertiliser applications.

2.2 Products

2.2.1 Indemnity insurance products

With indemnity insurance products, the risk of loss (i.e. the size and frequency of the loss) is determined from empirical information on the loss (Rolski et al 1999). For example, in quantifying the risk to crops from hail damage in a locality, an insurance company would obtain historical data on the frequency of hail storms and the damage done to crops by the hail in that locality. There is a range of indemnity crop insurance products available in Australia.

2.2.2 Named peril crop insurance

Named peril crop insurance insures against specific perils (e.g. hail or fire). Commercial named peril crop insurance products are currently available for sugarcane crops. For example, Primacy insurance company offers sugarcane growers cover for fire and hail (pers. comm. Tan Ratanapaeoomon 2017; Table 2-1).

Table 2-1: Some insurance products previously or currently available for the Australian agricultural industry.

Company	Type of product	Product name	Crops covered	Variable that triggers a claim
Primacy	Named peril crop insurance (fire and hail)	Broadacre Crop Insurance	Sugarcane	Yield
CGU through Canegrowers	Named peril crop insurance (fire and hail)		Sugarcane	Yield
Primacy	Multi Peril Crop Insurance (MPCI)	Primeguard	Wheat, barley, oats, canola, tritcale	Yield
WFI	MPCI	Early Bird Crop Insurance	Broadacre crops	Yield
MPCI Australia Latevo	MPCI	Multi-peril crop insurance	Broadacre crops	Yield
	MPCI	Agricultural income protection	Broadacre crops	Revenue
SureSeason	MPCI	SureSeason Revenue MPCI Broadacre Winter Crop Protection	Winter crops	Revenue
ProCrop	Weather derivatives	ProCrop	Wheat, barley, oats and canola	Weather and revenue
CelsiusPro	Weather derivatives	Climate		Weather

2.2.3 Multi-peril crop insurance

Multi-peril crop insurance (MPCI) insures against a loss of yield from any of a range of perils such as flood, excessive rainfall, hail, frost, snow, damage from wildlife or pests, disease, drought, heat stress and fire. They can indemnify yield or revenue (Table 2.1). Application for a MPCI product generally requires the farmer to provide comprehensive historical farm data (e.g. yields, revenue and expenses for the last five years) to enable the company to undertake a risk assessment.

MPCI products have been introduced to Australia on multiple occasions over the period 1974 to 2010 but have struggled to succeed (Hatt et al 2012). The early schemes were withdrawn, commonly after 1 to 3 years. In 2014, MPCI products were reintroduced to Australia with multiple companies offering cover against loss of yield for selected broadacre crops (e.g. wheat) grown within specific areas (Primacy 2017, MPCI Australia 2015, WFI n.d.; Table 2.1). By 2019, many of these products had been withdrawn (Grain Growers 2019) although Latevo continued to offer MPCI under a mutual fund structure (described below). There are a number of reasons for the commercial failure of these products. Farmers perceive the cost of the premiums to be a barrier (Grain Growers 2019) and drought in the 2017 and 2018 grain cropping season resulted in high payouts for the insurance companies.

2.3 Parametric products

MPCI products face numerous challenges, described below. These challenges have led to the increased popularity of parametric insurance products (Hazell and Hess 2017, Linnerooth-Bayer et al 2019). Parametric insurance differs from traditional insurance in that the trigger for

claims is an observable external variable, an “index”, that the farmer or insurance company has no control over (Miranda and Farrin 2012, Binswanger-Mkhize 2012, Hazell and Hess 2017).

An ideal variable is objective, able to be measured reliably, accurately reflects the losses of the insured, and cannot be influenced by any interested party (Miranda and Farrin 2012). Indexes used include weather variables, regional yields, flood levels, and satellite measured vegetation indices (Miranda and Farrin 2012). Weather products such as CelsiusPro (CelsiusPro 2012) are based on a weather variable (Table 2.1). Rainfall is a commonly used variable for weather derivatives products. For example, a claim may be made if rainfall is above or below an agreed amount over a specified time period.

Yield index insurance products predict farmer yields through modelling. Yields for the coming season are predicted based on a range of variables including district average yields, climate factors, crop phenology and crop management (Hatt et al. 2012). A claim is triggered if the actual yield falls below the original prediction. An example of a yield index product is YieldSheild, released by Primacy in 2009 but no longer available. YieldSheild covered for traditional named perils (hail and fire) as well as crop water stress from insufficient or excessive rainfall. Water stress was simulated with a crop model calibrated to shire scale yields (Hatt et al. 2012).

2.4 Mutual funds

A mutual fund is a financial structure that functions in a similar way to an insurance product (Hatt et al 2012). Fund members pool a portion of their income into an investment fund. A member can make a withdrawal from the fund if an event triggers a loss of yield or income (Hatt et al 2012). Re-insurance is used to cover the risk to members of claims exceeding capital available in the fund. Alternatively, government support may be needed to meet the needs of farmers who experience losses from multiple perils (Grain Producers Australia 2014). Mutual funds have been successfully used as risk management tools in the European agricultural sector (European Commission 2006) and a scheme existed during 2011-12 for grain growers in Western Australia (Hatt et al. 2012). Latevo also established a mutual fund in 2019 (<https://www.latevofarmersmutual.com/about-2/>). More recently, Qld Farmers Federation have investigated the feasibility of establishing a discretionary mutual fund to support a parametric cyclone insurance product (<https://www.qff.org.au/presidents-column/insuring-ensure-future-agriculture/>).

An advantage of mutual funds is the vested interests fund members have in the success of the scheme (Russell Mehmet pers. comm. 2017). This means that products offered by mutual funds should be less susceptible to some of the challenges facing insurance products (described below), particularly adverse selection and moral hazard. Also, if the fund is profitable and capital reserves grow, re-insurance costs will be reduced which will reduce premiums.

However, the fund still needs a mechanism to define the “event” that triggers a claim. In this sense, the requirements for creating a product within a mutual fund structure are the same as those for creating a more conventional commercial product.

2.5 Perils associated with a product

2.5.1 Adverse selection

Adverse selection is when there is asymmetric information (which refers to one party having more information than another party) prior to an agreement being made – it has been referred to as the “problem of hidden information” (Quiggin et al 1993). For example, farmers may have more information about the potential for crop failure than the insurer (Makki 2000, Hertzler 2005, Smith and Glauber 2012). Thus, farmers with a high probability of yield loss would be more likely to take out insurance and get higher returns from insurers than farmers with a low probability of yield loss (Miranda and Farrin 2012, Khuu and Weber 2013). This situation arises where the risks on which a product is based are treated as homogeneous, at some spatial scale, whereas in fact they are heterogeneous. Adverse selection can result in market failure because low risk farmers do not take out insurance and high-risk farmers are over-represented in the product pool (Miranda and Farrin 2012, Khuu and Weber 2013). The availability of high quality, detailed, relevant datasets can minimise the risk of adverse selection (Grain Producers Australia 2014) because such data can allow heterogeneities in risk to be quantified. Alternatively, adverse selection can be minimised by high farmer uptake, achieved through incentives or regulation (Boyd et al. 2011). Basing insurance products on publicly available information can also help reduce risk of adverse selection (Miranda and Farrin 2012).

2.5.2 Moral hazard

Moral hazard is when the insured changes their behaviour after an agreement has been made, increasing the chance of a claim (Hertzler 2005, Boyd et al. 2011, Miranda and Farrin 2012). For example, a farmer may intentionally mismanage their farm to increase their chances of obtaining an insurance payout (Miranda and Farrin 2012). It has been referred to as the “problem of hidden action” (Quiggin et al 1993). It happens because insurance shifts the risk of loss from the insured to the insurer (Khuu and Weber 2013). Moral hazard poses a significant challenge for MPCl products (Miranda and Farrin 2012, Smith and Glauber 2012, Wang et al. 2013). It may be difficult for insurers to identify if a loss of yield has occurred from a peril covered in the insurance policy or from intentional mismanagement of the farm. While some actions that relate to or impact an insured product can be observed and monitored, other actions are more costly and difficult to monitor. For example, it can be difficult to ensure a farmer has followed best practice with fertiliser applications (Smith and Glauber 2012).

A way to mitigate moral hazard is to require the policy holder to share some of the loss (Smith and Glauber 2012). Commonly used approaches are the use of excesses, co-insurance and/or coverage levels, where the insurer may only cover a portion of production (e.g. 65%) (Hertzler 2005, Hatt et al 2012). In addition, requiring that crops be insured over multiple years can mitigate against moral hazard (Vercammen and Van Kooten 1994, Smith and Glauber 2012).

Conversely, moral hazard poses a much smaller risk for parametric insurance products which are based on measured variables external to the farm over which the farmer (and the insurer) have no control (Miranda and Farrin 2012, Hatt et al 2012). As noted above, mutual funds may reduce the risk of moral hazard through the interest the members have in the fund.

2.5.3 Systemic risk

Systemic risk is the possibility that an event could trigger the collapse of an entire market. An ideal condition of successful insurance markets is that individual risks are independent (Miranda and Glauber 1997, Makki 2000, Boyd et al. 2011, Miranda and Farrin 2012). Agriculture often violates this condition as the effects of drought, excessive rainfall, disease, and pests can be widespread and occur for long periods of time (Makki 2000, Miranda and Farrin 2012). This problem is one of the reasons there are so few private markets for crop insurance (Miranda and Glauber 1997). Thus, systemic risk always poses a challenge for the agricultural insurance industry, particularly in regions with inherently variable climate, such as Australia. Systemic risk can affect both indemnity and parametric insurance products. Re-insurance provided by global re-insurance companies or Government that can diversify the risks away from a region may alleviate systemic risk (Hertzler 2005, Boyd et al 2011). However, the cost of re-insurance provided by re-insurance companies can increase the cost of the product, which can reduce its attractiveness (Miranda and Farrin 2012).

2.5.4 Basis risk

Basis risk is a risk that affects parametric products. It refers to when the index on which the insurance is based is poorly correlated with the losses experienced by the insured (Wang et al. 1998, Golden et al 2007, Miranda and Farrin 2012). For example, a farmer may experience a significant loss but not receive a payment as the conditions to trigger a claim were not met for the index on which the insurance is based. Conversely, a farmer may have high yields, but receive a payment as the index trigger for the claim was met (Wang et al 1998). The benefit of a parametric product to the insured will depend on the correlation between the index underlying the product and the losses experienced by the insured (Miranda and Farrin 2012). The availability of high-quality data at a fine scale that can be used as indices may facilitate correlation between an index and realised losses.

2.5.5 Credit risk

This is the risk that an insurance company may not be able to pay a claim because of financial difficulties (Golden et al 2007). This risk has not been cited as a barrier to farmers purchasing crop insurance in Australia (Grain Growers 2017, 2018, 2019), although it has overseas (Golden et al 2007).

A similar risk is that during the loss adjustment process, insurance companies will find reasons to deny a claim. This fear was raised repeatedly in our interactions with farmers during this project (section 6). This risk is lower with parametric products because the criteria for triggering a claim are objective and, ideally, not influenced by either the insured or insurer.

2.6 Challenges

2.6.1 Data requirements

The development of relevant datasets (both specific and integrated) to better inform the actuarial models behind traditional insurance products may assist in managing adverse selection, asymmetric information, and moral hazard (Grain Producers Australia 2014). These datasets will also assist in minimising basis risk associated with parametric products. However, access to the information to assemble these datasets may be difficult, time consuming, and/or

costly. Obtaining long-term historical data (e.g. climate or productivity data) at a fine scale for the region of interest has been a problem for MPCl products in Australia (Hatt et al 2012) and is seen as important in overcoming general problems with parametric products (Hazzell and Hess 2017). There are many climate stations already in operation in Australia that provide historical climate data (via the SILO database, <https://www.longpaddock.qld.gov.au/silo/>; Jeffrey et al., 2001). However, climate data may be required at a finer scale than what is currently available (Hazzell and Hess 2017), especially in topographically complex regions with strong orographic effects on climate, like coastal north eastern Australia. There may be a role for the Australian Government (through the Bureau of Meteorology) in providing additional infrastructure and managing assets that facilitate climate data collection (Hatt et al 2012).

2.6.2 Farmer uptake

A high farmer participation rate is required to maintain the long-term viability of commercial agricultural insurance schemes (Boyd et al. 2011). Australian farmers have been reluctant to take up crop insurance, apart from named peril products (Hatt et al 2012, Grain Growers 2019). Australian farmers are skilled at farming in an inherently risky environment (Kimura and Anton 2011, National Rural Advisory Council 2012) and so may see crop insurance as an unnecessary expense. Many farmers manage their income so funds are saved in the good years so they can be available in the difficult times (i.e. self insurance), diversify by growing a variety of crops or incorporating livestock, or operate farms in different regions (Hertzler 2005, Boyd et al 2011). Farmers may be resistant to take out new insurance policies that require a large quantity of historical data, are a financial cost, and may impose auditing.

Developing an insurance product that is attractive to farmers requires careful consideration. Collaboration and communication with farmers, farmer groups and other stakeholders will assist in developing a suitable product (Hazzell and Hess 2017, Grain Growers 2017, 2018).

2.6.3 Government support

Government can play a substantial role in facilitating the uptake and long-term viability of insurance products for the agricultural industry (Hertzler 2005, Boyd et al. 2011, Miranda and Farrin 2012). This is particularly relevant for MPCl products as they receive substantial government support in many countries, but not Australia (Hatt et al 2012, Grain Growers 2019). Canada, the United States of America, the European Union, Japan, and Brazil have range of government supported MPCl products that have been available for decades. Governments provide considerable support, largely in the form of subsidies for premiums (Hertzler 2005, Boyd et al 2011). This enables the viability of the product as indemnity payouts are frequently greater than premiums paid (Hertzler 2005, Miranda and Farrin 2012). For example, in the USA, the federal government subsidises premiums and provides financial support to insurance companies for the operating and administrative costs for MPCl products (Boyd et al 2011). As a result of this federal support, MPCl crop insurance is affordable to most American farmers and ranchers (Crop Insurance America n.d.).

In Australia, the Managing Farm Risk Programme was a federally supported MPCl facilitation uptake scheme giving 8,000 farmers \$2,500 to take out MPCl (Australian Government 2016). There are a range of other ways that governments could support MPCl and/or other forms of insurance (Table 2-2), although there are issues associated with each.

Table 2-2: Potential role for government to facilitate the uptake of MPCl products, the action by government to date, and some of the issues associated with these approaches (Hatt et al 2012, Independent Pricing and Regulatory Tribunal 2016).

Potential role for government	Action by government	Issues
Subsidies application fees and premiums	There is currently a subsidy for the application fee for MPCl; the NSW Government is considering subsidising premiums for MPCl products (Locke 2017)	Expensive to government, distorts market incentives
Make compulsory		Distorts market incentives (benefits riskier farmers)
Provide regional and farm level data (e.g. install additional rain gauges)	The installation of additional rain gauges and weather stations	Expensive, demand may still be insufficient
Provide re-insurance		May reduce systemic risk, but not other issues
Improve sharing of information with insurers		May be difficult to coordinate
Provide education	The Farm Business Skills Professional Skills Development Program commenced in November 2015	May not result in increased uptake of insurance
Waive stamp duty on multi-peril crop insurance premiums		May not reduce price adequately to increase uptake of insurance

It should be noted that the Australian Government provides support to farmers to assist them through times of drought and other hardship through a range of programs including the Farm Business Concessional Loans Scheme and Farm Household Allowance (Australian Government 2016). In the past, federal support to farmers affected by severe drought has been substantial. For example, in 2007-2008, 23 per cent of farmers received support totalling \$994 million (Khuu and Weber 2013).

2.6.4 Start-up costs

History shows that private insurance companies have rarely initiated agricultural parametric insurance products for various reasons (Hazell and Hess 2017): (1) Unknown demand, (2) high setup costs and other barriers to entry, and (3), if they do develop a new product, it may be easily replicated by other companies making it hard for the originator to recoup costs. This final point is a particular barrier in new markets. The problem of recouping R&D and establishment costs may justify some level of public support for product development if it provides societal benefits. Further, feasibility studies and pilot tests of new products with the involvement of local, private sector partners and farmers can help quantify demand for the product.

2.7 Implications for insuring production risk from reduced N fertiliser applications

Development of a successful insurance product requires innovative solutions to significant challenges. Firstly, comprehensive historical datasets are required to quantify risk. For a product focused on yield risk from reduced N fertiliser applications these data could come from historical N response experiments, and the number and distribution of these experiments would need to be investigated. Alternatively, simulation of N responses could be used, especially with a parametric product. Secondly, a framework is needed to enable identification of a loss to the insured. This constitutes a considerable issue for an indemnity product due to moral hazard and adverse selection but is less of a problem for an index-based parametric product. For the latter however, basis risk is an issue. Thirdly, systemic risk needs to be quantified – do the weather conditions that cause yield to be sensitive to N fertiliser applications at one site have that effect at many sites? Fourthly, under what conditions might farmers be interested in such a product? As stated in section 1 over-application of N fertiliser is a rational risk management strategy for sugarcane farmers. Close involvement with farmers during product development would be needed to identify the conditions under which insurance would provide them with benefits (e.g. helping meet regulatory requirements, being able to access benefits of market-based incentives to reduce N fertiliser applications) and ensure the product design meets their needs.

