Drought Climate Adaptation Program

Producing Enhanced Agricultural Crop Insurance Systems

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Executive Summary

Queensland farmers are subject to highly variable climatic conditions, including drought and floods, which can undermine production. Insurance could play an important role in helping Queensland farmers manage their climate risk. However, currently the use of insurance to manage climate related production risk is poorly understood and utilised by farmers. This project aims to address this gap by providing information on climate risks and the role of insurance for managing these.

This project conducted focussed reviews on climate risk in agriculture and on how insurance products could be used to address these risks. The project also carried out on-ground surveys from cotton and sugar industry and conducted modelling to assess risks and the role of insurance for cotton and sugar cane farmers in Queensland. Prototype climate assessment risk and reporting tools were also developed.

The reviews carried out in this project identified that Queensland's agricultural sector is highly exposed to production volatility as a result of weather risks. It is our view that the Queensland agricultural sector has an excellent opportunity to provide its farmers with protection against uninsured seasonal risks to crop production.

Key climate and farming systems risks were identified by interviewing a total of 55 farmers (23 cotton growers and 32 sugar cane growers) across Queensland. Key climate risks to the cotton industry include hail, drought/dry years (lack of rainfall during planting and season), quality downgrade (discolouration), excessive heat, floods and wet weather (during season and especially during harvest). Similarly, for the sugar industry, key climate risks include, drought, flood, excessive rainfall during harvest, cyclone, pests and disease. Key messages from farmer surveys are that current insurance products available to Queensland farmers (specifically, cotton and sugar cane farmers) may not address critical risks to the production and/or profitability of these systems and that farmers would prefer to have comprehensive insurance products available that cover them against profitability losses across multiple risk factors.

A 'climate and agricultural risk assessment and reporting tool' (prototype) was developed as part of the project. This 'tool' allows quantification of key climate risks, initially for the sugar and cotton industry. The tool provides an option to generate a detail climate risk report based on historical data and a future seasonal climate forecast for an individual location. The tool data also serves as a dataset portal, allowing for the download of data in a required template.

Cotton and sugarcane crop models APSIM and DSSAT were employed to simulate the growth and yield for 10 and 12 sites, respectively, across Queensland over the period

1940-2017 for various crop management factors. Comparing the simulated yields (from each model or the mean simulated value from ensemble models) to the observed yield (available at regional scale) the trend in year to year variability is satisfactorily captured for cotton on average, whereas for sugarcane there is a trend to overestimate or underestimate the yield depending on the site.

Based on survey findings three prototype insurance products were developed for the cotton industry Insurance products developed were Drought Cover: insufficient rainfall during the planting season – August to November; Drought Cover: insufficient rainfall during growing season – November to February; and Wet Harvest Cover: excessive rainfall during harvest season – March to June

Two prototype insurance products were developed for sugar industry. They include; Cyclone Cover: crop damage during cyclone season – November to April; and Wet Harvest Cover: excessive rainfall during harvest season – June to December

Rainfall-indexed based worked examples were also developed for sugar and cotton industry growers to better appreciate the insurance mechanisms.

1. Introduction

Australia is susceptible to volatile changes in temperature and precipitation, whilst also being the driest inhabited continent (Botterill & Hayes 2012; Parry et al. 2007). These changes have large implications for agricultural production, farm financial viability and the agricultural sector's contribution to Australia's economic stability (Webb 2006). Despite the extreme vulnerability of Australian agriculture, Australian farmers are some of the least protected in a globally competitive market.

While several types of insurance products are currently available in Australia, they are not sufficiently comprehensive to address farmers' concerns (NRAC 2012). Among the available options is the incorrectly named 'multi–peril crop insurance' (MPCI) which is misleading as it only covers just a portion of risk (e.g. fire, frost, hail) but fails to cover certain events including drought, which is one of the most problematic of all risks faced by farmers.

Given the nature of drought and other climate risks, and with the abandonment of Exceptional Circumstance (EC) grants in 2012, there is an urgent need to investigate options to establish a liquid and viable market for agricultural insurance in Queensland, and as well as in other Australia states.

Agricultural insurance can assist farmers effectively manage the risks associated with extreme climate and weather events (Hatt et al. 2012). However, prior research concludes that currently available crops insurance is currently not commercially viable. Further, the demand for unsubsidised agricultural insurance products including index-based and weather derivatives that have been introduced into the Australian market has been limited, causing problems with market liquidity and resulting in the withdrawal of many of these products (DAFWA 2009, Hatt et al. 2012, NRAC 2012).

While there has been a policy trend led by government within Australian to wind back direct and ongoing industry assistance and protection, there may be a role for government to facilitate the development of a robust agricultural insurance market. Rather than by premium subsidy, this would most likely be through support for the provision of data collection, verification and supply systems needed to refine risk models and reduce information asymmetries. The intended consequence of this would be to reduce the price of insurance and reinsurance.

An identified issue that is consistent across all products introduced in Australia to date is access to independent and reliable information. This data problem impacts re/insurance product design, pricing, administration and the ability to obtain reinsurance (NRAC

2012). Hatt et al. (2012) concludes there may be a case for government to facilitate the provision of the needed data and/or assist the development of new products. Similarly, NRAC (2012) considers there is a role for government to assist farmers to become more self-sufficient through provision of information needed to enhance decision making and assist insurance product development.

Aims and objectives

The objectives of the proposed research are to investigate how re/insurance companies, agricultural industries and government can establish and maintain a liquid and viable market for agricultural insurance in Queensland, and Australia.

The research involves:

1. A focused review of current and potential data sources and models needed to facilitate the development of affordable and effective re/insurance products in Australia;

2. Unravelling long-term climate data, their patterns and their mechanistic causes with linkage to crop modelling over the long-term (this aspect could be linked with other DCAP program activities; DCAP7.2 and DCAP14);

3. Working closely with key insurance industry leaders (eg: Willis Towers Watson, Suncorp and Allianz, IAG, Latevo re/insurance companies) and investigate new re/insurance products that could be developed based on improved data and modelling, and considering affordability and market liquidity; and

4. Consultation with re/insurance company representatives (e.g. Willis Towers Watson, Suncorp and Allianz, IAG and Latevo re/insurance companies re/insurance companies), farmers/farmers organisations (QFF, Growcom etc.), governments and other key stakeholders to ‘test out’ the potential insurance product innovations identified and determine the willingness of growers to pay the expected premiums.

2. Literature review

Introduction

Australian agriculture operates under uncertain climatic and market conditions. Climate change is projected to increase the frequency of extreme weather events, including drought. Australian farmers must therefore not only constantly manage the risks of changing global market settings and volatile domestic growing conditions, including enhanced climate risks. The purpose of this review paper is to identify and evaluate options for managing the risks faced by Australian farmers against extreme climatic events. In our paper we look at three aspects of risk management. First, we look at farm-level management of risks. This is followed by market based solution such as multi-peril crop insurance (MPCI), weather derivatives, yield index, and area yield insurance. This is followed by government initiatives designed to mitigate risk in Australian agriculture.

The major feature of the natural environment that affects farming in Australia is rain during the growing season. Rain varies greatly from one year to the next, and thus the supply of water for irrigation from rain that runs off the land and into catchments and underground is limited and highly variable. The amount of rainfall also varies greatly across Australia. The monsoon areas of the tropical north have summer maximum rainfalls and the temperate south-west and south-east have winter maximum rainfall. Eighty per cent of the land receives less than 600 mm of rain per year, and 50% of the land receives less than 300 mm of rain each year. The dry centre receives less than 200 mm of rain each year. South, between the dry centre and the coastal regions, annual rainfall is 200- 400 mm on average. Table 2-1 graphically presents the agricultural climate zones in Australia.

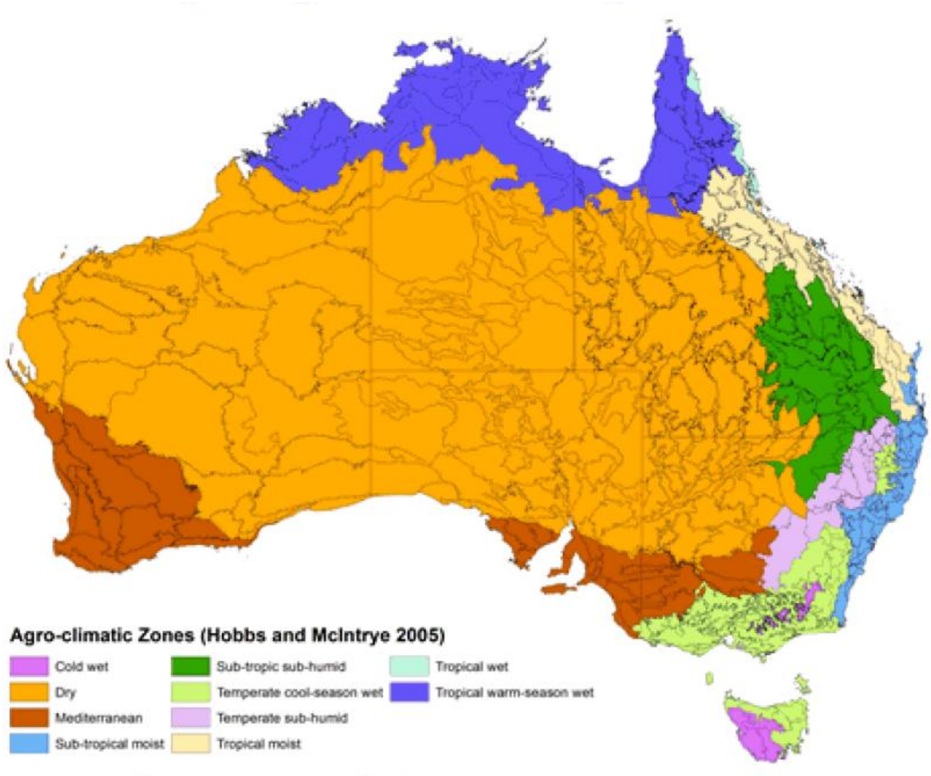


Figure 2-1 Agricultural climate zoning in Australia. Source: Hobbs and McIntyre (2005)

One view is that the frequency and severity of droughts in Australia has increased due to climate change. Modelling done by IPCC (ARD models) shows that about 50% of the rainfall decrease in South Western Australia since the late 1960"s is probably due to increases in greenhouse gases (Cai and Cowan, 2006). The historical record indicates that the percentage of area having exceptionally low rainfall between 2002-2007 is higher than the average of the last 16 and 108 years in all regions (Table 2-1). However, it also shows that the percentage area with exceptionally low rainfall in the last 16 years is lower than the average of the last 108 years, except for Victoria and Tasmania and Southwest WA.

Table 2-1 Average percentage area having exceptionally low rainfall

	1900-2008	1993-2008	2002-2007
Queensland	5.5	3.9	7.5
New South Wales	5.5	5.0	10.7
Victoria and Tasmania	5.5	7.0	14.1
South Australia	5.5	3.4	5.4
Northwest Australia	5.6	2.4	5.6
Murray-Darling Basin	5.5	4.8	11.4
Southwest WA	5.5	9.0	10.6
Australia	**5.5**	**3.1**	**5.1**

Source : Productivity Commission (2009).

The projection made by BOM and CSIRO in 2008 shows that the areal extent and frequency of exceptionally hot years has increased over recent decades and that this trend is expected to continue. The trend in exceptionally low rainfalls years is dependent on the period, but in some regions it is expected that the exceptionally low soil moisture years will increase over the next decades.

Australian farmers face a high degree of production risk compared to other sectors of the economy as shown below in Figure 2. Since 1975, agriculture has exhibited the highest degree of volatility, at 3.1 times higher than the average sector. The volatility of the agriculture industry is nearly double that of any other industry.

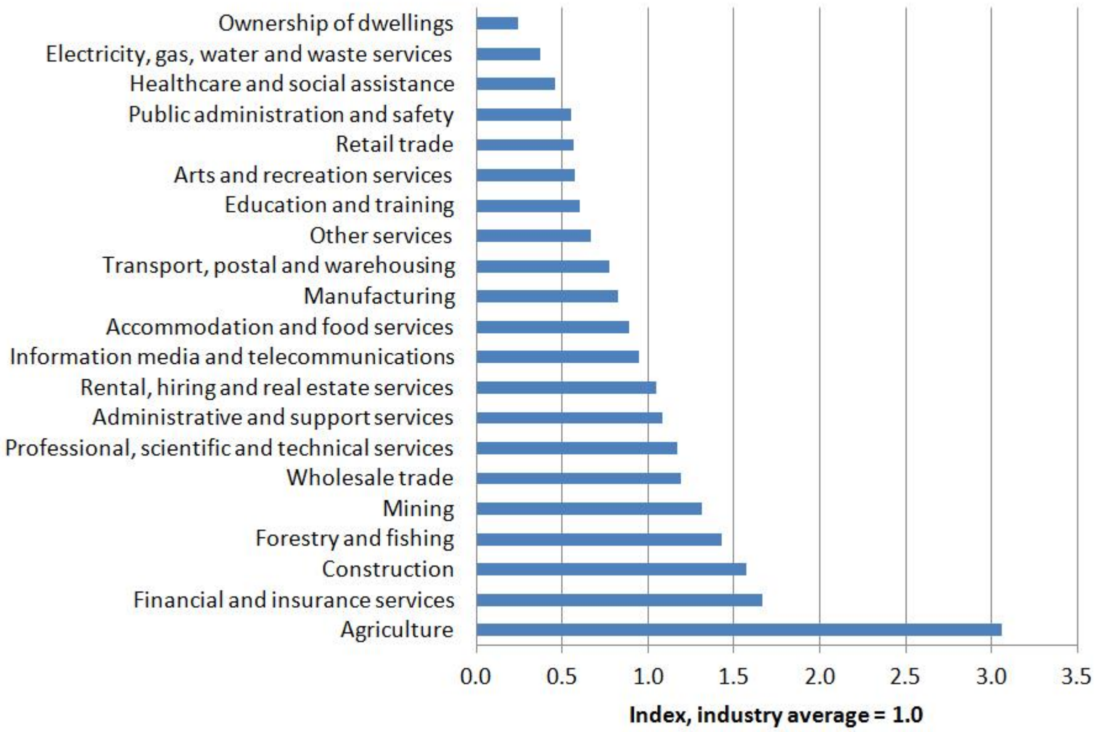


Figure 2-2 Industry output volatility, 1975–2011.Note: Industry volatility is calculated by taking the standard deviation of the percentage difference between actual and trend production. Trend data are estimated using a Hodrick-Prescott smoothing filter. Data are in chain volume measures. Data source: ABS 2011

Since the majority of agricultural commodities are exported to international markets, output price risks are based mainly on the international price and exchange rate. Australia has a long history, until deregulation in recent decades, of using marketing boards for export and domestic marketing of major commodities. Marketing boards pool the price risk and usually offer a single price for all participating farmers. Under this type of scheme, the fluctuation of the international price and exchange rates are mitigated through the pooling mechanism, but farmers do not have access to other price risk management instruments. Recent deregulations in commodity marketing arrangements have made it possible, and necessary, for farmers to manage price risk themselves. Within agriculture, there are substantial variations in the degrees of output volatility across products and regions. Grains and oilseeds exhibit the highest degree of volatility in the value of farm production, at 1.8 times the average as shown in Figure 2-3 below.

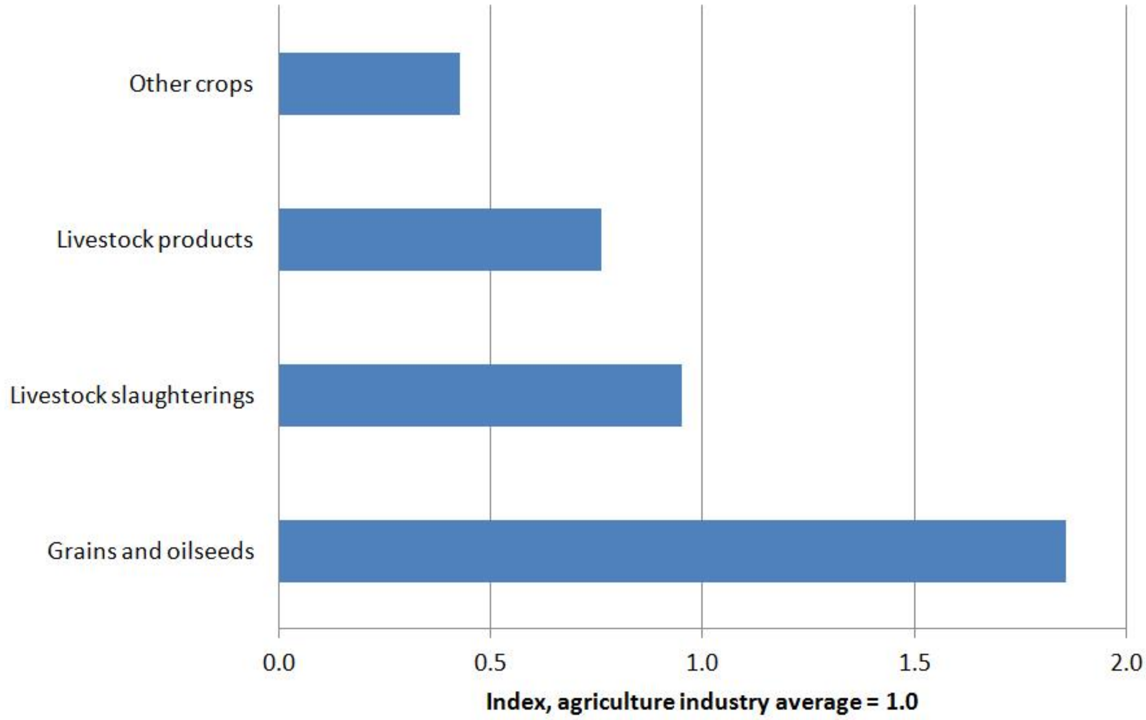


Figure 2-3. Volatility of the value of Australian farm production, 1966–2011. Note: Industry volatility is calculated by taking the standard deviation of the percentage difference between actual and trend production. Trend data are estimated using a Hodrick-Prescott smoothing filter. When comparing indexes in this figure with those in Figure 1, note that the volatility index for the agricultural industry has been rebased to 1.0. Data source: ABARES 2011.

Due to the climate characteristics of Australia, yield risk is generally the predominant source of risk in agriculture. Yield risk derives from the variability of seasonal weather conditions, especially rainfall prior to the start of the growing season for crops and pastures and spring rains, in the Mediterranean climate regions of south eastern and south western Australia and the temperate climate regions of eastern Australia. Other sources of yield risk includes natural disasters such as flood and bushfire, animal or plant disease outbreak, and hail and frost risk. Hail and frost may cause catastrophic damage to crops, but private insurance markets are well developed due to the less systemic nature of these risks.

For dryland farmers, weather and yield risks are foremost in their planning; the many other risks are significant but secondary. Farmers using irrigation face the risk of receiving highly variable and sometimes very low allocations of water for irrigation. Nguyen *et al.* (2005) provide empirical indicating that the most important risks perceived by land extensive farmers in SA and Queensland are climatic variability, followed by financial risk,

Insurance products generally cover yield risk, as opposed to price risk, because options for farmers to hedge price risk, such as forward contracts and futures, already exist. By contrast, limited options are available for farmers to protect themselves from yield risk.

In general it is easier for the market to provide options to hedge price risk rather than yield risk. First, because yield risks are less systemic than price risks, they can be localised and do not affect all farmers in the same way, meaning a higher degree of customisation is required for yield risk management options. Second, individual farmers can easily influence their own yield levels, meaning insurers need to determine whether a yield loss was caused by a trigger event, or sub-optimal management practices. This moral hazard problem is not an issue when dealing with price risk as price levels are virtually beyond the control of individual farmers. Finally, farmers generally have a better idea than insurers about their risks and expected yields. When this occurs, insurance companies are not able to distinguish between high risk and low risk farmers and price premiums accordingly. This adverse selection problem is not an issue in the context of market price movements as farmers do not have better information on price movements than the market as a whole.

Agricultural insurance is more appropriate for rare and extreme events as shown in Figure 2-4. Claims made against insurance policies frequently add to the cost of insurance by increasing the costs of loss adjustment. The cost of insurance also needs to be considered against the cost of alternative risk management practices. In particular, less significant risks may be managed more economically through savings or borrowings.

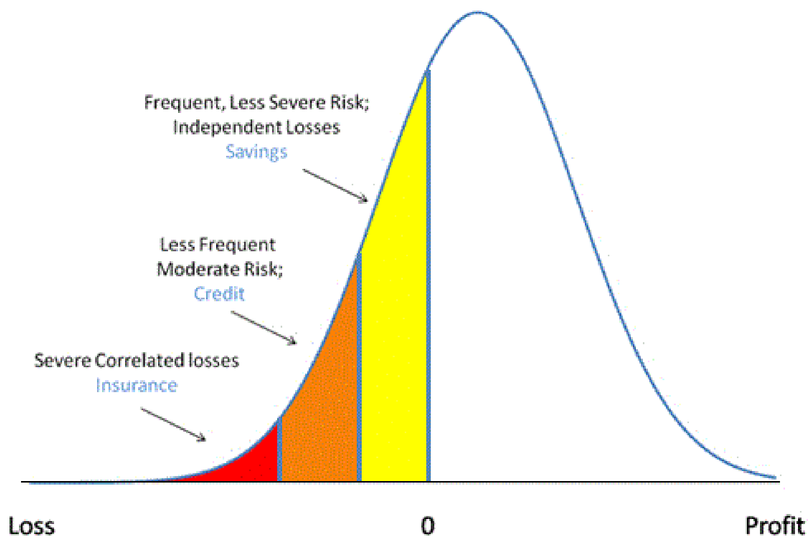
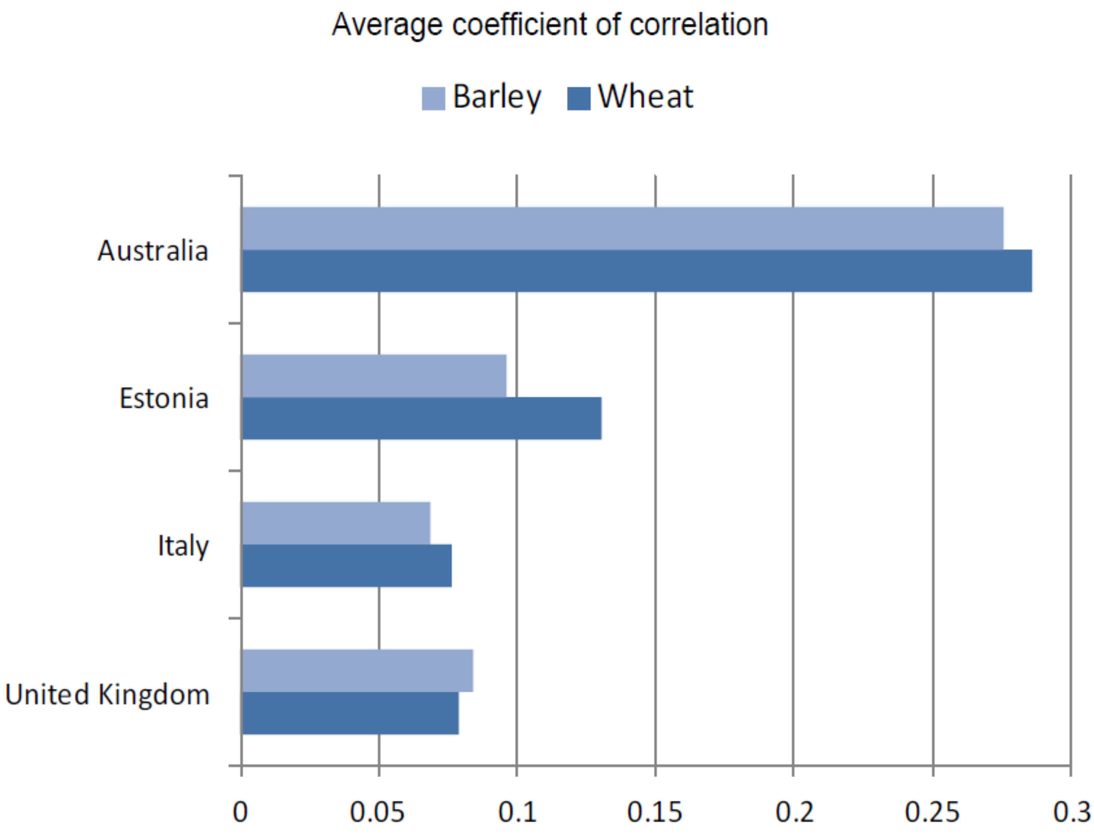


Figure 2-4. The role of insurance. Source: DAFWA 2011

Insurance cannot provide protection against events which are almost certain to occur, such as climate change. This is because insurance is not designed to be a subsidy to farmer income, but a tool that allows farmers to reduce downside risk. However, insurance can protect against climate variability, where a farm is profitable over the long term but exhibits an undesirable level of volatility on a year-by-year basis.

Another significant characteristic of yield risk in Australia is its systemic nature. As shown in Figure 2-5 below, Australian farmers are exposed to much more systemic yield risk than farmers in three European countries because Australia suffers from catastrophic events, in particular drought, more frequently, which affects farms in many different locations simultaneously. In the European countries, yield risk is found to be more location/farm specific so that farmers face less systemic yield risk.



Source: OECD (2010b).

Figure 2-5 Correlation of yield across farms

Price related risks are also perceived to be important in Australia where the majority of products are exported to international markets. Risks that derive from the export commodity markets that Australian farmers face include price volatility, exchange rate fluctuations and market access risk. Financial risk – the gearing ratios of farm firms – exacerbates the business risks of yield, price, disease and pest outbreaks.

Figure 2-6 below presents the average price coefficient of variation for wheat, barley and oilseeds. In comparison with the European countries, the Australian mixed crop farm faces higher price risks. Unlike three countries in Europe, where cereal price intervention systems exist for wheat and barley and the proportion of export in crop production is low, Australian farms are more exposed to price fluctuation in international markets. Moreover, the average price coefficients of variation are found to be less than the yield coefficient of variation except for wheat, which is consistent with the risk perception of farms that yield risk dominates other risks.

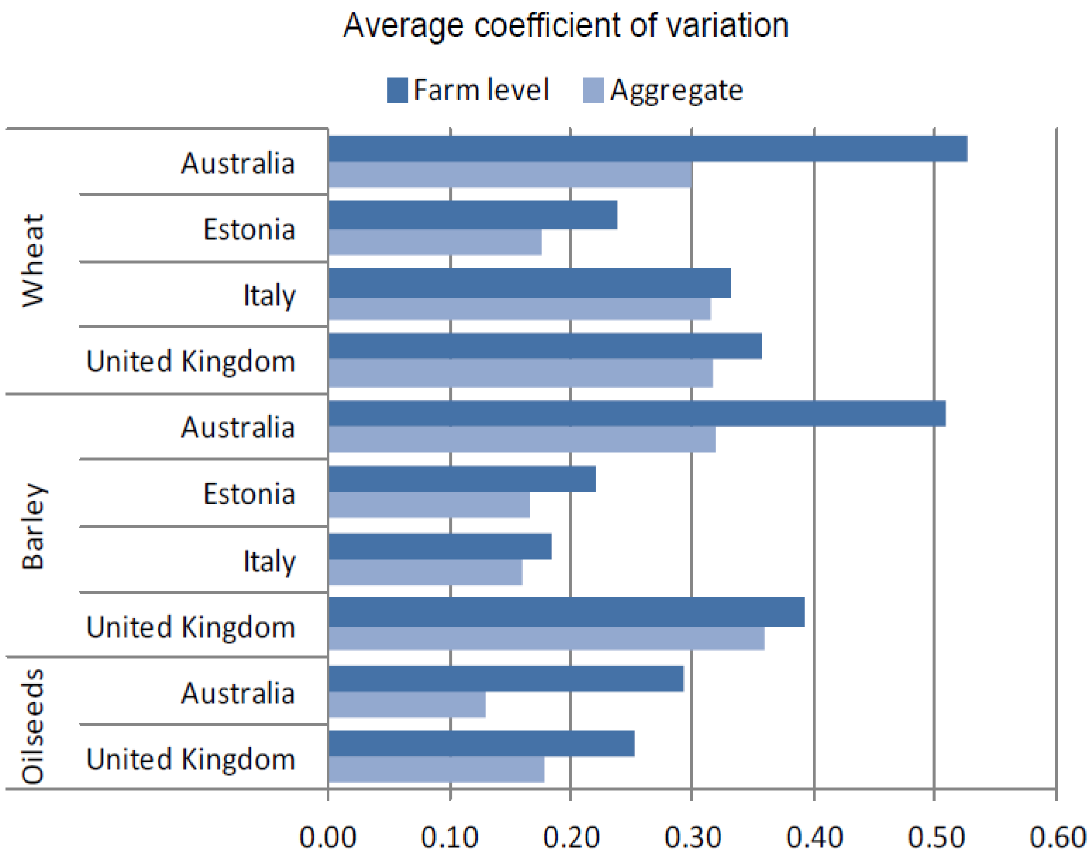


Figure 2-6 Variability of crop prices: Australia versus other countries

Overall, farm risk has certain unique distinguishing features in Australia. Yield risk is higher and more systemic here than in other countries. Price risk is higher due to the exposure to world markets and exchange rate variability. Also, negative price yield correlations at the farm level are comparable to other countries. These specific characteristics of yield risk in Australia have significant implications for good risk management policy.

Weather and Climate Risk in Agriculture

Agriculture is considered to be extremely susceptible to weather risk particularly drought (DAFF 2012; George et al. 2005; Hatt, Heyhoe & Whittle 2012; Keogh, Tomlinson & Potard 2013). Several scholarly debates have focused on this risk particularly in the context of climate change (Rosenzweig et al. 2001; Stern 2006; Webb 2006; Parry et al. 2007; Hennessy et al. 2008; Hertel & Rosch 2010; Cuevas 2011; Keogh 2013). In the context of Australian agriculture scholars have identified three broad categories of risk layers. The first layer occurs frequently but has low impact. The third layer has low probability of occurrence but has the highest level of impact. The second layer is in between the two in terms of probability of occurrence and magnitude of impact. Since farmers are generally able to handle the first layer well by themselves, we focus more on the second and third layers in this paper. The risk to Australian agriculture due to extreme weather events falls in the third layer category and has been more challenging.

Another way of characterising risk in Australian agriculture is the risk due to the occurrence of droughts and floods. Australian climate has been associated with El Nino Southern Oscillation (ENSO) Index and La Nina events (BoM 2012b). The droughts of 1902, 1972, 1982 and 2002 are associated with ENSO events while the floods of 1973, 1974, 1999 and 2000 are attributed to La Nina events. The La Nina events over the period 2010 to 2012 resulted in the record rainfall and floods in Australia. The two events, El Nino and La Nina are both naturally part of the global climate system that result from the interaction between the Pacific Ocean and the atmosphere above it (BoM 2012b). The link between sea surface temperature and its impact on agricultural losses were emphasised by (Hoppe 2007) while the impact of the ENSO and ocean temperature is addressed in Botterill and Hayes (2012).