3. RISK OF YIELD LOSS: PRODUCT PRICE

3.1 Introduction

There are a number of factors that go into developing the technical price of an insurance product (Linnerooth-Bayer et al 2019). The first is the expected annual average loss. This is called the actuarially fair value or pure premium. For our research, that is the average loss of yield for a change in N fertiliser rates and value of sugarcane (e.g. price per tonne). In addition to the pure premium, insurance companies add loadings to premiums for (1) the cost of offering and administering the product; (2) costs of holding a risk reserve and/or having re-insurance to ensure claims can be paid; and (3) the company's profit margin. The first loading is affected by, amongst other things, the type of product. Parametric products are more efficient to offer and have a more efficient loss adjustment process (i.e. determining a payout on a claim) than traditional indemnity insurance. Thus, they are cheaper to offer. The second loading is affected by systemic risk; i.e. if risks are correlated there is a high likelihood of multiple claims and a high total payout in a year, and so the requirement for greater risk reserves or re-insurance. Uncertainty in estimates of systemic risk or average losses can result in additional loadings.

Thus, quantifying risk, i.e. the change in yield for a change in N fertiliser rates and how this varies across years in response to year-to-year variability in climate, is central to determining the technical price of an insurance product. For traditional indemnity insurance products, the risk of loss (i.e. the size and frequency of the loss) is determined from empirical information on the loss (Rolski et al 1999). For example, in quantifying the risk to crops from hail damage in a locality, an insurance company would obtain historical data on the frequency of hail storms and the damage done to crops by the hail in that locality. This approach is also used with parametric (index-based) products, where the distribution of the frequency and size of the index (e.g. rainfall compared against some threshold; e.g. Kath et al 2019) is analysed. If a simple weather index cannot be found for a particular crop-related risk, an alternative approach is to use crop modelling which takes account of a comprehensive range of weather variables, such as rainfall, temperature and solar radiation (Binswanger-Mkhize 2012, Leblois and Quirion 2013). This approach can result in a parametric product. Thus, the quantification of risk depends on the data available, which in turns affects the type of product that can be developed.

In this section, we examine the data available on the relationship between N fertiliser applications and sugarcane yield. Those data may be empirical, e.g. from experiments, and be useful for developing a traditional indemnity insurance product. Alternatively, they could come from simulating yield changes under different N rates which would allow development of a crop model-based parametric N insurance product. In order to develop a potential insurance product for use in the Wet Tropics for sugarcane farming, we examined using empirical data and found that there are insufficient empirical data available on which to base a product. Conversely, there is well developed capability to simulate growth and yield of sugarcane under different rates of N fertiliser. We undertook the simulations necessary to quantify risk and derive technical prices for the conditions in the Wet Tropics region, then show resultant technical prices and their variability. There are a high number of combinations of the biophysical and management factors which means it is impractical to show results for all combinations. Thus, we focus on results for two case studies within the region. Further, to

make these data available to stakeholders and collaborators during the project (described in section 6), we developed a web-based “app” that allowed the user to specify these factors and the value of sugarcane to see the resultant technical price.

3.2 Empirical data on sugarcane N responses

3.2.1 Data availability

The data required to quantify N risk are sugarcane yields under different N fertiliser application rates across a range of soil types and locations. The main source of these data are publications on “N response” field experiments, where sugarcane has been grown under different rates of N fertiliser. Sugarcane growth and yield responds differently to N fertiliser on different soils and under different climates (Schroeder et al 2014, Thorburn et al 2017), so a broadly applicable N insurance product would need to be based on N response experiments covering multiple soils and climates (i.e. climate zone in the Wet Tropics). There is substantial interannual climate variability in the Wet Tropics region (Nicholls et al 1997), so data would be needed across multiple years to capture this variability. N response experiments would also need to include a sufficient range and number of N application rates to cover all the rates that farmers might want to insure.

We collated results from published experiments in the different sugarcane producing regions (updating the work of Thorburn et al 2018). There were 10 experiments that had a unique combination of climate, soil and year, and an adequate range in N application rates (Table 3-1). Four were in the Herbert region and six in the Tully region.

Table 3-1: Brief summary of ten unique combinations of region (climate zone) and soil where experiments have been conducted in the Wet Tropics. In some cases, the location of specific experiments differed but the soil-climate zone combination was the same so they could be grouped together. The soil names and area of the soils came from data reported by Wilson and Baker (1990), Murtha (1986), and Cannon et al. (1992), and the area (ha and %) of that soil in the region is shown. Each experiment had at least three N fertiliser rates.

Region	Soil name	Area (ha)	Proportion of region (%)	Texture description	Number of crops (and years they were grown)	Reference
Herbert	Leach	1915	1.2	Silty clay over clay	4 (2009-2012)	Wood et al., 2008
Herbert	Macknade	6114	3.9	Loam over loamy sand	2 (2009, NA)	Wood et al., 2008
Tully	Bulgun	5764	3.6	Clay over silty clay	4 (1998-2000; 2012-2015)	Skocaj, 2015; Hurney and Berding, 2000
Tully	Coom	11109	7.0	Clay	6 (2005-2010)	Hurney and Schroeder 2012
Tully	Mossman	3277	2.1	Silty clay loam over clay loam	2 (2008-2009)	Skocaj et al., 2012
Tully	Thorpe	13116	8.2	Sandy loam	3 (1998-2000)	Hurney et al., 2003
Tully	Tully	22312	14	Silty clay over loam	6 (1999-2000; 2008-2010)	Hurney et al., 2003; Skocaj et al., 2012
Tully	Warrami	1444	0.9	Sandy loam over clay	3 (2008-2011)	Skocaj et al., 2012
Herbert	Unknown			Loam	1	Wang et al., 2016a
Herbert	Unknown			Silty clay loam over silty clay	1	Wang et al., 2016b

3.2.2 Implications for product pricing

There are a number of limitations of these experiments for characterising risk of yield loss. One is the limited area represented by the experiments. Within the Herbert region, the experiments on known soil type (Leach and Macknade) represent approximately 5% of the area of the region (Table 3-1). The situation is better in the Tully region (36% of the region is represented) but still the majority of the region has no N response data. The regions north of Tully, which include South Johnstone, Babinda and Mulgrave had no suitable experiments. The small number and limited coverage of the N response experiments would undermine confidence that risk of yield loss was characterised adequately. Farmers in regions and/or with soils with no experiments either could not be insured or would have to accept that the product assumed the response of their crops to N fertiliser was the same as those in one (or more) of the experiments. We know biophysically that is not tenable, and it is likely most farmers would not see a product based on such data as relevant to their farm or soils.

There are two other problems with relying on these experiments to characterise risk of yield loss. Firstly, the experiments were only conducted for a relatively short time (1 to 6 years, Table 3-1) during which the climate may not have been representative of other years. Secondly, there are a limited number of N rates in each experiment (usually 3 or 4, and exception being Tully-Bulgun that had 11). If farmers wanted a product for different N rates, the yield response (and

thus product) would have to be based on data interpolated (from fitted curves) from the rates in the experiment. An advantage of quantifying risk from empirical data is that the results are based on “real” data. Using interpolated data negates that advantage.

3.3 Simulation for quantifying risk of yield loss

3.3.1 Capability to simulate sugarcane N responses

In the absence of an adequate field-based empirical data on which to quantify yield loss, we investigated crop modelling as the basis for a parametric product. The most widely used and tested model for sugarcane N responses is the APSIM Sugarcane model (Keating et al 1999, Thorburn et al 2005, 2017). APSIM has been validated using experiments established across the Australian sugarcane growing regions from Bundaberg to Babinda (Table 3-2), and the model has performed well in all regions. At the time of writing, it was also being used to simulate an experiment near Cairns within the NESP-funded project (5.1.1; Improved water quality outcomes from on-farm nitrogen management). The results were similar to those in Table 3-2 (Tony Webster unpublished data).

Table 3-2: Summary of APSIM validations. Reported validation assessment statistics such as R^2 , RMSE, index of agreement (d) and modelling efficiency (ME) are included.

Region	Soil texture or class	Long-term mean rainfall (mm yr ⁻¹)	Year of harvest	Reference	Statistical assessment of validation
Bundaberg	Sandy loam to sandy light clay	997	1997–2001	Thorburn et al (2003)	$R^2 = 0.79$ RMSE = 17 Mg ha ⁻¹ d = 0.94 ME = 0.76
Mossman	Sandy clay	2,599	2004–2006	Thorburn et al (2011a)	
Maryborough	Sandy clay loam	995	2005–2007	Thorburn et al (2011a)	
Mulgrave	Sandy clay	2,082	2005–2008	Thorburn et al (2011a)	
Innisfail	Light clay	3,623	2006–2008	Thorburn et al (2011a)	
Tully	Bulgun	4,104	2012-2014	Everingham et al (2018)	$R^2 = 0.66$
Tully	Coom	4,104	2005-2009	Everingham et al (2018)	$R^2 = 0.71$
Babinda	Coom	4279	2000-2001	Meier and Thorburn (2016)	RMSE = 16 Mg ha ⁻¹ d = 0.98 ME = 0.72
Babinda	Malbon	4279	2000-2001	Meier and Thorburn (2016)	RMSE = 13 Mg ha ⁻¹ d = 0.99 ME = 0.84
Babinda	Coom	4279	2000-2001	Meier and Thorburn (2016)	RMSE = 14 Mg ha ⁻¹ d = 0.98 ME = -0.45
Abergowrie, Herbert	Loam / Red dermosol	1700	1981-1994	Meier and Thorburn (2016)	RMSE = 13 Mg ha ⁻¹ d = 0.79 ME = 0.08

Thus we used the APSIM model to provide the data on sugarcane yield responses, for a wide range of N fertiliser application rates, and soils and climates (Tully – Cairns) found in the Wet

Tropics. In the following sections we describe the details of the APSIM model and the configuration in this project of the simulations, climate data, soil and crop parameters and management. We then describe the simulations undertaken and the derivation of yield loss risk and product price.

3.3.2 The APSIM model

The Agricultural Production systems SIMulator called APSIM (version 7.8; www.apsim.info) was used to simulate the risk of yield loss with reduced N application rates across a range of climate zones, soil types and crop management in the Wet Tropics region.

APSIM is a deterministic model run on a daily time step and driven by meteorological data. APSIM simulates the interactions of climate, soil and crop processes for this project in the context of a sugarcane farming system. The model for the project was used as one-dimensional model.

APSIM consists of large number of sub-models which can be configured in a multitude of combinations. For this project the main sub-models used were SoilN, SoilWat, SurfaceOM (Probert et al 1998) and Sugar (Keating et al 1999). However, many other crop sub-models and alternative soil water models are available. A brief description of each of these sub-models is provided below and more detail can be found in Probert et al (1998) and Holzworth et al (2014).

Soil nitrogen processes (contained in the SoilN sub-model) are developed around the concept of several organic matter pools with transfers of C and N between the pools (i.e. decomposition) occurring at rates sensitive to soil temperature and moisture. Fresh organic matter (FOM) is introduced into the soil through the senescence of roots and incorporation of surface residues (e.g. sugarcane trash). The soil organic matter is represented by two pools that conceptually relate to the humus and microbial biomass fractions and are referred to as HUM and BIOM respectively. An inert fraction is also specified and forms a fraction of the HUM pool. The model user supplies parameters that describe these pools which include total organic carbon for all layers of the soil profile. The C:N ratio of the soil is also supplied and used to determine the C:N ratio of the organic matter pools. As carbon is transferred between organic matter pools via decomposition, carbon dioxide (CO₂) is released. Any excess organic N produced during decomposition is mineralised into the ammonium form. This ammonium can be transformed into the highly mobile nitrate form. At this point it is susceptible to loss via runoff, leaching and denitrification. Immobilisation of nitrogen is possible if the C:N ratio of the introduced FOM is sufficiently high.

Soil water movement was simulated in this project using a tipping bucket type model (within the SoilWat sub-model). Rainfall or irrigation is either partitioned between runoff and infiltration using a curve-number approach. Using this approach, the amount of infiltration can also be modified to capture the effect of cultivation and surface residues. The presence of surface residues will also affect evaporation. Moisture content at air-dried, drained upper limit (field capacity), lower limit (wilting point), and saturation are supplied by the model user which define the plant available water capacity.

APSIM-Sugar sub-model uses intercepted radiation (derived from the radiation supplied in the meteorological inputs) to determine potential biomass production each day. This potential increase in biomass is moderated by temperature, soil water and soil nitrogen supply. The biomass production is partitioned between the crop components such as leaf, stalk, roots and “cabbage”. Luxury uptake of nitrogen has been observed (Muchow and Robertson 1994) and is represented in the sugar sub-model by the difference between maximum and critical N concentrations (Keating et al 1999).

Many farm operations can be represented in the model such as sowing, harvesting, fertilisation, cultivation and irrigation.

3.3.3 Climate data

Climate data was sourced from the Australian Bureau of Meteorology (BOM) via the SILO gridded database (Jeffrey et al (2001); <https://www.longpaddock.qld.gov.au/silo/gridded-data/>), starting in 1949. This dataset consists of a 0.05° x 0.05° grid of virtual climate stations that have been developed via a range of interpolation methods (~29.5 km² at -17.5° latitude). The best representative meteorological station was selected for each sugarcane growing region.

3.3.4 Soil parameters

Where possible bulk density (BD), drained upper limit (similar to field capacity; DUL), lower limit (similar to wilting point; LL15), pH, total organic carbon (OC) and total nitrogen (N) were extracted from data obtained in previous soil surveys (Cannon et al 1992, Murtha 1986, Murtha et al 1992). Texture data (i.e. clay, silt and sand) was also obtained from these reports and used as inputs for pedotransfer functions (PTF) to estimate other necessary parameters.

A complete set of necessary APSIM soil parameters were developed following the method described by Barboux et al (2018) and validated by Biggs et al (2018). Most soil survey measurements were made on undisturbed (e.g. rainforest) locations and so a detailed process was followed to generate soil parameters more typical of soils which have been under cultivation for ~70 years. Specifically, OC declines with time under cultivation in soils of this region (Wood 1985). OC concentrations influence other soil properties and thus APSIM soil parameters (Palmer, 2014) so many of the properties of cultivated soils will be different to those in the soils prior to cultivation. This process for estimating the parameters more representative of cultivated soils is summarised here in the following steps:

1. Pedotransfer functions (PTF) were used to estimate missing parameters (e.g. BD, SAT, DUL, LL15) using an ensemble approach averaging the predictions provided by the pedotransfer functions (Palmer, 2014). These functions used OC and soil texture to estimate the parameter values.
2. Saturated hydraulic conductivity (Ks) was estimated using two PTFs (Puckett and Cosby, cited by Minasny and McBratney 2000). One was of these PTFs performed better for sandy soils and was used preferentially when the texture was classified as sandy. These functions used soil texture to estimate the parameter values.
3. The number and thickness of each soil layer was based loosely on that used in the soils reports with a minimum thickness of 0.15 m.

4. Missing soil OC values deeper in the profile were estimated by fitting an exponential function with OC values declining with increasing depth.
5. Other missing data which did not fit an exponential function well were estimated by fitting a polynomial surface using local fitting (i.e. loess; Cleveland et al 1992).
6. To obtain 'cultivated' parameters we first simulated the reduction in OC due to long-term cultivation by simulating ~70 years of burnt sugarcane production followed by ~30 years of trash blanketed production. This provided new values for OC and defined the structure of the various carbon pools (as defined by the APSIM parameters fbiom and finert).
7. We then substituted the 'cultivated' OC values for the undisturbed value in the PTF in steps 1 and 2 and thus estimated BD, SAT, DUL, LL15 and Ks values more relevant to the cultivated soils.
8. Other necessary parameters, such as the proportion of soil water above the drained upper limit that drains in one day (SWCON), the gas diffusivity in soil at field capacity used in estimating the partitioning of denitrified N into N₂ and N₂O (k1), diffusivity used to estimate unsaturated water flow defined by two parameters (diffus_const, diffus_slope), and the curve number for average antecedent rainfall conditions used to estimate runoff (cn2_bare), were developed according to the soil texture class (i.e. Sandy, clay or loam) or their similarity to experiment-based modelling work conducted previously.

If necessary, after obtaining expert local knowledge, location-specific information was also incorporated into the soil parameterisation such as propensity to flood or high water tables. Both important characteristics are not reported in enough detail if at all within the soil survey reports.

In the simulations, the initial soil conditions and amount of surface residues were reset at the beginning of each crop. This was done to remove the impact of preceding management on the current crop which might confound the effect of within crop climate. Parameter values specifying the initial soil conditions are presented in the next section.

To estimate nitrate-nitrogen (NO₃-N) lost via surface run-off, additional algorithms were included as described by Biggs et al (2013).