Both ENSO and La Nina are related to the Southern Oscillation Index (SOI) which has a strong relationship with wheat yield in Australia (Rimmington & Nicholls 1993). The movements in these weather indices have been the underlying influence of the temporal and spatial variability of wheat yield in Australia because of their interconnectedness with rainfall variability (Potgieter, Hammer & Butler 2002). The implication of these relationships is that these climatic indicators are in some ways related to agricultural productions in Australia because of their relationship with the Australian climate particularly rainfall (McIntosh, Ash & Smith 2005; Webb 2006).

In an attempt to capture this interconnectedness, Sea Surface Temperature (SST) was related with the gross output of Australian crops. It was noted that more than fifty per cent variance in gross value was explained by Sea Surface Temperature (Hammer, Nicholls & Mitchell 2000). The implication is that as these events influence meteorological characteristics of the Australian climate, they also affect the hydrological characteristics with consequent implications on the agricultural output and eventually the social welfare of the Australian community (Wilhite 2007).

Webb (2006) established that the variations in Australian agricultural output vary from year to year, with a consequent loss of as much as 10% of farm production value. The author cited the drought of 2002 which cost 70,000 jobs, 30% reduction in agricultural output and 1.6% reduction in GDP. Drought could have cost implications for the farmer in that pasture production will be low and given that demand is higher than supply, the cost will rise. Paddock cost was $15, 858 per year in non-drought years but jumped to $42, 440 in years of drought in Tocal homestead in (DPI 2013). Other costs may however not follow the same direction but may not make up for the increase to a commensurate extent. This increase in costs of input explains why prices of primary products could rise during droughts (Gray et al. 1995). In addition to the passing through of increased costs of production to the consumers, demands would tend to outweigh supply giving additional incentives to suppliers to increase the prices of their products in the case of crops but the converse is the case for livestock.

Besides rainfall forecasting, other sources of risk that are significant include frost, hail and fire risk. Bush fires may not be directly related to weather conditions but bush fire index shows an indirect relationship to weather (Sivakumar & Motha 2007; ABS 2012). The index combines expected wind speed, humidity, temperature and a measure of vegetation dryness on a daily basis to facilitate preparedness. The implication is that these other risks that farmers face are not unrelated to weather and climatic conditions. For example, the years following major floods tend to be followed by heavy bush fires because of the wild growth of forest in the preceding years that serve as fuel for the fire.

Climate and weather risk events lead to yield and price shocks in Australian agriculture. Weather risk affects all parameters of farm income but yield risk is of higher significance than price risk and input risk (Malcolm 1985; Hammer, Woodruff & Robinson 1987; George et al. 2005; Hatt, Heyhoe & Whittle 2012). The variability in prices has been attributed to the focus of the Australian agricultural productions on exports and the fact that there is currently no government price support although there are other options that individual farmers could adopt to hedge their risks (Craik & MacRae 2010; Kimura & Antón 2011; NRAC 2012). Given that the prices received by farmers could be highly variable because of reasons unrelated to domestic demand and supply and the Australian export is largely dependent on commodities particularly wheat, Australia is prone to high variability on commodity prices (Malcolm 1985). The case of Australia is peculiar because as much as 60% of its agricultural productions are exported annually and about 80% for wheat (NRAC 2012, p.11). It is believed that farmers are price takers because they are operating in an atomistic market (Longworth 1967; Newbery & Stiglitz 1979; Kimura & Antón 2011; Hatt, Heyhoe & Whittle 2012; NRAC 2012). The existence of other mechanisms like forwards to manage price risk has alleviated the risk.

Climatic conditions could also influence commodity prices to some extent. Profitability concern determines farm management decisions rather than gross revenue on which most analyses have been based. Since production costs are usually difficult to estimate in agricultural enterprise particularly for labour in an owner-managed enterprise farm context (Quiggin, Karagiannis & Stanton 1994), most models have been based on gross revenue (Vedenov & Barnett 2004; Kapphan 2012; Khuu & Weber 2013). The interrelationship between production and the demand and supply of agricultural products links to the impact of weather on input cost which is a part of the profitability equation (Profit = Yield *Price – Input cost) (MunichRe 2011). The net income of the farmer is the most important variable from the farmer's perspective and is less related to yield than the gross revenue because of the additional consideration of input costs which is largely determined by a farmer's unique management skills and anticipated output price (Malcolm 1985). In times of drought, variations in the cost of labour and other material inputs could further impact profitability. Therefore, all three parameters in the profitability equation are indirectly linked to the weather.

The implications of weather extremes make climate forecasting an integral part of agricultural management decisions (Khuu & Weber 2013). Nevertheless, weather forecasting may not be relevant to agricultural management decisions if the lead time to making the decisions is not sufficient (McIntosh, Ash & Smith 2005). The use of these phenomena to make agricultural weather forecasts could only be valuable if useful and readily grasped management response can be based on them (Rimmington & Nicholls 1993; McIntosh, Ash & Smith 2005).

An Overview of Weather Risk Management in Agriculture

An overview of risk management strategies used in Australian agriculture is summarised in Table 2-2. The strategies are classified in the table according to the criteria outlined in the framework in OECD (2009): whether it reduces the probability of occurrence (risk reduction), the magnitude of the damage (risk mitigation) or the impact on consumption (risk coping), and whether its main action takes place at farm household / community level, through markets or through government measures. As can be gleaned from the table, there are three ways by which risk in agriculture may be managed. First, the farm households could take initiatives to reduce, mitigate or cope with the risk. Second, a number of market based solutions such as the use of insurance products or futures products may be employed for managing risk. Finally, government assistance and support may be used to manage risks to Australian agriculture.

Table 2-2 Risk Management Strategies Used in Australian Agricultural Sector. Source: Kimura and Anton (2011)

	Farm household	Market	Government
Risk reduction	• Adoption of water conservation farming technique • Irrigation • Training		• Water rights trading • Bio-security border measures • Training programmes
Risk mitigation	• Financial management • Crops/livestock diversification • Stock management • Off-farm employment and investment	• Price hedging through forward contracting and futures markets • Exchange rate hedging	• Farm Management Deposit Scheme • Emergency response to animal/plant disease outbreak • EC interest rate subsidy (ECIRS)
Risk coping	• Cost reduction through minimising other expenses		• EC relief payments (ECRP) • National Disaster Relief and Recovery Arrangement

A survey by the Queensland Department of Primary Industry on drought management strategies strategies indicates that farmers undertake many steps to manage the risks they face. The results The results are shown in

Table 2-3. A common drought management strategy used widely across farm sectors is the saving of farm maintenance and operating expenses. Further, a wide range of financial management strategies such as cutting down personal expenses and using cash reserves are adopted. The survey shows the importance of having high equity and reserves of liquid assets, as well as diversified income sources in order to cope with drought risks. The survey also highlights several sector specific drought risk management strategies. Crops farms use the making of an early decision on planting and planting different types of crops as the main strategies while stock management of livestock and fodder is the key strategy for the livestock sector. Conserving fodder in times of surplus to use in times of shortage is a key strategy in extensive livestock production. The survey also shows that off-farm income is earned mainly from off-farm wages, and salary and investment incomes have increased in real terms during the past 40 years. Payments from government have also increased. On average, off farm income represents over 30% of total farm income (ABARE 2006). Broadacre farmers with off-farm wages increased from 25% in 1977-78 to 45% in 2007-08. For dairy farmers, the percentage receiving off-farm wages increased from 26% in 1977-78 to 35% in 2007-08.

A diversification strategy is an integral part of risk management of crop farm systems. First, livestock are vital to many cropping systems as they utilize crop residues and graze the areas of crop farms that are not cropped in any given year. Second, diversification in continuous cropping systems is inevitable because of the need to have disease break crops after a series of cereal crops. Therefore a mix of cereals, oil seed and grain legume crops are grown in any cropping system in any year. Diversification, even within specialized cropping systems, has the effect of exposing the business to a range of crop markets and prices, and to crop and livestock markets and prices.

Table 2-3 Drought Management Strategies in Queensland Agriculture (percentage of farms). Source: Queensland Department of Primary Industry (2004)

	Extensive livestock	Intensive livestock	Cropping	Horticulture
Livestock strategies				
Sold stock earlier than otherwise	89.1	68.9	48.9	15.1
Put stock on agistment	30.3	16.4	12.0	4.1
Used fodder that had been stored	65.0	75.4	48.9	12.3
Purchased extra feed	79.4	73.8	32.6	11.0
Plant industry strategies				
Made an early decision not to plant a crop	17.2	34.4	59.8	34.2
Planted a different type of crop to normal	9.1	29.5	46.7	21.9
Purchased additional water allocation	3.1	8.2	3.3	12.3
General strategies				
Used climate forecast	48.1	47.5	54.3	52.1
Reduced the workforce	25.0	34.4	46.7	60.3
Cut down on farm maintenance	62.2	68.9	63.0	50.7
Minimized other farm operating expenses	78.4	80.3	89.1	84.9
Extra off-farm work	35.3	26.2	46.7	37.0
Accessed FMDs	15.6	11.5	21.7	8.2
Used other cash reserves	63.4	57.4	62.0	57.5
Sold farm assets	15.6	23.0	26.1	19.2
Sold off-farm assets	12.2	11.5	23.9	16.4
Took out new loans/ increase overdraft	46.9	37.7	57.6	45.2
Reduced debt	30.0	29.5	33.7	31.5
Cut down personal spending	85.0	83.6	88.0	76.7

Table 2-4 presents the average coefficient of variation of per hectare return for each diversified production at the farm level. The farmer can benefit from diversification as long as the coefficient of correlation of returns across crops is less than one. Table 2-5 shows the correlation matrix of per hectare return across crops and each production element. It is clear from these tables that a farmer can gain advantages from diversifying production. The variability of per hectare return of crop production is lower than that of wheat, barley and oilseed production. Moreover, since the data shows the negative correlations between crop and livestock, the potential for diversification between crops and livestock is particularly important in Australia. The coefficient of variation of per hectare output is significantly lower than the coefficient of variation of both crop and livestock outputs, indicating that in fact producers are benefiting from production diversification between crop and livestock sectors.

Table 2-4 Variability of per hectare return

	Average coefficient of variation across farms
Crop production	0.80
Wheat	0.47
Barley	0.54
Oilseed	0.46
Livestock production	0.51
Total output	0.33

Table 2-5 Correlation of per hectare revenue

Average coefficient of correlation across farms

	Wheat	Barley	Oilseeds	Crop production	Livestock production
Wheat	1	0.28	0.15	0.86	-0.05
Barley		1	0.37	0.67	-0.01
Oilseeds			1	0.61	-0.02
Crop production				1	-0.05
Livestock production					1

The major risk faced by cotton growers in recent years is the availability of water. This has resulted in a more opportunistic approach to cotton production, with diversification to other dryland cropping activities as part of the whole farm system. Further, cotton is completely exposed to export markets and because of the exposure to exchange rate risks, there is a greater tradition of using futures pricing instruments than is the case in any other activity. The majority of cotton growers actively manage price risk exposure using forward and futures pricing instruments, whereas only a small proportion of cereal growers use forward pricing methods.

Market Based Solutions

In this section, we review market based solutions to deal with risk in the context of Australian agriculture. First, we review the existence and use of crop insurance. Second, we review the use of price hedging through futures market and forward contracting. Finally, we review the use of water markets as a risk management tool.

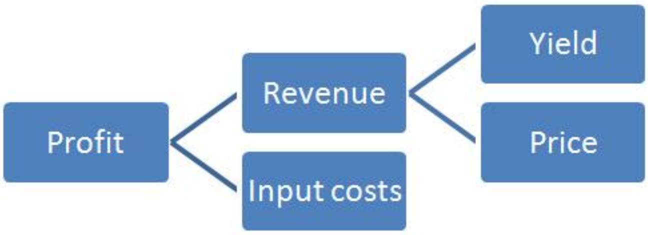


Figure 2-7 Risks faced by farmers

As shown in the figure above, farmers are subject to revenue risk, of which yield and price are components. Price risk may be managed through hedging products such as futures and forwards. Yield risk is handled by using insurance products. There are two types of insurance products – traditional insurance products and index based products. Named peril insurance, multi-peril crop insurance and crop revenue insurance for the three types of traditional insurance products that are in prevalence.

Named peril insurance products provide farmers with protection against specific risks such as hail, frost and fire. These products are available in Australia and many farmers use them. Insuring vulnerable crops against hail damage is common for most crop farms. Insuring farm assets, including animals, against loss by fire is extensively used by farmers. Insurance against frost damage is available for horticultural crops. Crop insurance against the risk of loss by hail, fire, and frost amounts to around $7-10 billion worth of crops insured each year, with a total premium around AUD 200 million, spread amongst 6-7 insurers. Around 85% of this exposure is then reinsured with reinsurers (Kimura and Anton, 2011).

Multi-peril crop insurance (MPCI) is also known as yield insurance because payouts are based on loss of yield while the cause of the loss is not assessed. For each crop covered under the policy, the insurer agrees with the grower on projected yield and projected value ($ per tonne). Hence, there is an agreed value on each crop covered by the policy. No such schemes operate currently in Australia. However, a number of industry groups have called for government support for multi-peril crop insurance. A number of feasibility studies have been conducted by the Governments or researchers during the past 25 years. Most studies conclude that multi-peril crop insurance would not be commercially viable without government support (Government of Western Australia 2009). An Ernst & Young study on the feasibility of multi-peril crop insurance found that only 18% of farm businesses were likely to subscribe to insurance at viable premium levels (Ernst & Young 2000).

Crop revenue insurance insures a farmer against both yield and price risk. It provides protection against revenue loss. A projected price and yield is determined when the insurance contract is entered into, and farmers are insured for production at that price. Currently crop revenue insurance is not available in Australia.

There are three types of index-based insurance products that are in prevalence - weather derivatives, yield index insurance and area yield index insurance. Farmers can use these tools to insure against yield risk. An index may simply be a set of numbers representing a single variable, such as rainfall or temperature over a given cropping season or a more complex calculation involving many variables, such as various climatic data or shire-level yield data that are expected to have an impact on farm yields.

Weather derivatives, or weather certificates, are comparatively simple products based on an index representing a single variable, such as rainfall or temperature. They are similar to financial derivatives, that is, they are *derived* from an underlying variable. Weather derivative indexes are developed using data from weather stations. An index can be developed for any weather station where sufficient data exists. The farmer chooses the closest weather station to his or her farm to ensure that the weather index is the nearest approximation to conditions on their farm. The weather derivative would payout if, for instance, rainfall is below a pre-specified amount over a pre-specified time period. One example of a weather derivatives product, CelsiusPro, currently operates in Australia.

Yield index insurance is a complex insurance product that brings together several variables to predict farmer yield through computer modelling. Variables may include shire-level yields and climate related factors, as well as crop specific factors, such as timing of planting, crop phenology and crop management practices. The model provides a forecast for a farmer’s yield based on this information. At the end of the season the model provides an updated estimate of farmer yield based on realised weather conditions. If the estimate is lower than the original forecast, the farmer receives a payout. A typical yield index insurance product, YieldShield, is currently available in Australia.

An area yield index, or group risk plan, is between a traditional insurance product and the newer index product. An area yield index is based on regional level yields. Farmers receive payments if average yields in their region fall below a pre-specified level, as opposed to receiving payout for a fall in their own individual yields. Currently this product is not available in Australia.

As can be seen in Table 2-6 and Table 2-7, forward and futures contracts are available for several agricultural commodities. However, the use of these derivative markets varies significantly between major commodities. The Australian Wheat Board extensively uses futures and option contracts on commodity price and exchange rates. However, the fully deregulated grain market has experienced a significant increase in grain marketing opportunities and methods. Wheat growers have the choice of selling directly to a large number of export buyers or into private cooperative pools. Grain can be sold directly to end users, increasingly making use of established relationships and forward contracting. There has been an increase in on-farm storage to allow selling throughout the year. This enables growers to hedge by selling through time and into several markets. Use of futures pricing methods is increasing, mainly in the form of over-the-counter products provided by financial institutions. Futures and options products are available, based on the Australian futures exchange or the Chicago mercantile exchange. The potential of options to manage price risk is increasingly being recognized, although mostly large growers currently make use of them.

Futures markets for trading futures contracts in wool and wheat are available at the Sydney Futures Exchange (now ASX). Historically, there have been futures markets for lamb and beef cattle. Wheat futures are also traded in the Chicago mercantile exchange. Interest rate and exchange rate futures also trade in the market. Little use is made of commodity futures trading instruments due partly to its inability to cover the individual basis risk. Instead, the main users of futures markets are commodity marketers. Table 7 summarizes the main futures markets used by Australian commodity marketers by commodity. The use of international futures markets, such as Chicago Board of Trade, has the advantage of high liquidity of trade, but the participants suffer from higher basis risk than when trading on the Australian futures market. Over the past two decades, several futures contracts such as lamb, and cattle have ceased to trade in the Australian futures market due to lack of interest.

Table 2-6 Futures and forwards used in Australian agriculture sector

	Major risk	Diversification strategy	Production management	Price risk management
Extensive mixed farm (Broadacre farm)	Rainfall, output price	Production diversification and off-farm income diversification	Conservation of soil moisture	Storage, forward contract and price pooling
Cotton	Rainfall, output price, exchange rate	Production diversification	Water management	Futures and forward contract
Wool and lamb	Output price, exchange rate	Production diversification and off-farm investment	Stocking rate management	Spot market trading
Beef	Output price, exchange rate		Stocking rate management	Forward contract
Dairy	Input cost	Specialization	Feed production and storage	Price pooling through co-operatives
Horticulture	Plant disease, irrigation water	Production diversification	Pest management	Forward contract

Source: Department of Agriculture, Fisheries and Forestry of the Australian Government

Table 2-7 Providers of Forward Contracts

Commodity	Key providers
Cotton	Integrated ginners/marketers Large multinational marketers Small specialist marketers
Grains	Australian Wheat Board Integrated bulk handlers/marketers Large multinational grain marketers Domestic marketers Banks
Sugar	Queensland Sugar Limited Millers
Wool	Wool brokers Banks

Source: Department of Agriculture, Fisheries and Forestry of the Australian Government

After the deregulation of commodity markets, a wide range of commercial marketers started to offer various forward contracts as shown in Table 6. Forward contracting of sales is common in large, intensive horticultural and animal activities. Forward purchase agreements for feed inputs are widely used in dairying and intensive animal activities such as pig, egg and broiler production. The major proportion of all milk produced in Australia is processed and sold by farmer-owned dairy processing co-operatives. These co-operatives supply inputs, including credit, and are eligible for some concessionary taxation treatments of aspects of their business operations. Also, numerous small farmer co-operatives exist for marketing of grains, wool, lambs, and for purchasing inputs. Commercial banks have become a major provider of forward contracts for agricultural commodities. In order to reduce the transaction costs associated with forward contracts, Meat and Livestock Australia has prepared a standard form of forward contract, with trading terms and conditions between cattle producers and marketers.

Cotton growers are the most prominent users of futures to manage price risk (Ada *et al*., 2007). It is not as common in the wool industry where less than 5% of woolgrowers use wool futures (Lubulwa *et al*., 1997). Around 20% of wheat growers use market price risk management techniques such as futures contracts, options, and over the counter products such as swaps. Around 10% of the annual wool production is sold using forward contracts or with some other form of price protection, with 85 to 90% of wool continuing to be sold at auction each year (Deane and Malcolm, 2007). The top 25% wool producers, in terms of financial performance, dedicate 8% of their annual wool production to price risk management, while for the remaining 75% of farms, only 4% of their production is subject to price risk management (ABARE, 2006).

Development of water markets

Variable rainfall and the frequent risk of drought make efficient water management a key risk management strategy for Australian farmers. Water trading is the process of buying, selling, leasing or otherwise exchanging water access entitlements (permanent trade) or water allocations (temporary trade). The water markets for irrigation allow farmers, and the public, to compete to obtain water for alternative uses, including environmental uses. The aim is to ensure that irrigation schemes operate more effectively and that farmers, by paying the market price for water, are forced to use water as efficiently as other potential buyers and competing users of water. Buying and selling water on the market enables irrigation water to move from less valuable to more valuable uses.

Water markets contribute to a producer's drought risk management in multiple ways. First, water markets provide an incentive for farmers to use water more efficiently, depending on climate conditions. Producers can purchase water allocations in wet periods at low prices and expand farming operations, while selling their water allocations at high prices and reduce the size of their operation. Second, selling permanent water entitlements can mitigate the adverse impact of droughts on farm income. The asset value of water entitlement is, by nature, counter-cyclical with the availability of water.

Role of Government

The Australian government facilitates risk management in the agriculture sector through a variety of initiatives. Broadly, these may be classified into Catastrophic Risk Management, Drought Relief, Training, and Tax Relief.

Catastrophic risk management

In Australia, most government measures that deal with risk management are focused on management of catastrophic risks such as natural disasters and animal/plant diseases. There are two main policy frameworks that manage weather related risks: the National Disaster Relief and Recovery Arrangement (NDRRA) and the National Drought Policy (NDP). The former provides *ad hoc* type *ex post* assistance for communities and individuals to deal with different types of catastrophic climate risks except for drought. The latter is specifically addressed through drought risk management, which originally was considered as one of the natural disasters covered by NDRRA. More frequent, damaging and longstanding droughts have led to the creation of a separated National Drought Policy framework (NDP) in 1992. In addition, Bio-Security Partnership Arrangement provides the public-private partnership arrangement to share the risk of animal/plant disease outbreak among the stake holders.

In Australia, federal, state and local government agencies combine to administer disaster relief, depending to some extent on the nature and area of the disaster. The Natural Disaster Relief and Recovery Arrangements (NDRRA) is a policy framework under which State governments develop their own programmes and measures, make the assessment of circumstances and trigger assistance. The federal government only provides partial reimbursement of measures that fall under the designated categories. The NDRRA is automatically triggered when state/territory expenditures on an event exceeds AUD 240 000. NDRRA covers losses due to bushfire, earthquake, flood, storm, storm surge, cyclone, landslide, tsunami, meteorite strike and tornado, but not drought, frost, human or animal epidemic. Under the NDRRA, relief or recovery aid applies only to compensate damage or distress arising as a direct result of a natural disaster. It does not provide compensation for losses and farmers are generally not eligible for support if insurance can cover the loss.

Drought Policy

The commonwealth has had numerous drought assistance schemes over the years. Assistance for drought has previously been available through the above mentioned

NDRRA scheme but was removed when drought was redefined and no longer considered a 'disaster'.

One of the most involved and high level drought assistance schemes was the National Drought Policy (NDP). The objectives of the NDP were to: 1) encourage primary producers and other sections of rural Australia to adopt self-reliant approaches for managing climate variability; 2) maintain and protect Australia's agricultural and environmental resource base during periods of extreme stress; and 3) ensure early recovery of agricultural and rural industries that are consistent with long-term sustainable levels. Providing short-term assistance to long-term viable producers was the key operational policy objective of NDP.

The policy support became available in a region only after a government declaration of 'Exceptional Circumstance' (EC). These were defined as "rare and severe events outside those a farmer could normally be expected to manage using responsible farm management strategies". Three operational criteria were used to determine an EC:

- must be rare, that is it must not have occurred more than once on average in every 20 to 25 years;
- must result in a rare and severe downturn in farm income over a prolonged period of time (e.g. greater than 12 months);
- must be a single event that is not part of long-term structural adjustment processes or of normal fluctuations in commodity prices.

These operational criteria are assessed, within the context of local practices, on the basis of meteorological conditions, crop yield, pasture and stock conditions, water supplies, and farm income levels. Once an area is declared EC, three main programmes were made available to farmers: the EC Relief Payment, the EC Interest Rate Subsidy and the EC Exit package.

The *EC Relief Payment (ECRP)* covered the essential day-to-day living expenses of farm households, with payments equivalent to the unemployment allowance for the non-farm sectors (Newstart allowance). In 2008-09, approximately 24 500 farm households received ECRP payments, totalling AUD 339 million.

The *EC Interest Rate Subsidy (ECIRS)* aimed to support the long-term viability of an enterprise suffering from financial difficulty due to a EC event. Both farm business and farm dependent rural small business in EC declared area were eligible to apply for ECIRS. It covered up to 50% of the interest payable on all loans excluding recent property purchases in the first year and up to 80% in subsequent years. Since the eligibility for ECRP and ECIRS wasn't mutually exclusive, a farmer could have accessed both ECRP and ECIRS at the same time. The ECIRS payments were limited to AUD 100 000 per 12-month period, with cumulative support capped at AUD 500 000 over five years.

Finally, EC Exit Package was designed to assist non-viable farms to exit the sector. It consisted of an Exit Grant, which provided a taxable one-off payment of up to AUD 150 000, an Advice and Retraining Grant and a Relocation Grant up to AUD 10 000 for relocation expenses. A farmer receiving an exit package had to declare that they will not return to the agricultural sector within five years. As of 5 December 2008, only 98 applicants received the package out of 469 claims. Of those who received exit assistance, 64 also received either ECIRS or ECRP before leaving the industry. The exit package is hardly used partly because it imposed more restrictive criteria with an asset test of AUD 350 000.

Currently the Farm Household Allowance (FHA) is the available assistance for farmers' in drought. This provides farmers and their families experiencing financial hardship financial support. This payment is managed through the Department of Human Services and is tailored to farmers, taking in to account off farm income (Applicants' income must be below the cut-off point for Newstart Allowance or Youth Allowance) and a two-part asset test. Part 1 is the non-farm and liquid assets test and Part 2 total net farm assists test – the total mush be below AUD 2.55 million.

Tax policy

The Australian government provides tax incentives to retain a certain cash reserve. The Farm Management Deposits (FMD) scheme allows farmers to deposit up to AUD 800 000 of income earned that is then excluded from taxable income until it is withdrawn from the FMD if kept for at least 12 months. This financial year (16/17) the early access trigger during times of drought was re-established; and the law preventing FMDs being used as offset accounts against primary production business debt was removed.

FMDs defer and save tax, and aim to provide a means to reduce inequity that may derive from highly fluctuating incomes and progressive income tax schedules, thereby achieving the increased self-reliance. As at March 2017, aggregate FMD holdings totalled over AUD 42 billion, with over AUD 900 million in FMDs in Queensland. In addition to the FMD scheme, primary producers can also use a tax averaging scheme that allows their current taxable income to be assessed at the tax rate applicable to their average income in the current year and the four preceding years. Under this scheme, a farmer pays lower taxes when they have higher taxable income than the average of previous five years, but a higher tax is imposed when the taxable income is lower than the average of the previous five years. This scheme also has the effect of smoothing income by avoiding a higher tax rate that would be applicable in high income years.

Policy directions

The major policy challenge for risk management in Australian agriculture is to refocus from mitigating financial impacts of adverse weather effects to facilitating farmers' adaptation to climate changes. Since it is unlikely that the current framework of drought risk management is sustainable, we consider the following policy directions.

- Firstly, a feasibility study of developing commercially viable insurance products to cover drought risk is strongly recommended. The potential demand for such products is high due to high yield variability and the systemic nature of yield risk for many crops. The study should include consultations with insurers, farmers and other stakeholders and should consider an appropriate system for information sharing on risks. Further, the study should identify potential obstacles that preclude the viability of the commercial crop insurance market.
- Secondly, the feasibility of index-based insurance should be explored. The systemic nature of yield shocks in Australia associated with a drought makes this study especially more meaningful since the high correlation between rainfall in weather stations and farms results in low basis risk.
- Finally, a study regarding information and training support to empower farmers to undertake strategies for adapting to climate change should be explored.

3. Methods

Survey data collection

We used a structured questionnaire (Appendix A) to survey a total of 55 farmer responses (23 cotton growers and 32 sugar cane growers) across Queensland (Figure 3-1). Surveys were conducted by research project partner, Queensland Farmers' Federation (QFF).

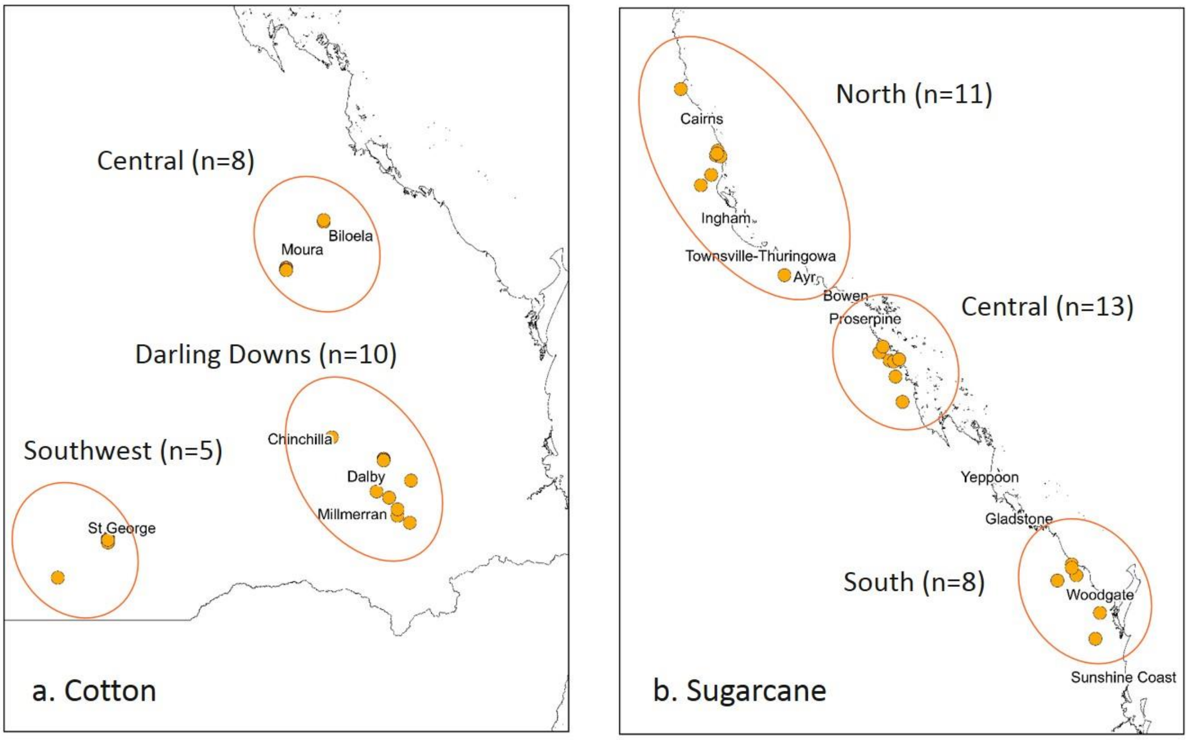


Figure 3-1 Distribution of survey participants across (a) three cotton growing areas and (b) three sugar cane growing areas in Queensland.

The survey asked for general information about the farming context and risk management practices, including industry Best Management Practice (BMP) certification. Participants were asked to score their perceptions of the severity and likelihood of particular risks on a 5-point scale, and to estimate the impact such events had had on the productivity/profitability of their cropping enterprise. A number of questions were open ended, to which participants could provide extended answers. Survey responses were collated and, where relevant, summarised (average values ± 1 standard error). Insufficient numbers of samples were available for more robust statistical analysis of differences between groups in most instances.

APSIM analysis

Background

Agricultural production depends upon a variety of interconnected factors (e.g. environmental, crop genetics, agronomic practices). Crop growth models are increasingly used in a management and policy setting to quantify the impact on yield of changes due to climate or crop management (Asseng et al., 2013; Martre et al., 2014). These models provide information on the health and maximum attainable yield of a crop.

Given the variety of crop growth models and their relative strengths and weaknesses, ensembles of crop models are being progressively developed for yield/production forecasting purposes. This approach helps improve accuracy and consistency in simulating growth dynamics under various environmental conditions.

An integrated crop yield/production forecasting system (which combines crop growth and climate models, and statistical tools) may provide industry stakeholders such as growers, commodity traders and policy developers with early warning of the potential climate risks, the likely impacts and their severity to expected crop yields at different lead times.

The objective of this activity was to develop an operational integrated seasonal climate-crop modelling system for yield and production forecasting of major Queensland crops (wheat, sorghum, sugarcane and cotton). The modelling approach is based on a multi-model ensemble approach for crop growth simulation.

The modelling framework developed here as well as the simulated variables will be used in the sister projects DCAP USQ 6 ("Enhanced multi-peril crop insurance") and DCAP USQ 14 ("Crop production modelling under climate change and regional adaptation").

Materials and Methods

Model selection

A careful review of literature was carried out to identify the potential crop models that can be used in the ensemble crop models. Most crop models simulate the dynamics of phenological development, biomass growth and partitioning, water and nitrogen cycling in an atmosphere–crop–soil system, driven by daily weather variables of rainfall, maximum and minimum temperatures and solar radiation. A summary of the main modelling approaches involved in the selected crop models reviewed is given in Supplementary Table S1. The main criteria used for selecting relevant models for our study include: (1) the popularity of the model (at national and international levels), (2) its performance as reported in published studies, (3) the model structure and easiness of use within the project time frame (e.g., implementation, data collection and calibration, etc.), (4) the availability of model updates, and (5) a crop model which considers the various aspects of climate change as drivers (including rainfall, atmospheric CO2, temperature and ozone).

Among the 16 crop models reviewed, the Agricultural Production Systems Simulator (APSIM; Keating et al., 2003) and the Decision Support System for Agrotechnology Transfer (DSSAT; Jones et al., 2003) were by far the crop models meeting our criteria. They both share some similarities (e.g., point-specific model, minimum number of climate input variables, light interception and utilization, etc.); but also present some differences (Supplementary Table S1) that make them suitable to capture a range of uncertainties. They have been used in several crop models comparison studies (e.g., Asseng et al., 2013; Martre et al., 2014; Marin et al., 2015; Asseng et al., 2016; dos Santos Vianna and Sentelhas, 2016; Stokes et al., 2016), and for various agricultural purposes, including crop growth monitoring and yield forecasting, impact studies of crop management practices, decision support tools (see http://www.apsim.info/Products/Publications.aspx; http://dssat.net/publications). However, unlike APSIM, DSSAT has not been used widely for operational purpose in Australia.

APSIM version 8 and DSSAT version 4.6 were used in our analysis.

Study sites and climate data

Figure 3-2 shows the sites used for simulating crop growth in APSIM and DSSAT. Overall, 10, 12 and 19 sites were considered for cotton, sugarcane, and wheat and sorghum, respectively. Daily climate data (minimum and maximum temperatures, rainfall, solar radiation, and evaporation) for the 1940-2016 period retrieved from SILO's patch point data set (https://www.longpaddock.qld.gov.au/silo) (Jeffrey et al., 2001) were used. These weather data were converted in a format suitable for DSSAT using the WeatherMan (v. 4.5; Pickering et al., 1994).

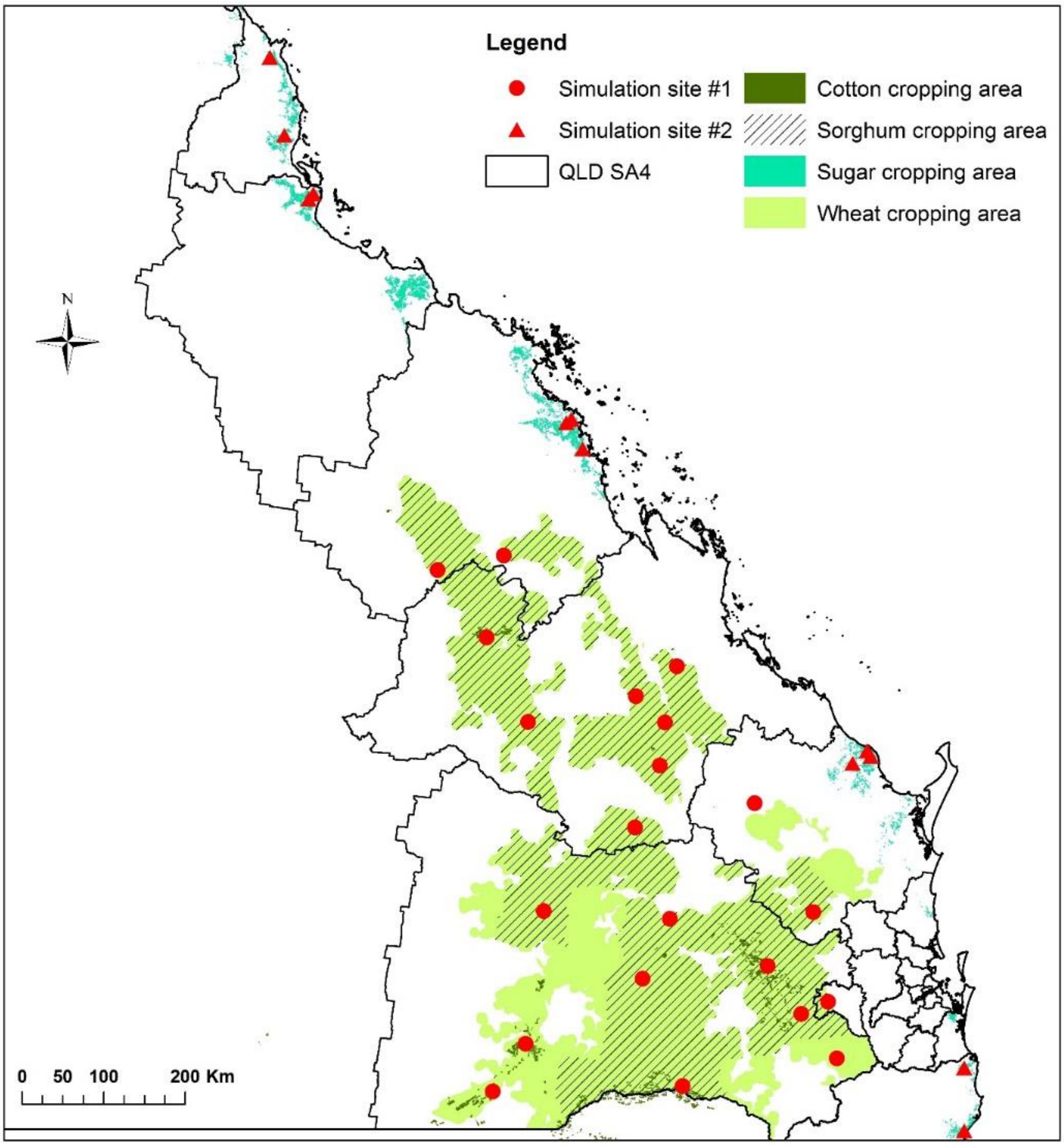


Figure 3-2 Simulated sites considered for crop growth simulations in APSIM and DSSAT. Simulation site #1: sites used for simulating wheat, sorghum and cotton yields; Simulation site #2: sites used for simulating sugarcane yield. QLD SA4: Queensland statistical area level 4 as for 2016. (Source: Queensland Spatial Catalogue – QSpatial; http://qldspatial.information.qld.gov.au).

Configuration of simulations

Different levels of inputs and management factors were simulated. These factors include the crop type, sowing date, sowing/planting density, nitrogen fertilizer rate, and plant available water capacity (PAWC). A summary of the simulation options used is provided in Table 3-1. Pests, diseases, and weeds were not simulated and it was assumed that the grower would take all reasonable steps to control these in any case. Consequently the simulated yields are potential yields.

The nitrogen fertilizer amount considered for wheat, sorghum and cotton growth were set to represent the common practice in the growing regions. They ranged from 25 to 150 N kg ha-1. Regarding sugarcane growth, they were chosen based on the average annual applications in sugar-producing districts, which range from 150 to 200 N kg ha-1 (Bell et al., 2015).

Irrigation was applied only for sugarcane growth simulation. The irrigation requirement (IR) was based on the values of sugar producing district to which they belong (Hardie et al., 2000). IR varies from 0 to 1,400 mm (nil to supplementary to full irrigation). For example, full irrigation is required in the Burdekin district (IR = 1,070 mm), extensive and moderate to extensive supplementary irrigations in Bundaberg (IR = 780 mm) and Mackay/Proserpine (IR = 860 mm), respectively (Hardie et al., 2000). In our analysis, irrigation dates were arbitrarily fixed since they vary from farm to farm in a given same district. However, a minimum period of 14 days between irrigation applications was kept.

For all simulated sites for sugarcane a planting stalk density of 10 plants/m2 was used for a cycle including one plant crop (14 months) and 4 ratoons (12 months each).

Table 3-1 Parameters and factors used for simulating cotton and sugarcane in APSIM and DSSAT. The level column refers to the abbreviation used for output referencing purposes.

Cotton		Sugarcane	
Cultivar	Level	Planting date (doy)	Level
Default	C1	15-may (135)	P1
		15-jun (166)	P2
		15-jul (196)	P3
Sowing density			
5	P1	Irrigation (mm)	
7.5	P2	30	I1
10	P3	50	I2
12.5	P4	70	I3
Sowing date (doy)		N Fertilizer	
01-Oct (274)	S1	100	N1
15-Oct (288)	S2	150	N2
01-Nov (305)	S3	200	N3
15-Nov (319)	S4		
15-Dec (349)	S5		

Eight different soils retrieved from the APSoil database (Dalgliesh et al., 2012) were used according to the site for the simulation of sugarcane in APSIM (Table 2). While for wheat, sorghum and cotton, two main "default" vertosol soil types were used according to the geographical position of the site. Soil parameters were set according to the dominant soils in that region as reported in the APSoil database and expert knowledge. The PAWC considered ranged from 80 to 240 mm. An example of soil parameters for vertosol soils with PAWC = 190 mm is presented in Table 3. For their use in DSSAT, default soils were built based on corresponding information available in the soil files used in ASPIM. Values of missing soil parameters were retrieved from the Soil and Landscape Grid of Australia website (http://www.clw.csiro.au/aclep/soilandlandscapegrid/) or estimated based on functions implemented in DSSAT- soil module (Uryasev et al., 2004).

Table 3-2 APsoil soil types used for the simulation of sugarcane in APSIM and DSSAT.

APsoil soil type	Site	Climate station ID
Hydrosol (No 878)	Meringa	31040
Brown Dermosol (No 648)	Macknade	32032
Yellow Dermosol (No 647)	Tully	32042
	Victoria	32045
Silty clay loam over light clay (No 682)	Burdekin	33002
	Farleigh	33023
	Plane Creek	33059
Medium clay (No 820)	Pleystowe	33060
Loam (No 706)	Mackay	33119
Loam (No 1074)	Fairymead	39037
Redoxic Hydrosol (No 650)	Bundaberg	39174
Red Ferrosol (No 1064)	Bingera	39186

Table 3-3 Soil parameters for 2 vertosol soils (PAWC = 190 mm) used for the simulation of cotton growth APSIM.

		Cotton		
Vertosol #1	Depth	LL	PAWC	KL
	(cm)	(mm/mm)	(mm)	(/day)
	0-15	0.28	36.8	0.08
	15-30	0.29	34.5	0.08
	30-60	0.305	63	0.08
	60-90	0.325	55.5	0.08
Vertosol #2	0-15	0.3	30	0.08
	15-30	0.305	28.5	0.08
	30-60	0.32	48	0.08
	60-90	0.34	40.5	0.08
	90-120	0.355	34.5	0.07
	120-130	0.365	10	0.06

BD: bulk density; AirDry: air dry mm water/ mm soil; LL15: lower limit of plant-extractable soil water (i.e., water content at 15 bar); DUL: volumetric water content at drained upper limit; SAT: volumetric water content at saturation; PAWC: plant available water capacity; KL: root water extraction rate.

Default crop cultivars for wheat, cotton and sorghum (as available in the standard release of APSIM v.8) were used for APSIM simulations. Modified crop cultivars were used for sugarcane for APSIM and for all crops in DSSAT. Details are provided in the next subsections.

Sugarcane cultivars in APSIM

Preliminary analyses based on the crop varieties available in the standard release of APSIM-sugar and historical sugar mill data suggest the need of an update of key crop parameters. Although the most used sugar varieties in papers consulted during the literature review are "Q117" and "Q124" (see for example Keating et al., 1999; Carberry et al., 2009; Meier and Thorburn, 2016), it appears that those varieties are no longer (or barely) used on farms (QCANESelectTM, Sugar Research Australia, 2017). For instance, the proportions of area planted by variety in Australia from 1999 to 2013 show that the percentage of varieties Q117 and Q124 decreased from 7.7% and 45.6% to nil (Figure 3-3). The same could applied to the remaining varieties available in APSIM-sugar. The modifications performed are given in Table 3-4. The values of the selected parameters were varied within a range constituted by their corresponding values as reported in the standard release of APSIM-sugar. Simulated cane yield and CCS were then compared to the historical mill data, and the better combination (the one resulting in low mean square and absolute errors) was kept. Obviously, historical mill data encompass several varieties and different crop management practices across a given region.

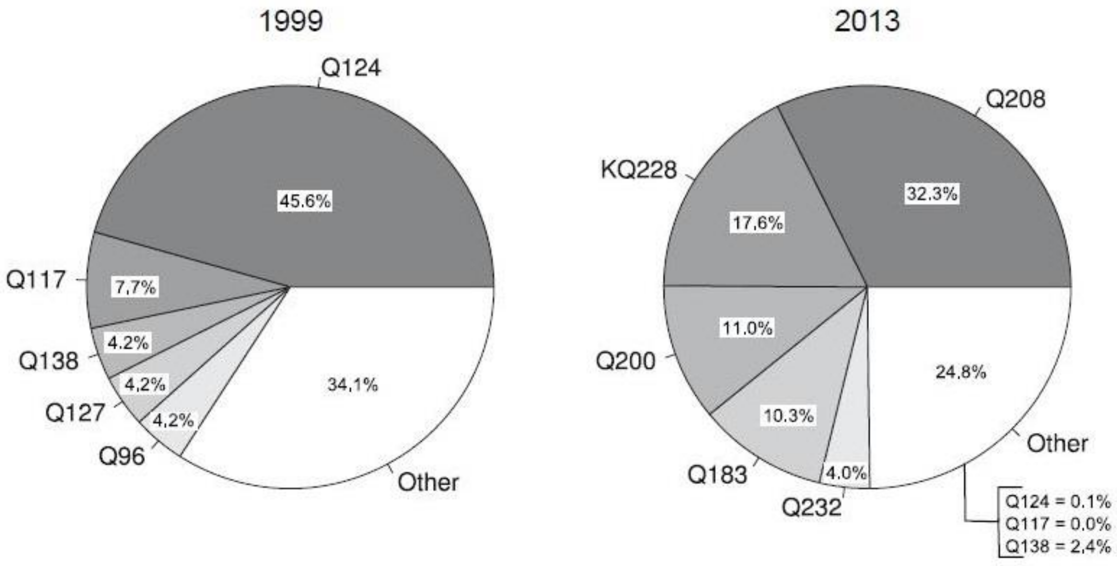


Figure 3-3 Percentage of hectares grown by sugarcane variety in Queensland and New South Wales for 1999 and 2013 (Source: Sexton, 2015).

Table 3-4 Ranges of selected variety parameters as reported in the standard release of APSIM-sugar, and modified parameters. The modifications applied both to the plant crop and ratoons. Q177: default cultivar; Q117_m and Q117_n: modified cultivars.

Crop parameter	Description	Unit	Range	Q117	Q117_m	Q117_n
cane_fraction	Fraction of accumulated biomass partitioned to cane	g g-1	0.65 - 0.86	0.70	0.82	0.75
sucrose_fraction_stalk	Fraction of accumulated biomass partitioned to sucrose	g g-1	1.0··0.55 – 1.0··0.64	1.0··0.55	1.0··0.52	1.0··0.59
min_sstem_sucrose	Minimum stem biomass before partitioning to sucrose commences	g m-2	800 - 1500	800	1000	1500
green_leaf_no	Green leaf number	leaves	10 - 13	13	10	10

Crop varieties used in DSSAT

Default cultivar coefficients were modified based on published studies and their corresponding values in the standard release of APSIM. Those for cotton were based on the works of Cammarano et al. (2012), Pathak et al. (2007), and Ortiz et al. (2009); whereas for sugarcane, values of cultivar coefficients were modified based on Jones and Singels (2008) and dos Santos Vianna and Sentelhas (2016). The parameters modified used are reported in Table 3-5.

Table 3-5 Genotype coefficients used for cotton and sugarcane growth simulation in DSSAT. The description of the coefficients is provided in Annexe 1.

Cotton		Sugarcane	
Parameter	Cultivar1	Parameter	Cultivar1
CSDL	23	MaxPARCE	9.9
PPSEN	0.01	APFMX	0.88
EM-FL	48.46	STKPFMAX	0.65
FL-SH	10	SUCA	0.58
FL-SD	12	TBFT	25
SD-PM	34.28	Tthalfo	250
FL-LF	85.16	TBase	16
LFMAX	1.4	LFMAX	12
SLAVR	175	MXLFAREA	360
SIZLF	200	MXLFARNO	15
XFRT	1	PI1	69
WTPSD	0.19	PI2	169
SFDUR	5.5	PSWITCH	18
SDPDV	30	TTPLNTEM	428
PODUR	14.7	TTRATNEM	203
THRSH	70	CHUPIBASE	1050
SDPRO	0.153	TT_POPGROWTH	600
SDLIP	0.12	MAX_POP	30
		POPTT16	13.3
		LG_AMBASE	220

Climate risk assessment

A 'climate and agricultural risk assessment and reporting tool' (prototype) was developed as part of the project. The tool can be accessed through http://icacs.usq.edu.au/risk/ , but is currently password protected. This 'tool' allows quantification of key climate risks, initially for sugar and cotton industry. The outputs from this tool are given in Climate assessment risk and reporting tool - Risk Quantification and data presentation

Example efficiency analysis of rainfall index on northern Queensland regional sugar cane yield

Here we present example analysis for sugar cane in northern Queensland as a proof of concept. We modelled sugar yield as a function of rainfall, temperature and radiation. We focus on rainfall, but acknowledge the potential for similar insurance instruments to be derived from temperature or other climatic variables that are important determinants of crop yield. In northern Queensland high rainfall is related to crop loss. Even though we focus on high rainfall the approach outlined is applicable to other climatic drivers of crop loss (e.g. drought, heat waves, frost, etc.).We compare our modelled results with on ground survey results for verification.

Methods

Regression model of sugar cane yields relationship with climatic factors

Sugar cane yields were modelled as a function of rainfall, radiation and temperature. Sugar cane yields were detrended total sugar cane yields (tonne/ha) for each year from 1972-2014 from the northern Queensland sugar producing regions in Queensland (data from the Australian Bureau of Statistics 2016). Climate data was from stations which were distributed across the regions (BOM 2017). Models were fit using a generalized additive model, which fits non-linear models using a spline and a Markov chain Monte Carlo (MCMC) algorithm implemented in JAGS 4.2.0 called via the R package rjags 3.10 (Plummer 2003, 2016), R2jags (Su and Yajima 2015) and the Mgcv package (Wood 2016) in R (R Core Team 2016). We ran 3 chains of 1,000,000 iterations, retaining every 10th sample (Gelman et al. 2004) and with a burnin of 50,000. An uninformative prior was used on all parameter priors, so the posterior distribution (i.e. parameter estimates and predictions) were completely informed by the data. We checked values of the Brooks-Gelman-Rubin diagnostic, which indicated chain convergence was achieved. An effective sample size of 10,000 was also achieved for each parameter estimate (after Kruschke 2015).

The regression model for the response variable (de-trended sugar cane yield) d*yield* at time *i* with a smooth effect (*f*) for rainfall, max temperature and radiation.

$dyield_i \sim N(\mu_i, \sigma);$

$dyield_i = \alpha + f(\text{rainfall}_i) + f(\text{max temperature}_i) + f(\text{radiation}_i) + \mathcal{E}_i$

$\mathcal{E}_i \sim N(0, \sigma^2)$

Efficiency analysis of rainfall index

Two methods adapted from Adeyinka et al. (2015) and Vedenov and Barnett 2004 were used to carry out efficiency analysis. The first, following Adeyinka et al. (2015) uses rainfall percentile values and estimates crop losses that are proportional to changes in rainfall percentiles. The second, following Vedenov and Barnett (2004) estimates crop losses based on regression modelling. Using this method strikes and premiums are derived from a probability distribution (as a pure premium of rainfall values and how these relate to difference predicted yields from the regression model.

Calculating premiums from regression model

Max liability was the max revenue loss predicted from regression model (i.e. the revenue anomaly predicted at the maximum rainfall value recorded). The premium is calculated as a pure premium (after Chen 2011) where the annual indemnity of the rainfall index predicted sugar cane yield from our probability distribution is multiplied by its occurrence probability.

$$P(x) = E[Loss] = \frac{1}{n}\sum_{i=1}^{n} IND_i$$

Here, P(X) denotes the insurance contract pure premium, n is the number of rainfall values in our probability distribution,1/n denotes the probability of each rainfall values level and its corresponding indemnity from the rainfall probability distribution, IND represents the indemnity amount (adapted from Vedenov and Barnett 2004 & Chen 2011).

Measures of assessing risk

We assessed risk in four ways, briefly outlined below. The details of these risk efficiency measures are provided in appendix 1.

- Conditional tail expectation (CTE). CTE measures the hedging efficiency of insurance at different strike levels (Adeyinka et al. 2015).

- Certainty equivalence revenue (CER). CER accounts for peoples tendency to be risk averse and is measure of willingness to pay (Vedenov and Barnett 2004; Adeyinka et al. 2015).

- Root mean square loss (RMSL). The RMSL shows the extent to which a contract reduces downside risk below the mean is minimised (Vedenov and Barnett 2004).

- Value at risk (VaR). VaR emphasizes the maximum reduction in revenue that will not be exceeded at a certain probability (Vedenov and Barnett 2004).

The results of this efficiency analysis will be submitted as a separate report.

4. Survey results

Results are separately presented for each sector/cropping system (cotton, sugar cane). Risk, severity, loss and adaptive response data are summarised by (1) all surveys for that system, (2) region and (3) by industry sector accreditation; accredited farms being those that used any accredited or self-assessed best management practices (BMPs). Results are presented as average values, with error bars that are plus or minus one standard error plotted on the average values, for groups. Error bars that overlap indicate that any apparent difference between groups is likely to be due to random variation (i.e. non-significant); where errors bars are not overlapping, this suggests that there is a greater probability that there are significant (non-random) differences between the groups, but only at a low level of confidence (ca.67% confidence level). As such, these results should be interpreted as indicative. Where no error bar is shown, there was only one sample and so uncertainty (standard error) could not be calculated.

Cotton growers

General Information

The size of cotton farms surveyed ranged from 200 to 10,000 ha, with an average area of around 1500 ha (Figure 4-1). The average area of cotton planted was around 550 ha, while on average around 80% (range: 20-100%) of the area of farms surveyed were irrigated (Figure 4-1).

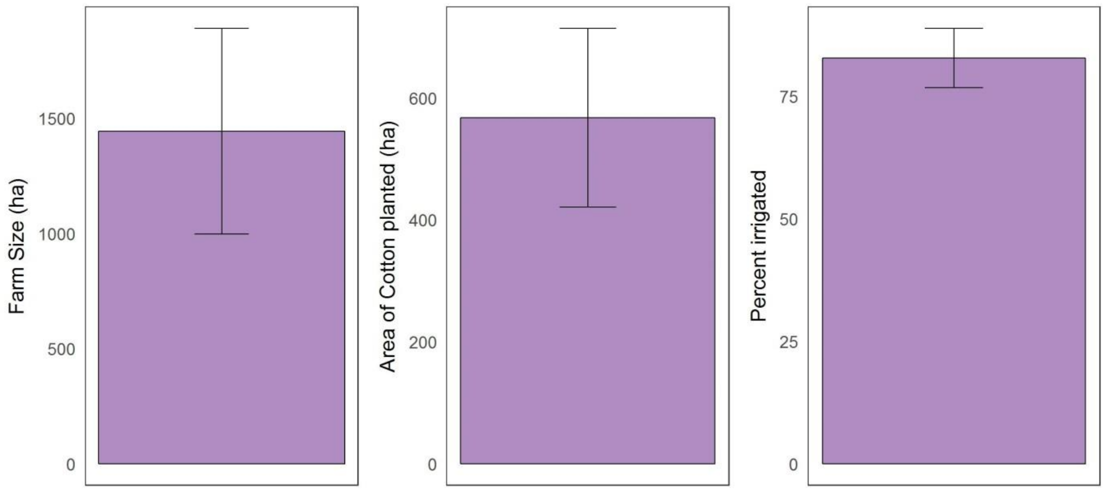


Figure 4-1. Summary of general information across all surveyed cotton farms. Values are average scores; error bars are ±1 one standard error.

There was little notable difference across the regions for farm size, the area of cotton planted, or the proportion of crop irrigated (Figure 4-2). Similarly, there was little apparent difference between accredited (n = 13, overall) and non-accredited farms (n = 10) in terms of farm size or area of cotton planted; however, accredited farms appear to have somewhat higher levels of irrigation (91.9% ± 6.03%) than non-accredited farms (67.9% ± 11.13%) (Figure 4-2).

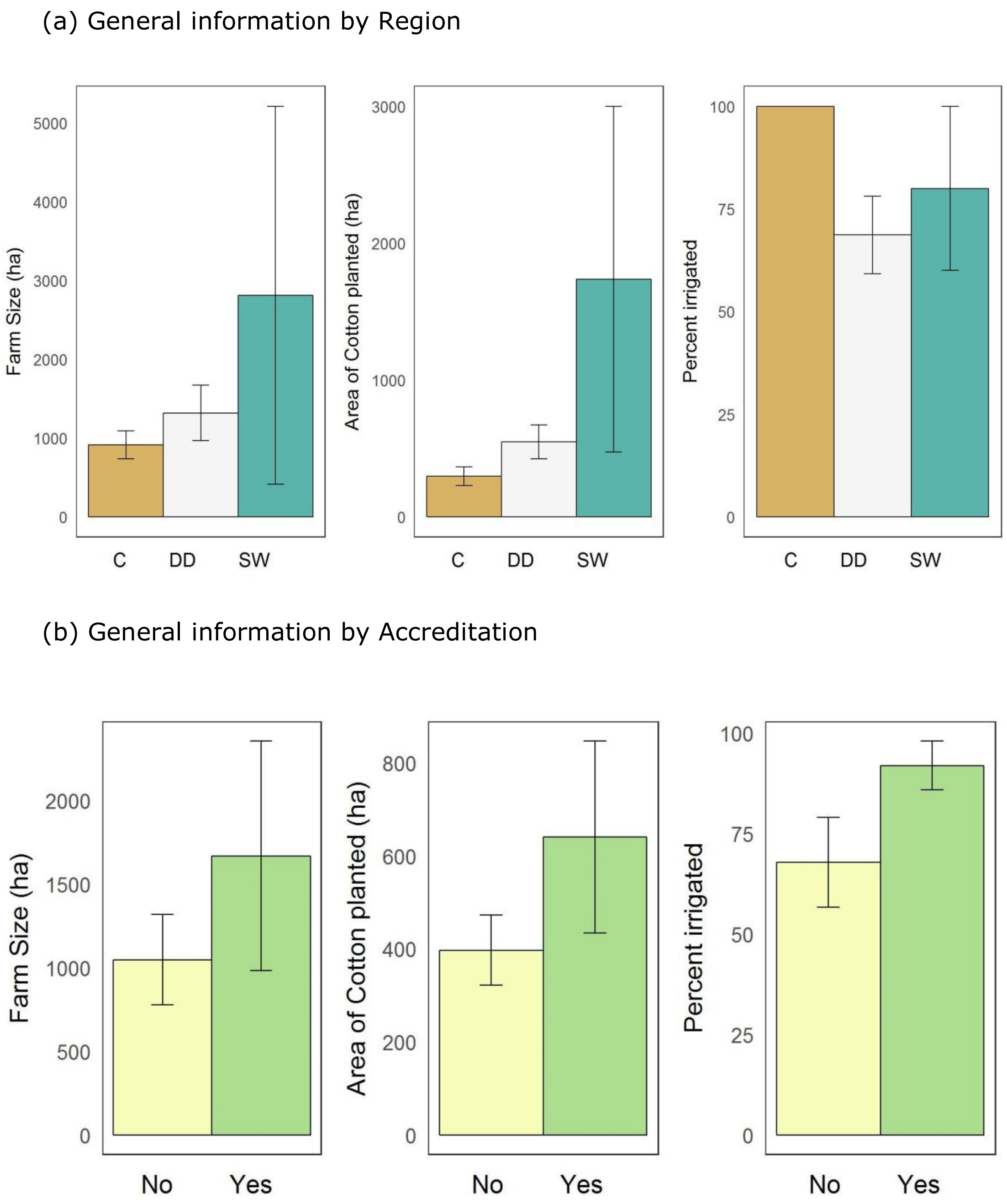


Figure 4-2 Averages for general information by (a) cotton growing region (C: Central Queensland; DD: Darling Downs; SW: south-west Queensland) and (b) accreditation (Yes: accredited; No: not accredited). Values are average scores; error bars are ±1 one standard error.

Crop yields

Cotton crop yields reported by survey participants show significant variation over time (Figure 4-3). Visual inspection of yields through time (along with the minimum and maximum values) suggests no major differences in crop yields between the Darling Downs and Central Queensland regions. Values for the South-west Queensland region are not plotted due to insufficient data. There also appears to be little difference in yields reported by accredited and non-accredited cotton growers (Figure 4-3).