3.3.5 Crop parameters

Default APSIM Sugarcane parameters were modified based on sugarcane-specific research (Table 3-3). It was important for this task to ensure simulated yields were like those typically achieved in the regions to ensure that N uptake by the crop was realistic, thus leading to more realistic yield reductions with reduced N inputs. Models such as APSIM often are best at simulating potential yields, i.e. yields possible given the available solar radiation and water. However, these potential yields are often not achieved even with high N and water inputs due to several reasons such as lodging, decline in leaf N, disease, pest damage, etc. This issue has been previously referred to as Reduced Growth Phenomenon (RGP; Park et al., 2005). To represent RGP a simple growth slow down process (Dias et al 2019) was implemented.

Table 3-3: Non-default APSIM-Sugar parameters used in this project and the relevant references.

Parameter	Description	Value
crit_residue_wt	Amount of residue above which decomposition is slowed (Thorburn et al 2001)	10000
opt_temp	Maximum (or potential) decomposition rate (Thorburn et al 2001)	30
pot_decomp_rate	Optimum temperature for maximum decomposition (Thorburn et al 2001)	0.06
transp_eff_cf	Transpiration use efficiency (Inman-Bamber and McGlinchey 2003)	0.0087
sen_detach_frac	Rate of detachment of senesced leaf and cabbage (Thorburn et al 2001)	0.004

Waterlogging (oxygen deprivation) due to temporary shallow water tables and saturated conditions are common in the Wet Tropic soils. Waterlogging is represented in APSIM via a modified rate of photosynthesis based on the proportion of the root profile which is in saturated soil layers (Figure 3-1).

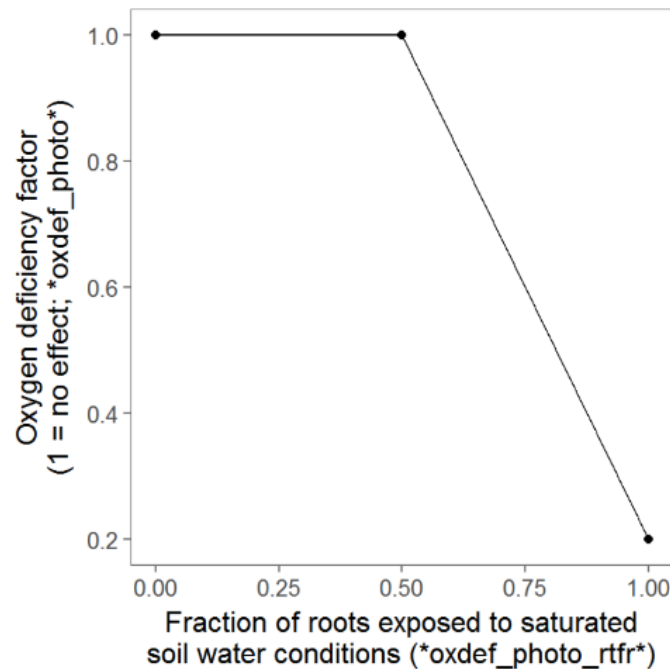


Figure 3-1: Effect of oxygen deficiency on photosynthesis as represented in APSIM-Sugar (Biggs et al 2013).

3.3.6 Management

Information such as harvest date (which marks the start of the crop's growth), fertilising date, N fertiliser rate, trash management, needs to be specified for simulating a sugarcane crop. Crop management was based on that identified in previous studies in the region (Everingham et al 2018, Biggs and Thorburn 2017). All simulations consisted of 12-month long ratoon crops that had the same management (except for varying N fertiliser rates) and crop start dates.

The crop start time has been identified as an important determinant of risk of sugarcane N response (Biggs et al 2020) so three crop starts were simulated (15-Jul, 15-Sep, and 15-Nov) representing early, middle and late times during the harvest season.

Crops were simulated for every year in which climate data were available, i.e. from 1949. Soil mineral N, water content and surface residues were reset to initial values at the beginning of every crop. This meant that climatic effects were not confounded by carry-over effects of previous years, i.e. the simulations “sampled” the climate. Twenty-five different N rates were simulated in steps of 10 kg N ha⁻¹ from 0 to 240 kg N ha⁻¹.

3.3.7 Simulation output, risk and product price

The dataset output from the simulations contained 225 unique soil-climate zone combinations. These came from 37 soils simulated in each of the Mulgrave, Babinda and South Johnstone climate zones and 57 soils in both the North and South Tully. When combined into a factorial with the three crop starts and 25 N fertiliser rates, 16,876 simulations were required with each running for 69 years (from 1949-01-01 to 2019-01-01) producing 1,164,375 simulated years.

Risk of yield loss due to reduction in N fertiliser applications was determined from the simulation output. The primary parameter in the calculation was the change in yield between two different N application rates for a specified climate, soil and crop start date. The two N rates were defined as the baseline rate, i.e. the rate normally applied by the farmer, and the reduced rate. For example, the baseline N rate maybe 150 kg N ha⁻¹ and the reduced rate 120 kg N ha⁻¹ (or a reduction of 30 kg N ha⁻¹). The risk of yield loss was given by the distribution of yield changes (i.e. difference in yield at baseline and reduced N rates) across the 69 years simulated, e.g. in how many years did the loss equal 1 t ha⁻¹, 2 t ha⁻¹, etc?

The pure premiums were based on biophysical and management factors, together with the net value of sugarcane (i.e. the price of sugarcane less the cost of harvesting). We calculated the average annual loss of sugarcane yield (t cane ha⁻¹) for the specified biophysical and management factors, i.e. baseline reduced N rate at a given climate, soil, crop start. The difference in yield between the baseline rate and the reduced rate was not always negative; simulated yield sometimes increased with lower N fertiliser applications. [The emergent result from the simulations is also seen in sugarcane experiments (Thorburn et al 2018).] Positive values were not included in the averaging. The value of the loss was the product of the average annual yield loss and the value of sugarcane.

We used a simplified approach to account for the loadings added to the pure premiums. Rather than attempting to estimate the value of each loading, we assumed that the loadings will be related to the volatility (i.e. variance) of the losses from year-to-year (Rolski et al 1999). We calculated the technical price as the annual average loss (pure premium) plus a premium loading equal to a proportion of the variance. That proportion was set at 20% of the standard deviation (Julian Roberts pers. comm.).

3.4 Model testing

While the APSIM model has been shown to reproduce N responses in experiments (Table 3-2), it has little testing north of the Tully region. In absence of N response data in those regions, we tested whether the model could capture the year-to-year climate variability in regional yields. We did that by comparing area-weighted average simulated yields for regions with yields measured at that scale by sugar mills in the Mulgrave, Babinda and South Johnstone

climate zones. A similar analysis has been previously undertaken for the Tully region (Everingham et al 2018, Biggs et al 2018).

Crop management specified in the simulations was the same as that described above. The rate of applied N fertiliser specified was the same as that commonly applied by farmers, i.e. close to the industry recommended rate (Biggs and Thorburn 2017, Everingham et al 2018). We assumed there is an equal proportion of each of three crop start times in the region. The area-weighted average simulated yields were the yields simulated for each soil type in each climate zone in the region, averaged in proportion to the proportion of the region occupied by that soil-climate zone. There are two sugar mills in the South Johnstone climate zone and without information on the area serviced by each mill the simulations for the whole climate zone was compared with records from both mills (Figure 3-2).

The model performance was acceptable, capturing the reduced yields in the wet years (Figure 3-1) and the better performing dry years (e.g. early 1990s). The years 2000-2001 were years coinciding with the outbreak of the disease orange rust (Magarey et al 2004) which will have reduced yields in some regions but is not accounted for in the model.

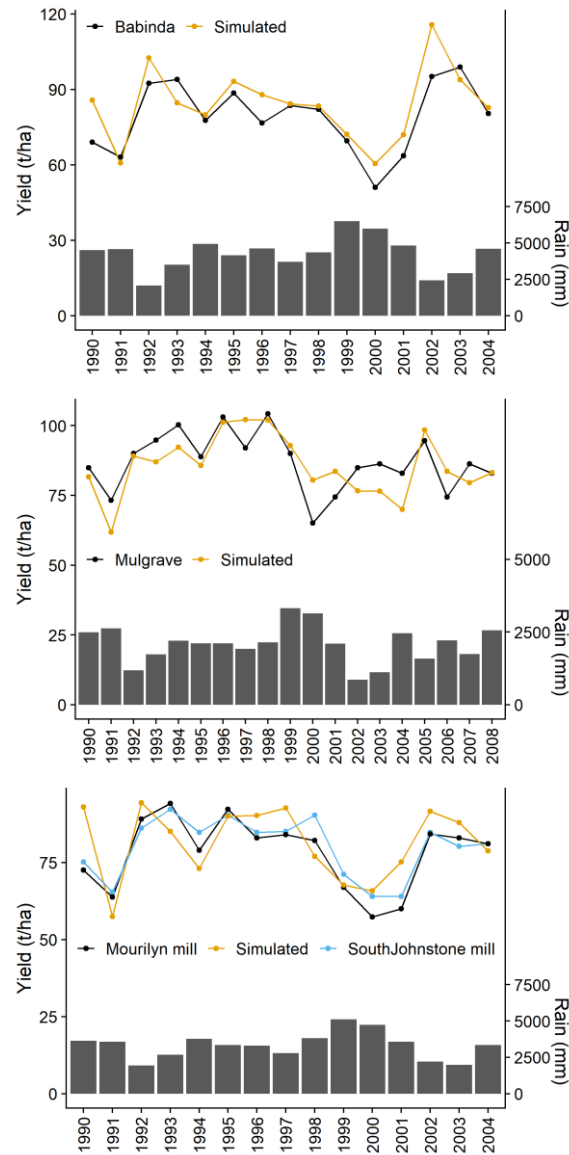


Figure 3-2: Comparison of simulated yields (soil area-weighted average) and historical mill yields for the Babinda, Mulgrave, and South Johnstone climate zones. For the South Johnstone zone, two mills fall within the climate zone. Average annual rainfall during the crops is also shown.

3.5 Technical prices

As described above, the loss of sugarcane yield depends on multiple biophysical and management factors (i.e. the climate, soil, crop start date, and baseline and reduced N fertiliser rates) thus technical price will vary with those factors as well as the value of sugarcane. For the Wet Tropics study region, there are over 1.1 million combinations of the biophysical and management factors and it is impractical to show results for all combinations. To make these data available to stakeholders and collaborators during the project (described in section 6), we developed a web-based “app” that allowed the user to specify these factors and the value of sugarcane to see the resultant technical price (Figure 3-3).

Insurance Project Interactive Data Tool

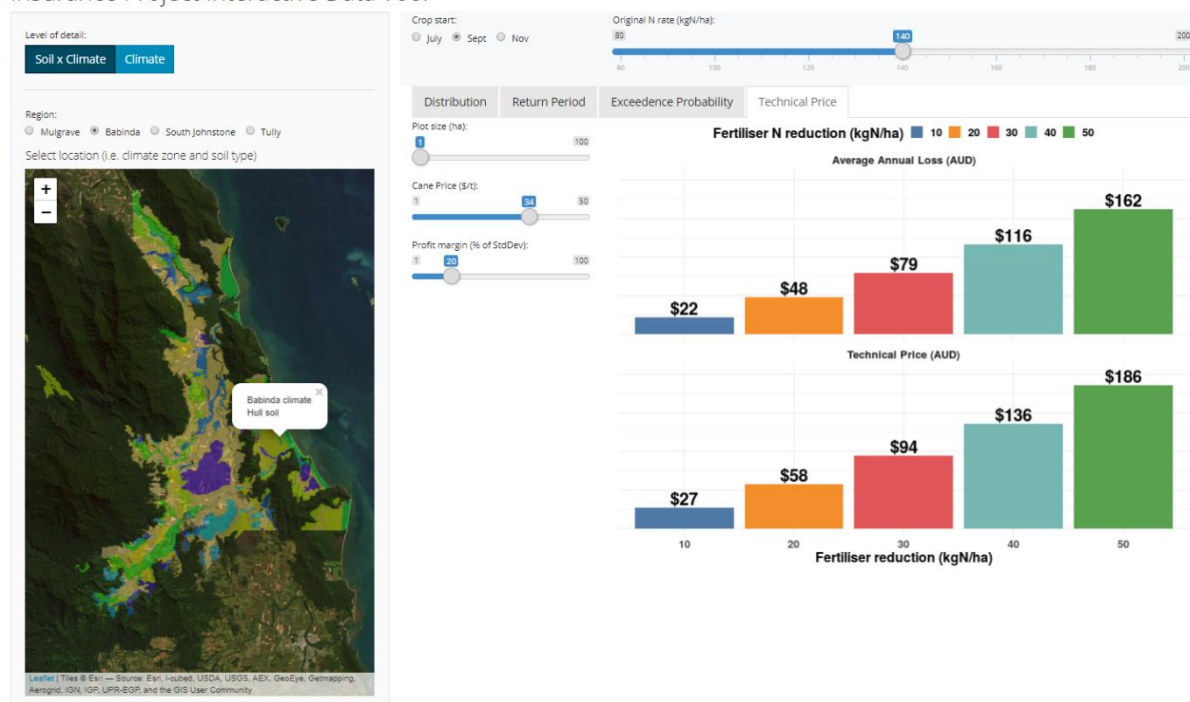


Figure 3-3: Web-based “app” for calculating technical price of a product to insure against sugarcane yield loss cause by reduction of N fertiliser applications.

The climate and soil type are specified by “clicking” a point in the interactive map on the left of the interface. The baseline N rate is set using the “slider” at the top of the interface, and the crop start set with the “radio buttons”. The size of the field being insured, the value of sugarcane and the premium loading (for the insurance company’s profit margin) set with the sliders in the centre of the interface. Both the average annual loss (i.e. pure premium) and technical price are displayed for five different reductions in N application from the baseline rate. A range of other statistics (not shown) can be accessed by the user.

Although we cannot analyse all technical prices, it is useful to see some examples of the prices and their variability across climates, soils and crop start times. One general result was that, as expected, technical prices were higher for low baseline N rates and greater reductions in N fertiliser applied. For example, the risk of yield loss (and hence technical price) was higher for a baseline rate of 130 than 180 kg ha⁻¹. Similarly, the risk was greater for a reduction of 50 compared with 30 kg ha⁻¹. Other results were context specific. We will look at results from two regions, Gordonvale and Babinda, to illustrate the results.

For the Gordonvale region (Figure 3-4), technical prices vary across the 27 soils. They also vary between crop start dates, being less for the July crop start (average of ~\$20) than the other two dates (average of ~\$40). This result reflects that, across all soil types in the region, at these baseline and reduced N rates, the risk of yield loss was lower for a July than a September or November crop start. There are interactions between soils and crop start in the region. For example, the Bulgun soil has a high technical price relative to other soils with the July start but one of the lower prices for November. The actual price for a November start for the Bulgun soil was also lower than July. In contrast, the Holloway soil has a higher price in November than July. The patterns in technical price are different in the Babinda region (Figure

3-5). In contrast to Gordonvale results, the average technical price across soils decreases from July, to September, to November. They are also substantially higher in Babinda for July and September crop starts.

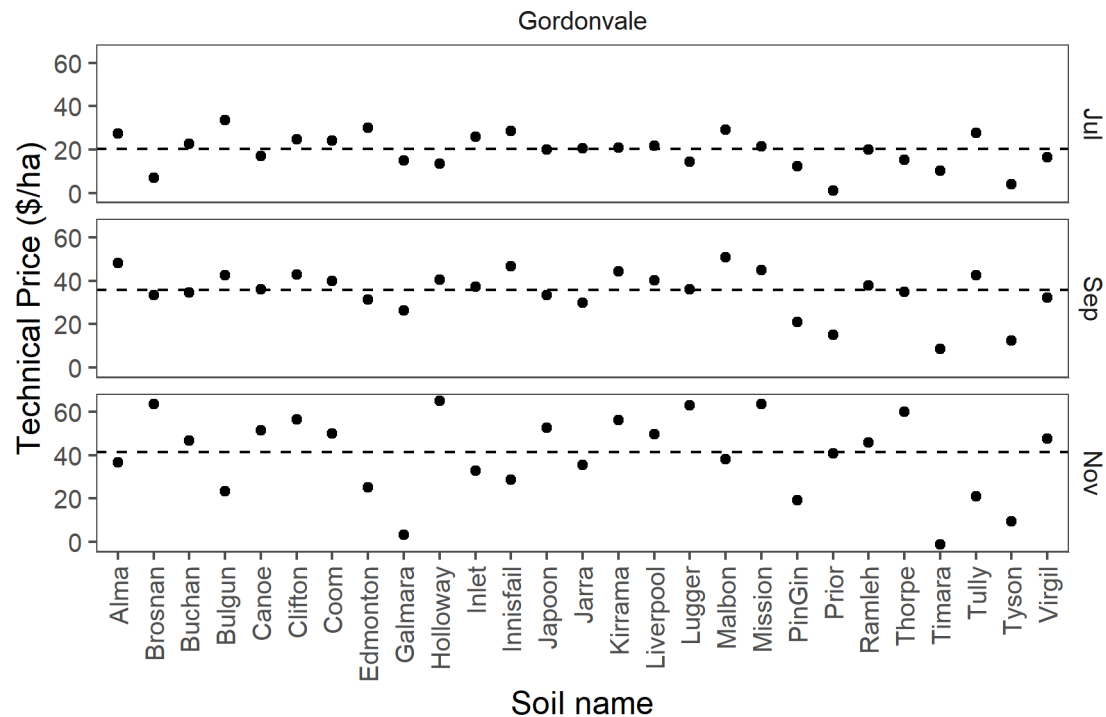


Figure 3-4: Technical prices of a product to insure against sugarcane yield loss cause by reduction of N fertiliser applications for all soils in the Gordonvale region for crops started in July, September and November. The baseline N fertiliser application rate was 150 kg ha⁻¹, the reduced rate to 120 kg ha⁻¹ and the value of sugarcane \$34 t⁻¹. The dashed line is the average technical price across soil types.