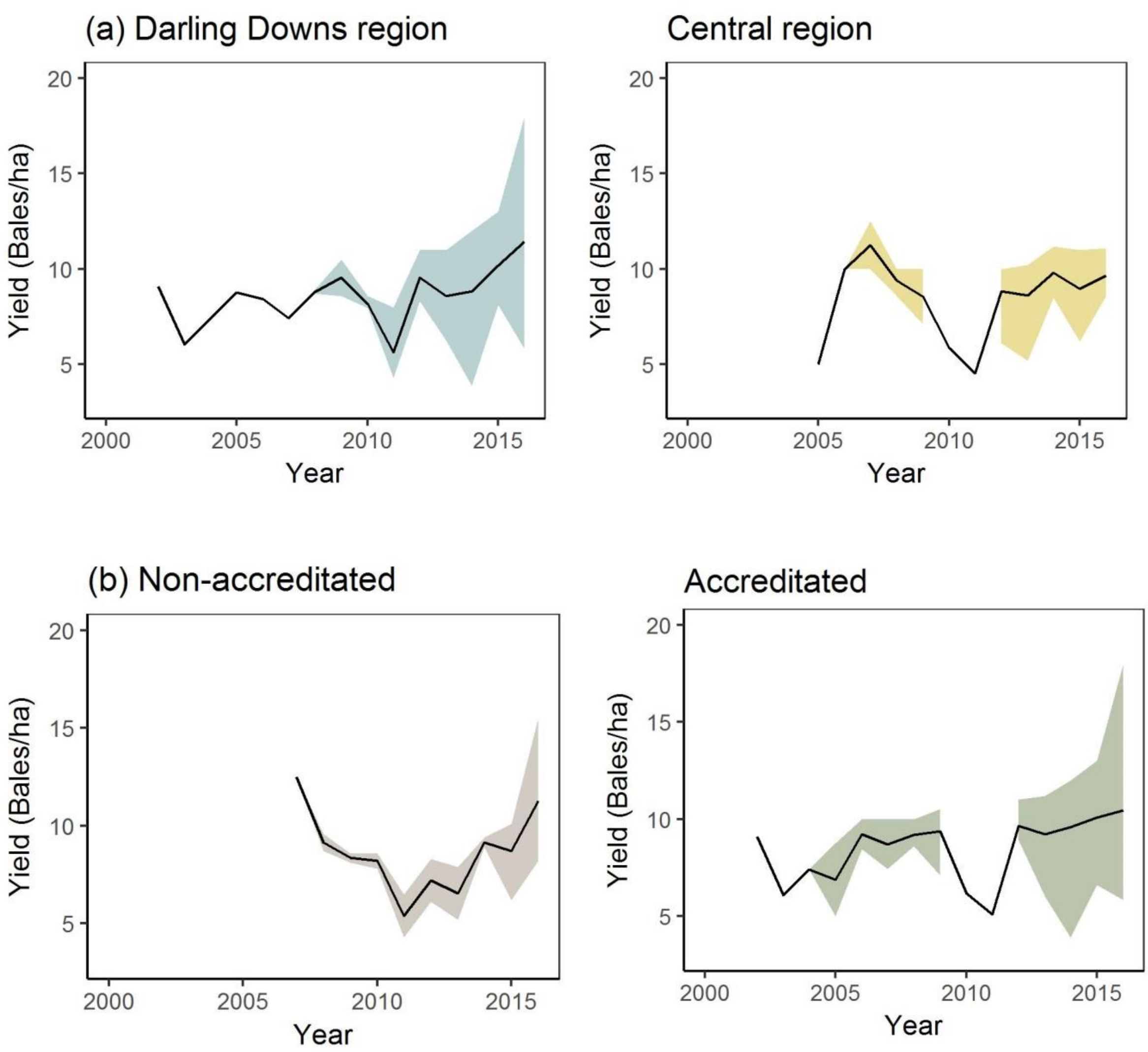


Figure 4-3 Survey participants' reported cotton yields by year for (a) the Darling Downs and Central Queensland region and (b) non-accredited and accredited cotton growers. Insufficient data is available for the south west Queensland region. Black line is average yield and the shaded coloured area represents the range (minimum–maximum) of reported yields for that year.

Risk

Perceived likelihood of risk

The risks with the greatest overall perceived likelihood of occurring were lack of rain during the season (mean score: 3.4; range: 2–5), lack of rain at planting (mean: 3.0; range: 1–5) and hail (mean: 2.9; range: 2–4) (Figure 4-4). Overall the risks perceived to be the least likely to occur were gin breakdown (mean: 1.1; range: 1–2), malicious damage (mean: 1.2; range 1–4) and fire (mean: 1.2; range: 1–3) (Figure 4-4).

- The perceived likelihood of risks was consistent across the regions (Figure 4-5).
- The perceived likelihood of risk was similar for most risks across accredited and non-accredited farms (Figure 4-6); however, the perceived likelihood of excess rain at planting, over-spray and frost were slightly higher for non-accredited farms compared to accredited farms (Figure 4-6).

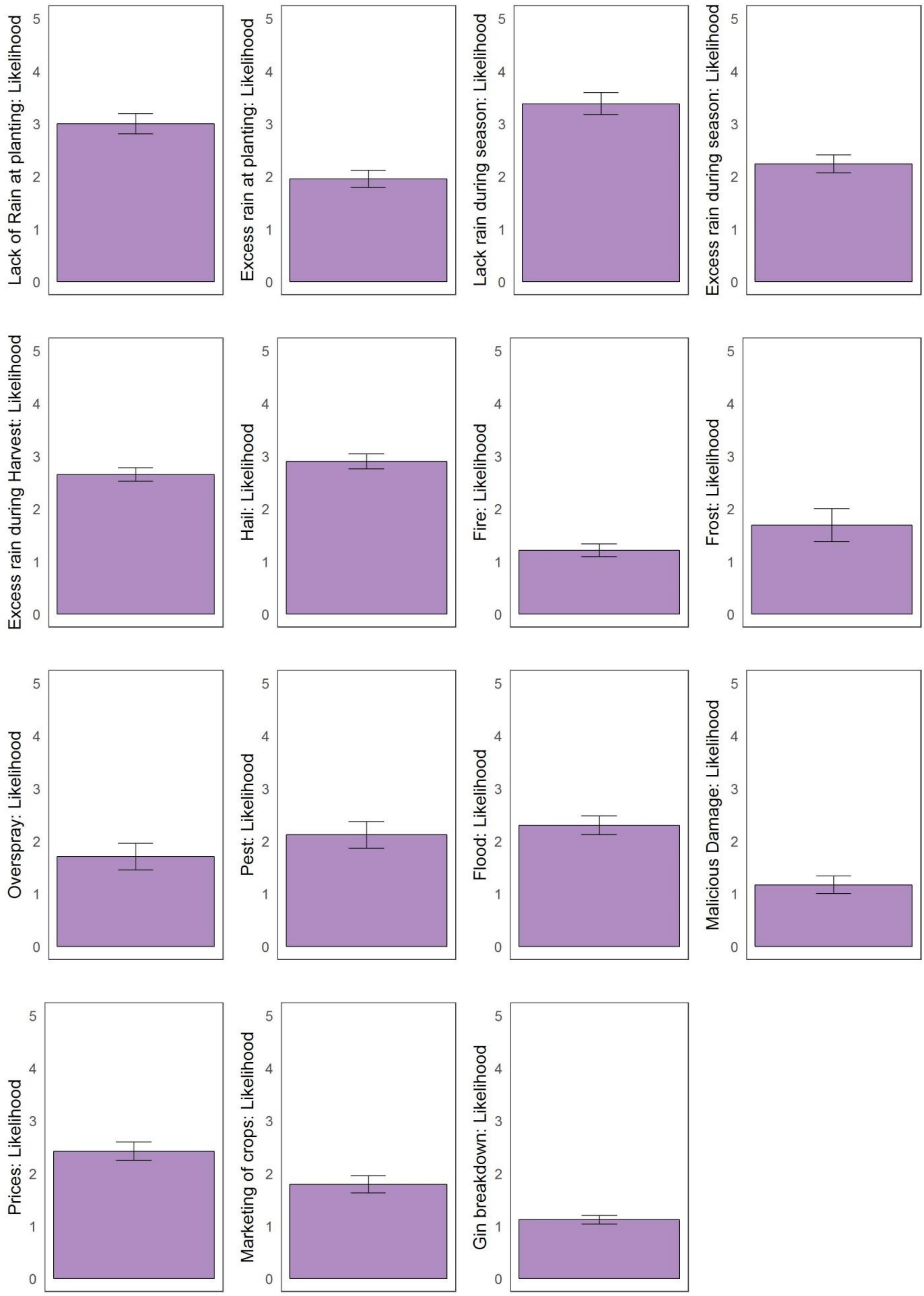


Figure 4-4 Overall perceived likelihood of risk amongst Queensland cotton farmers. Values are average scores; error bars are ±1 one standard error.

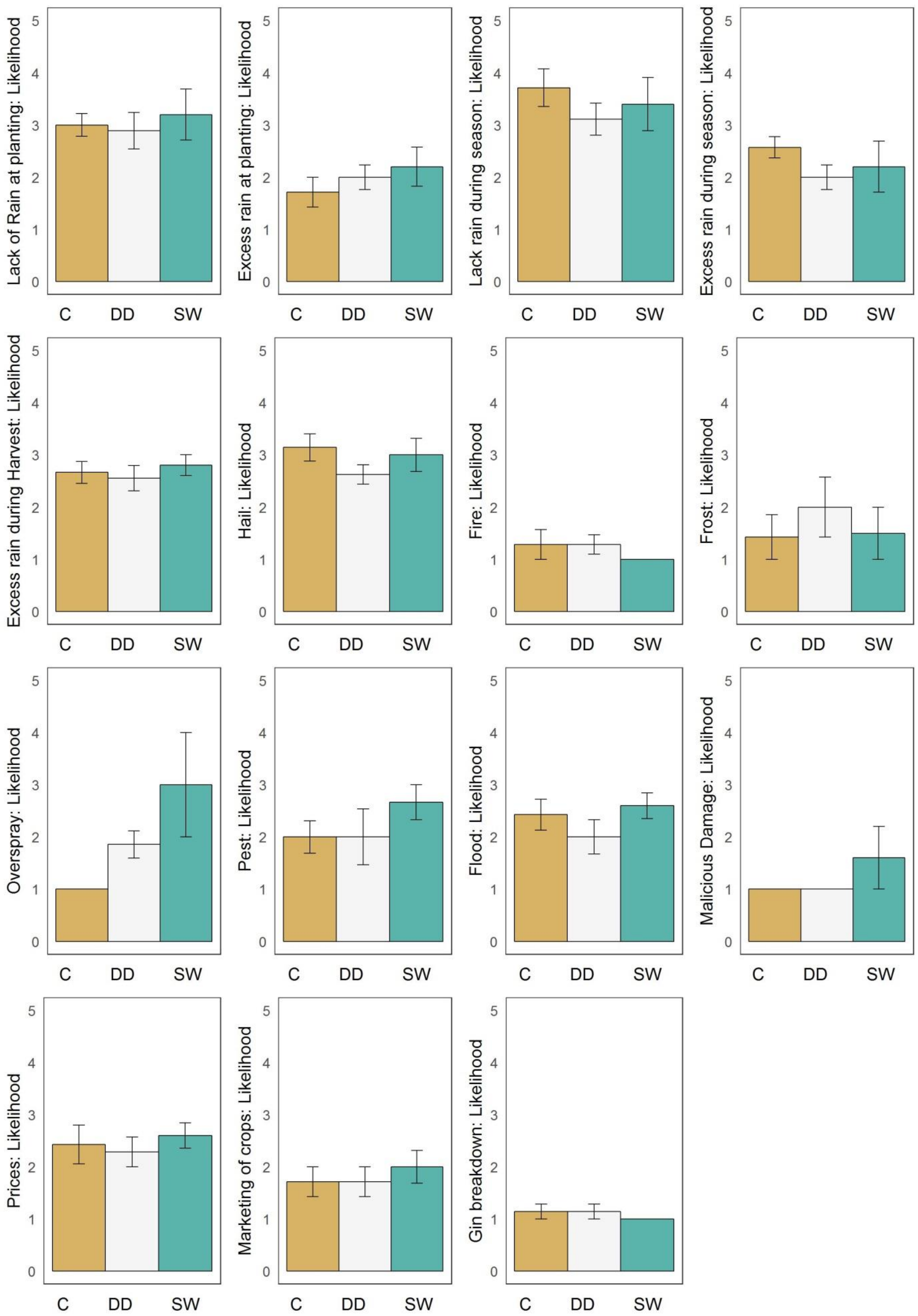


Figure 4-5 Perceived likelihood of risk across Queensland cotton regions. Values are average scores; error bars are ±1 one standard error. C=Central Queensland, DD=Darling Downs, SW=South West Queensland.

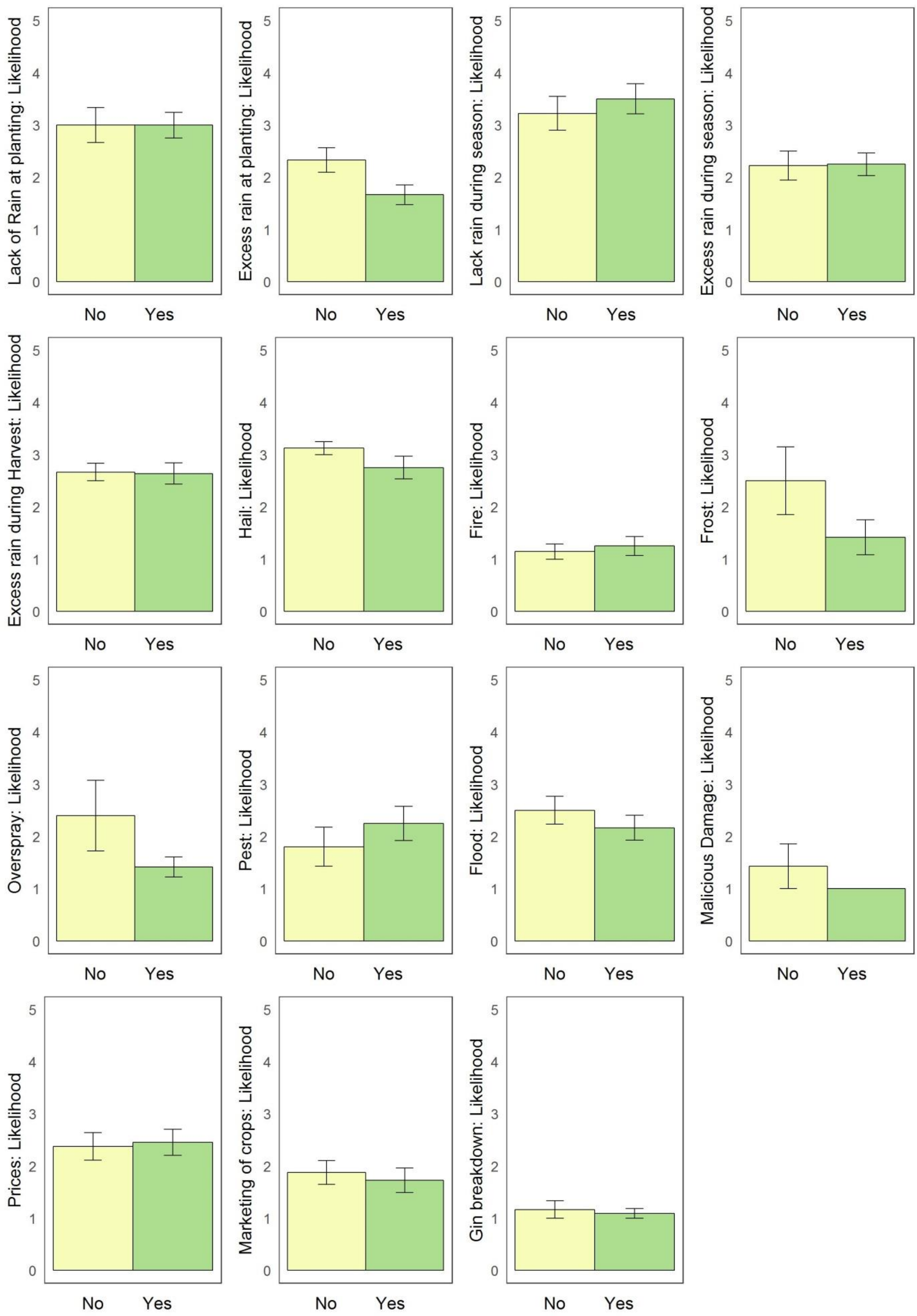


Figure 4-6 Perceived likelihood of risk by accredited (Yes) and non-accredited (No) cotton growers. Values are average scores; error bars are ±1 one standard error.

Perceived severity of risk

Overall the risks with greatest perceived severity were flood (mean score: 4.0; range: 1–5), excess rain during harvest (3.5; 2–5), lack of rain during season (3.2; 1–5), hail (3.2; 1–5) and excess of rain during season (3.0; 1–4) (Figure 4-7). The risks with the lowest overall perceived severity were gin breakdown (1.4; 1–3), frost (1.3; 1–2), malicious damage (1.2; 1–5) and fire (1.2; 1–2) (Figure 4-7).

- The perceived severity of most risks was similar across regions (Figure 4-7). Perceptions of the severity of excess of rain during the season were on average slightly greater amongst the Central region cotton growers (3.4 ± 0.74) than on the Darling Downs (2.6 ± 0.70) (Figure 4-8).
- The perceived severity of most risks was similar across accredited and non-accredited farms (Figure 10). Excess rain during the season was perceived to be a greater risk amongst accredited cotton growers (3.2 ± 0.80) than amongst those who were not accredited (2.6 ± 0.88) (Figure 4-9).

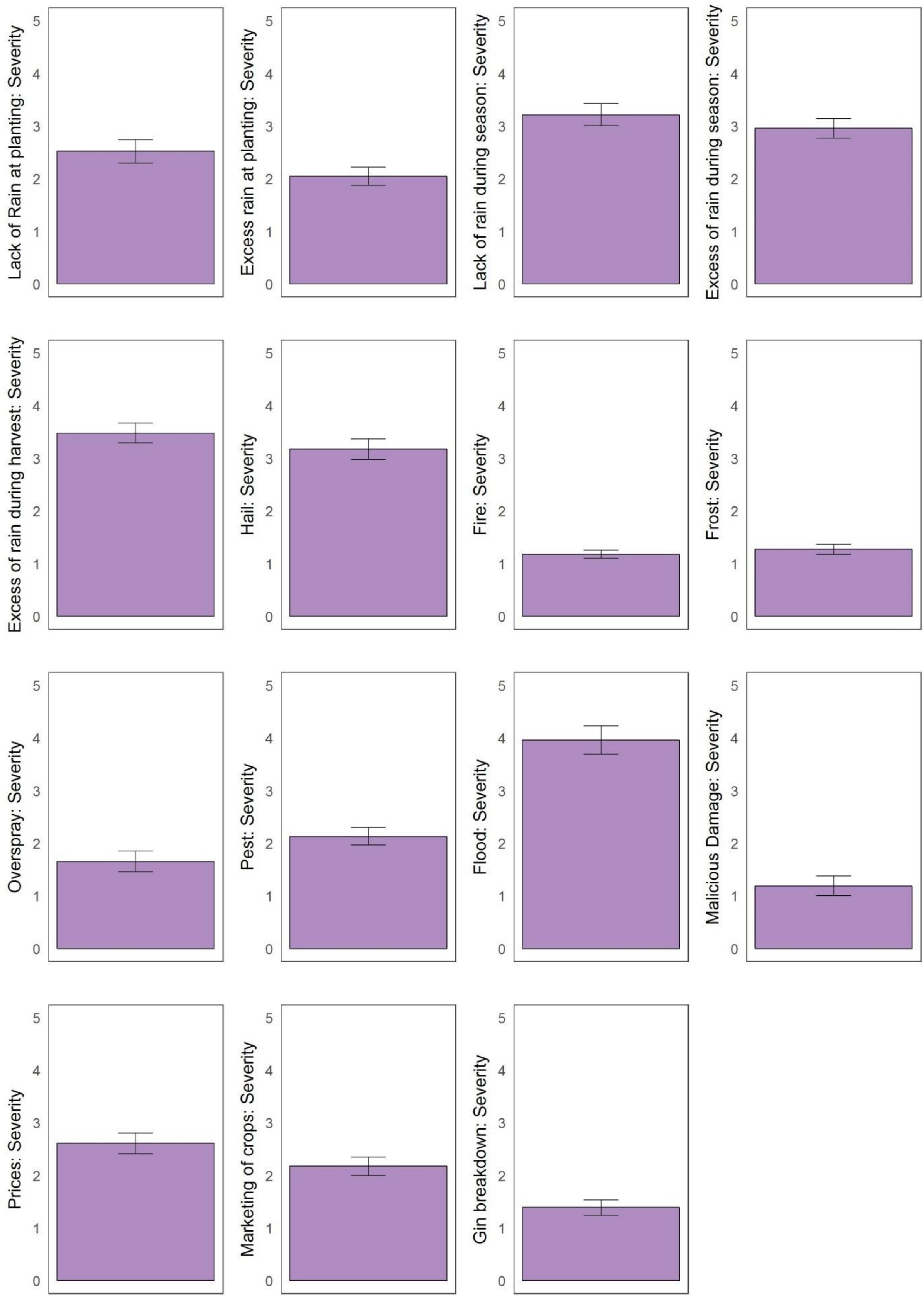


Figure 4-7 Overall perceived severity of risk amongst Queensland cotton farmers. Values are average scores; error bars are ±1 one standard error.

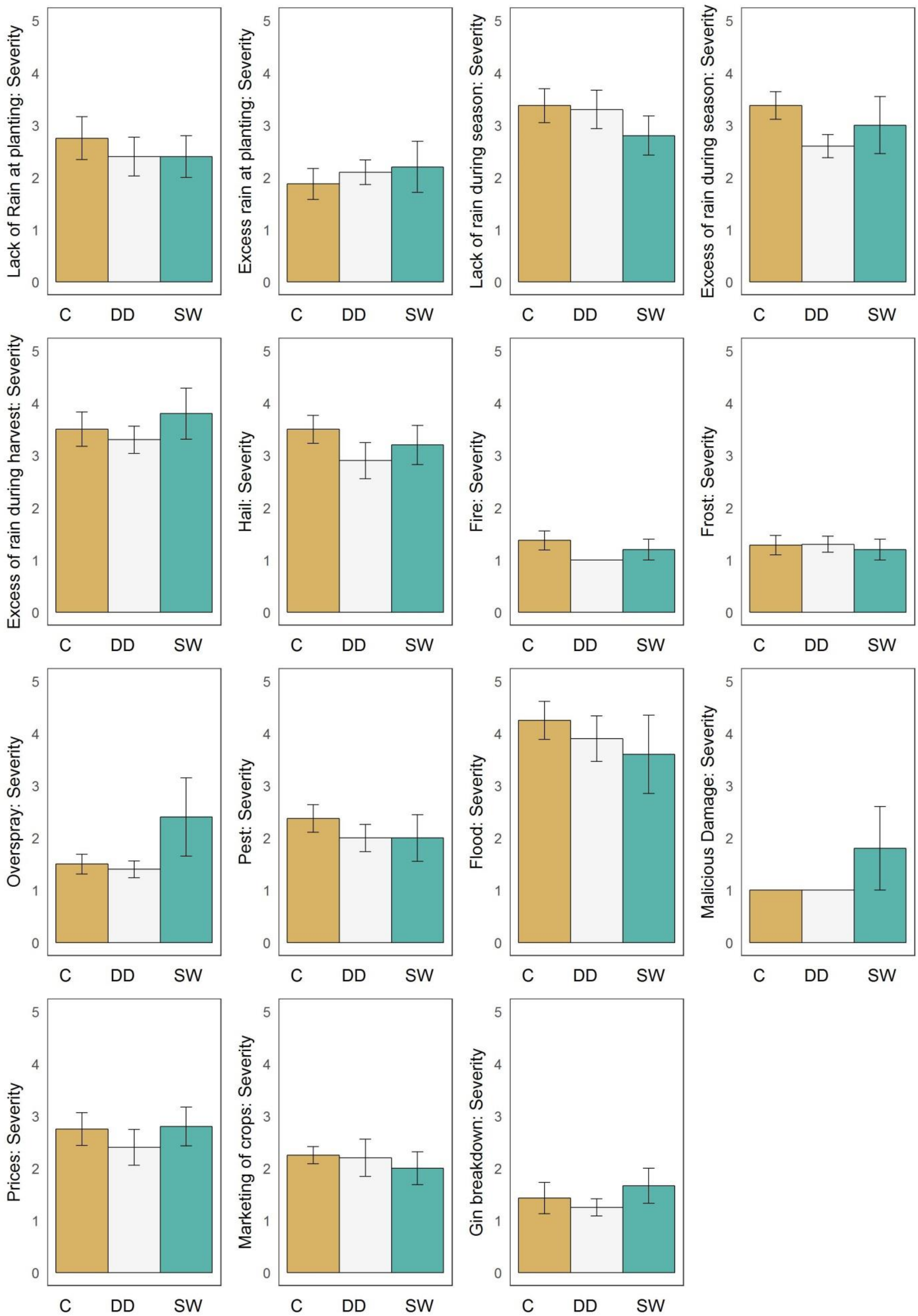


Figure 4-8 Perceived severity of risk across Queensland cotton regions. Values are average scores; error bars are ±1 one standard error. C=Central Queensland, DD=Darling Downs, SW=South West Queensland.

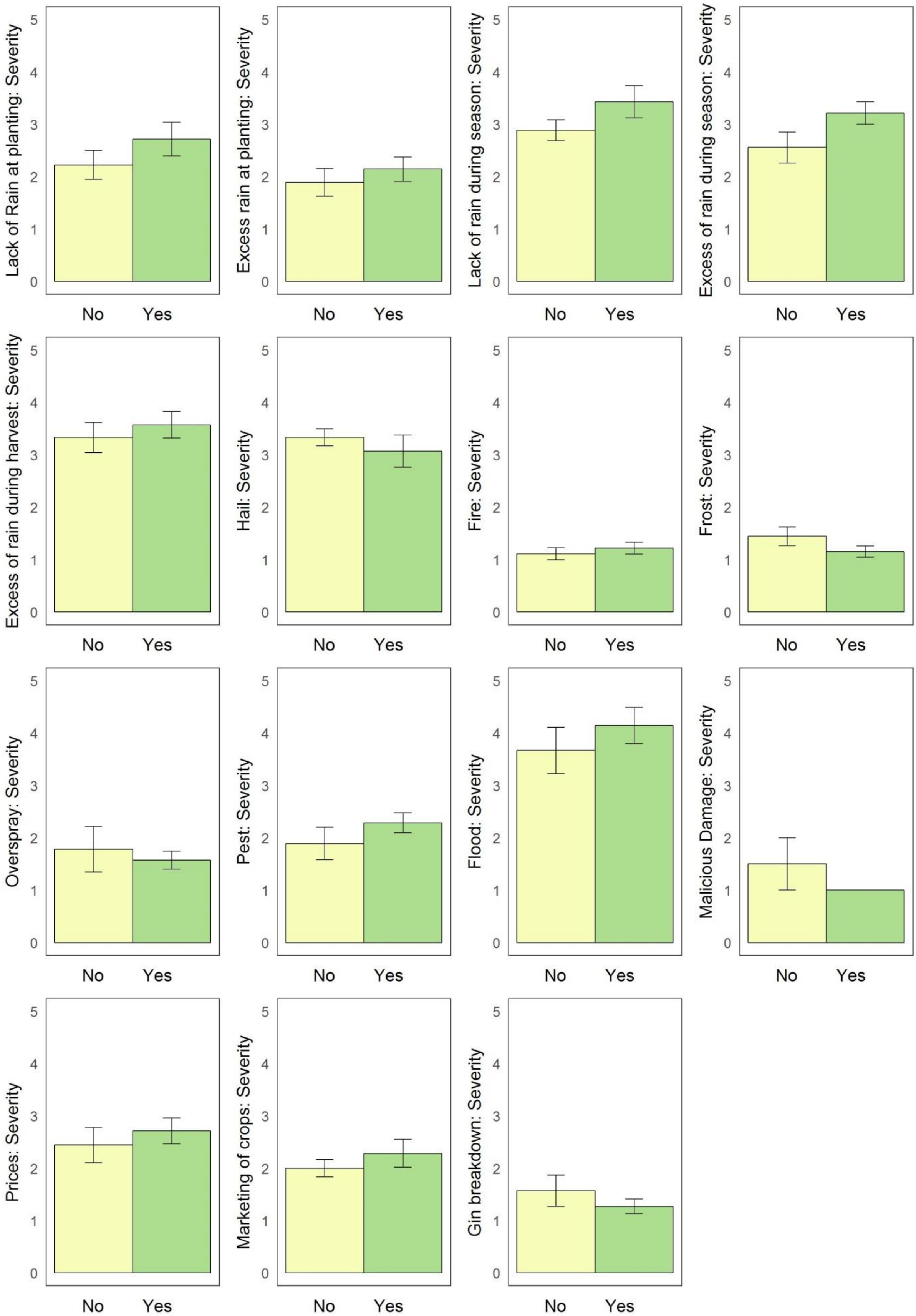


Figure 4-9 Perceived severity of risk by accredited (Yes) and non-accredited (No) cotton growers. Values are average scores; error bars are ±1 one standard error.

Estimated losses due to specific risks

Overall, the risk perceived to cause the greatest potential loss (with estimated impacts of 20% or more on farm productivity/profitability) was flooding, with a mean estimated loss of almost 50% (ranging from 10–90%). The next most costly event identified was hail, with estimated losses ranging from 5 to 80 %, followed by fire (0–80%) and lack of rain at planting and during the season (up to 65% and 70%, respectively) (Table 4-1).

Table 4-1 Estimates of losses by risk category amongst Queensland cotton growers.

Risk	*n*	Mean ± SE	Range
Lack of rain at planting	*7*	27.1 ± 7.39	5–65
Excess rain at planting	*4*	10.0 ± 2.04	5–15
Lack of rain during season	*13*	25.8 ± 5.37	10–70
Excess rain during season	*10*	19.5 ± 2.52	10–35
Excess rain during harvest	*11*	24.1 ± 2.85	10–40
Hail	*10*	30.0 ± 7.49	5–80
Fire	*3*	28.33 ± 25.87	0–80
Frost	*2*	5.0 ± 0.00	5–5
Overspray	*1*	5.0	-
Pest	*3*	5.0 ± 0.00	5–5
Flood	*16*	48.4 ± 6.20	10–90
Malicious Damage	*0*	-	-
Marketing of crops	*2*	10.0 ± 0.00	10–10
Price	*3*	18.3 ± 4.41	10–25
Gin breakdown	*1*	0.0	-

By region, the most costly events (with estimated impacts of 20% or more on farm productivity/profitability) were:

- in Central Queensland, flood, hail, excess rain during harvest and lack of rain at planting, with individual growers reporting impacts of up to 80 and 90% for hail and flood damage (Table 4-2);
- for Darling Downs cotton growers, flood, lack of rain during the season, lack of rain during planting, excess rain during harvest and lack of rain at planting; one grower reported losing 80% of annual revenue due to fire (Table 4-2); and
- in south-west Queensland, flood, excess rain during the season and during harvest, and hail (Table 4-2).