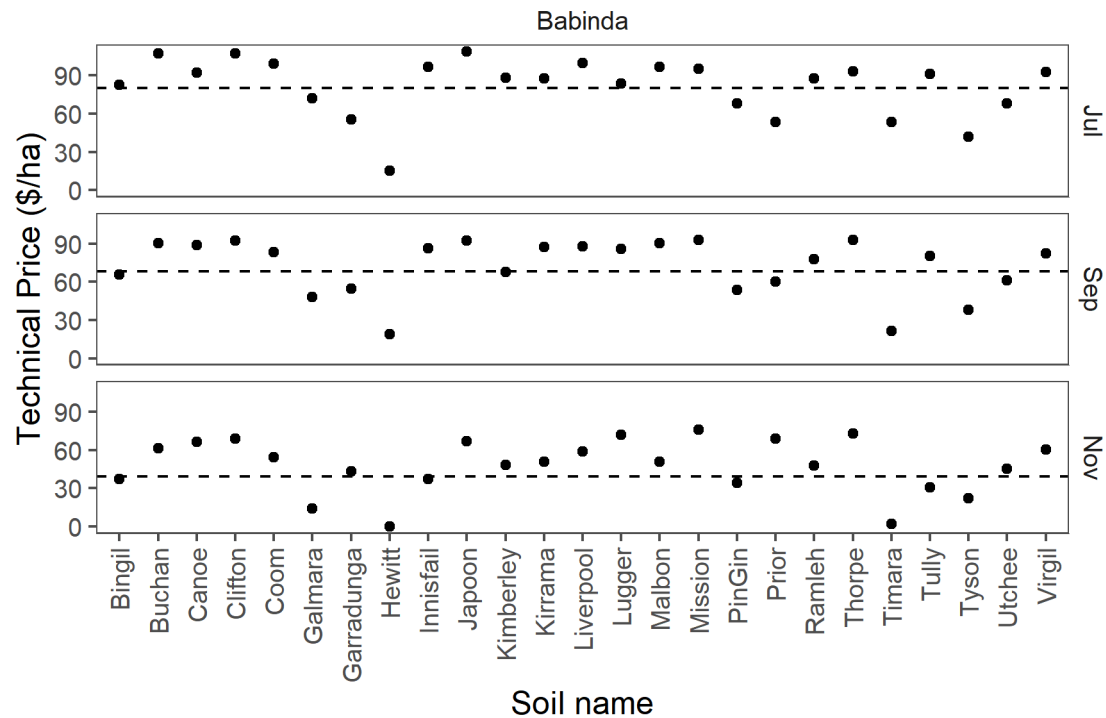


Figure 3-5: Technical prices of a product to insure against sugarcane yield loss cause by reduction of N fertiliser applications for all soils in the Babinda region for crops started in July, September and November. The baseline N fertiliser application rate was 150 kg ha⁻¹, the reduced rate to 120 kg ha⁻¹ and the value of sugarcane \$34 t⁻¹. The dashed line is the average technical price across soil types.

3.6 Discussion

Quantifying change in sugarcane yield under reduced N fertiliser applications is the cornerstone of pricing an insurance product (Rolski et al 1999). Different sources of data may be available to quantify the risk (empirical data on losses, data on an index related to the loss, or data from a more comprehensive model of the loss) and these data types lead to different products. We found that there were insufficient empirical data available on the relationship between N fertiliser applications and sugarcane yield to develop a traditional indemnity-based product. Conversely, there is well developed capability to simulate growth and yield of sugarcane under different rates of N fertiliser, which provides the basis for developing a parametric N insurance product. We thus undertook the simulations necessary to quantify risk and derive technical prices for the conditions in the study region.

Yield response is affected by a number of biophysical and farmer management factors. These include soils, climates and the time of the year at which the crop starts to grow (Schroeder et al 2014, Thorburn et al 2017, Biggs et al 2020). Yield response also depends on the baseline N rate (i.e. the rate normally applied by the farmer) and the reduction in N fertiliser. For the simulations of our study region, there are over 1.1 million combinations of these biophysical and management factors. Further, the value of sugarcane can vary considerably, contributing further variability to the value of yield loss and hence the technical price. Thus, it is difficult to analyse and/or communicate technical prices for all these combinations to stakeholders and collaborators. To overcome that difficulty, we developed a web-based “app” that allowed the user to specify these factors and see the resultant technical price.

Given these technical prices, how attractive might it be for farmers to insure against loss of yield if they reduced their N fertiliser rates? In the examples described above (Figures 3-4 and 3-5), N fertiliser application rate was reduced by 30 kg ha⁻¹ (i.e. from 150 to 120 kg ha⁻¹). If we assume that N fertiliser costs \$1 (kg N)⁻¹ (a very conservative estimate) reducing applications by 30 kg ha⁻¹ would provide a farmer with saving of \$30 ha⁻¹. In the example for Gordonvale (Figure 3-4), the average technical prices for the July crop start is ~\$20, with the range around this technical price being relatively small. So, insurance may be financially attractive to many farmers in this region for this crop start. Conversely, technical prices at Babinda (Figure 3-5) for that crop start average ~\$80, with only one soil (Hewitt) having a price below \$30. Thus, for this crop start insurance would not be financially attractive to most farmers in Babinda. However, for some soils and the two later crop starts in Babinda technical prices are more attractive. The results for these examples will change under different values for sugarcane and prices of N fertiliser, neither of which are under the farmer's control. So, the financial attractiveness of N insurance will depend on the endogenous biophysical and management factors, as well as the exogenous values and costs of sugarcane and N fertiliser, respectively.

4. LOSS ADJUSTMENT

4.1 Introduction

If a farmer has insured a crop against an N fertiliser-related yield loss, a method needs to be developed to determine if a loss has been suffered (Skees et al 1997), i.e. if the crop's yield was reduced by the lower N fertiliser application. This process is called loss adjustment. The type of product influences the methods used for the loss adjustment process. For example, with an indemnity product like hail insurance the insurance company would require evidence of the extent and severity of the crop damage (loss) before settling the claim. Conversely, with parametric insurance once the index is triggered (e.g. rainfall at a specified location fails to reach an agreed trigger value) the claim is paid. The loss adjustment process can be expensive and contributes to the cost of an insurance product (Leblois and Quirion 2013). The process can be greatly simplified in parametric products, and this is one of the attractions of parametric approaches to crop insurance (Binswanger-Mkhize 2012).

In this project we investigated two loss adjustment processes: (1) direct comparison of yields under different N rates, which is an empirical approach that would lend itself to an indemnity product, and (2) modelling the yield at two different N rates, a parametric approach. In this section we explore the practicalities and implications of both approaches.

4.2 Empirical approach

4.2.1 Overview

This approach is based on having empirical data about the yield of a sugarcane crop at the different N rates (baseline and reduced) specified in the insurance. For this to be a practical loss adjustment method, there needs to be an area of the crop grown at the baseline rate and another at the reduced rate. Given that the risk of loss is specific to a climate, soil type and crop start date (as described in section 3), the crops grown at the baseline and reduced rates would need to be grown under the same specified conditions. This requirement rules out using common, pre-existing information on sugarcane yield response to N fertiliser, such as existing N rate experiments within a region, as these would only be relevant for the soil type on which they were established and the time at which the crop started in the experiment. Additionally, regional N rate experiments may not include rates the same as the baseline and reduced rates. Thus, an empirical approach to loss adjustment would require establishment of areas of the crop receiving the baseline rate of N fertiliser at quite a local level. These areas could take several forms, for example:

1. Having two blocks of sugarcane on a farm with the same soil type and crop start date, but different N fertiliser rates (baseline and reduced).
2. A block of sugarcane fertilised at the reduced rate, that contained within it a small "reference area" fertilised at the baseline rate.
3. A "reference area" established within a block of sugarcane (as in example 2) but used as a reference for multiple insured blocks with the same soil type and crop start date, not just the one in which it was located.

Establishing reference areas will take work and thus impose a cost to an insurance product (either to the insurance company or the farmer). So, there will be motivation to minimise the number of reference areas. That would be achieved by example 3 above. For that method, the question arises about the magnitude of the yield variation between blocks caused by things other than the different N fertiliser rates, and thus how large a yield difference would need to be before it could be attributed to reduced N.

We explored this question by obtaining data on sugarcane yields in blocks over several years for four farms. In each year, we compared the yields of blocks on the farm (thus within the same climate zone) that had the same soil type and crop start date. Given these had received the same application of N fertiliser, the between-block variability in yield is an indicator of the yield difference caused by factors other than different N rate, and thus the minimum yield difference needed to establish whether yield was reduced by N, i.e. answer the question whether a loss was suffered.

4.2.2 Block yield data

Historical sugarcane productivity data was obtained from four farms located in Cairns, Gordonvale, Tully and Herbert regions within the Wet Tropics (Table 4-1). Crops had been grown under different N fertiliser rates at Farm 1. Often the data were available only in hardcopy form. Therefore, Optical Character Recognition software (ABBYY FineReader; ABBYY 2018) was used to digitise and clean the data.

Table 4-1: Summary of available productivity data and assignment of spatial information across years.

Farm ID	Number of unique block-years	Years with productivity data	Assignment of spatial data to years with no spatial data
Farm 1	176	2010-2017	2013 -> (2010, 2012)
Farm 2	92	2005-2017	2006 -> (2005, 2007, 2008); 2012 -> (2009-2011); 2018 -> 2017
Farm 3	317	2014-2018	2017 -> 2016
Farm 4	108	2011-2017	2018 -> (2011-2017)

Datasets from each farm were standardised and merged under common column names (Table 4-2). Farm block boundaries were digitised using ArcGIS Desktop (ESRI 2017) from existing KML files and supplied farm maps and joined by Block and SBlock IDs to farm productivity data. In years where no block boundaries were available, block productivity data were matched to the spatial data from the closest year available (Table 4-1).

Table 4-2: Description of productivity data.

Column Name	Description
Farm_ID	farm identifier
Block_ID	main block identifier
Sblock_ID	sub-block identifier
Year	year of harvest
Variety	sugarcane variety
Class	crop class
Harv_F	date of harvest start
Harv_L	date of harvest finish
CSS_Rel	relative CCS
CSS_Abs	absolute CCS
Cane_Ha	cane yield (t ha ⁻¹)
Sugar_Ha	sugar yield (t ha ⁻¹)
Harv_T	cane harvested (t)
Harv_Ha	area harvested (ha)
Note	additional comments

In order to merge productivity data across years into a single dataset we used a union operation, which resulted in a composite dataset with overlapping block boundaries. For this newly created composite dataset we then calculated area, perimeter and ratio (ratio = perimeter / area) values and removed blocks with a ratio > 0.3 and area < 500 m² (i.e. “sliver” blocks). Finally, in order to make our productivity data inter-comparable through time we generated unique identifiers. For this we created a new column UNIQUE_ID and filled it using the following procedure:

1. Run find identical tool in ArcGIS to identify any records in a composite dataset that have identical geometries
2. Assign blocks with identical geometries a unique identifier, which consisted of the Farm_ID and sequence from 0 to the number of features with identical geometries

Blocks with a yield greater than 200 t ha⁻¹ in any year were assumed to be aberrant values and completely removed from the analysis.

The soil type in each block within the four farms was determined by the intersection of block boundaries and the regionally relevant soils survey map. Where more than one soil type occurred in a block, the dominant soil by area within each block was selected as representative of the block.

For each farm, yields from blocks with the same soil type and month of crop start were compared. When simulating sugarcane yields to determine risk of yield loss (section 3) we used three crop starts, July (early season), September (mid) and November (late). Rather than aggregating the productivity data into three dates, we aggregated data into months (effectively seven possible crop starts) to provide greater precision (i.e. comparing data from more similar crop starts). Confidence intervals (95 %) were calculated for the yields for each soil type and crops start in a given year.

4.2.3 Results

At Farm 1, 95% confidence intervals for a given N rate, soil and crop start varied between 4 and 66 t ha⁻¹ (Figure 4-1). There was no consistent pattern in variability across crop starts or soil type. The variability tended to be greatest in the blocks that received the lowest N rate. Results were similar at Farms 2, 3, and 4 (Figure 4-2). The 95% confidence intervals for a given soil and crop start varied between 1 and 60 t ha⁻¹ and there was no consistent pattern in variability across crop starts or soil type. Possible causes of this variability include consignment errors (where production from one block is erroneously assigned to another block, increasing the apparent yield of the former and decreasing the latter) and varying effects of pests, diseases and weeds between blocks on crop growth.

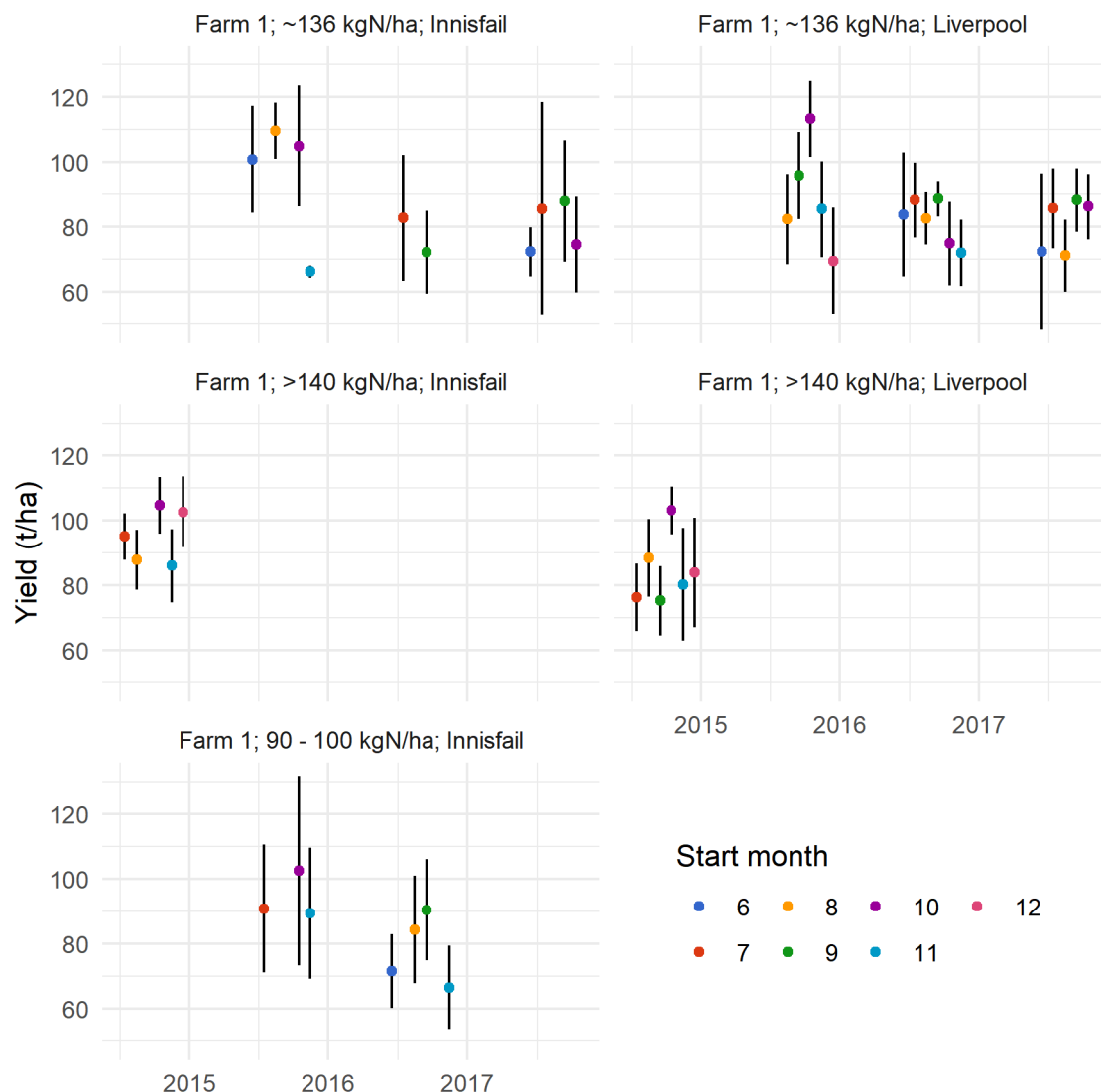


Figure 4-1: Mean (dots) and 95% confidence interval of the mean yield (lines) for Farm 1 at each crop start month (6-12), soil type (Innisfail and Liverpool), and fertiliser N application (90-100 kg ha⁻¹, ~136 kg ha⁻¹, and >140 kg ha⁻¹). Confidence intervals varied between 4 and 66 t ha⁻¹ (numbers shown on bars).