Table 4-2 Cotton growers' estimates of losses by risk category across Queensland cotton growing regions.

Risk	Central Queensland			Darling Downs			S-w Queensland		
	n	Mean ± SE	Range	*n*	Mean ± SE	Range	*n*	Mean ± SE	Range
Lack of rain at planting	*4*	21.3 ± 5.91	5–30	*3*	35.0 ± 16.07	10–65	*0*	-	-
Excess rain at planting	*1*	10.0	-	*3*	10.0 ± 2.89	5–15	*0*	-	-
Lack of rain during season	*6*	19.2 ± 3.27	10–30	*5*	42.5 ± 13.77	10–70	*3*	16.7 ± 6.67	10–30
Excess rain during season	*5*	20.0 ± 4.74	10–35	*2*	15.0 ± 5.0	10–20	*3*	21.7 ± 1.67	20–25
Excess rain during harvest	*5*	23.0 ± 5.15	10–40	*4*	27.5 ± 4.79	20-40	*2*	20.0 ± 0.00	20–20
Hail	*5*	43.0 ± 11.36	10–80	*2*	12.5 ± 7.50	5–20	*3*	20.0 ± 10.00	10–40
Fire	*1*	5.0	-	*2*	40.0 ± 40.00	0–80	*0*	-	-
Frost	*1*	5.0	-	*1*	5.0	-	*0*	-	-
Overspray	*0*	-	-	*1*	5.0	-	*0*	-	-
Pest	*1*	5.0	-	*2*	5.0 ± 0.00	5–5	*0*	-	-
Flood	*6*	47.5 ± 12.09	10–90	*7*	55.7 ± 8.34	20–80	*3*	33.3 ± 12.02	10–50
Malicious Damage	*0*	-	-	*0*	-	-	*0*	-	-
Marketing of crops	*0*	-	-	*2*	10.0 ± 0.00	10–10	*0*	-	-
Price	*1*	20.0	-	*2*	17.5 ± 7.50	10–25	*0*	-	-
Gin breakdown	*0*	-	-	*1*	0	-	*0*	-	-

Accredited growers were more likely to be able/willing to provide estimates of losses due to particular events. There was little apparent difference between these groups in terms of the estimates of impact on farm productivity and profitability (Table 4-3).

Table 4-3 Accredited and non-accredited cotton growers' estimates of losses by risk category.

Risk	Accredited			Not accredited		
	n	Mean ± SE	Range	*n*	Mean ± SE	Range
Lack of rain at planting	*7*	27.1 ± 7.39	5–65	*0*	-	-
Excess rain at planting	*4*	10.0 ± 2.04	5–15	*0*	-	-
Lack of rain during season	*10*	26.5 ± 6.83	10–70	*3*	23.3 ± 6.67	10-30
Excess rain during season	*7*	17.1 ± 2.64	10–25	*3*	25.0 ± 5.00	20–35
Excess rain during harvest	*7*	24.3 ± 3.52	10-40	*4*	23.8 ± 5.54	15–40
Hail	*7*	28.6 ± 6.43	5–50	*3*	33.3 ± 23.33	10-80
Fire	*3*	28.3 ± 25.87	0-80	*0*	-	-
Frost	*1*	5	-	*1*	5	-
Overspray	*1*	5	-	*0*	-	-
Pest	*3*	5 ± 0	5–5	*0*	-	-
Flood	*10*	47.5 ± 8.34	10–90	*6*	50 ± 9.92	10–75
Malicious Damage	*0*	-	-	*0*	-	-
Marketing of crops	*2*	10.0 ± 0	10–10	*0*	-	-
Price	*3*	18.3 ± 4.41	10–25	*0*	-	-
Gin breakdown	*1*	0	-	*0*	-	-

Risk management practices

The most frequently reported risk management practices adopted by Queensland cotton growers were reported (by >85% of survey participants) to be irrigation, soil testing and agronomic advice, specialised planting techniques and reduced tillage (Table 4-4). Insurance and adoption of BMPs were the least utilised risk management tools, with 61% and 57%, respectively, of growers reporting using these (Table 4-4).

Table 4-4 Proportion of Queensland cotton growers reporting use of risk management practices. (Practices are ranked according to the frequency reported.)

Risk	***n***	**% using**	**Rank**
Irrigation	*23*	100.0	1
Soil testing agronomic advice	*23*	100.0	1
Planting techniques	*23*	95.7	2
Reduced tillage	*23*	87.0	3
Soil moisture monitoring	*23*	82.6	4
Special varieties	*23*	82.6	4
Futures contracts	*23*	81.8	5
Weather forecasts	*21*	81.0	6
Laser levelling	*23*	78.3	7
Insurance	*23*	60.9	8
BMPs	*23*	56.5	9

Based on the survey responses, the greatest adoption of risk management practices appears to occur amongst Central Queensland cotton growers and least amongst those in southwest Queensland (Figure 4-10). However, insurance uptake in the Central Queensland region appears to be relatively low at 50% of growers, as is adoption of BMPs on the Darling Downs at 30% of growers surveyed (Figure 4-10).

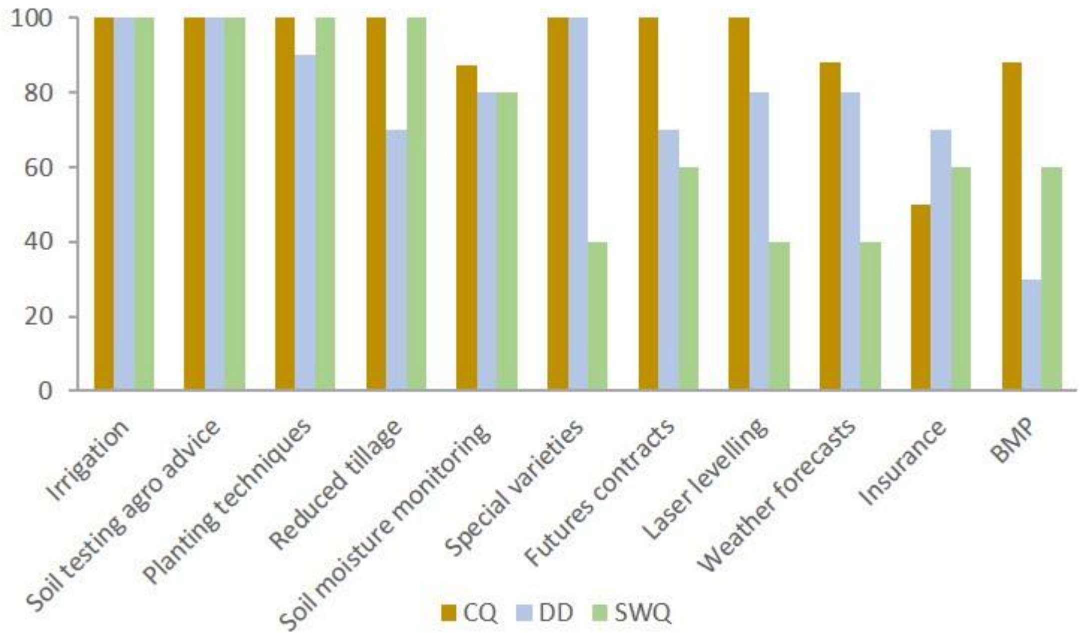


Figure 4-10 Percentage of Queensland cotton farms by regions using different risk management tools. CQ=Central Queensland (n=8), DD=Darling Downs (n=10), SWQ=S-w Queensland (n=5).

In general, a higher proportion of accredited farms reported using use risk management tools, although this did not appear to be the case for insurance products or weather information (Figure 4-11).

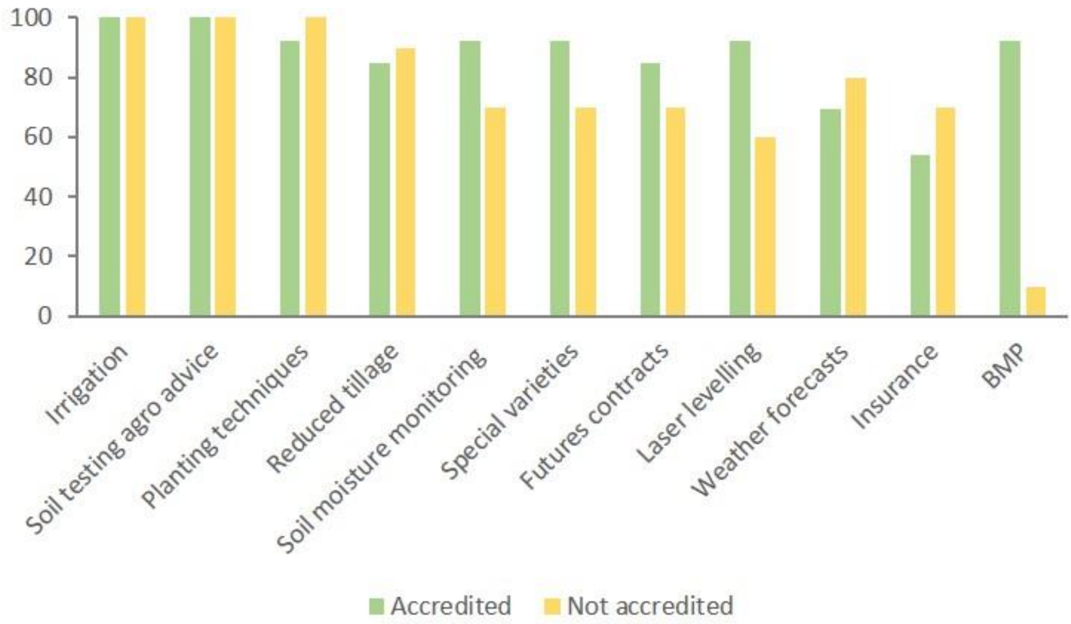


Figure 4-11 Proportion of Queensland cotton farms using different risk management tools by Accreditation. (Accredited: n = 13; Not accredited: n = 10).

Sugarcane growers

General Information

The size of sugar cane farms surveyed ranged from 34 to 800 ha, with an average area of around 220 hectares (Figure 4-12). The average area of cane planted was around 150 ha, while on average just over 55% (range: 0–100%) of the area of farms surveyed were irrigated (Figure 4-12).

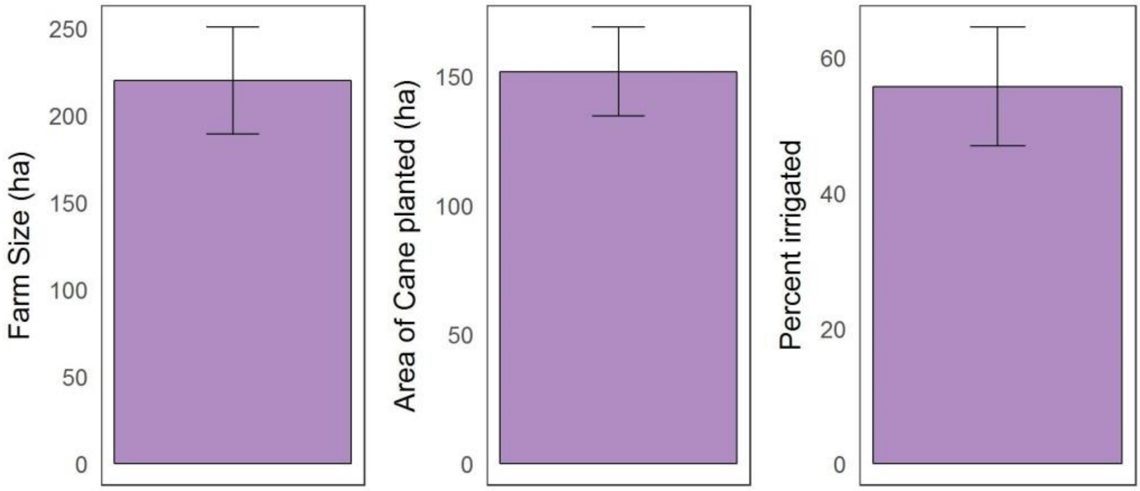


Figure 4-12 Summary of general information across all surveyed sugar cane farms. Values are average scores; error bars are ±1 one standard error.

There was little notable difference across the regions for farm size or the area of sugar cane planted (Figure 4-13). There was no irrigated sugar cane production reported in the northern sugar cane growing region, while just over 50% of farm areas in the central region were irrigated, and most (around 90%) farm areas were irrigated in the south (Figure 4-13). There was little apparent difference between accredited (n = 18, overall) and non-accredited farms (n = 14) in terms of farm size, area of sugar cane planted or percent of the crop irrigated (Figure 4-13), nor between irrigated (n = 18) and non-irrigated farms (n = 14) in terms of farm size or area of sugar cane planted (Figure 4-13).

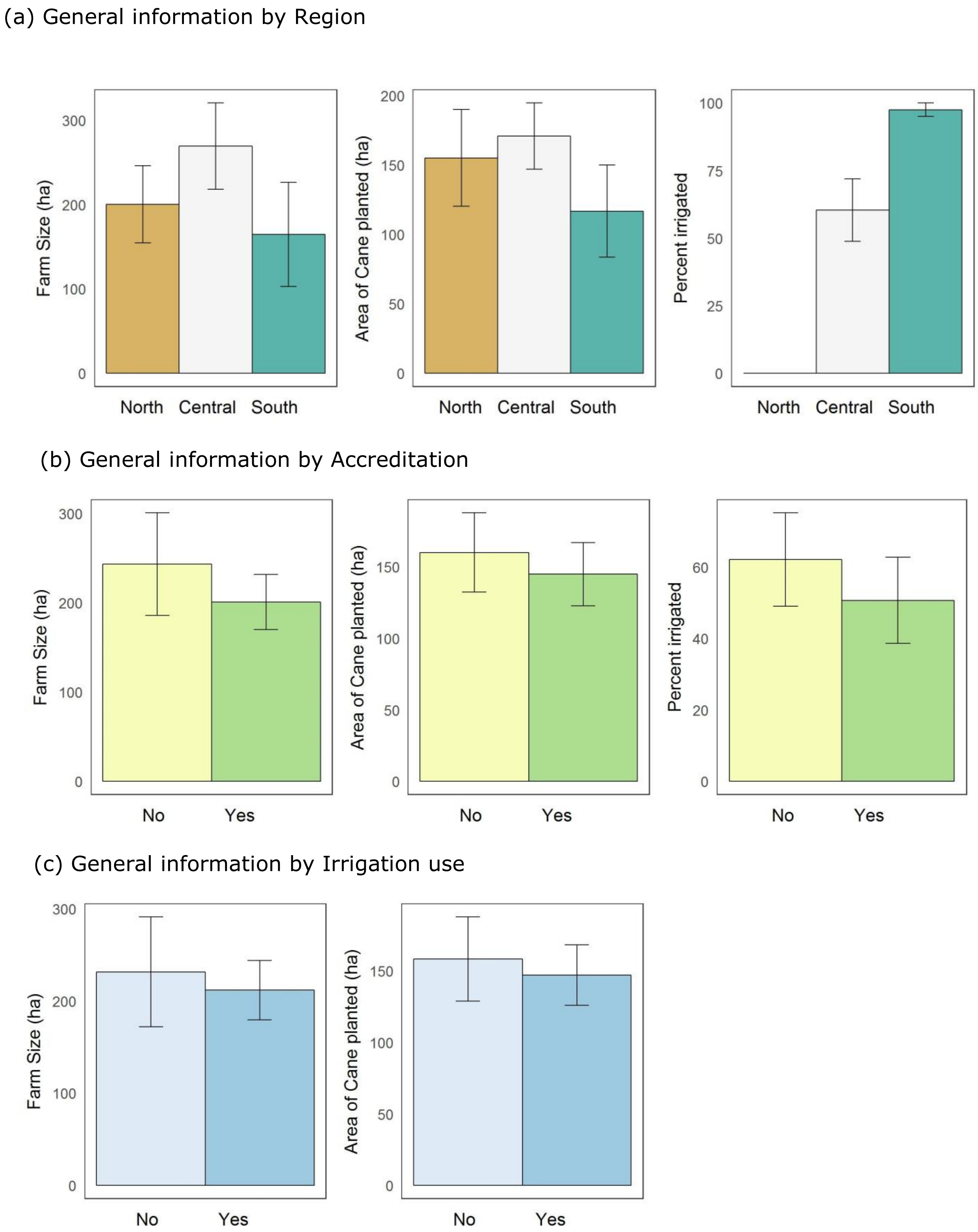


Figure 4-13 Summary of general information across surveyed sugar cane farms by (a) region (North, Central, South), (b) BMP accreditation (No: not accredited; Yes: accredited) and (c) irrigation use (No: not irrigated; Yes: irrigated). Values are average scores; error bars are ±1 one standard error.

Crop data - yields

Sugar cane crop yields reported by survey participants show significant variation over time (Figure 4-14). Yields for the Central sugar cane growing region were not plotted due to insufficient data (n = 1). Visual inspection of yields through time (along with the minimum and maximum values) suggests little difference in average crop yields between the southern and northern region, but far greater spread (i.e. variability) in reported yields across the southern region (Figure 4-14); this could in part be a result of different numbers of samples in each of these regions (North: n = 3; South: n = 7). Similarly, little difference in reported sugar cane yields was evident between irrigated (n = 8) and non-irrigated farms (n = 3) (Figure 4-14), or between accredited (n = 6) and non-accredited farms (n = 5) (Figure 4-14).

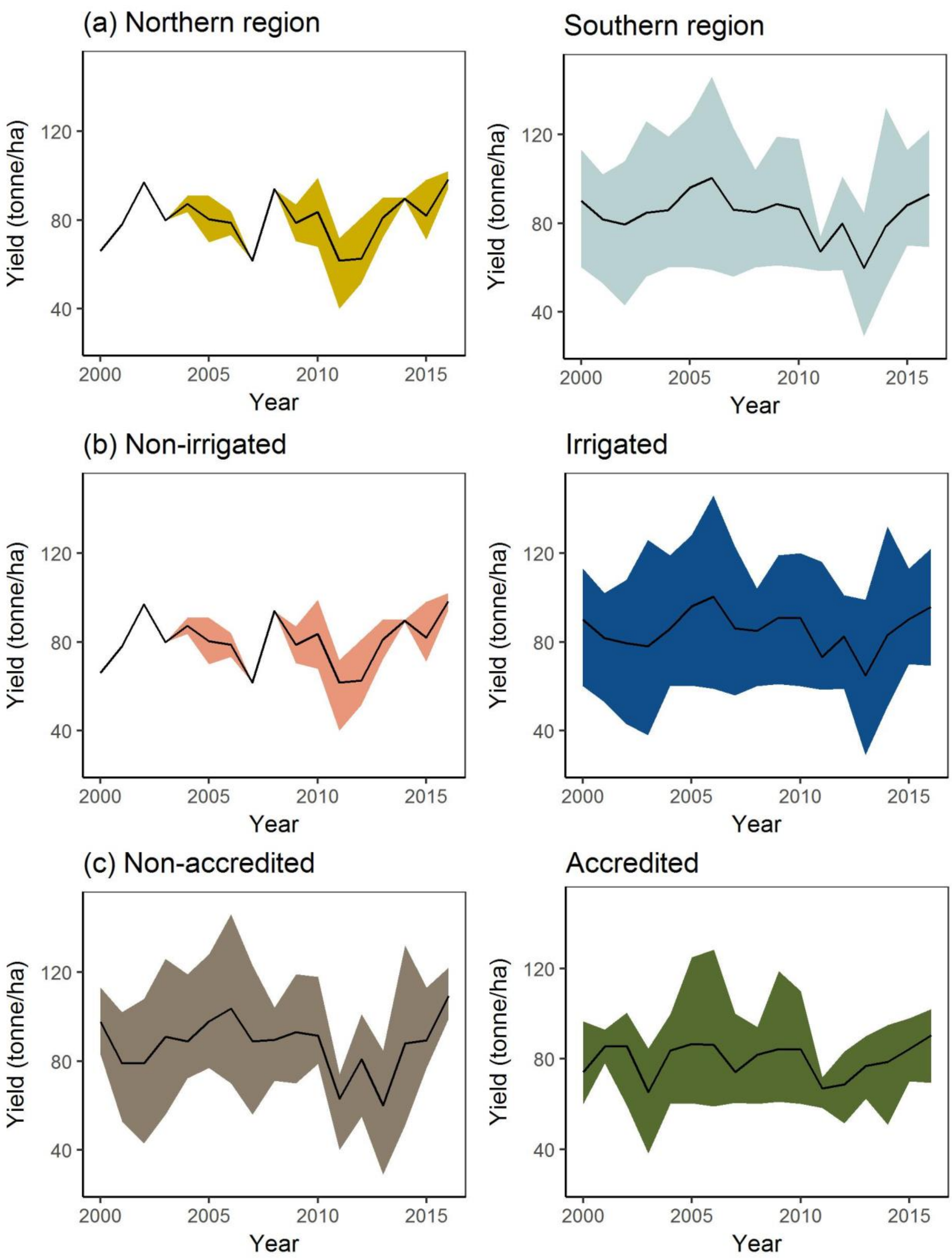


Figure 4-14 Survey participants' reported sugar cane yields by year for (a) Northern and Southern sugar cane cropping regions; (b) non-irrigated and irrigated; and (c) non-accredited and accredited. The black line is average yield and the coloured areas represent the range (i.e. minimum–maximum) in reported yields for that year.

Risk

Perceived likelihood of risk

The risks with the greatest overall perceived likelihood of occurring were excess rain during harvest (mean score: 3.5; range: 1–5); mill breakdown (3.5; 1–5); and prices (3.4; 1–5) (Figure 4-15). Overall the risks perceived to be the least likely to occur were overspray (1.3; 1–3); hail (1.4; 1–4); and frost (1.5; 1–4) (Figure 4-15).

- The perceived likelihood of most risks was consistent across the regions (Figure 4-16); although, compared to the other regions, in the north the perceived likelihood of a lack of rain during season was lower, while the perceived likelihood of cyclone and malicious damage was higher (Figure 4-16).
- The perceived likelihood of risk was also similar for most risks across accredited and non-accredited farms (Figure 4-17); however, the perceived likelihood of excess rain at planting and flood were slightly higher for accredited farms compared to non-accredited farms, while the perceived likelihood of risks associated with prices was greater for non-accredited compared to accredited farms (Figure 4-17).
- The perceived likelihood of risk was mostly consistent across irrigated and non-irrigated farms (Figure 4-18).

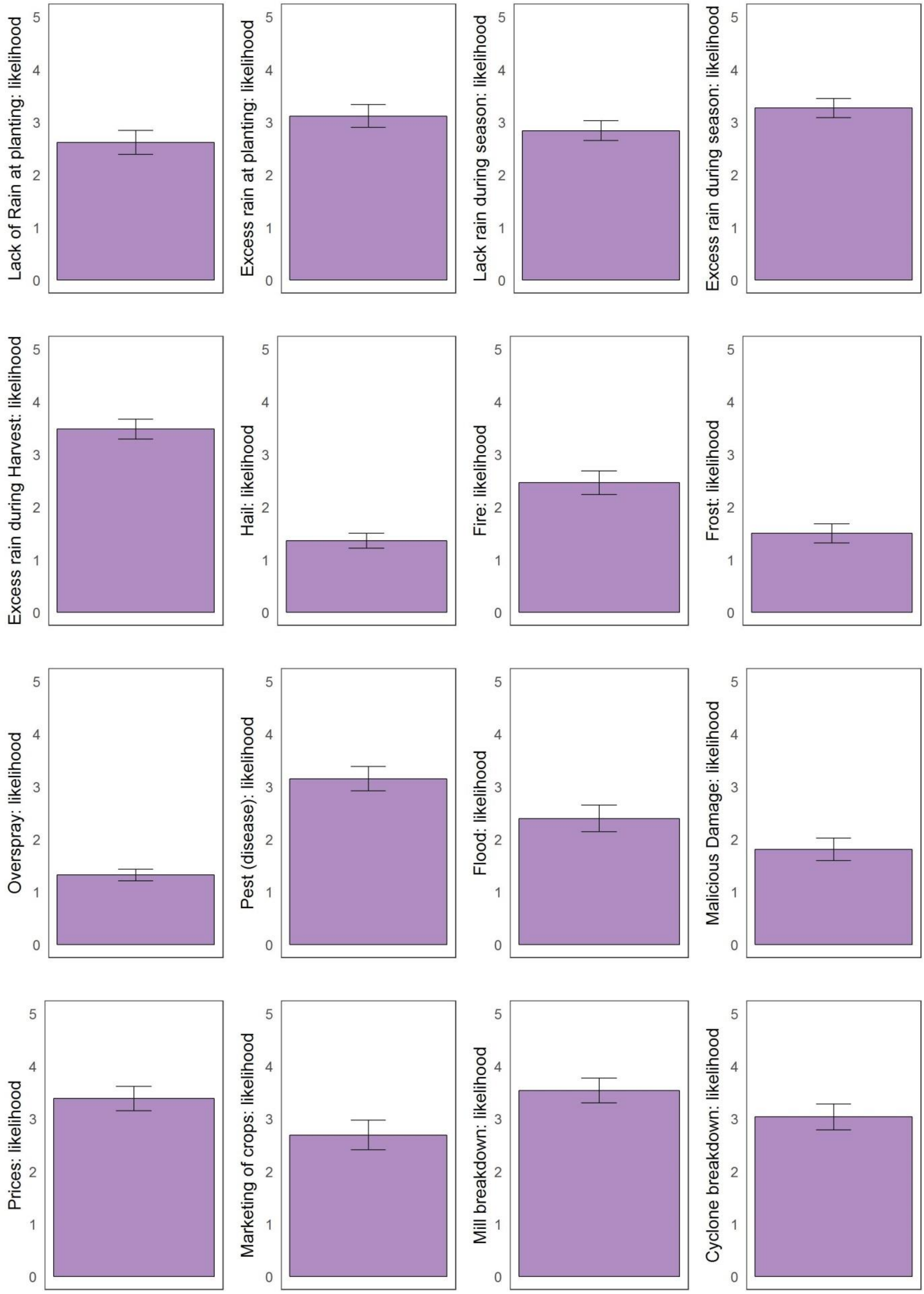


Figure 4-15 Overall perceived likelihood of risk amongst Queensland sugar cane farmers. Values are average scores; error bars are ±1 one standard error.

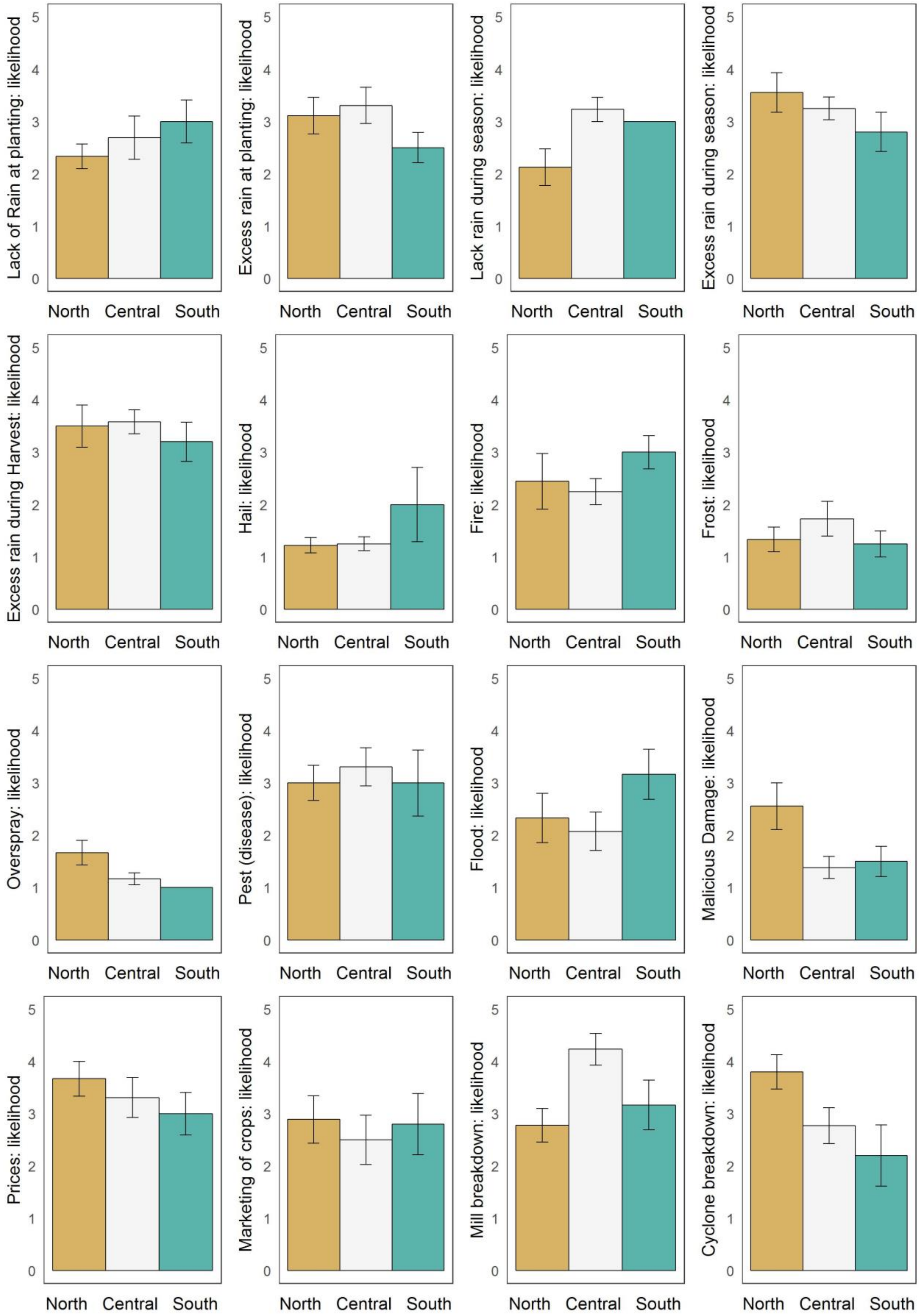


Figure 4-16 Perceived likelihood of risk across Queensland sugar cane cropping regions. Values are average scores; error bars are ±1 one standard error.