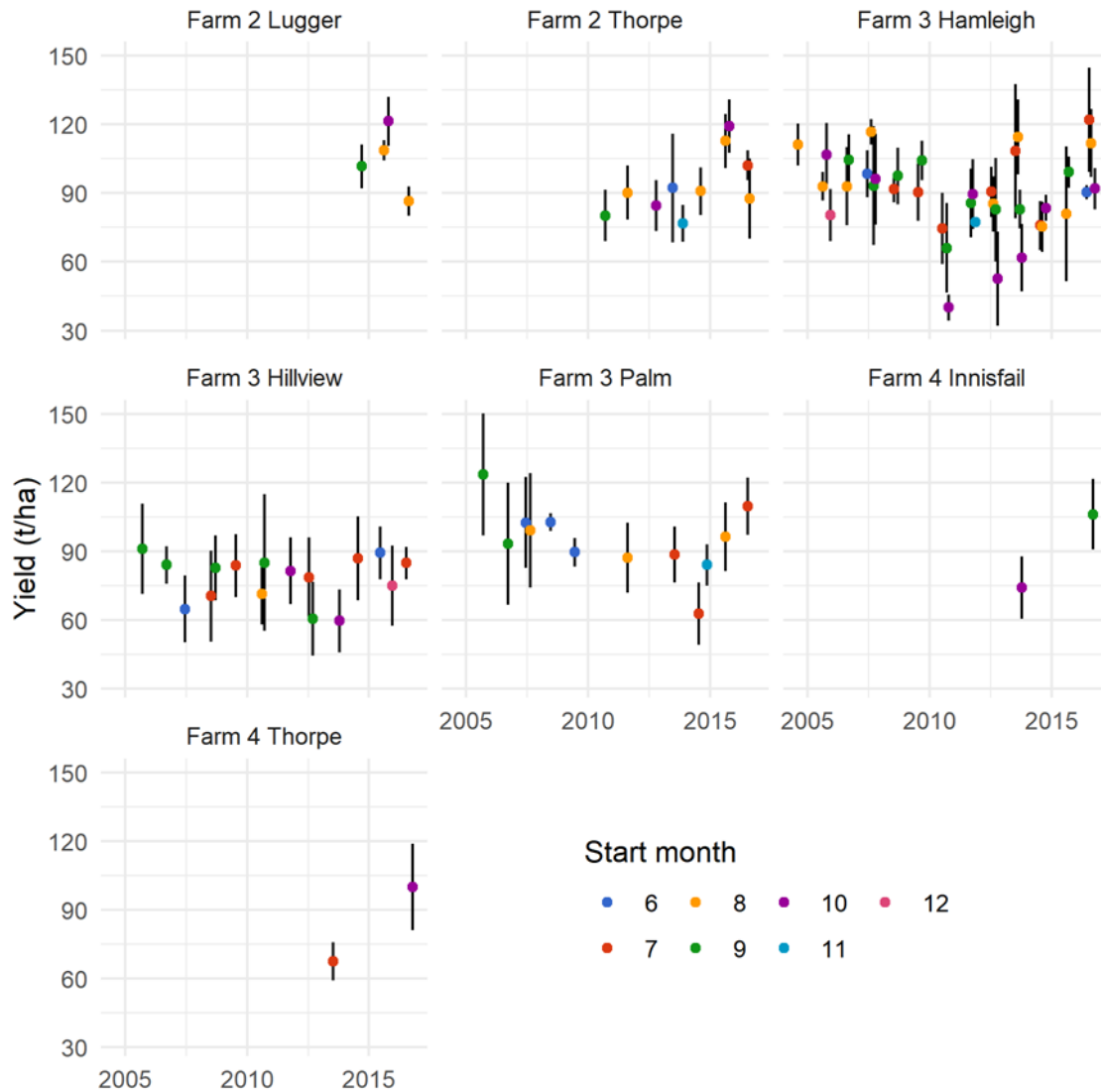


Figure 4-2: Mean (dots) and 95% confidence interval of the mean yield (lines) for Farms 2, 3 and 4 at each farm, crop start month (6-12) and soil type (Luggar, Malbon, Thorpe, Hamleigh, Hillview, Palm, Innisfail and Timara). Approximate fertiliser N application rates were 150 kg ha⁻¹. Confidence intervals varied between 1 and 60 t ha⁻¹ (numbers shown on bars).

4.2.4 Considerations around implementation

Unprotected risk

The 95% confidence interval results provide an indication the yield difference needs between some “reference area” and an insured block receiving less N fertiliser. The median difference observed at the farms we studied, 25 t ha⁻¹, represents a loss of around \$850 ha⁻¹ that would have to be suffered by farmers before a loss attributed to N could be claimed, that is a risk not protected by insurance. This loss is around 8 to 28 times the example technical prices given in section 3. Anecdotal comments made by farmers during the project (in the interactions described in section 6) suggest that having to suffer a loss of this magnitude before a loss was established for insurance purposes would make a product based on empirical determination of a loss unattractive.

Moral hazard and credit risk

As well as considering the magnitude of the yield difference needed to establish if a loss was suffered, there are also considerations around the implementation of an empirical approach to loss adjustment that influence the practicality of this approach, and thus the attractiveness of a product using the approach. Two of these considerations, both of which would increase the price of a product, are moral hazard (described in section 2) and the systems required to reduce it.

Crop management and consignment of cane at harvest (the process of linking harvested sugarcane to the field harvested) are controlled or can be influenced by farmers creating the opportunity for moral hazard. A reference area would need to be managed the same way, apart from N fertiliser applications, as the insured crop to make the yield comparison valid, i.e. that the management of the insured crop was not changed to reduce yield (e.g. poorer weed and pest control relative to the reference area). Farmers would need to keep accurate and verifiable documentation of the N fertiliser rates applied to, and general management of, the insured crop and reference areas. There would then need to be a mechanism for auditing this information. Likewise, there would need to be checks in place to ensure the consignment of cane from the reference and insured areas was accurate, as consignment errors are an established source of uncertainty in sugarcane block yield data (Bramley and Jensen 2014).

Doubt or breakdown in the processes and procedures to guard against moral hazard could see insurance companies denying a claim by arguing the loss was not necessarily caused by reduced N fertiliser additions. Farmers could see this as a form of credit risk (Golden et al 2007). Anecdotal comments made by farmers during the project suggested they perceived “unfair” denial of a claim would be a major deterrent to taking out N insurance (indeed, many forms of insurance).

Cost

If the number of insurance contracts was high, it would be impractical for the management and harvest records of all insured and associate reference crops to be audited, and it is therefore likely only a sample would be audited. The sampling approach would result in uncertainty in the loss adjustment process, i.e. some of the losses claimed not being true losses but the result of moral hazard. The result of this uncertainty is that an insurance company would put an additional loading on the product’s premium, increasing the premium and reducing the attractiveness of the insurance product.

Another consideration would be the cost of establishing a reference area and collecting the information required to verify the existence of both the reference area and insured crop. Establishing reference areas and collecting the information would require additional work, and thus cost, for farmers. This additional cost would also reduce the attractiveness of the insurance product. Thus, a product based on empirical loss adjustment would not only be unattractive because of the size of the loss that would have to be suffered before a claim was paid, but also because an empirical loss adjustment process would add further cost to the insurance product (Leblois and Quirion 2013).

4.3 Parametric

4.3.1 Overview

The foregoing analysis of an empirical approach to loss adjustment illustrates some of the shortcomings of a conventional, indemnity approach to crop insurance. These problems are overcome by a parametric approach to insurance, where the insured is indemnified based on the observed value of a specified “index” (Miranda and Farrin 2012; Binswanger-Mkhize 2012). Ideally, the index is an objective and readily measurable parameter, that is highly correlated with the losses insured, and also measured by a third party, not involved in the insurance transaction. A commonly used index is some function of weather, be that a correlation between yield and annual rainfall (e.g. sugarcane yield insurance; Kath et al 2019) or a more complex function of weather based on multiple attributes (e.g. growing degree days, Conradt et al 2015). Weather-based indexes are popular because: (1) weather influences crop growth and therefore should be correlated with crop performance, (2) weather data are readily available in many places, and (3) weather is often measured by a third party, such as a government meteorology organisation. Thus, the aim of this research was to develop and test an index that could form the basis of a parametric approach to determining if yield was affected by reduced N fertiliser applications.

4.3.2 Weather Derivative Index

As described in section 2, one of the problems with parametric insurance is basis risk, where the index is not well related to the risk being indemnified (Miranda and Farrin 2012). One way to reduce basis risk is to move from simple to more complex functions, as exemplified above by the move from single (e.g. rainfall) to more complex attributes of weather. Another way to reduce basis risk is to have large datasets that better capture the relationship (i.e. giving a higher correlation) between the insured risk and the index (Hazell and Hess 2017). As described in section 3, there are relatively few experiments on the response of sugarcane yield to different N fertiliser application rates. This means that relationships developed on these data will be weak, because of the small number of data, and/or those data will only be applicable to the soils on which the experiments were located. Thus, this approach to developing an index is likely to result in substantial basis risk.

The response of sugarcane yield to N fertiliser application rates is complex; in particular, it is not related to the yield of the crop (Thorburn et al 2018). Thus, trying to directly relate the change in yield to a difference in N fertiliser applications based on weather alone (e.g. a certain amount of rainfall) will likely be inaccurate. Rather than using weather data directly, we propose an index that is a derivative of weather data – a *Weather Derivative Index* – that is based on simulating the yield of an insured crop resulting from reduced N applications under the weather experienced by that crop.

General concept

The concept for using APSIM simulations as a parametric approach for N insurance is illustrated in Figure 4-3. It is an extension of the workflow used to determine risk of yield loss (i.e. the “development” in Figure 4-3). Whereas risk of loss uses historical climate to generate many years of loss data for a range of soil types, crop starts and N fertiliser rates (baseline and reduced), using the model to assess the loss that has occurred only uses the weather of the season during which the insured crop grew and the stipulated soil types, crop starts and N

fertiliser rates of the insured crop (“Operation” in in Figure 4-3). These weather data are obtained from the Bureau of Meteorology weather station in the region that the crop was located, from the same station that was used in the assessment of risk of yield loss. All other factors in the modelling are the same as in the loss risk simulations; thus, it is only the weather during which the crop grew that influences the prediction of whether yield was lost due to reduced N fertiliser applications and thus whether a payout will be made in respect of yield that was lost due to reduced fertiliser application.

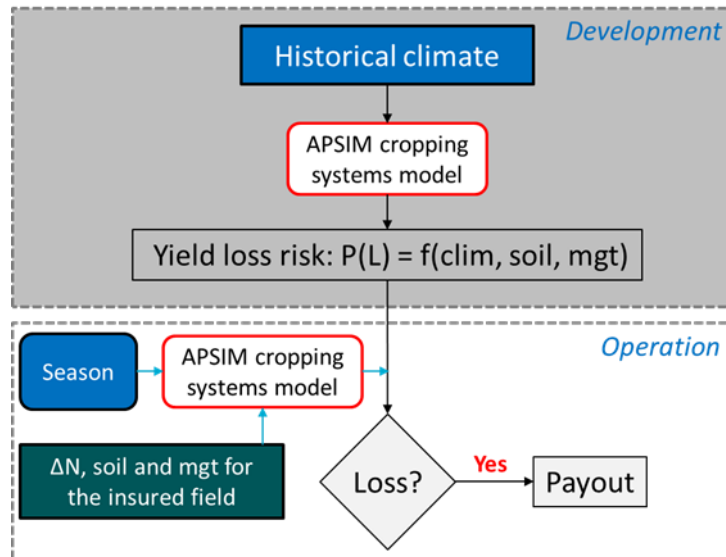


Figure 4-3: Diagram of the workflow for both assessing risk of yield loss resulting from reduced N fertiliser application rates (“Development”) and assessing whether a loss has occurred in a particular crop (“Operation”). ΔN indicates the baseline and reduced N fertiliser rates, clim is the climate experienced by the crop, soil is the soil type on which the insured crop grows and mgt indicates relevant management factors that need to be specified (in our study, that is crop start date).

Example

Here we provide a worked example of the parametric approach to assessing yields loss. The risk of yield loss is calculated by comparing yields at two specified rates of N fertiliser for a soil type in a district given a crop start time (Figure 4-4a). As described in section 3, the risk of loss and technical price are derived from the yield difference between the two N rates over the historical simulations.

A crop that is insured grows under a climate not contained within the historical information, so its growth under the “new” climate that it experienced is simulated (2018 in Figure 4-4b). The difference in yield (if any) at the two N fertiliser rates determine the loss and payout.

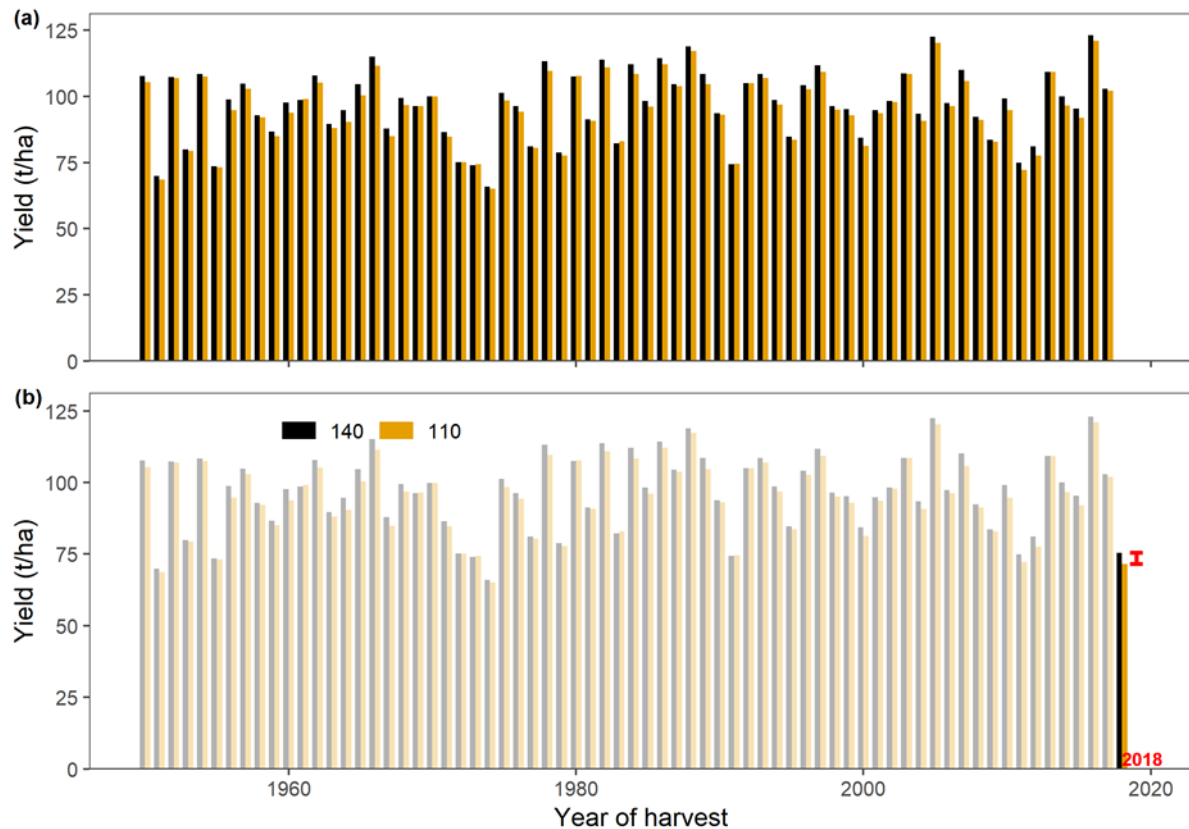


Figure 4-4: Simulated sugarcane yields at two N fertiliser application rates; 110 (orange bars) and 140 (black) kg ha⁻¹, for a Coom soil under the Gordonvale climate over (a) 69 years of historical climate and for (b) one additional year (2018, the year in which the insured crop grew) added.

Value of loss

For this project, we assumed that value of the loss suffered was the product of the yield loss simulated (t cane ha⁻¹) and the value of sugarcane (\$ t⁻¹) specified in the insurance contract. We assume that the value of sugarcane is specified in pricing the insurance contract. This is necessary as it will directly affect the technical price (see section 3). It could be set by either the insurer or the insured.

However, the value of loss could be defined in other ways that could be more appropriate to marketing an N insurance product. For example, there could be an excess applied to the contract, so that losses would only be paid after a loss was suffered greater than a pre-determined threshold (e.g. >3 t cane ha⁻¹). Excesses are used to reduce moral hazard (Linnerooth-Bayer et al 2019), a problem overcome by the parametric approach. However, having an excess would reduce the price of the insurance product, as it reduces the average annual loss, and thus may make it more attractive. If included, the size of the excess could be set in the process of specifying the contract. Our parametric approach to loss assessment can be applied to almost any means of defining the value of a loss.

4.4 Discussion

Once a crop is insured against yield loss, a method is needed to determine if the crop's yield was reduced by the lower N fertiliser application. We have shown that an empirical approach based on direct comparison of yield under different N rates is complex and creates the

opportunity for moral hazard. It would add to the cost of the N insurance product (either directly or indirectly) both through the need to fund the processes of establishing and verifying the yield loss and the loading put on the pure premium by insurance companies to compensate for moral hazard. Parametric insurance overcomes these problems as it is based on an “index” that is objectively observable, readily measurable and correlated with the losses insured (Miranda and Farrin 2012; Binswanger-Mkhize 2012).

There exist no weather-only approaches for predicting N responses for sugarcane crops in Australia. Further, given the complexity of the factors determining sugarcane N responses (Thorburn et al 2018), it is unlikely that an accurate weather-based approach could be developed. Thus, we developed the *Weather Derivative Index*, an index derived from weather data, which is the loss predicted with the APSIM model that would have occurred in that season, if all things (except the weather during the crop’s life) remained the same. The *Weather Derivative Index* retains the essential advantages of other weather-based indexes, but overcomes some of the likely problems caused by the complex nature of the relationship between weather and sugarcane response to N fertiliser. The APSIM model is clearly able to simulate crop yield responses to N fertiliser (section 3.2) and is thus a useful tool to estimate sugarcane response to changes in N fertiliser input. While our approach is more complex than a simple weather index it is likely to have greater accuracy and lower basis risk than a weather-only index.

Once the magnitude of loss (if any) has been determined, the value of the loss, and hence payout needs to be ascertained. For this project we assumed the value of the loss was the product of the yield loss (t cane ha^{-1}) and value of sugarcane ($\text{\$ t}^{-1}$). While this approach fits well with the *Weather Derivative Index* approach to assessing loss, the approach could be used with many mechanisms to determine the value of loss.

5. SYSTEMIC RISK

5.1 Introduction

One of the problems that hinders the viability of crop insurance from the insurer's perspective is that risks are often correlated (Makki 2002, Leblois & Quirion 2013). For example, if one farm is affected by a cyclone or drought, many farms will be similarly affected and there will be a large number of claims and a large total payout in that area. This risk is known as systemic risk (Miranda and Glauber 1997). Insurance companies have strategies for mitigating systemic risk, such as having a larger risk reserve (a pool of capital to ensure sufficient funds are available to pay claims) and/or re-insurance (Rolski et al 1999, Linnerooth-Bayer et al 2019). It is important for insurance companies to be able to estimate the potential frequency and size of claims to be able to determine the size of the risk reserve and/or amount of re-insurance needed for a product.

For the N insurance product developed in this project, the size and frequency of claims has both spatial and temporal characteristics. The spatial dimension is the proportion of insured fields that suffer a loss in a climate zone, in a given year. It is likely that only a proportion of fields in a given climate zone will be insured, thus there is a chance that the insured fields will disproportionately happen to have the soil type and/or crop start date that exhibit high losses in a particular year. This risk is likely to vary with the proportion of fields in a climate zone that are insured: The smaller the proportion, the more possible it is that these fields will happen to cluster in a "high risk" soil and/or crop start, whereas if all fields are insured there will be both high and low risk areas insured. Thus, it is important to explore claim size and frequency as a function of the proportion of fields insured in a climate zone.

The temporal dimension to the size and frequency of claims will be driven by annual variation in weather and if there is a particular set of weather conditions that increase the risk of yield loss. For example, is risk of yield loss due to reduced N application higher across all soil types and crop starts in wetter (or drier) than average years? If so, these will be years with a high number of claims. Conversely, if in these years there is only be a sub-set of soil types and/or crop starts in which yields are reduced by lower N applications the number of claims may be similar to those in a year with more average weather. Therefore, it is also important to compare claim size and frequency over many years.

There is no standard method for determining systemic risk of crop insurance products (Dr Sarah Conradt, SCOR Agri & Specialty Risk Modelling, pers. comm. February 2020). Further, the insights from assessing systemic risk for other products may not apply to sugarcane N insurance because of the different structure of the product compared to other crop insurance products. Thus, we developed an original approach to determine systemic risk for this product. It is based on quantifying the uncertainty of the gross margin of the N insurance product (a simple measure of profits, defined below), across time under different assumptions about the factors driving spatial variability. As with technical prices there are a high number of combinations of the biophysical and management factors involved in the analyses, so here we report the analysis of risk for the same two case study regions in section 3, Babinda and Gordonvale. Likewise, we developed a web-based tool that allowed insurance companies to examine systemic risk across all regions and assumptions.

5.2 Methods

While systemic risk arises from correlated losses, variability of losses alone will not determine the profitability of an N insurance product because of the variability in technical price (i.e. revenue). Thus we used gross margin as a simple indicator of potential profit for an insurance company (Hazell 1992), and explored the uncertainty of gross margins in different scenarios of (1) the proportion of “fields” in a climate zone insured, (2) the distribution of those fields within a zone (which determined the soil type and crop start), (3) the baseline and reduced N rates, and (4) the value of sugarcane.

5.2.1 Gross margin

We calculated the gross margin (GM) of insurance for a climate zone as the difference between the revenue received across the zone and the claims paid out. The revenue received is the product of technical price (\$ ha⁻¹) and the area insured (ha). The area insured is a specified proportion of the climate zone that will have a range of soil types and crop starts. The way soil types and crop starts were selected is described below. The technical price also depends on the value of sugarcane, and the baseline and reduced rates of N fertiliser, which were specific to the scenario.

Total claims paid out was calculated knowing the magnitude of the yield loss (t ha⁻¹), if any, for each soil type/crop start, the value of sugarcane (\$ t⁻¹) and the area of the claims (ha).

For the scenario, we calculated the gross margin in each year for 69 years of climate data, 1950 to 2018, the multiple years giving us the temporal dimension of gross margin. We assumed the value of sugarcane and price of N fertiliser, and thus the technical price, were constant through time.

5.2.2 Nitrogen fertiliser rates

To simplify the analysis, we examined one scenario of reduced N applications; changing from 30 kg ha⁻¹ above the industry recommended N rate to the recommended rate. This scenario was selected because it represents a clear situation where farmers may find insurance attractive, i.e. being compelled under regulations to reduce N applications to the recommended rate (Queensland Government 2019). The Australian sugar industry has a well-developed recommendation system (Schroeder et al 2014), which is determined by the organic carbon in the soil (0-0.3 m depth) and the region in which the soil is located, from which we calculated the industry recommended N rate for the soils in a climate zone.

5.2.3 Uncertainty

Bootstrapping

We used the technique of “bootstrapping” to calculate the uncertainty within a climate zone of gross margins. We also included in our analysis the inputs to the calculation of gross margin (technical prices and payouts) and yield losses in insured crops. The later parameter was included because it potentially has impacts in the sugarcane value chain “down stream” of the farm (see sections 5.3.4 and 7.3.5.). The bootstrapping was performed with the R statistical package (R Core Team 2020).

For this work we conceptually defined an “insured field” as a combination of a soil type and crop start (e.g. Coom soil, early start) in a climate zone. The insured fields in a climate zone represented a “population” in the zone. In the bootstrapping, this population was sampled *randomly with replacement* according to certain constraints (described below) to generate a new dataset with the same number of members as the original population (i.e. a single bootstrap sample). The medians of gross margins, technical prices, payouts and yield losses were calculated for the new population generated by the sampling. This process of random sampling to generate a new dataset was repeated a set number of times (e.g. 1000 bootstraps), resulting in the same number (e.g. 1000 values) of median values of the parameters being produced. This was performed for each of 69 years in a specified climate zone (Babinda and Gordonvale results being presented in this report). The distribution of the medians was visualised using boxplots for individual years (i.e. each boxplot summarising 1000 medians in a single year) and violin plots across all years (i.e. each violin plot summarising 69000 medians over all years). An overall median (i.e. median of medians) is shown in the boxplots and violin plots.

Constraints

The constraints placed on the creation of a population in the bootstrapping could affect the uncertainty of gross margins and other parameters. Thus we examined uncertainty under different constraints. The effect of the population size on uncertainty was tested by creating populations of insured fields that either contained 80% of all possible fields or 5%. Having populations less than 100% represented the likelihood that not all fields in a climate zone will be insured.

If the population of insured fields was created by completely random sampling all fields, it is possible that fields representing one particular soil type and/or crop start combination could be over-sampled, e.g. a greater proportion of fields selected from a soil type than the proportion of that soil in the region. We undertook two different sampling strategies to investigate the effect of these strategies on uncertainty. The first was sampling completely randomly, allowing the possibility that certain soils could be over represented in the sample, which we refer to as “equal weighting”. The second strategy imposed the constraint that the insured fields were selected across soil types in proportion to the relative area of that soil type in a climate zone (realistic weighting), e.g. if a Coom soil occupied 30% of a zone, fields were selected so that 30% of them were Coom soil.

Crop start could also be constrained in the sampling bootstrapping to be any proportion of early-, mid- and late-start specified in the analysis (e.g. equal occurrence, 20%, 50%, 30%, etc). It is important to note that for the specified proportions of crop starts, the link between crop start and soil type was random, i.e. if 20% of insured fields had early crop starts, those fields could occur more frequently on one soil type than another, subject to the soil type selection constraint described above.

Number of bootstraps

We also examined the effect of the number of bootstraps (from 100 to 5000) on the results. This was done as increasing the number of straps increases the accuracy of estimates of sample medians and uncertainty for a specified scenario, but also the computation time. The main results were not practically sensitive to the number of bootstraps so we only report analyses for 1000 bootstraps.

5.3 Results

5.3.1 Gross margin

In all scenarios analysed, the median gross margins were positive (Figure 5-1), ranging from \$10.93 ha⁻¹ (Gordonvale, 80% sampled, equal soil weighting, equal crop starts) to \$12.51 ha⁻¹ (Babinda, 80% sampled, equal soil weighting, equal crop starts). Gross margins were little affected (e.g. median +/- \$0.29 ha⁻¹) by the type of sampling strategy for soil weighting, i.e. whether sampled in proportion or the relative area of soil in a region or sampled randomly. The proportion of insured fields in the climate zone that was sampled (80% or 5%) had only a small effect on median gross margins (e.g. +/- \$0.81 ha⁻¹), but a large effect on the range of gross margins. Both maximum and minimum median gross margins were greater (in absolute terms) when 5% of the region was sampled than 80%.

The distributions of median gross margin were not highly skewed, although there was a greater chance of having a higher loss (i.e. more negative gross margin) than profit. This was more pronounced for 80% of the region sampled than 5%.

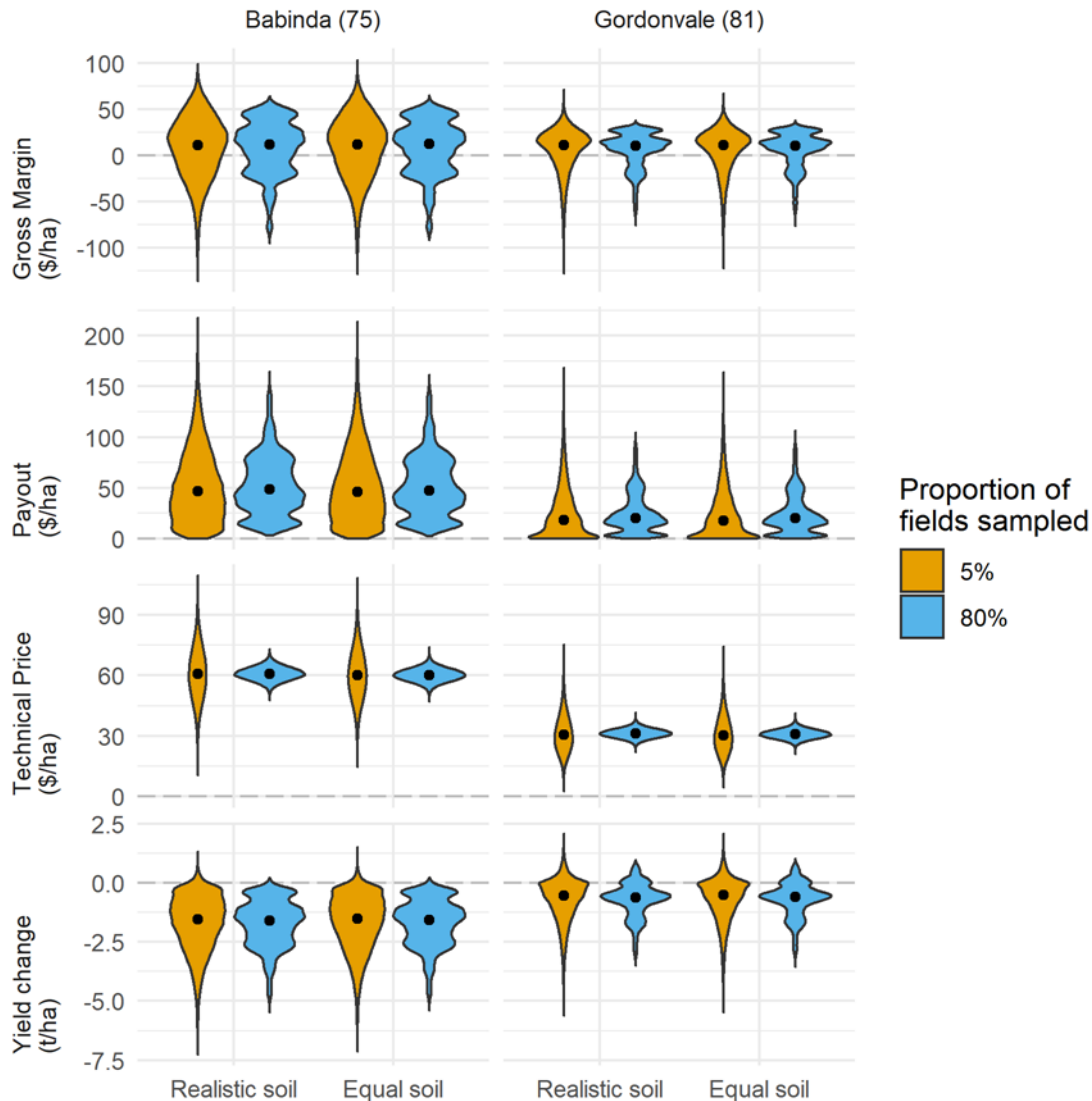


Figure 5-1: The distributions of median gross margin, payout (claims paid), technical price (revenue received), and yield change in the bootstrap analysis for the Babinda and Gordonvale regions across the 69 simulated years resulting from 1000 bootstrap samples. The dot in the centre of the distributions show the median value of the 69000 bootstrap medians across all the samples taken in the bootstrapping, and the width of the distributions indicates the proportion of the bootstrap analyses that gave that value. The range of values arises from the different (random) sampling of fields in the bootstrap analysis over the 69 years. Results show the effect of proportion of fields sampled (5% and 80%) and soil weighting (realistic (i.e. soil sampled in proportion to their area in a region) and equal weighting (i.e. soil sampling not constrained by the area in a region) on the outputs. The number of soil-crop starts combinations (i.e. fields) in each region are shown at the top of each panel. In the bootstrap sampling, the three crop start times were sampled equally, N fertiliser rate reduction was from 30 kg ha⁻¹ above the recommended rate to the recommended rate, and 1000 samples were “taken” in bootstrap analysis. Financial assumptions for the calculation of technical prices and payouts (and hence gross margins) were the same as used in the results of section 3.

5.3.2 Claim payouts

Patterns in results for claim payouts were similar to those for the gross margins (Figure 5-1), noting that payouts cannot be negative. Median payouts were little affected by the type of soil sampling strategy used or the proportion of the region that was sampled (80% or 5%). Maximum payouts were higher when 5% of the region was sampled than 80%, and in the Babinda region than Gordonvale.

5.3.3 Technical price

Median technical prices (Figure 5-1) were also little affected by the type of soil weighting used or the proportion of the region that was sampled (80% or 5%). They were much higher in Babinda than Gordonvale, as expected from the results in Figures 3-4 and 3-5.

The range in technical prices was strongly affected by the proportion of the region that was sampled being less when 80% was sampled than 5%.

5.3.4 Yield change

Given that yield change (loss or gain) directly determines the payout, the variations in yield change mirror those with payouts (Figure 5-1). One exception is that yield changes can be positive, i.e. yield can increase at lower N fertiliser rates, with these changes excluded from payouts.

Yield changes, themselves, will be of little interest to insurance companies apart from their role in determining payouts and hence gross margins. However, they will be of interest to others in the sugarcane value chain “downstream” of the farm for whom “tonnes of cane” influence profitability, notably those in the harvesting and milling sectors (Antony et al 2005). In all scenarios analysed (Figure 5-1), the median yield change was between -0.5 and -1.6 t ha⁻¹, although there was large uncertainty in yield change. The greater the proportion of the region that was sampled, the smaller the range in yield changes, in both Babinda and Gordonvale regions.