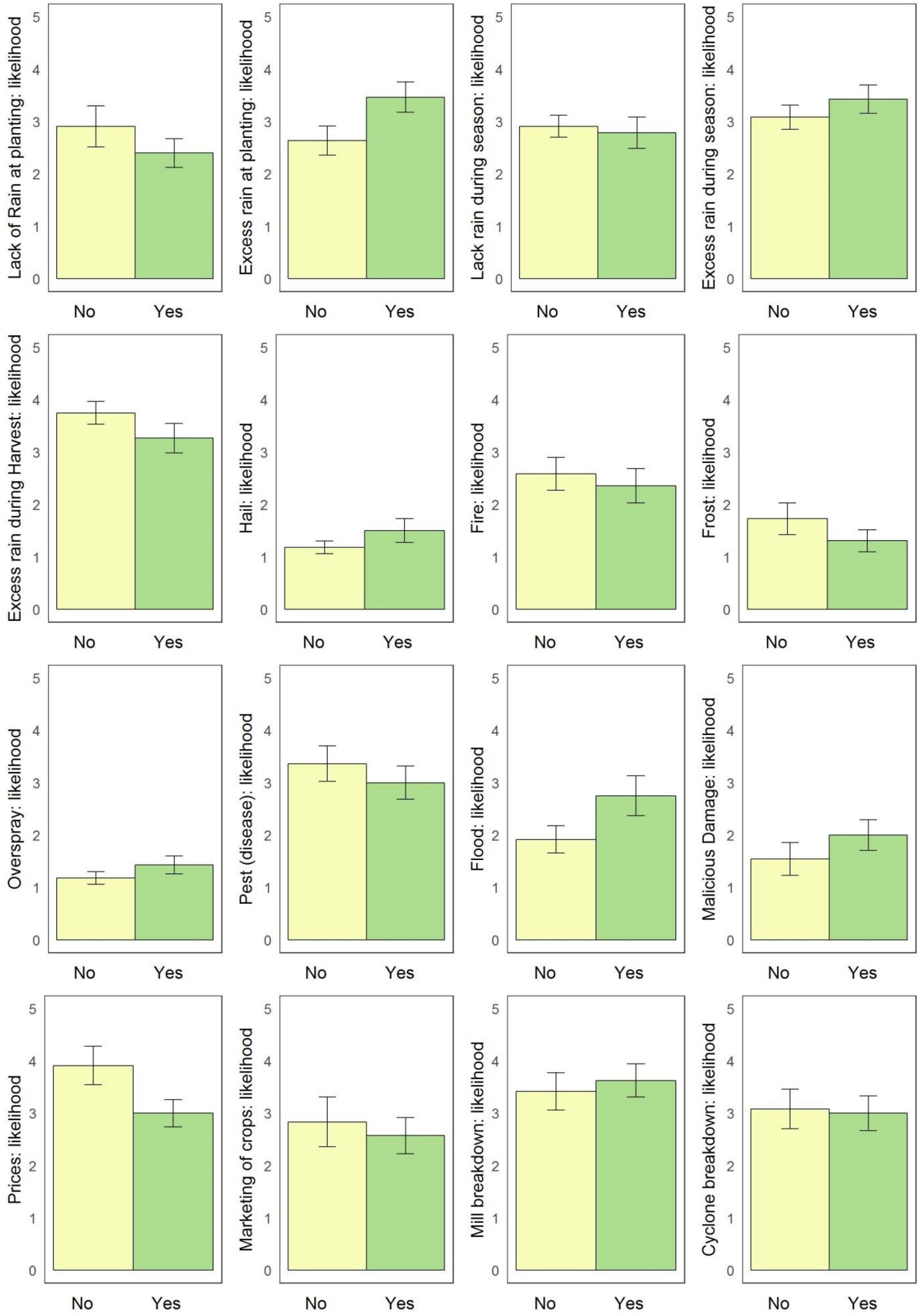


Figure 4-17 Perceived likelihood of risk by accreditation status (No: not accredited; Yes: accredited). Values are average scores; error bars are ±1 one standard error.

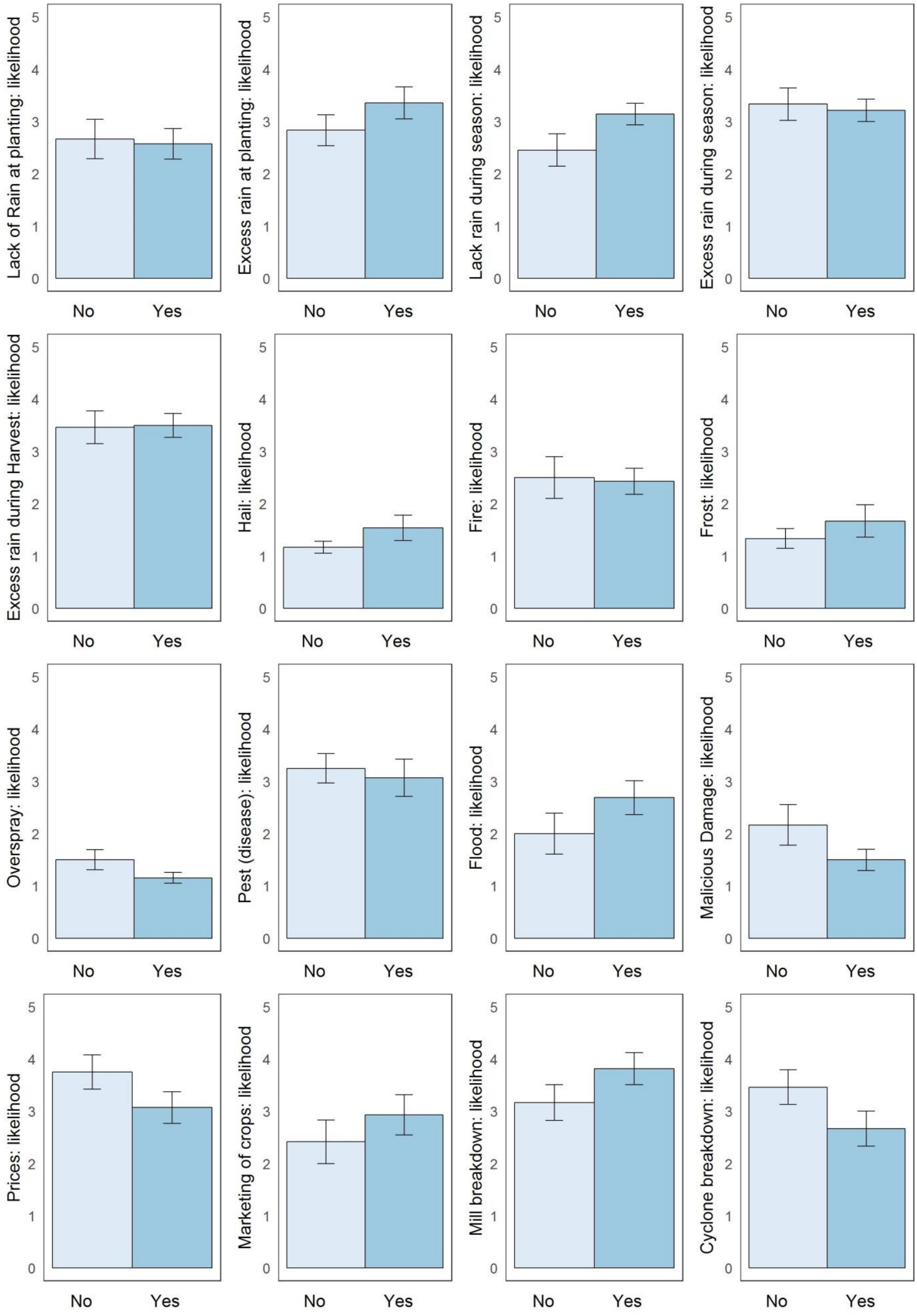


Figure 4-18 Perceived likelihood of risk by irrigation use (No: not irrigated; Yes: irrigated). Values are average scores; error bars are ±1 one standard error.

Perceived severity of risk

Overall the risks with greatest perceived severity were cyclone (mean score: 3.9; range: 1–5) and mill breakdown (3.8; 2–5) (Figure 4-19). The risks with the lowest overall perceived severity were overspray (1.6; 1–4) and hail (1.9; 1–5) (Figure 4-19).

- The perceived severity of most risks was similar across regions (Figure 4-20). However, in the north, the perceived severity of cyclone (4.6 ± 0.15) and malicious damage (3.1 ± 0.44) were higher and frost (1.3 ± 0.21) was lower than in other regions. Flooding was seen as a higher severity risk (4.6 ± 0.26) in the south than in other regions. Fire was seen as a lower severity risk (2.8 ± 0.28) in the central region than in other regions (Figure 4-20).
- The perceived severity of most risks was similar across both accredited and non-accredited farms (Figure 4-21).
- There was also little difference in the perceived severity of most risks across irrigated and non-irrigated farms; although the perceived severity of flood and frost were higher on irrigated compared to non-irrigated farms and lack of rain at planting and malicious damage was seen as a more severe risk in non-irrigated compared to irrigated farms (Figure 4-22).

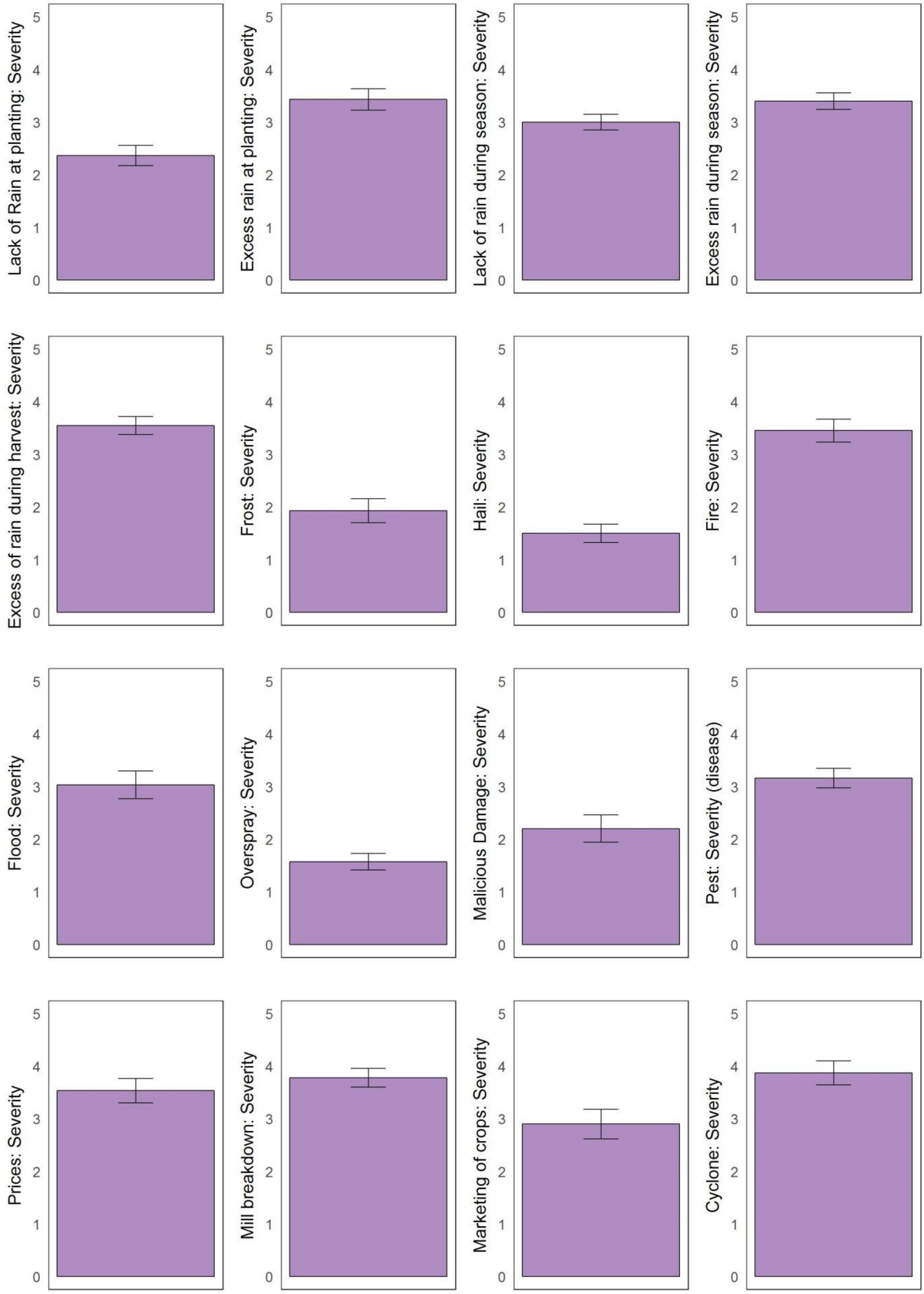


Figure 4-19 Overall perceived severity of risk on Queensland sugar cane farms. Values are average scores; error bars are ±1 one standard error.

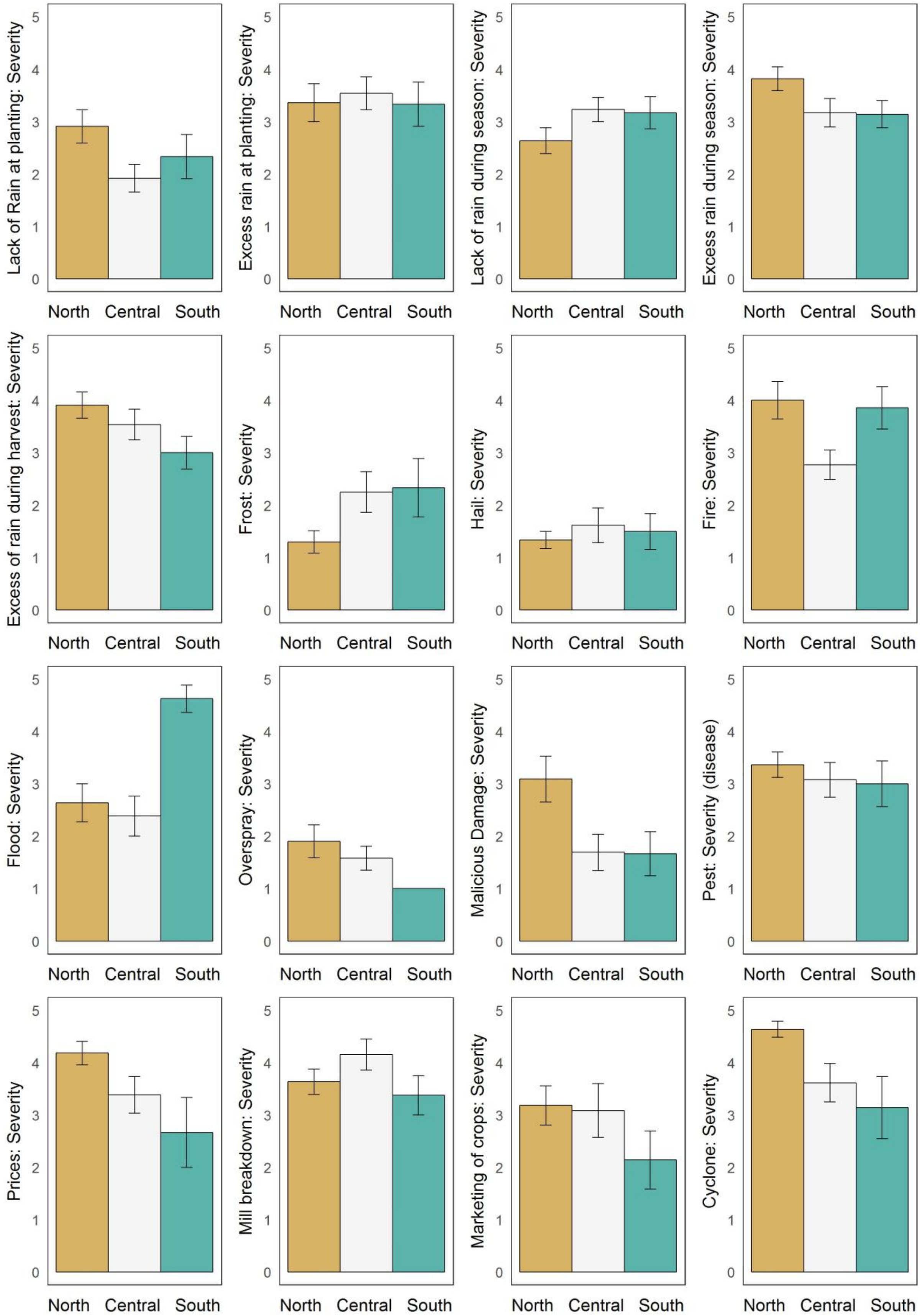


Figure 4-20 Perceived severity of risk by Queensland sugar cane farming region. Values are average scores; error bars are ±1 one standard error.

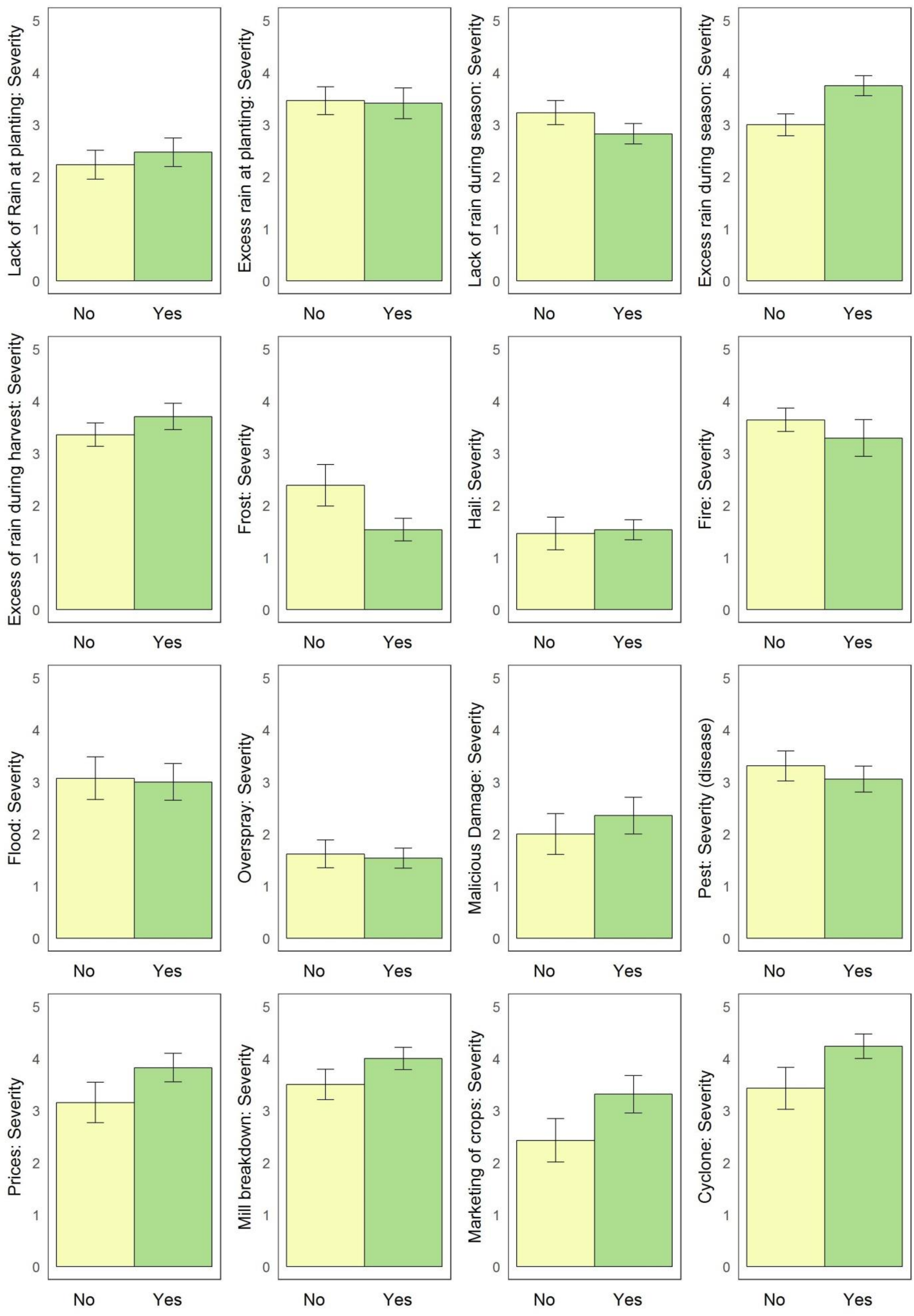


Figure 4-21 Perceived severity of risk by accreditation (No: not accredited; Yes: accredited) on Queensland sugar cane farms. Values are average scores; error bars are ±1 one standard error.

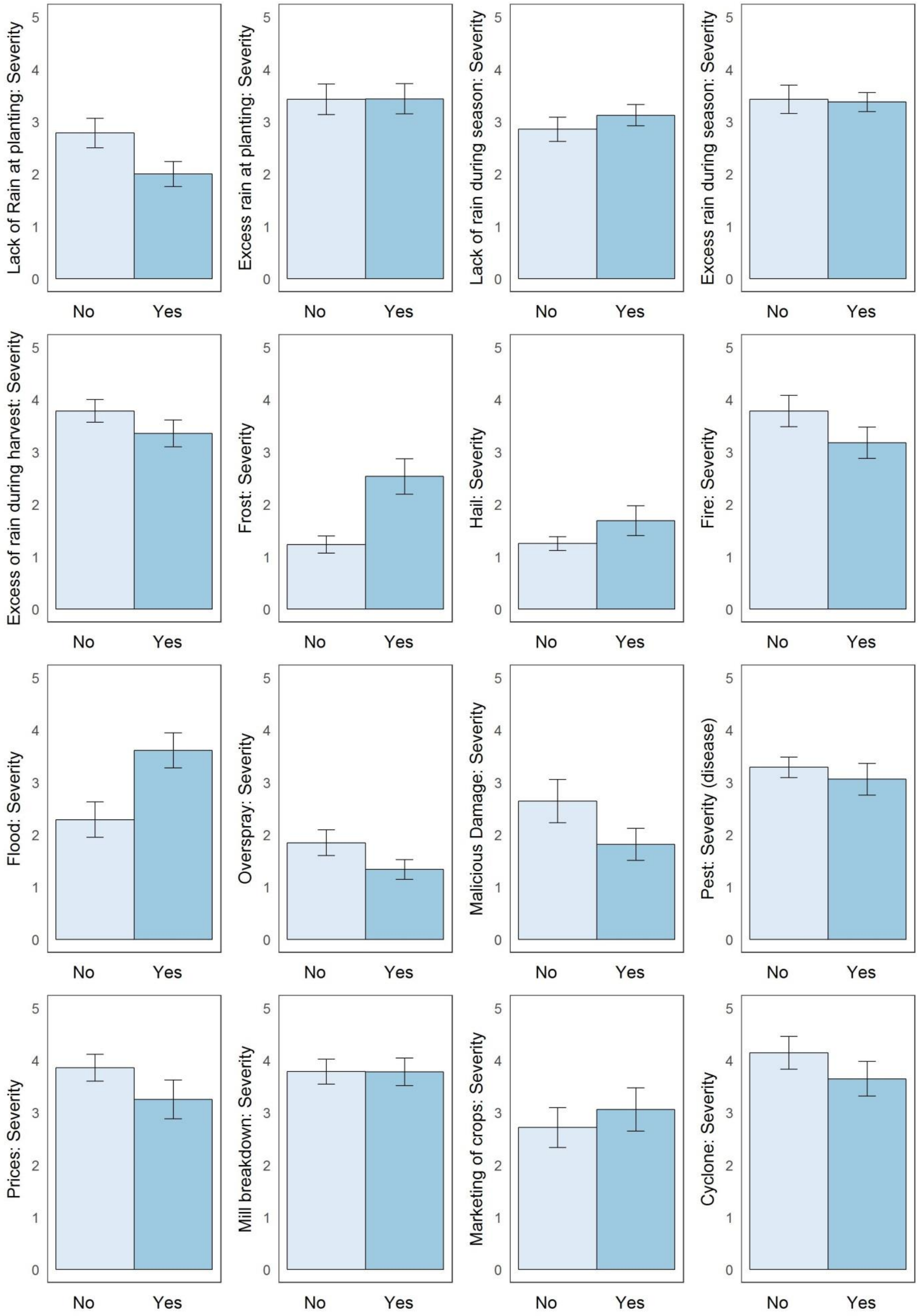


Figure 4-22 Perceived severity risk by irrigation use (No: not irrigated; Yes: irrigated) on Queensland sugar cane farms. Values are average scores; error bars are ±1 one standard error.

Estimated losses due to specific risks

Overall the risk perceived to cause the greatest potential loss (with estimated impacts of 20% or more on farm productivity/profitability) was cyclone, with a mean estimated loss of almost 50% (ranging from 0–75%). The next most costly events identified were sugar cane price (with estimated losses ranging from 5 to 60 %); flood (0–60%); pests (10–60%); excess rain at planting (7–70%); excess rain during harvest (3–60%); and fire (1–60%) (Table 4-5).

Table 4-5 Estimates of losses by risk category amongst Queensland sugar cane growers

Risk	*n*	Mean ± SE	Range
Lack of rain at planting	*13*	13.5 ± 2.85	0–30
Excess rain at planting	*16*	25.0 ± 4.81	5–70
Lack of rain during season	*12*	21.9 ± 4.12	3–50
Excess rain during season	*13*	18.5 ± 2.57	1–30
Excess rain during harvest	*16*	23.9 ± 3.32	3–60
Frost	*8*	13.5 ± 8.26	0–60
Hail	*8*	4.6 ± 2.52	0–20
Fire	*12*	23.8 ± 6.00	1–60
Flood	*14*	26.4 ± 6.58	0–60
Cyclone	*12*	48.8 ± 6.63	0–75
Overspray	*5*	2.4 ± 1.12	0–5
Malicious Damage	*6*	17.7 ± 16.49	0–100
Pests & diseases	*12*	26.3 ± 4.81	10–60
Prices	*10*	32.0 ± 4.84	5–60
Mill breakdown	*11*	19.1 ± 2.68	5–30
Marketing	*8*	2.6 ± 0.56	1–5

By region, the most costly events (with estimated average impacts of 20% or more on farm productivity/profitability) were:

- in North Queensland, malicious damage (with individual growers reporting impacts up to 100%), prices (40%), fire (60%) and excess rain at planting, during the season and at harvest (50%, 30% and 30%, respectively) (Table 4-6);
- in Central Queensland, prices (up to 60% losses); pests and diseases (60%), excess rain at planting and at harvest (70% and 30%, respectively) but lack of rain during the season (50%) (Table 4-6); and
- in southern Queensland, flood (60%), cyclone (40%), fire (40%) and excess rain at planting and at harvest (both up to 60%) (Table 4-6).

Table 4-6 Sugar cane growers' estimates of losses by risk category across Queensland sugar cane growing regions.

Risk	North			Central			South		
	n	Mean ± SE	Range	*n*	Mean ± SE	Range	*n*	Mean ± SE	Range
Lack of rain at planting	*3*	15.0 ± 5.00	5–20	*8*	12.5 ± 4.33	0–30	*2*	15.0 ± 5.00	10–20
Excess rain at planting	*3*	26.7 ± 12.02	10–50	*9*	23.3 ± 6.61	5–70	*4*	27.5 ± 11.09	10–60
Lack of rain during season	*2*	20.0 ± 0.00	20–20	*9*	22.6 ± 5.57	3–50	*1*	20.0	-
Excess rain during season	*3*	25.0 ± 2.89	20–30	*9*	15.7 ± 3.21	1–30	*1*	25.0	-
Excess rain during harvest	*3*	26.7 ± 3.33	20–30	*10*	20.3 ± 3.14	3-30	*3*	33.3 ± 14.53	10–60
Frost	*1*	0.0	-	*7*	15.1 ± 9.28	0–60	*0*	-	-
Hail	*2*	10.5 ± 9.50	1–20	*6*	2.67 ± 1.67	0–10	*0*	-	-
Fire	*3*	38.3 ± 16.91	5–60	*8*	16.4 ± 5.52	1–50	*1*	40.0	-
Flood	*3*	16.7 ± 14.24	0–45	*7*	15.7 ± 8.12	0–60	*4*	52.5 ± 2.50	50–60
Cyclone	*1*	5.0	-	*2*	5.0 ± 0.00	5–5	*1*	40.0	-
Overspray	*2*	1.0 ± 1.00	0–2	*3*	3.3 ± 1.67	0–5	*0*	-	-
Malicious Damage	*2*	50.5 ± 49.50	1–100	*4*	1.3 ± 1.25	0–5	*0*	-	-
Pests & diseases	*3*	16.7 ± 6.67	10–30	*7*	32.1 ± 7.23	10–60	*2*	20.0 ± 0.00	20–20
Prices	*3*	30.0 ± 5.77	20–40	*6*	34.2 ± 7.79	5–60	*1*	25.0	-
Mill breakdown	*3*	15.0 ± 5.00	5–20	*8*	20.6 ± 3.20	5–30	*0*	-	-
Marketing	*2*	3.5 ± 0.50	3–4	*5*	2.0 ± 0.77	1–5	*1*	4.0	-

There was little apparent difference between accredited and non-accredited sugar cane growers in terms of estimated losses for many of the risks covered in this study, although non-accredited sugar cane farmers appear more likely than accredited farmers to experience/perceive greater estimated impact on farm productivity and profitability due to events such as lack of rain during the season, frost, fire and malicious damage (Table 4-7).

Table 4-7 Accredited and non-accredited sugar cane growers' estimates of losses by risk category

Risk	Accredited			Not accredited		
	n	Mean ± SE	Range	*n*	Mean ± SE	Range
Lack of rain at planting	*4*	6.25 ± 1.25	5–10	*9*	16.7 ± 3.63	0–30
Excess rain at planting	*6*	27.5 ± 11.95	5–70	*10*	23.5 ± 3.66	5–30
Lack of rain during season	*6*	13.8 ± 2.95	3–20	*6*	30.0 ± 6.32	20–50
Excess rain during season	*6*	17.7 ± 4.84	1–30	*7*	19.29 ± 2.77	5–30
Excess rain during harvest	*7*	23.3 ± 7.26	3-60	*9*	24.4 ± 2.42	10–30
Frost	*2*	3.0 ± 2.00	1–5	*6*	16.7 ± 10.85	0-60
Hail	*3*	4.0 ± 3.00	1-10	*5*	5.0 ± 3.87	0–20
Fire	*5*	12.2 ± 7.10	1–40	*7*	32.1 ± 7.86	5–60
Flood	*5*	29.0 ± 11.00	5–60	*9*	25.0 ± 8.66	0–60
Cyclone	*7*	47.1 ± 7.14	20–70	*5*	51.0 ± 13.45	0–75
Overspray	*1*	2.0	-	*4*	2.5 ± 1.44	0–5
Malicious Damage	*2*	3.0 ± 2.00	1–5	*4*	25.0 ± 25.00	0–100
Pests & diseases	*5*	22.0 ± 7.35	10–50	*7*	29.3 ± 6.59	10–60
Prices	*3*	38.3 ± 7.26	25–50	*7*	29.3 ± 6.21	5–60
Mill breakdown	*4*	18.8 ± 5.15	5–30	*7*	19.3 ± 3.35	5–30
Marketing	*4*	3.8 ± 0.63	2–5	*4*	1.5± 0.50	1–3-

Between sugar cane farmers, those that farm under irrigation were more likely to experience/perceive greater estimated impact on farm productivity and profitability due to events such as flood, pests and diseases, frost, price and mill breakdown, while dryland sugar cane farmers experienced/perceived more significant losses due to lack of rain during the growing season, malicious damage and fire (Table 4-8).