5.4 Discussion

Systemic risk is important for insurance because it is a risk that needs to be mitigated by managing risk reserves and/or purchasing re-insurance. This mitigation adds to the cost of an insurance product (Linnerooth-Bayer et al 2019) making it less attractive to potential clients. Of particular concern are “heavy tailed” payout distributions, where the frequency of a large payout is greater than that of a small payout (Rolski et al 1999). Here we have chosen to look at a simple metric of profit, gross margins, rather than just payouts, because of the variation in technical price across biophysical and management factors; that is we are less concerned by a high payout if it is “balanced” by high technical price (revenue). Heavy trailed gross margin distributions are those that are markedly skewed to the negative. The degree of skewness will impact the strategies to put in place by a company to mitigate systemic risk which in turn will affect the product price set by actuaries within insurance companies. It is possible that our systemic risk results are different to those factored (implicitly) into our methods of calculating technical prices, so the technical price we calculated may not reflect those of a commercial product (which may be higher or lower than ours). While we cannot comment on the impact of systemic risk on price, we have developed a web based “app” (Figure 5-2) to facilitate insurance companies and other stakeholders to accessing the results on uncertainty in revenue, payouts and gross margins across a range of N insurance scenarios.

Systemic Risk Analysis

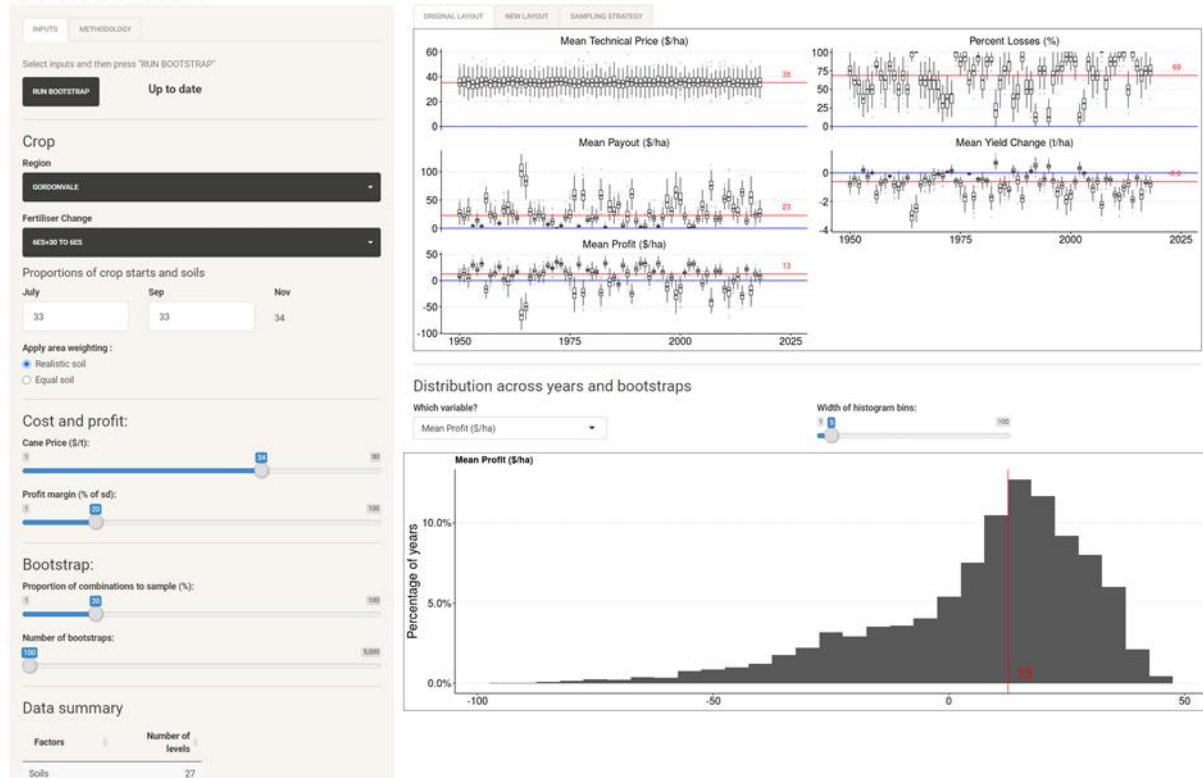


Figure 5-2: Web-based tool for analysing systemic risk of a product to insure against sugarcane yield loss cause by reduction of N fertiliser applications.

Although we have no benchmarks for what constitutes a problematic heavy tailed distribution, it is not hard to image that very large losses occur infrequently with disasters such as droughts or cyclones. In comparison, large losses (negative gross margins) in the scenarios analysed in this study were more frequent than large gains, but the difference was small. Thus, the distributions of median gross margins were reasonably symmetrical suggesting systemic risk will likely not be as large a problem for sugarcane N insurance as for some crop yield products.

Why are the median gross margin distributions reasonably symmetrical? We propose that the main reason is because we developed the product at fine spatial resolution. This has two effects. Firstly, the biophysical and management risks (soil type, crop start, N rate) at this resolution are variable (Figures 3-4 and 3-5) but in our approach higher risk situations have higher technical prices “balancing” the likely higher payout. Further, accounting for heterogeneity of risk will reduce the likelihood of adverse selection, which is more likely if risk, and thus price, is treated as uniform across an area, allowing farmers to insure the more risky fields but not the less risky. However, although reducing adverse selection is a positive for an insurance product, it might not be the only contributor to a heavy tailed distribution. The second effect we propose is that the effect of weather on sugarcane **N response** varies with different soil types and crop starts (Biggs et al 2020). Thus, a given weather pattern (e.g. wetter than average year) will increase the risk of yield loss on some soils but not others. Likewise with crop starts. This “balancing” of risks will be more evident where greater proportion of a climate zone is insured, as was seen in the scenarios analysed (Figure 5-1). Thus, from the perspective of systematic risk, this N insurance product is likely to be more successful if taken up at scale, rather than in “pockets” in some regions. Another benefit of being taken up at scale

is that, in the scenarios analysed, variability in median technical price reduces as the area insured increases. It would be useful to extend our analyses of the effect of increased uptake on systemic risk from within a single climate zone to uptake across the whole Wet Tropics region, or beyond.

The discussion so far has focused on the implications of an insurance product mainly from the perspective of an insurance company and the farmers looking to manage the risk of yield loss from reduced N applications. However, yield changes (reductions or increases) from reducing N fertiliser will be of interest to the harvesting and milling sectors (Antony et al 2005). Median yield reductions in the order of 1 t ha⁻¹ (Figure 5-1) would not be detectable at a farm given the magnitude of the block-to-block variability across blocks with similar soil type, harvest date and N rate (Figures 4-2 and 4-3). However, when considered at a regional scale the loss may be important to the financial performance of the harvesting and/or mill sectors.

6. STAKEHOLDER ENGAGEMENT AND PARTICIPATION

6.1 Introduction

An abundance of opinion, research and case studies on the importance of/and approaches to stakeholder engagement and participatory processes in agricultural development exist. Studies on evaluative participation approaches where “products or services” aim to address the risk of farming whilst reducing reliance of public support to do so are particularly relevant to this project (Banerjee et al 2019, Zhang et al 2018). Further, stakeholder engagement was particularly important for this project to (1) ensure the approach/product developed was technically sound and met insurance company objectives, and (2) build understanding and trust amongst sugarcane farmers, the institutions that support them and government. The participatory engagement and evaluation activities undertaken with stakeholder groups are explained below, along with a summary of stakeholder views expressed in these engagement processes and evaluation activities.

6.2 Key stakeholders engaged

Engagement activities were focussed on three groups of stakeholders, the insurance companies, industry institutions and sugarcane farmers (Figure 6-1).

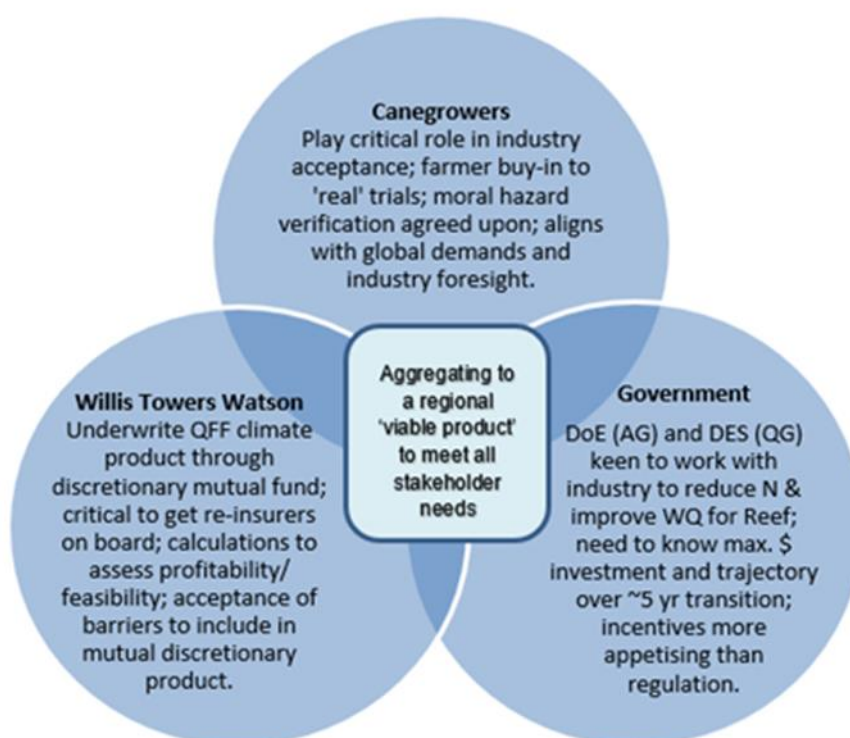


Figure 6-1: The engagement “jigsaw” that has been critical to taking this work to an outcome that provides: cane growers with an incentive to reduce fertilisers; enables the industry to maintain viability; and improve water quality in the GBR.

6.2.1 Insurance sector

A review of insurance products and insurance providers was undertaken at the outset of the project (Table 2-1) to gain an understanding of both the products offered in the Australian agriculture sector and the insurance companies associated with these products. The review was based on both literature and informal interviews with company representatives. After interacting with these companies, a sub-set agreed to be involved in discussions regarding development of this product, including: CGU, Alliance, Latevo and Willis Towers Watson (WTW). As the project progressed, it became clear that WTW were most interested in the approach this project was taking and could see the innovation in the development. WTW have thus become integral to the product development – providing an introduction to the Catastrophe Analytics Team of Willis Re (Sydney) who provided advice on methods and, as the product became fully developed, connecting us with international re-insurance companies (AXA Climate, Descartes Underwriting and Liberty Mutual) who provided feedback on the product and requirements to establish commercial viability. We have also obtained similar feedback from SCOR and Swiss Re.

6.2.2 Industry institutions

The project team engaged at length with the peak industry body for sugarcane farming, Canegrowers, as well as the Queensland Farmers Federation. This engagement was via a number of strategic discussions enabling input and feedback as the project progressed. These engagements were crucial to develop the technical analyses that underpin the prototype product, and to explore ways in which the concept of insurance could support industry initiatives on adoption of best management practices.

6.2.3 Sugarcane farmers

Farmers are the ultimate clients for this insurance product. They thus formed a major stakeholder group with ongoing engagement and participation via multiple methods. The methods included formal workshops to share progress on the project and gain their input into the development and features of a potential product (Table 6-1). We sought feedback on their views about modelling yield loss and whether this insurance may be a useful risk management tool. We also interacted with farmers one-on-one. A notable outcome, and example of the depth of these interactions was being granted access to data on block productivity for four farms to test empirical methods of loss assessment (section 4).

Table 6-1: Formal, participatory workshops with sugarcane farmers and industry representatives across the Wet Tropics, and international re-insurance companies.

Date	Location	Purpose – feedback sought on	Numbers engaged
July 2017	Ingham	How insurance, as a concept, may help farmers manage production risk.	16 farmers
May 2019	Cairns	(1) Acceptability of a model-based product. (2) Attractiveness of the prototype product.	9 farmers
October 2019	Innisfail, Tully, Ingham	Attractiveness of the prototype product.	25 farmers
February 2020	Various	(1) Potential soundness and viability of the product. (2) Steps needed to increase and/or demonstrate viability.	AXA Climate, Descartes Underwriting, Liberty Mutual, SCOR and Swiss Re.

6.3 An ‘insurance game’ to facilitate understanding

Early in the project, an important insight that emerged from our engagement with farmers in the Ingham region (Table 6-1) was the lack of trust farmers had in insurance companies. This lack of trust inhibited farmers thinking conceptually about insurance. Thus, we learnt that it was not productive to take a “blank page” to farmers; we needed to build a prototype product and a mechanism with which farmers could engage deeply in a potential insurance product.

We used a participatory rural appraisal approach to subsequent workshops, designing a “game” that enabled farmers and industry stakeholders to experiment with the way the N insurance product might “play out” on a farm over multiple years. Using “games” is an effective way to build understanding and capacity about crop insurance (Patt *et al* 2009).

The game consisted of establishing a mock farm (Figure 6-2) with 12 blocks, each of which had a unique combination of soil type (4) and crop start (3). The soil types existed in the Wet Tropics, although they were deidentified to avoid the situation where participants felt they were at a disadvantage because the specific soils didn’t exist on their farm. However, it was important participants could have some information on the soils, so pedological information and the industry recommended N rate (marked “6ES” in Figure 6-2) was provided. Participants went through the following steps:

- They selected what they thought was a credible baseline N rate for each soil.
- The technical prices were then revealed for different crops starts and N rate reductions (Figure 6-2, inset).
- They then chose the level of N rate reduction for each block, recorded the technical price and decide whether or not to “buy” insurance for that block.
- The yield loss (if any) and payout were then revealed.
- They finally assessed their decisions – did purchasing insurance, or not achieve their objectives?

The game was played for three years, the first a demonstration round where the project team took participants through the “mechanics” of the game, then two rounds when the participants drove the process.

The technical prices were based on the results of N response simulations for the soil in a climate zone at the crop start. Payout were the product of the yield loss (rounded to the nearest t ha⁻¹) and value of sugarcane. In the years for which the game was played, the yield outcomes at reduced N were simulated with the weather for the specified year. That is, the insurance decisions were being made for a crop starting in 2016 and being harvested on 2017, the actual weather in that climate zone for 2016-2017 was used in the simulations.

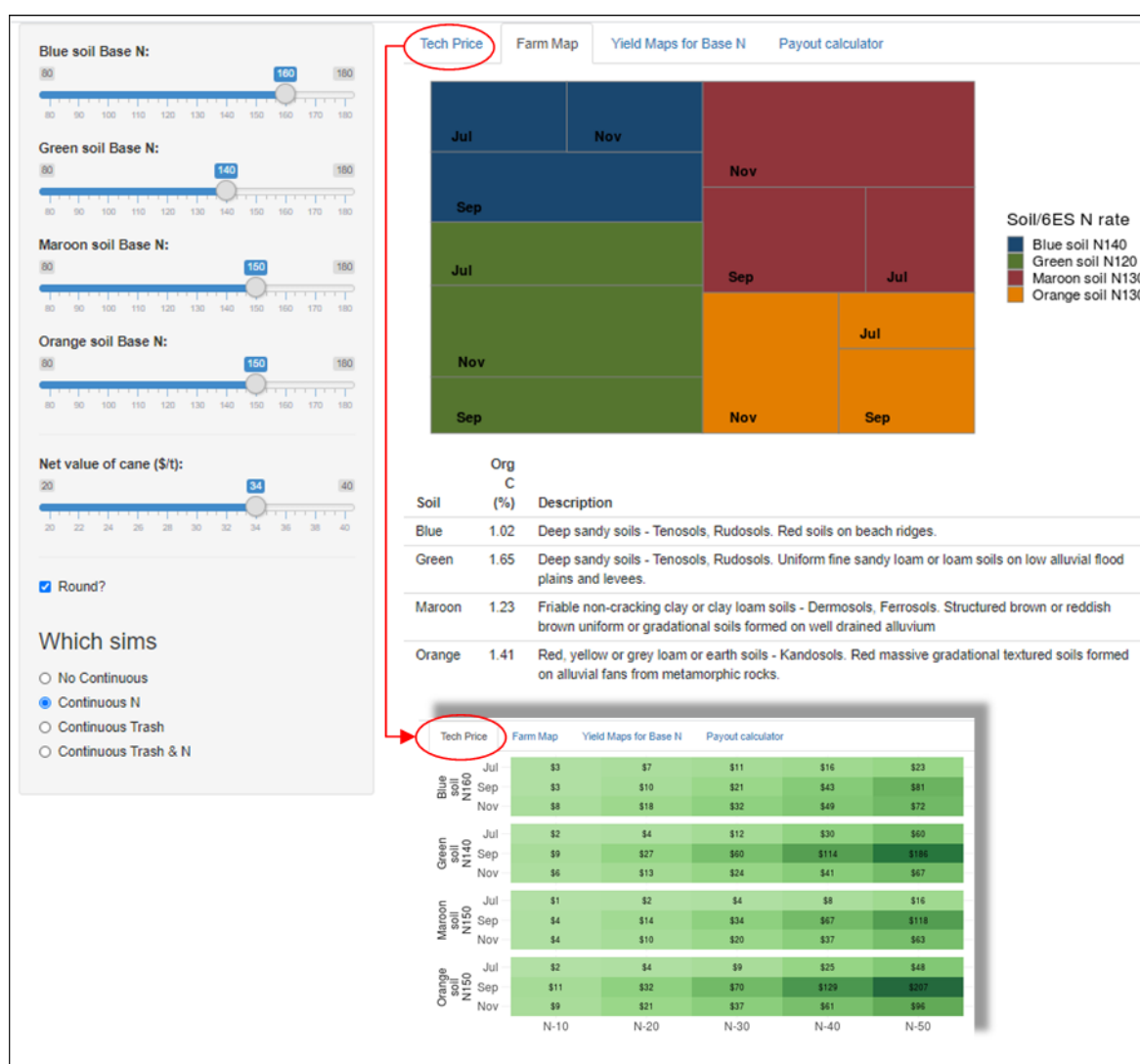


Figure 6-2: Example of the web “app” used to allow stakeholders to interact with the insurance product while learning about the product, its operation and how it would be used on a farm. The inset shows the technical prices for different reductions in N fertiliser rate for the baseline N rate selected for each of the four hypothetical soils and sugarcane value. The intensity of the green shading is directly related to the technical price.