Table 4-8 Farmers' estimates of losses by risk category for irrigated and non-irrigated sugar cane farms

Risk	Irrigated			Not irrigated		
	n	Mean ± SE	Range	*n*	Mean ± SE	Range
Lack of rain at planting	*7*	10.0 ± 2.67	5–20	*6*	17.5 ± 5.12	0–30
Excess rain at planting	*10*	25.5 ± 6.85	5–70	*6*	24.2 ± 6.64	5–50
Lack of rain during season	*10*	14.7 ± 2.64	3–20	*5*	32.0 ± 7.35	20-50
Excess rain during season	*7*	17.3 ± 3.96	1–30	*6*	20.0 ± 3.42	5–30
Excess rain during harvest	*10*	25.3 ± 5.06	3–60	*6*	21.7 ± 3.07	10–30
Hail	*3*	5.3 ± 2.60	1–10	*5*	4.2 ± 3.95	0-20
Fire	*6*	18.5 ± 8.56	1–50	*6*	29.2 ± 8.60	5–60
Frost	*4*	26.5 ± 14.19	1–60	*4*	0.0 ± 0.00	-
Cyclone	*6*	45.0 ± 7.64	20–70	*6*	52.5 ± 11.38	0–75
Overspray	*0*	-	-	*5*	2.4 ± 1.12	0–5
Pests & disease	*6*	34.2 ± 8.21	10–60	*6*	18.3 ± 3.07	10–30
Flood	*8*	40.0 ± 7.07	10–60	*6*	8.3 ± 7.38	0–45
Malicious Damage	*1*	5.0	-	*5*	20.2 ± 19.95	0–100
Price	*4*	41.3 ± 8.26	25–60	*6*	25.8 ± 4.90	5–40
Marketing of crops	*3*	3.7 ± 0.88	2–5	*5*	2.0 ± 0.63	1–4
Mill breakdown	*5*	26.0 ± 2.48	20–30	*6*	13.3 ± 2.79	5–20

Risk management practices

The most frequently reported risk management practices adopted by Queensland sugar cane farmers were reported (by >75% of survey participants) to be soil testing and agronomic advice, reduced tillage, insurance and futures contracts (Table 4-9). Least used were soil moisture monitoring (31% of farmers), while none of the surveyed farms used risk management systems (Table 4-9).

Table 4-9 Proportion of Queensland sugar cane farmers reporting use of risk management practices. (Practices are ranked according to the frequency reported.)

Risk	*n*	% using	Rank
Soil testing agro advice	*32*	100.0	1
Reduced tillage	*32*	87.5	2
Insurance	*32*	81.3	3
Futures contracts	*31*	75.0	4
Planting techniques	*31*	68.8	5
Laser levelling	*32*	62.5	6
Sub surface drainage	*32*	56.3	7
Weather forecasts	*31*	56.3	8
Special varieties	*29*	46.9	9
Soil moisture monitoring	*32*	31.3	10
Risk management system	*31*	0.0	11

Based on the survey responses, the greatest adoption of risk management practices appears to occur amongst central Queensland sugar cane farmers (including insurance uptake) and least amongst those in southern Queensland (Figure 4-23).

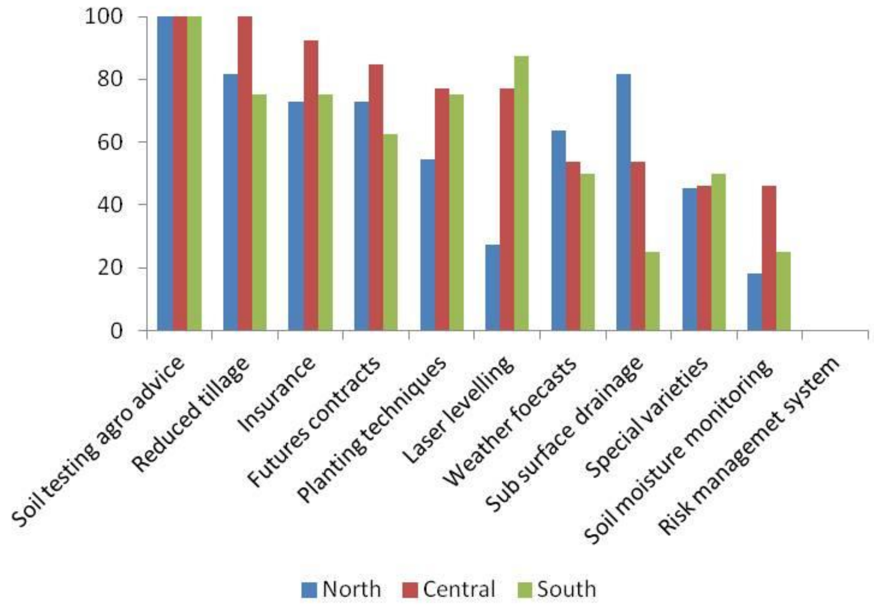


Figure 4-23 Percentage of Queensland sugar cane farms within regions using different risk management tools. North=North Queensland (n=13), Central=Central Queensland (n=11), South=Southern Queensland (n=8).

There appears to be very little difference between accredited and non-accredited sugar cane farms in the frequency of use of risk management practices/tools (Figure 4-24).

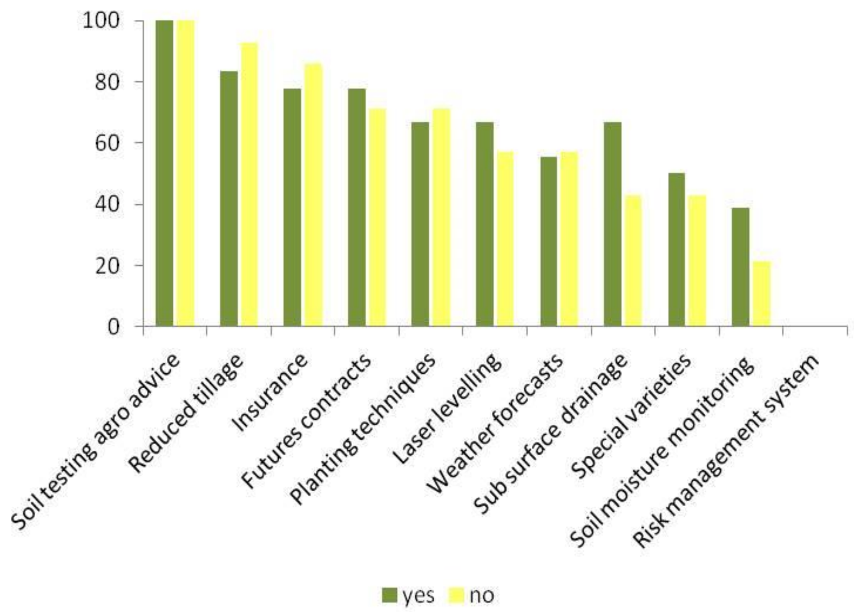


Figure 4-24 Proportion of sugar cane farms using different risk management tools by accreditation. (Accredited: n = 18; Not accredited: n = 14).

In general, a higher proportion of irrigated sugar cane farms reported using specialised cultivation techniques, while non-irrigated farms were more likely to employ subsurface drainage and weather/climate information. The reported use of insurance products was similar for both groups (Figure 4-25).

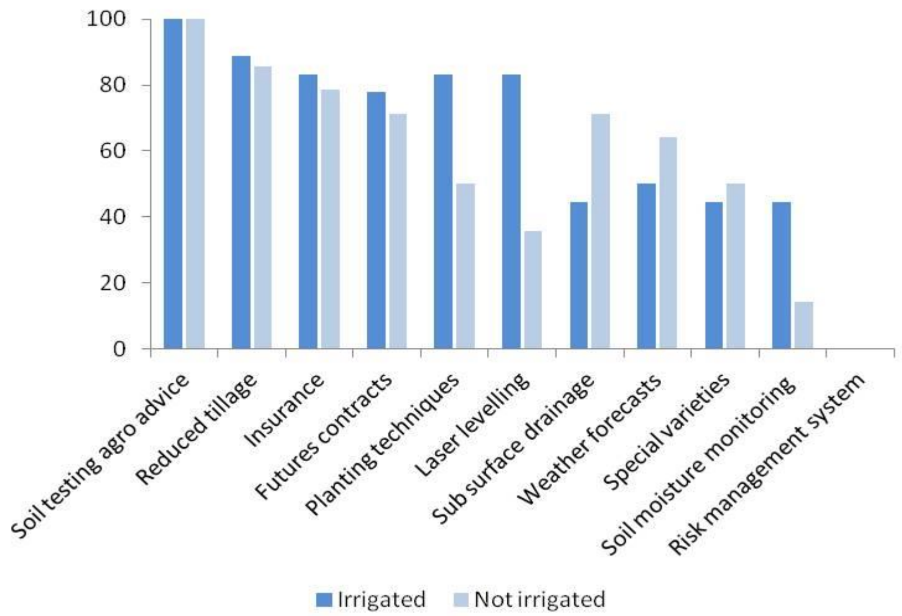


Figure 4-25 Proportion of sugar cane farms using different risk management tools by irrigation. (Irrigated: n = 14; Not irrigated: n = 18).

Crop risk insurance

Of the crop insurance products currently available to Queensland cotton and sugar cane farmers, fire and hail cover appear to be the most commonly utilised. Both groups indicated that they might be prepared to take out insurance to cover either the costs of production, the value of production or a level of income (Table 4-10).

Table 4-10 Current uptake of insurance products amongst Queensland cotton and sugar cane farmers and preferred insurance cover/products.

CROP	Current insurance – risks (number of respondents)	Preferred insurance - risks	Preferred insurance – value (number of respondents)
Cotton	Hail (15) Fire (2) Colour downgrade (1) No insurance (8)	Drought/dry years Heat Flood Wet weather Rain at harvest Quality downgrade. No insurance (5)	Income (5) Production value (7) Production costs (6) Nominated amount (5)
Sugarcane	Fire (27) Hail (11) Flood (1) No insurance (5)	Drought Flood Wet weather Excess rain during harvest Cyclone Frost Hail Disease & Pests Mill performance Price No insurance (8)	Income (8) Production value (7) Production costs (15) Nominated amount (3)

Survey conclusions

While numbers of farmers participating in this survey were low, especially when we started to look at responses across regions and accreditation/irrigation groups within these industry sectors, the results provide indication of some interesting regional patterns and variations across risk management types and production systems. Key messages are that current insurance products available to Queensland farmers (specifically, cotton and sugar cane farmers) may not address critical risks to the production and/or profitability of these systems and that farmers would prefer to have comprehensive insurance products available that cover them against profitability losses across multiple risk factors.

5. Crop modelling results

Data from the Australian Bureau of Statistics (http://www.abs.gov.au) for wheat, sorghum and cotton over the 1999-2015 (1998/1999 – 2014/2015) period were used for the performance assessment of our simulations. These data are at different scales (i.e. statistical units) due to their availability: provincial level: 1999-2007; statistical division (SD) level: 2008-2010, and statistical area level 4 (SA4) level: 2011-2015. Thus, yield data at provincial and SD scales were assigned to the relevant SA4 for the periods 1999-2007 and 2008-2010, respectively.

Regarding sugarcane, data from the sugar-producing regions for the 1975-2014 period were used as observed data. Although such data encompass several sugar varieties, different soil types and crop management practices across a given region, they are more suitable to capture an overall picture in a given region.

For each site, an average total number of 400 cotton combinations of management practices were simulated using APSIM and DSSAT. For sugarcane 27 combinations were simulated for each of the sites. The main simulation outputs are lint, bale and seed yields for cotton (no bale yield for DSSAT); and cane yield and sucrose for sugarcane (the CCS was also simulated in case of APSIM).

For a given crop, the simulated output assigned to the ensemble of crop models is the mean of the values from the 2 models used, e.g.,
$Yield_{Ensemble} = \frac{1}{2}(Yield_{APSIM} + Yield_{DSSAT})$).

A series of graphs showing some examples of the year-to-year variability of observed regional and simulated yields for selected sites is presented in Figure 5-1 and Figure 5-2. Regarding the simulated data in these figures all the possible combinations for a given criteria are plotted.

Depending on the site and crop, there is a trend to yield overestimation or underestimation when comparing the observed regional yields to the predicted ones. Here models are applied in environments for which they have not been specifically calibrated, which is typically the situation in such impact studies at larger spatial scales (regional to national scales).

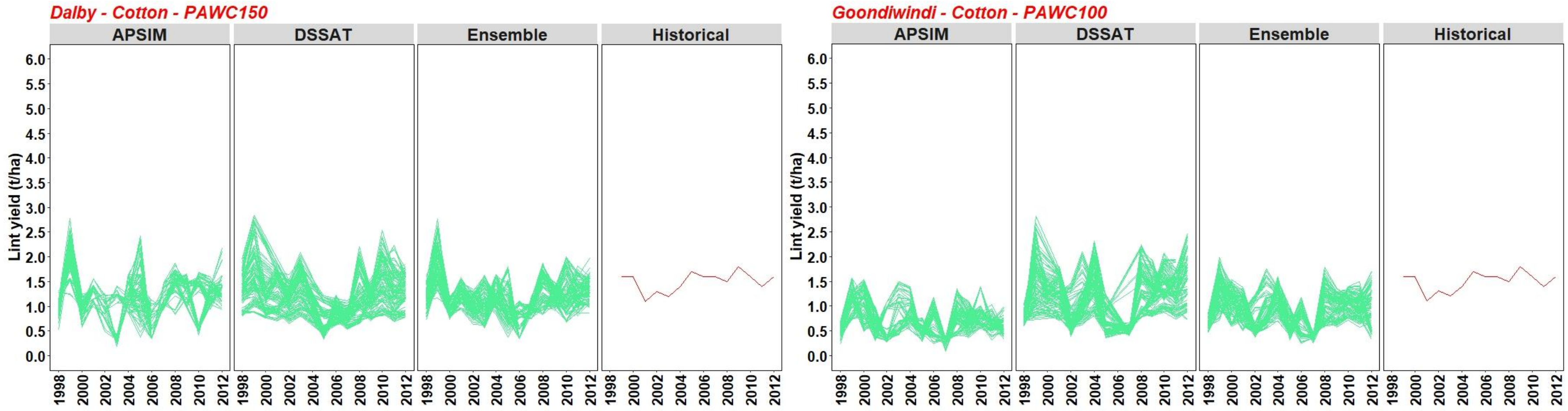


Figure 5-1 Lint yield at Dalby (left) and Goondiwindi (right). PAWC = 150 and 100 mm, for Dalby and Goondiwindi, respectively.

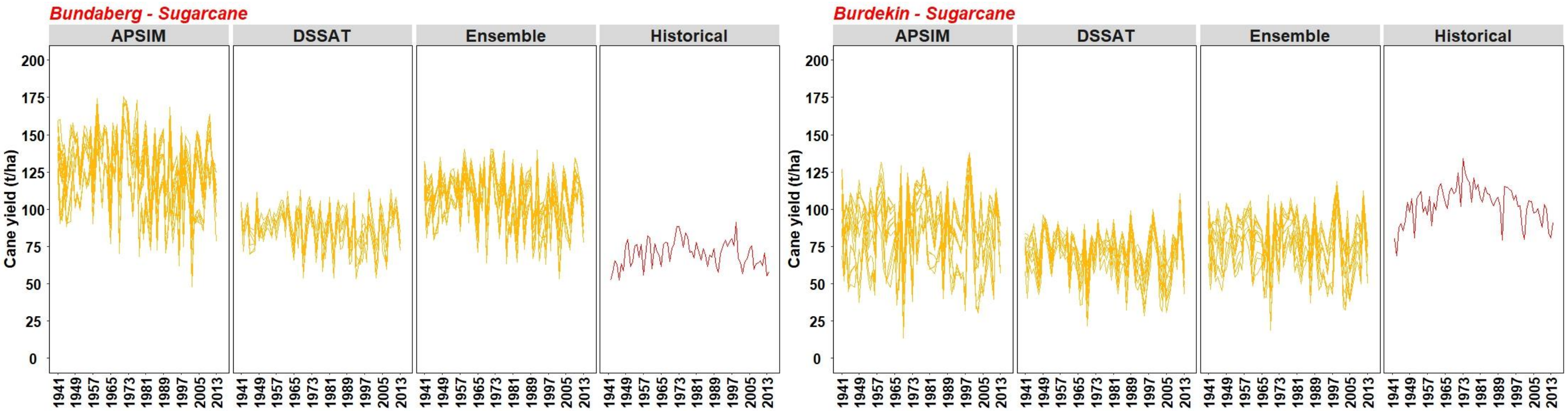


Figure 5-2 Year to year variability of observed and predicted sugar cane yield at Bundaberg (left) and Burdekin (right). Predicted values show the result of all possible combinations (management factors detailed in methods section) using the models APSIM and DSSAT. The Ensemble yield is the mean of the two simulated yields.

6. Climate assessment risk and reporting tool - Risk Quantification and data presentation

A 'climate and agricultural risk assessment and reporting tool' (prototype) was developed as part of the project. The tool can be accessed through http://icacs.usq.edu.au/risk/ , but is currently password protected. This 'tool' allows quantification of key climate risks, initially for sugar and cotton industry. The key risks included in the tools are rainfall, frost, heat (temperature), cyclone, yield and hail (see screen shots provided in Figure 6-1, Figure 6-2, Figure 6-3, Figure 6-4 and Figure 6-5 below).

The tool provides an option to generate a detail climate risk report based on historical data and future seasonal climate forecast for an individual location. The tool data also serves as a dataset portal, allowing for the download of data in a required template. The data sharing portal was used to share data with Willis Tower Watson (WTW) and Queensland Farmers Federation (QFF) to design innovative index based agricultural insurance products.

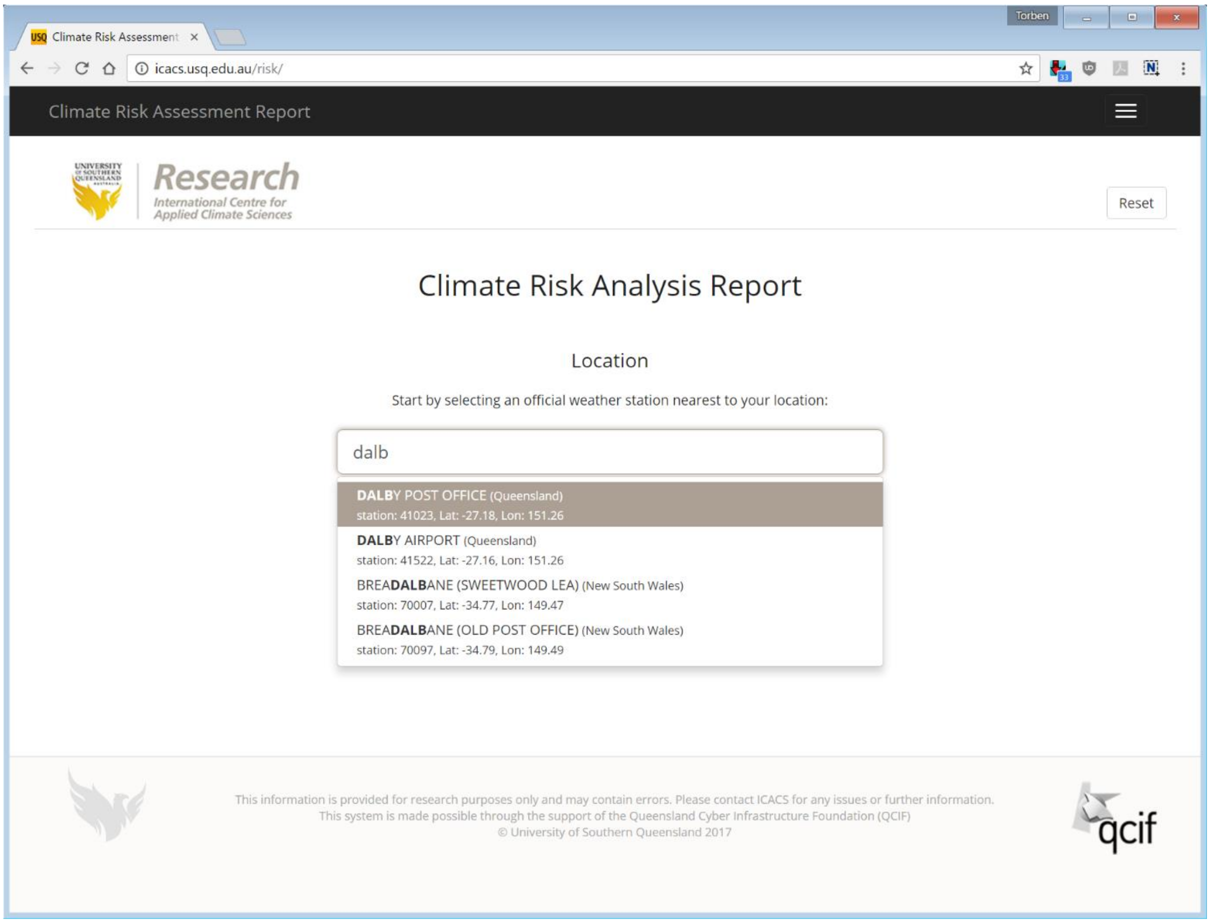


Figure 6-1 Climate risk analysis interface where locations can be selected

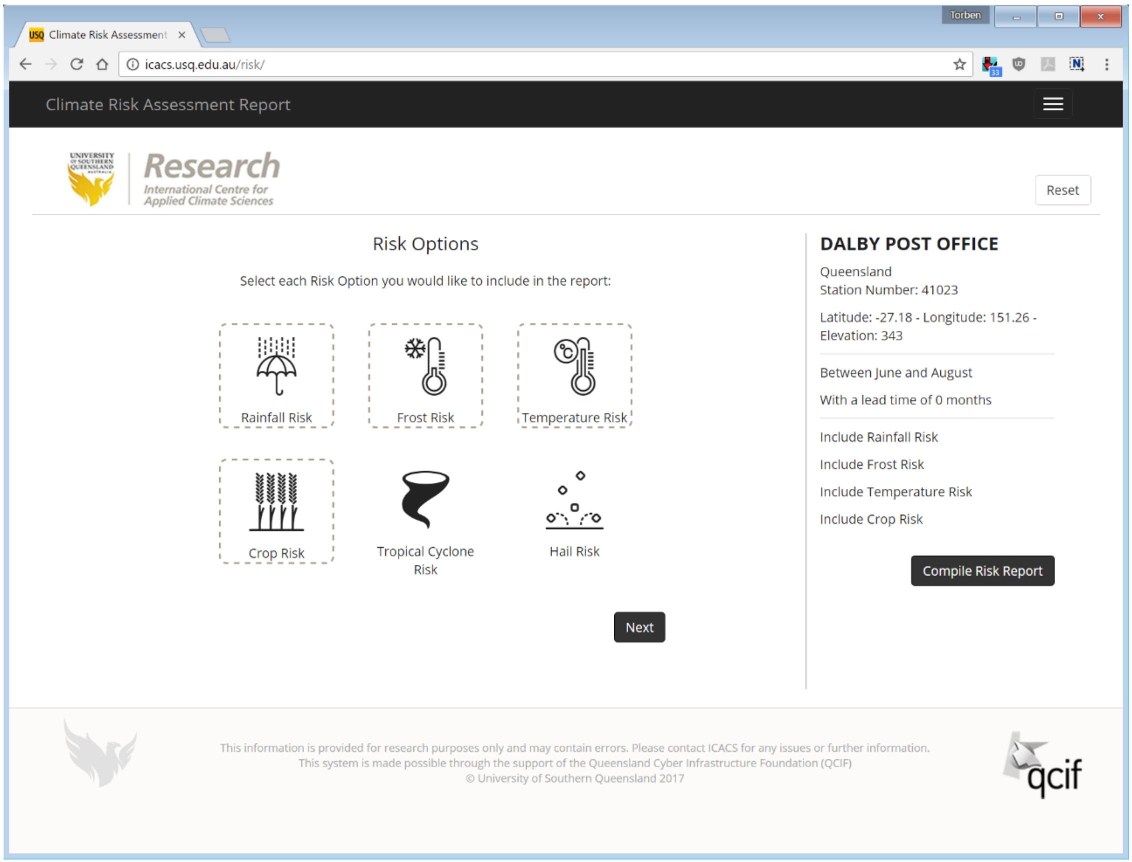


Figure 6-2 Climate risk analysis interface showing the different risk options that can be assessed for the Dalby post office station

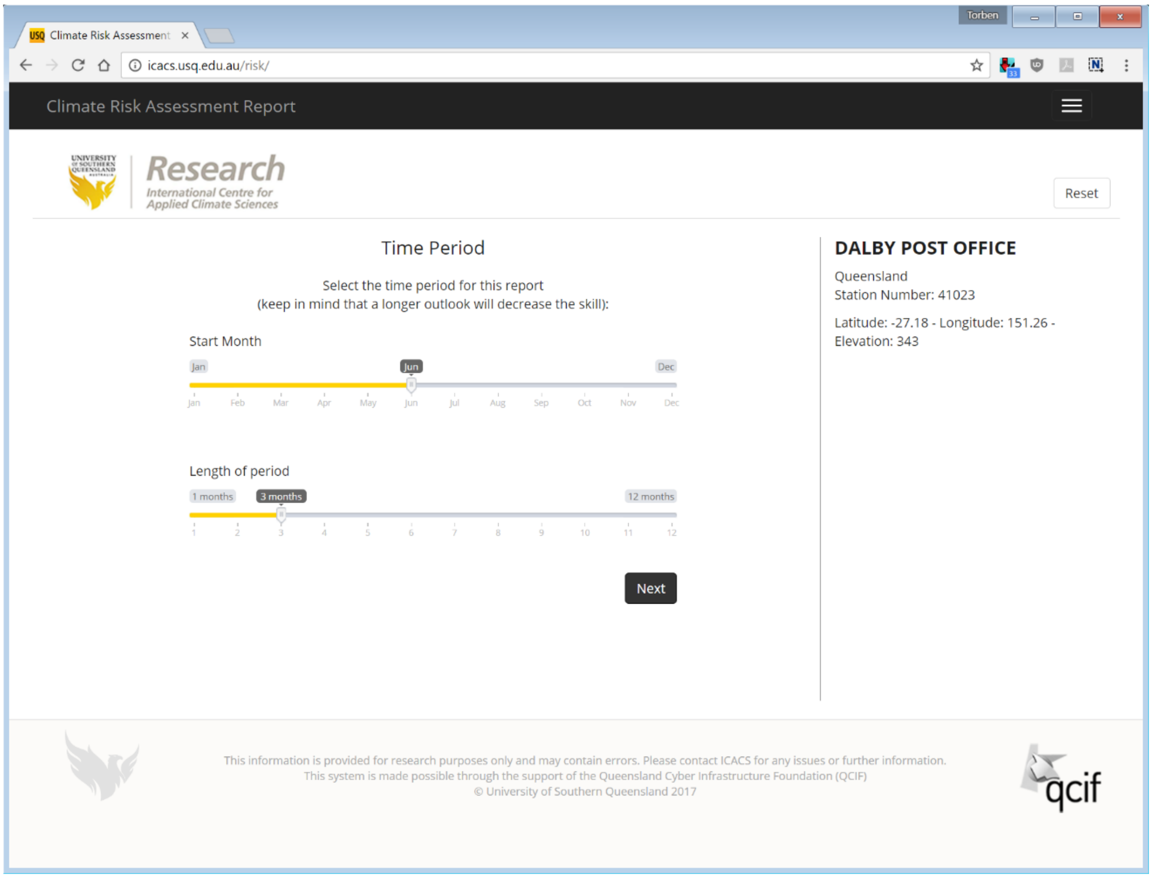


Figure 6-3 Climate risk analysis interface where different time periods can be selected

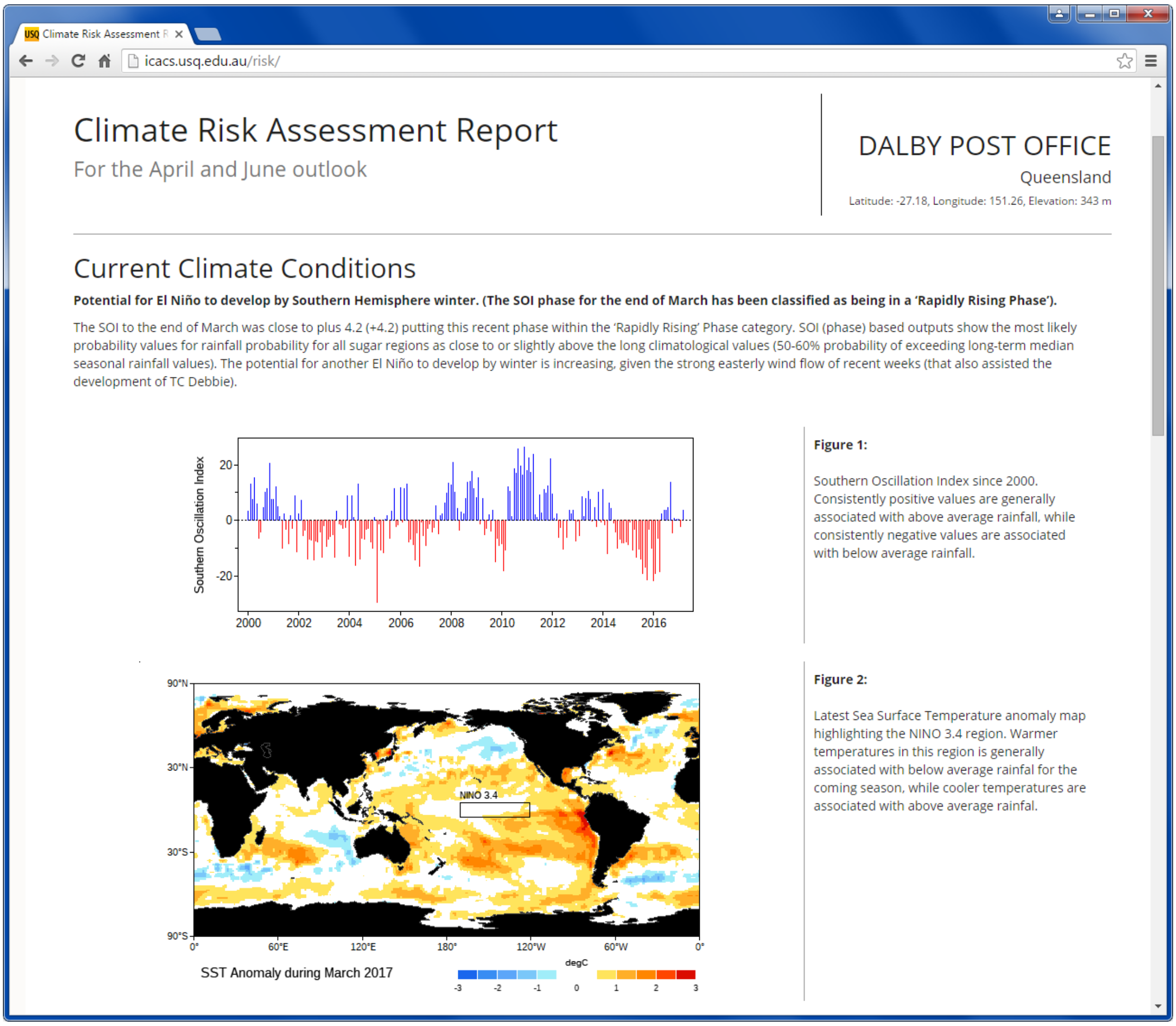


Figure 6-4 Example climate risk assessment risk report for a April to June outlook