6.4 Key messages from engagement

Key messages from the engagement processes have informed the development of the protocol product.

6.4.1 Using a modelling approach

There is historical distrust in modelling as an aid to farmer management in the Australian sugar industry (Thorburn et al 2011b) so it would be risky establishing a new concept like N insurance on modelling. Hence our efforts in exploring empirical means of quantifying risk of yield loss and assessing the magnitude of losses. As reported in previous sections, our research showed that empirical approaches were impractical.

In discussing empirical approaches to loss assessment with representatives of QFF, Canegrowers and WTW the concept was suggested (by Canegrowers) that we use modelling in the loss adjustment process. The comment made was along the lines of “the modelling of yields looks pretty good, why not use the model to assess losses?” As discussed previously, a modelling approach has considerable advantages in creation of the product. However, it was critical that this approach emanated from, and thus had implicit support of stakeholders. We received further support at the Cairns workshop (Table 6-1) where 8 of the 9 participants agreed that modelling yield loss was an acceptable approach to the product. The 9th participant didn’t reject the concept of a model-based approach but wanted more information before being able to answer the question.

6.4.2 Farmer feedback

The feedback provides insightful input that can help us to tailor a commercial product for testing. Following participation in “the game”, participants were surveyed (anonymously). Responses to the survey include 90% of farmers saying they would consider this product as one of their risk management tools when considering fertiliser application (Table 6-2). Another theme of responses was that while insurance helps mitigate risks of yield loss for farmers, it does not provide protection of others “downstream” in the value chain, notably harvesters and millers, who are affected by reduced production. While this statement is true, currently there is no “compensation” of these downstream value chain actors in situations where farmers’ practices (e.g. inadequate weed control) may reduce production. However, given what we have learned about crop insurance, we could develop another product to “de-risk” production variability for harvesters and/or mills. Thus, whilst other “system issues” are evident, we do not think this issue should be a major roadblock.

Table 6-2: Survey results and some quotes from industry stakeholders during workshops in 2019.

Evaluation questions asked	Participant responses
Do participants think that an insurance product that reduces risk from applying less nitrogen could be a useful risk management tool?	90% of participants responded “yes”.
Can you see an insurance product like this having a place in the sugar industry?	50% of participants responded “yes”, with 30% responding ‘maybe’ with mention of a range of issues: <i>“to counter-balance a govt driven decision (to cut N)”</i> <i>“would depend of cost of premiums, terms & conditions and exclusions”</i>
What would it take for you to take up this kind of insurance product? Are there any aspects you'd like to see addressed in a potential insurance product?	Respondents were generally positive, with the following feedback themes: • Savings on nitrogen have got to be more than the cost of insurance • Need to incorporate harvest costs & time of harvest • Payout would need to exceed premiums over [a] period
Other issues that need to be addressed; thoughts or other feedback.	Several times concerns were raised that, while insurance would compensate farmers for reduced production, the product demonstrated would not compensate harvesters (who get paid by the tonne) or mills.

6.4.3 Insurance stakeholders

As well as the interactions we had with insurance companies at the start of the project, and the ongoing interactions with and inputs from WTW and Willis Re (Sydney), we had a series of meetings (facilitated by WTW) with international re-insurance companies to receive feedback on the product and what would be needed to take it to commercial viability. Feedback on the product was generally positive, with comments along the lines that the project team “obviously understands parametric insurance”.

An important message on commercial viability was that local support would be important to get farmers to trust the product and insurance companies would want some indication of that support before investing. The local support probably translates to a regional “champion” building knowledge about the product, its value as a risk mitigation tool and the practical aspects of purchasing, claiming, etc. The insurance companies would then like to see an evaluation of farmers’ reactions to the product in this situation. They also would need access to technical information behind the modelling (both biophysical and statistical), so they can be confident of the fidelity of the analyses.

6.5 Discussion

Stakeholder input has been critical to this project. We would not have been able to create the prototype product and develop a vision of next steps towards commercial viability without input from insurance companies. Their valuable in-kind contributions to the development of this prototype product included providing advice, reviewing specific aspects of the product mechanics and facilitating connections. The engagement started with early interactions about available crop insurance products, which signalled the novel nature of our research question

and the need for an original solution. Interactions then resulted in advice about analytical methodologies and product concepts during the project and ended with clear recommendations about how to test and increase the likely commercial viability of the prototype product created in the project. These interactions have been crucial to the achievements in this project.

An important step toward commercial viability is building knowledge and confidence in the product, which is a well established message in reviews of crop insurance (Patt et al 2009, Leblois and Quirion 2013). We commenced this process through our participatory rural appraisal processes in product development with selected farmers and industry representatives. The result has been positive responses including, 90% of workshop participants in our 2019 workshops agreeing that N insurance could be a useful risk management tool, and comments from farmers like *“it’s the only way to get N rates down...”*

Stakeholder input has thus not only driven the development of the prototype product, it has provided a strong basis for the next phase of development, assessing commercial viability.

7. DISCUSSION, NEXT STEPS AND CONCLUSIONS

7.1 The challenge

Reducing N fertiliser application rates to sugarcane crops is an important action to protect the health of the Great Barrier Reef. Over the past 10 to 15 years there has been considerable investment in voluntary and regulatory approaches to helping/incentivising farmers to manage N fertiliser applications. More recently there has been interest in the role of market-based instruments in influencing N management because of the reduced reliance on public funding. Farmers apply high rates of N fertiliser to maximise the chance of achieving high yields (Thorburn et al 2013), i.e. to minimise risk of yield loss. This project examined whether insurance could be an effective instrument to mitigate the risk of yield loss from reduced N applications. The general history of crop insurance is problematic (Makki 2002, Smith and Glauber 2012). However, the opportunity for this insurance is supported by two factors: (1) most sugarcane farmers over-estimate the risk of yield loss, and (2) the money saved by farmers on reduced N fertiliser would effectively “subsidise” the premiums. During the period of this project, regulation of N fertiliser management of sugarcane crops was strengthened (Queensland Government 2019), creating further incentive for some sugarcane farmers to reduce N fertiliser application rates and explore new risk-management strategies.

7.2 The solution

Crop insurance has existed in various forms for centuries (Smith and Glauber 2012); however, there are no products suitable for N insurance. Thus, we developed, to prototype level, and tested a new product concept for insuring the risk to yield of sugarcane ratoon crops from reduced N rates in the Wet Tropics region of northern Australia. This is a world-first – there is no other insurance product that can potentially facilitate reduced risk and environmental outcomes. There are many problems that need to be solved in creating a new insurance product, both technical and social, to have a product suitable for both clients (farmers) and insurance companies. To maximise the likelihood of success we engaged extensively with farmers, their supporting institutions and insurance companies throughout the development process.

Our approach is a parametric product, a product structure that overcomes some critical problems associated with more traditional crop insurance products and is efficient to administer and deliver (Miranda and Farrin 2012, Hazell and Hess 2017, Linnerooth-Bayer et al 2019). The essence of a parametric approach is having both the risk of loss and the assessment of loss linked to an “index” that cannot be affected by the insurer or insured. Our solution was a *Weather Derivative Index*, where yield loss from reduced N fertiliser is simulated with the APSIM cropping systems model for specified biophysical and crop management attributes (other than N rates) using weather as an input (Figure 4-3). International crop insurance companies think the prototype is conceptually sound and could potentially be developed to commercial reality.

A drawback of a parametric approach is that it is conceptually complex, so will require understanding and trust to be built amongst the providers and their client base (Leblois and Quirion 2013, Hazell and Hess 2017), i.e. sugarcane farmers. Our inclusion of farmers and

Canegrowers via participatory rural appraisal processes has started to build that trust, with positive responses including comments from farmers like “*it's the only way to get N rates down...*” Proving that the product is efficient to administer and deliver, and building trust among farmers through trialing, will be critical steps in moving the prototype to commercial reality.

7.3 Implications

7.3.1 Price

We based insurance prices (called the technical price) on the “pure premium” (i.e. that needed to cover the average annual loss) plus a loading for various insurance company operating costs and profit (Linnerooth-Bayer et al 2019). Exploratory analyses show that there are indeed many situations where indicative premiums are likely to be less than money saved on fertiliser. However, generalisations are impossible because risk of yield loss is influenced by many farm biophysical and management factors, and the attractiveness of the product to farmers is influenced by both insurance company’s loadings (commercial decisions on cost of running the scheme, profit level, etc) and the value of sugarcane and cost of N fertiliser. For the Wet Tropics, there are more than one million combinations of farm-related factors. Further, the value of sugarcane can vary considerably, contributing further variability to the value of yield loss and hence the technical price. Thus, it is difficult to analyse and/or communicate technical prices for all these combinations to stakeholders and collaborators. To facilitate the exploration and analysis of pricing we developed a web-based “app” so stakeholders could set financial variables and see resultant prices at the field scale.

7.3.2 Claims

Assessing whether a loss has occurred can be a costly aspect of delivering an insurance product. The parametric approach we adopted greatly simplifies this process, and hence reduces the administrative cost of the product. It also makes the claims process objective and transparent, helping build trust in the product.

7.3.3 Systemic risk

A critical problem with crop insurance is covariance of risks, i.e. systemic risk (Makki 2002, Leblois and Quirion 2013), which is the likelihood that if one farmer has suffered a loss many others will have. An example is the effect of drought or a cyclone on yields in a region. This problem increases the cost of insurance because companies need large capital reserves and/or substantial re-insurance to support the high number of claims (and total payout) in the case of a disaster. We developed a statistical modelling approach to assess systemic risk.

There are multiple factors that affect systemic risk, and the analytical task to explore these is orders of magnitude greater than that for pricing. Indications are that systemic risk of N insurance in the Wet Tropics is not a significant issue because the weather conditions that increase the risk of yield loss with reduced N in one soil type will decrease it in another soil type. Systemic risk also decreases as the proportion of a region insured increases, so systemic risk will be reduced if or when the product achieves scale.

The effect on product prices on the level of systemic risk associated with the N insurance product would need to be calculated by actuaries within insurance companies. To facilitate

their analysis, we developed a web-based “app” so actuaries could examine how systemic risk varied under all the determining conditions.

7.3.4 Potential environmental benefits

What magnitude of fertiliser reductions might N insurance facilitate? In our workshops with farmers, they were free to choose the rate of N reduction in blocks on a hypothetical farm as part of the insurance “game” and most chose a reduction of 20 or 30 kg ha⁻¹. Given this was the first exposure of the participants to insurance this is likely a conservative choice. If insurance facilitated a 30 kg ha⁻¹ reduction in N applied to 180,000 ha of sugarcane (~50% of the area under sugarcane in GBR catchments) it would result in a reduction in DIN discharge of ~1,000 t yr⁻¹ (assuming a delivery ratio of 0.2). Achieving this environmental outcome, without the need for ongoing public funding would be a big “win” for the GBR and a likely no regrets outcome for farmers.

7.3.5 Value chain impacts

Insurance will help mitigate financial impacts on farmers of any yield reductions resulting from reduced N fertiliser applications. However, there will be financial impacts of yield reductions on others in the sugarcane value chain, downstream of the farm, whose business income is reliant on “tonnes of cane” (Antony et al 2005). For example, harvesters usually get paid a rate per tonne of sugarcane harvested, so a reduction in tonnes harvested translates directly to a reduction in income. Concerns over downstream impacts were raised by stakeholders (Table 6-2) because growing sugarcane is tightly linked to harvesting and, especially, milling. If sufficiently large, reduction in regional sugarcane production threatens mill viability (van Grieken et al 2013) and thus sugarcane growing in that mill region. These concerns impede uptake of insurance by farmers, as they also impede reducing N fertiliser applications.

How might these concerns be overcome? One possibility is actors in other sections of the value chain also insuring for loss of yield caused by reduced N fertiliser applications. However, since these actors have no direct interest in the production of the crop, they may not be legally allowed to take out insurance on the crop. Alternatively, there may be other insurance options available to them. Mitigating the risk of yield loss is the goal of many crop insurance products so harvesters and millers could mitigate their risk through these products. This raises the question of how the variability of sugarcane yield caused by N fertiliser management compares to that from interannual climate variability. Given the latter (e.g. Figure 5-1) is larger than the former (e.g. Figure 3-2), either stakeholders are overly concerned about the downstream effects of N insurance or the industry would benefit from weather-driven yield variability insurance. A weather index approach to sugarcane yield at the regional scale has been recently proposed for the Tully mill region in the Wet Tropics (Kath et al 2018). Alternatively, the model-based parametric approaches used in this study could easily be transformed to climate-driven yield variability which may reduce issues with basis risk that affect weather index products.

7.4 Next steps

What is needed to transform the prototype into commercial reality? The parametric structure of the N insurance product overcomes some critical problems associated with more traditional crop insurance products and is efficient to administer and deliver (Miranda and Farrin 2012,

Hazell and Hess 2017, Linnerooth-Bayer et al 2019). While international crop insurance companies think the prototype is conceptually sound and could potentially be developed to commercial reality, they still have many questions including (1) actuarial aspects (e.g. systemic risk and its implications), (2) establishment costs (e.g. linking with licenced advisors to sell the product) and (3) demand. The first two affect the cost of administering and developing the product (i.e. the price) and the last the revenue. Together they will determine whether the product is profitable (Leblois and Quirion 2013).

To help answer these questions related to price, some additional analyses are required. One is the effect on systemic risk of having the product taken up in multiple regions. We have demonstrated that systemic risk reduces when a greater proportion of a region is insured (Figure 5-1). The effect should be greater if crops are insured in multiple regions, further reducing systemic risk and the cost of mitigating it. Another question will be whether climate change affects risks and product viability in the long term (Hazell and Hess 2017).

What is the likely demand and hence revenue of the product? Due to the novelty of this product, there is no prior experience on which to estimate its likely uptake. Being a new and conceptually complex concept, it will also require considerable education and trust-building amongst farmers and their advisors to stimulate demand (Patt et al 2009, Hazell and Hess 2017). Our inclusion of farmers and Canegrowers via participatory rural appraisal processes in product development has started to build that trust, with positive responses including comments from farmers like *“it’s the only way to get N rates down...”* Proving that the product is efficient to administer and deliver, and building trust among farmers will be critical steps in moving the prototype to commercial reality.

We have noted above that there are many situations where indicative premiums are likely to be less than money saved on fertiliser, suggesting that pricing of the product will be attractive to farmers in these situations. Regulation of N fertiliser management also provides another incentive. However, will it be attractive for insurance companies to invest themselves in establishing the commercial viability of an N insurance product for the GBR? History shows that private insurance companies have rarely initiated agricultural parametric insurance products for various reasons (Hazell and Hess 2017): (1) Unknown demand (as discussed above), (2) high setup costs and other barriers to entry, and (3) if they do develop a new product, it may be easily replicated by other companies making it hard for the originator to recoup costs. Compounding these problems is the small potential revenue of sugarcane N insurance in Australia. The global insurance industry is worth more than \$7trillion. In comparison, the maximum revenue from cane N insurance in Australia is likely to be in the order of \$10M, with profits a fraction of that. Thus, while insurance is potentially a very useful tool for helping reduce N rates and protect the GBR, unknown demand, the risk of not recouping establishment costs and the small market size represent a substantial barrier for companies. This barrier is also larger than conventional parametric crop insurance products because we have developed a world-first approach that is based on substantial understanding of sugarcane agroecology. Thus, there is a lot more for insurance companies to comprehend in assessing this product compared to more conventional ones (i.e. insuring against the occurrence of an adverse weather event).

8. CONCLUSION

We have shown that insuring against the risk of sugarcane yield loss with reduced N fertiliser applications is technically feasible. Further, we have shown that it can be implemented in a way that overcomes many of the problems that have plagued traditional crop insurance. The prototype product has received support from international re/insurance companies, and sugarcane farmers and the institutions that support them. If widely adopted, it could facilitate substantial reductions in DIN discharged from GBR catchments. However, establishing commercial viability of this prototype product requires further effort from willing stakeholders, including those who were involved in this project. Without these next steps the opportunity to create an enduring market-based risk management tool that supports cane farmer behaviour change and water quality improvement will be lost.

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