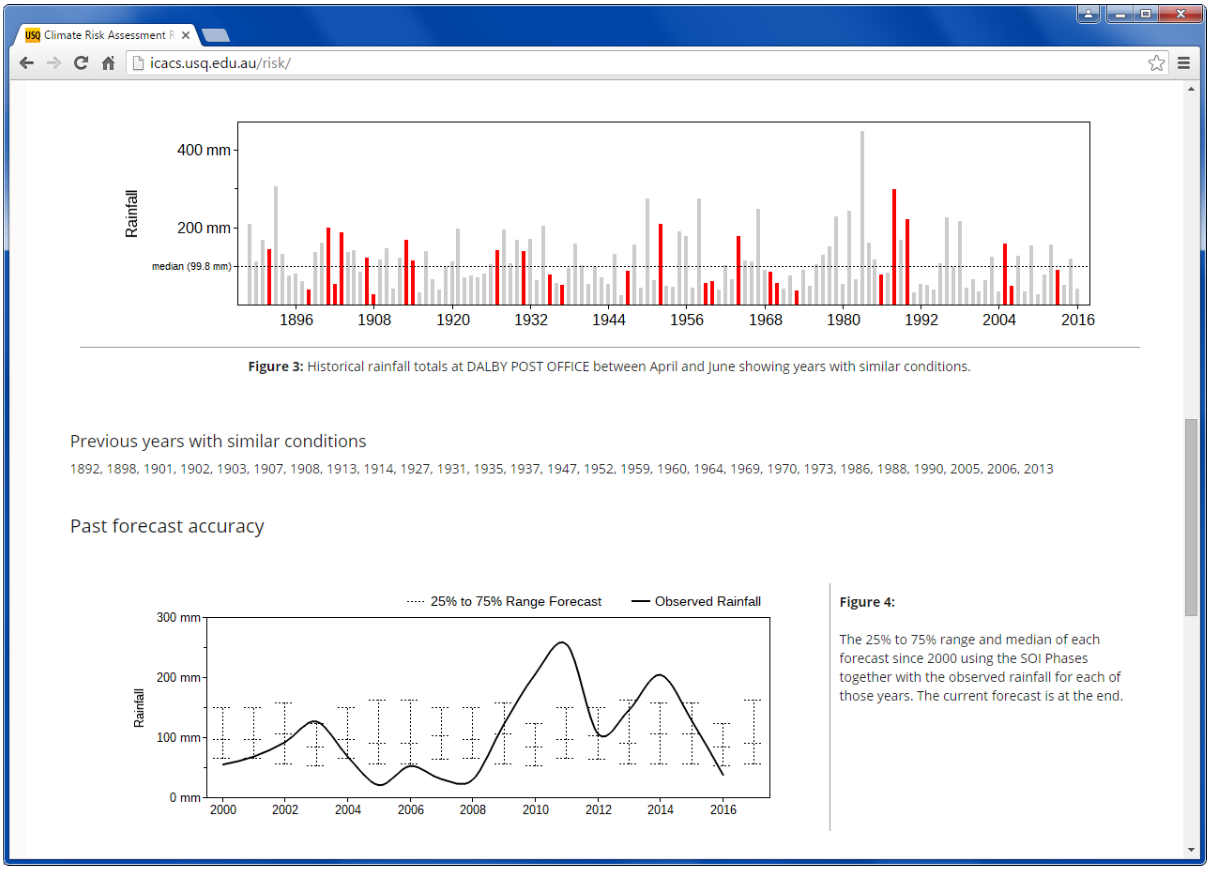


Figure 6-5 Rainfall risk for the Dalby post office

7. Insurance products – worked example on insurance products and their benefits

Insurance Products and Value Related Aspects

In this section we address the potential insurance products available from the insurance market that provide coverage against the key risks identified by sugarcane and cotton farmers. The concepts outlined herein are equally applicable to producers of other crops in any geographical region.

Willis Towers Watson's (WTW) collective resources – in Australia and the UK – have many years of experience in arranging adverse weather covers for a range of different industries, spanning the agribusiness, power, construction and entertainment sectors among others. This expertise can be harnessed to structure and execute the protections outlined in this paper. WTW likewise possess the actuarial and analytical resources required to support the recommendations in this report and are well placed to provide stakeholders with a full understanding of the potential risk transfer options.

Overview of the role of insurance

The payment of insurance premiums whether it be for one's home, possessions, car, business or even life may not be an expense that is always greatly appreciated. Yet few who chose to make such a payment would doubt the benefit of the coverage it provides.

Insurance – in one form or another – can trace its roots back through to trading systems of ancient (pre-Minoan) civilisations. The industry as we know it became more formally established following the Great Fire of London in 1666 and the development of insurance trading in Edward Lloyd's coffee shop in 1688. It was underpinned by the maxim that "the misfortunes of the few fall light upon the many".

Today insurance is an essential part of everyday life, playing a crucial role in both economic development as well as in supporting wider societal ends. Insurance helps oil the engine of the economy and it is impossible to conceive of commerce and civil society today without insurance playing its role.

Aside from the basics of issuing contracts of insurance and paying claims when called upon to do so, the insurance industry performs a broader role than is sometimes realised. For example in:

- Efficiently protecting the public through innovative risk management techniques.

    - acting as an agent for the promotion and, implementation of risk reduction standards
- Freeing up businesses and professionals from everyday risks and encouraging innovation and competition.
    - thereby protecting jobs
    - providing confidence and stability to promote growth and technological progress
- Relieving the burden from the state and providing comfort to individuals by providing safe, effective and affordable pension savings, protection and products that convert pension savings into retirement income
    - insurance companies are amongst the largest investors in any economy.

The insurance industry

The insurance industry is highly stratified in its structure, it is functionally divided into risk takers (insurance and reinsurance companies), sales and distribution (insurance brokers and agents) and service providers (loss adjusters and risk management experts). The assumption of insurance risk typically cascades down a chain of risk takers: starting with the insurance company that issues the original policy. In turn that insurance company may choose to share some of that risk either with another insurance company or to protect its overall portfolio of assumed risks in various ways. This is achieved by a reinsurance contact - the insurance of an insurance company - by a reinsurance company. Indeed reinsurance companies may seek to protect themselves in the same way using a process known as retrocession.

Insurance globally is a highly regulated industry. This regulation is intended to protect the consumer by ensuring that the insurance company is able to fulfil its obligation and remain solvent even under the most extreme set of claim events. This solvency is referenced against a level of capital requirements according to the nature and amount of risk assumed by the company. The purchase of reinsurance by an insurance company enables it to assume more risk than would otherwise be permissible under the standard of regulated capital adequacy by passing the obligations that exceed its capital to the reinsurer.

It is sometimes the case that insurance businesses, be they insurer, reinsurer, broker or agent are loosely referred to as 'insurance companies'. As can be seen, this is strictly-speaking not the case. This only matters to the extent that a buyer of insurance should be aware (or be made aware) of which is the entity that is financially responsible for paying his or her claim.

Companies within the insurance sector, as with other financial services' companies, include generalists and specialists: the largest of the insurance and reinsurance businesses may have both. It is not surprising perhaps that agricultural insurance is a specialist line of business: whereas there may be hundreds of general insurance businesses dealing with commonly purchased insurances (e.g. household, motor, commercial, travel etc.), there are very few businesses that specialise in agriculture.

Agricultural insurance: a brief history

With so much to merit the history of general insurance, agricultural insurance has also played its part albeit perhaps more discretely. It is not known precisely when the first agricultural insurance policies were issued but there is evidence of local mutual insurers being formed in the 17th century in Europe. But it was not until the 1900s and especially the 1930s when the US Federal Crop Insurance programme was established. Since that time, especially through the last quarter of the 20th century, crop insurance has established itself in every major agricultural economy across the globe.

During this period of development and expansion of crop insurance around the world, a number of themes have become evident. These themes perhaps reflect the underlying challenges and complexity of implementing agricultural, as opposed to more traditional, types of insurance. While there are many types of specialist insurance that require subject-matter expertise for underwriting and policy administration, agriculture is perhaps exceptional in its geographic dispersion. It therefore requires that the insurers involve, or the service providers have, sufficient resources to visit farms either for pre-underwriting (risk assessment) or claims handling. Under circumstances in which there may be many thousands of insureds spread thinly over a wide area, this presents not only a logistical challenge but also, critically, an economic one. How can the cost of these resources be paid for within a potentially modest base of premium? Globally there are few examples of successful agricultural insurance schemes that have emerged spontaneously without some form cross-subsidisation of the cost of introducing and maintaining the necessary infrastructure.

It is a matter of simple observation that where agricultural insurance exists at any scale, some degree of subsidy is provided either at local, regional or state level. The extent and manner of such subsidy may vary but it would be appear to be the catalysing component of crop insurance wherever it exists. Needless to say, it is not necessarily a panacea and poorly performing crop insurance programmes can be introduced notwithstanding with the benefit of substantial subsidised support.

Crop insurance in Australia

In Australia this chicken-and-egg situation has hampered the emergence and widespread take-up of crop insurance. Multi-peril products were first offered in Australia during the 1970s but ultimately they did not flourish as a result of a detrimental cycle of adverse selection, poor results and increasing premium costs.

Since that time a number of insurance companies and agencies have continued to offer products, especially so-called named peril coverage e.g. for example hail or frost. In addition other offerings are available such as farm level yield cover for broadacre crops and index-based products. The latter being relatively new to the market and, as discussed further, representing promising potential for development.

Australian farmers are not widespread adopters of crop insurance despite the fact that agriculture in Australia faces some of the greatest weather-related challenges of any developed farming economy. In simple economic terms, this suggests that the cost of insurance has not yet reached an amount at which supply and demand are reasonably satisfied.

Australian Crop Insurance Providers

Achmea	Leading Dutch based agricultural and horticultural insurer offering tailored winter crop insurance. Leader in greenhouse insurance.
AgriRisk	Broker offering MPCI for broadacre crops and defined perils cover for cotton.
MPCI	Underwriting Agent for Liberty Speciality Markets (Lloyds division), offering MPCI for broadacre crops.
Latevo	Formally agent of Assetinsure offering MPCI for broadacre crops.
SureSeason	Authorised Representative of Ironshore Australia (Lloyds' security) offering revenue MPCI cover.
Primacy	Agent of Allianz offering MPCI or defined perils cover for broadacre crops; specified perils cover for cotton and horticulture crops.
Rural Affinity	Agent of Great Lakes offering defined perils (including additional benefits) cover for broadacre, cotton and horticulture crops.
IAG/WFI/CGU	Offer defined perils (including additional benefits) cover for broadacre, sugarcane and cotton crops. MPCI pilot programme (Crop Income Protection) for wheat, barley and canola against yield shortfall caused by natural perils including flood, frost, drought and vermin offered to 100 Landmark customers in WA, SA, Vic and NSW.

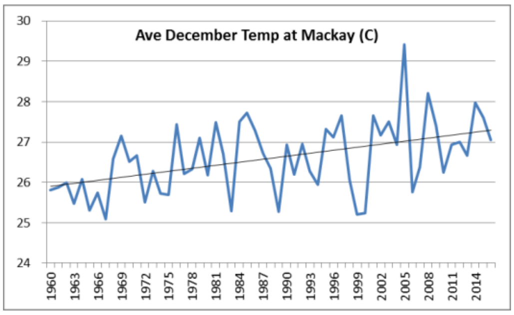
ProCrop	Agent of CGU (via Insurance House Pty Ltd) offering rainfall index, loss of revenue product to WA, SA and Victorian grain farmers only.
Elders	Agent of QBE offering defined perils cover for broadacre crops.
CelsiusPro	Climate consultant/agency that works with SwissRe to analyse data and structure indexed weather solutions for all industries through its association with WRMA. Offers index-based solutions in derivative form.

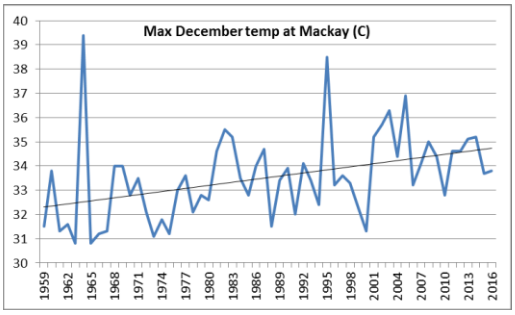
What is crop insurance for?

It is recognised that all crop producers confront season-to-season production and revenue volatility. Numerous factors are responsible for this variability but it is recognised that most of these are beyond the scope of management or control by the farmer. Crop insurance is best thought of as a means by which such exogenous risks can be transferred from the farm account: the overall yield of the farm business is thereby reduced by the amount of the premium paid but the downside unpredictability is taken care of. Crop insurance is usually a discretionary purchase as the farmer can choose whether or not to take it out and assume the cost of the premium within the farm budget. On occasions, it may be a requirement of a farm seasonal loan. As farm lending rises, so too does the potential for loan default and bankruptcy.

Crop insurance has an important role to play in a production environment confronting climate change and global warming. Few involved in the farming sector with first-hand experience of the impact of weather on their business would disagree that, even if trends are scarcely noticeable, weather extremes and seasonal uncertainty has become more frequent.

The charts below show the visible trend for temperatures recorded at Mackay, QLD (WMO: 94367) for the 59 year period on record from 1959 to 2017. Both charts, showing December temperatures (the average and the maximum for the month) show a marked increase of approximately 1.25°C and 2.5°C, respectively, across the period. These data were selected from a single site and a single month at random but, nonetheless, are representative of the pattern shown by the data more broadly.





So how do insurers play a role in assisting the farming sector deal with climate change? Clearly insurers cannot ignore the trend in these data and the calculation of a temperature-related contract would certainly take this into account. But it is the increased uncertainty about next year's temperature (or other weather element) which insurers can help to manage.

How much is crop insurance worth?

It is hard to determine what insurance is 'worth'. It is fair so say that most people who purchase insurance against their house being destroyed are prepared to do so because the cost of its replacement, were it to do so, would be beyond their means. The cost of the premium is not comparable against any other similar purchase so the only reference point as to its reasonableness is by comparison between insurance providers.

Yet for agricultural insurance there are few, sometimes if any, comparisons available to make such an evaluation. At the same time, agricultural production systems are rather high risk: the chances of something going wrong in a growing season are well recognised. And so – even when premium levels are calculated entirely fairly – the levels appear expensive. To make matters worse, when compared to other types of insurance that a farmer might buy, the premium (and the risk) make for a very poor comparison. So, on the face of it, it is all too easy to dismiss crop (especially multi-peril) insurance as simply being too expensive.

Insurers are rational traders, they are motivated to return a profit for their capital providers. However such rationality also extends to pricing the risk they assume at a reasonable level. Generally speaking this a matter for resolution by a competitive market place: price the risk too high and clients take their business elsewhere. Price a risk too cheaply, and claims will soon exceed premiums. There is no evidence to suggest that providers of crop insurance in the Australian market have over-priced the risk they offer to cover. So if the price does not match demand, something needs to be done.

Examples of Similar Work Undertaken Previously

There are numerous examples, too many to elaborate comprehensively in this report, of crop insurance schemes worldwide that enjoy levels of voluntary adoption by farmers such as to provide strong evidence that crop insurance can be feasible.

Looking at the largest and longest established schemes, those found in the USA, Canada, Mexico, India, China, Turkey and certain countries of the EU (notably Spain, France and Italy) all have a premium subsidy to a lesser or greater extent. These are all 'national' programmes – although some administered at state or provincial level – and are distributed by commercial insurance companies.

In each of these countries, the existence of a subsidised crop insurance offer tends to crowd out the existence of non-subsidised crop insurance. This is not surprising as it is obviously not possible to compete on premium price levels without a subsidy. However, and this is not definitive, it appears that the very existence of a subsidised programme seems to have some impact in deterring the development of other, innovative crop insurances.

It is very often the case that national crop insurance programmes – even the very diverse Federal programme in the USA – do not cater for all crop types and all farmers. In such cases, although the insurers involved do develop their own 'private' policies to address specific needs, it is seldom the case that insurers not otherwise engaged in the sector see themselves as sufficiently experienced or resourced to move into the sector.

At the large corporate level, where a product tailored to the needs of the individual farmer may not either be available or suitable, the commercial insurance and especially reinsurance market can respond with tailor-made programmes. By way of example of some of these, the following transactions have been successfully without any form of premium or cost subsidy:

1. Grain Crop Volume – Australia

Risk:	Grain crop volumes in Western Australia – all sources of variance
Index:	Actual volume of grain delivered
Structure:	State-wide grain receivals index, plus second trigger adjustment based on Australian Bureau of Statistics data

Risk protection buyer (the insured's) revenues are dependent on WA grain crop volumes each year. A captive (buyer-owned insurer) was utilised to provide protection to divisions of the business against downturns in crop volumes and WTW arranged a reinsurance protection for the captive to transfer this group exposure to the reinsurance market.

2. AFRICAN RISK CAPACITY – Africa

Risk:	Drought, as determined at the level of an individual country
Index:	Rainfall parameterised to reflect each country's staple crop's specific rainfall requirements

Structure:	Index-based aggregate excess of loss reinsurance

Africa Risk Capacity Insurance Company Ltd (ARC Ltd) is a Bermuda based mutual insurance company, set up to issue insurance policies against drought to any member country in Africa. It allows member countries to respond quickly to a developing crisis, and rely less on uncertain international aid in times of drought. Initially five African countries participated in the unique programme: Kenya, Mauritania, Mozambique, Niger and Senegal. Since then further countries have joined the programme pool. WTW has placed wholly commercial reinsurance coverage for this programme for each of its 4 years of operation. The transaction has won numerous industry awards for its innovation.

3. NFU Sugar – UK

Risk:	Extreme and prolonged freeze at the time of harvest
Index:	Temperature
Structure:	Weather index plus second trigger adjustment based on actual farm yield

The NFU (National Farmers' Union) Sugar transaction includes primarily a weather trigger but also benefits from actual farm delivery data to ensure accuracy of payment. All UK sugar beet farmers (who are represented by NFU Sugar) are covered by this industry-wide scheme.

4. Commercial Farming Group – South Africa

Risk:	Farm unit grain yield
Type:	Material damage to insured crops, protecting financiers' interests
Structure:	Traditional multi-peril crop insurance covering reduced yield as a consequence of natural perils.

Providing protection for a large farming group in South Africa and their financiers, covering a portfolio of growers and their combined 40,000 ha of assorted grain crops.

5. Commercial fruit grower – New Zealand

Risk:	Revenue reduction resulting from loss of export quality fruit
Index:	Actual crop pack-out
Structure:	Indemnity of loss in value

Uniquely for an index-based cover, this programme is triggered by a dual trigger reflecting not just the overall volume of fruit packed by the insured but also, critically, the quality of that fruit. As one of New Zealand's largest fruit exporters, only fruit of export quality is sufficient for the company to achieve its revenue targets. The tailor-made coverage replaced a traditional hail-only insurance policy which had failed to achieve the client's risk management objectives.

6. Vineyards - France

Risk:	Freeze at time of bud/flowering
Index:	Temperature (TMin)
Structure:	Payments are made on the basis of daily minimum temperatures recorded at a nearby national meteorological recording station. As TMin during the reference period (targeted at the critical few weeks for the vines) reaches successively lower temperatures incrementally greater amounts of the policy limits are payable up to the maximum agreed amount.

The grower in question, a highly renowned producer and global brand of premium quality wine, chose to take out this form of index-based insurance as opposed to a more conventional form of crop insurance due to its simplicity of operation, certainty of performance and speed of payment. As with all such index-based contracts the buyer was able to choose the policy parameters (dates, temperature thresholds, payment increments and policy limit) to best suit its economic needs and risk management requirements.

Protection for Growers

The individual farmer research carried out by the project team (by means of questionnaires and on-farm interviews) has established that there is generally a very low take-up of the 'conventional' crop insurance available to farmers at present. These insurances include:

- **Single/'named' peril crop insurance**: typically hail, frost or fire cover (higher take-up rate for cotton and sugarcane insurance)

- **Multi-peril crop insurance**: typically whole farm yield loss protection (equivalent to 'all risks') where exclusions are specified in the policy such as failure to carry out good farming practice
- **Area yield coverage**: though, to the best of our knowledge, it is not the case that this is available for either cotton or sugarcane growers in Australia; and, finally Weather index-based protection.
- **Weather index-based crop insurance**: as further described in this report and available from at least one provider in Australia.

Although an awareness of the potential use of crop insurance as a means of risk management was found to be widespread, its take-up was very low. The reason for its low take-up was generally cited as being due to its perceived high cost; and the relatively better value of other risk management strategies (whether or not they strictly deliver an equivalent level of protection). Typically these may be better described as risk avoidance strategies, such as alternative or no planting options.

That said, for both cotton and sugar cane, there is important demand for cotton hail protection and sugarcane fire coverage both of which appear to be largely well catered for by existing insurance products. These would appear to be perfectly adequate wheels that do not need reinvention.

It is also questionable how much awareness there may be of the different types of crop insurance that are commercially available.

However, again from the project's investigations, it is not clear that the insurance industry has gone far enough to explore what farmers might wish to buy if it were available. It is clearly not reason enough to maintain that premiums per se are just too expensive. If we make the assumption that the market for crop insurance is free and competitive, it follows that the market price for premiums would be 'fair' or, in other words, properly reflective of the underlying risk. And it is not refuted here that the underlying risk of crop insurance is potentially high; so it follows that the fair premium would logically reflect this and the loss history of the sector.

Nonetheless high premium cost is prohibitive and accounts for the very low take-up of crop insurance by Queensland farmers and, indeed, by farmers all over Australia and in other countries.

In certain countries, notably in the United States of America, Canada, India, China and parts of the EU, this premium cost barrier is lowered by government intervention by means of subsidies. These subsidies usually explicitly contribute a share to the cost of the premium (NB the underlying premium is still priced at fair value) such that the farmer only pays a prescribed fraction of the true premium. In addition the subsidy may contribute to the overall cost of the policy/programme administration and operation (including insurer overhead, margin and handling, such as loss adjustment). These costs would otherwise necessarily be included in the premium charged and borne by the farmer.

It may also be the case that the Government may choose to waive additional expense such as premium tax (Stamp Duty) or other ad valorem overheads that it might otherwise charge. This can amount to a valuable concession as such charges fall in the range of 2.5 up to 30%.

It is noted that the Victorian government have removed Stamp Duty amounting to a 10% saving in the premium cost, but there is no such exception for crop insurance policies purchased in Queensland. In its recent budget the government of New South Wales took also the decision to abolish Stamp Duty on crop and livestock insurance policies.

The authors recognise that any contribution to the reduction of cost of crop insurance would likely stimulate the demand for and take-up of crop insurance in Australia as has been the case elsewhere. In the absence of any such price support, we conclude that there is a need for the insurance industry to respond with self-supporting low cost protections.

The World Trade Organisation (WTO) is also influential on the extent to which the state may provide support to agricultural insurance. Whilst the overall concept of support remains compliant with its so-called 'Green Box' status, the extent and structural design of the insurance must adhere to to certain prescribed limits.

Weather Index-Based Insurance

Although, as set out above, weather indexed-based products have been available to farmers in Australia for a number of years but, as yet, have failed to achieve scale, it is the conclusion of this report that such products are best likely to meet farmers' needs for affordable and effective insurance to cover their key risks.

Weather risk management contracts have evolved over the past 25 years to protect weather sensitive industries against precipitation, temperature and other index-based weather perils. These contracts generally reference an independent arbiter of actual weather conditions, such as the Bureau of Meteorology (BOM) in Australia.

Key contract variables such as attachment points, pay-outs and limits are structured to compensate the buyer for a pre-defined weather outcome, as opposed to actual loss (or strict indemnity). For this reason, the analysis and structuring components of the cover are critical in order to eliminate, or at least minimise, basis risk – i.e. the risk that actual losses are not well represented by the index. Correlating weather outcomes to increased costs, or reduced revenue, is an actuarially driven process using either actual or modelled financial and historical weather data.

As outlined in earlier sections of this report, the project has entailed an in-depth understanding of the potential cost to farmers in the event of insufficient or excessive rainfall or extreme temperatures resulting in loss of yields. The information provided by individual farmers and industry bodies can be used to structure and execute any number of weather risk transfer contracts, although initially we address:

Cotton

- Drought Cover: insufficient rainfall during the planting season – August to November;
- Drought Cover: insufficient rainfall during growing season – November to February;
- Wet Harvest Cover: excessive rainfall during harvest season – March to June

Sugarcane (perennial crop)

- Cyclone Cover: crop damage during cyclone season – November to April
- Wet Harvest Cover: excessive rainfall during harvest season – June to December

We provide further details on the pages that follow. As already mentioned, the concepts outlined are equally applicable to a large number of adverse weather scenarios. It is the intention of this document to outline our understanding of a small sub-set of these exposures, demonstrate how these risks may be transferred and propose that we undertake a pilot programme prior to developing a range of other weather products for the benefit of sugarcane, cotton and potentially other farmers (as part of DCAP Phase 2).

Rather than competing with any existing insurance arrangements in place through other agricultural insurers, the concepts presented in this paper contemplate a totally distinct risk transfer service that the sugarcane and cotton industries could provide to farmers.

In the authors' opinion, the agriculture sector is uniquely positioned to deliver real innovation to farmers which could greatly reduce reliance on somewhat subjective Farm Household Allowance (FHA) payments and Natural Disaster Relief and Recovery Arrangements sometimes available from Government.

Basis risk

Weather index-based covers are a proxy for on-farm crop performance and yield levels generally. It is recognised that, unlike traditional indemnity-based covers, the index is not a perfect replica of actual yield and therefore there is likely to a mismatch between the two, referred to as 'basis risk'. This risk may result in an under or over payment by the contract when compared to the actual farm experience. It is the objective to minimise basis by optimal index design and by sourcing data from a measurement station that most closely match the farm weather.

However it is worth considering that the potential for this basis risk varies considerably according to (a) the nature of the weather element involved – rain, temperature etc. (b) the period of time over which the measurements critical to the index performance are taken and (c) the extent to which the index measurements will be triggered near to the average or a point whose occurrence is more infrequent. Taking each in turn:

The nature of the weather element: as is well known, on a daily basis, rain may fall heavily in one area whereas a location just a short distance away may receive no rain at all. Conversely, with the exception of micro-climatic influences such as frost hollows or extreme altitude, temperature tends to be more diffusely experienced over wider areas.

The period of time: the longer the period of time taken in a measurement series, the more representative it is likely to be of the location. A spot, say one day, recording includes all the randomness of that day. Whereas if drought is the matter of concern, then daily measurements taken over a period weeks or months will better reflect the actual weather impacting the crop. Longer periods of time measurement will similarly tend to reduce the geo-spatial randomness associated with a certain element, such as rainfall, as mentioned above.

The trigger point: as is well known, crop yield and production is influenced by numerous production factors. Selecting only weather factors, small variations around the mean are unlikely to influence the yield outcome greatly. Rather, it will tend to be other agricultural influences such fertility, pest load or plant genetics which determine yield variability. However, extreme weather events tend to become the predominant determinant of extreme low yield outcomes. So, an absence of rainfall at a critical period of plant growth, say at the time of planting/germination, is likely to impact the crop very markedly.

For this reason, weather index-based solutions in agricultural production are better structured where the defining parameter(s) are set far from the mean at a point at which the correlation of extreme event and crop impact tends to be high. This has the coincident benefit of reducing premium cost by reducing the expected frequency of triggering of the contract.

Compulsory vs Voluntary agricultural insurance

It is not specifically the objective of this report to contemplate any form of compulsion for farmers to become involved in any crop insurance as this would clearly be unacceptable in a free market. However, it merits pointing out that the desirable feature of choice introduces the concept of 'selection' or the rather less desirable 'anti-selection'. This is the potential for an unintended negative feedback loop whereby insurance is only taken out by those who perceive (or indeed know) that they need it most. The resulting poor claims results forces an upward movement on premium pricing which, in turn, confines affordability to a yet smaller and more exposed subset of potential buyers.

For reasons of lack of data or poor granularity of that data it is not always possible for insurers to reflect accurately the differing levels of risk presented by locality, let alone at individual farm level. So, inevitably the perception of risk is generalised which may or may not reflect accurately an individual farmer's perception of the risk he/she faces. Such perception will typically be informed by years of actual farming experience at the location itself. So it is by this information asymmetry that the effect of anti-selection can arise; and generally the toxic spiral that follows.

Conversely, where all farmers are automatically enrolled into a scheme, it follows that premium pricing distortions resulting from anti-selection do not occur. In turn this tends to result in the premium costing that matches more closely the true underlying risk; meaning that the insurance can be a more efficiently priced risk management instrument.

In farming systems where the risk is somewhat binary (it either is or is not an appreciable concern from farm to farm) it may be harder to mutualise risk in this way, as those farmers who do not consider themselves to be at risk, much or at all, will tend to object to their subsidisation of those other unfortunate farmers who are at risk. This situation is further exacerbated by circumstances in which a farmer may choose to implement other risk management strategies which obviate the need for insurance.

Where a risk – such as drought and cyclone – is largely systemic throughout a farming community, then aside from the challenge of ascribing fair premium rates that are properly commensurate with the risk that each farm presents, then the concept of mutualisation is likely to make more sense.

To conclude on this point – and to repeat – we do not advocate any form of compulsory insurance scheme as being a realistic proposition. It merely merits pointing out that certain all-too-important premium pricing efficiencies may be achieved from an 'all-in' scheme, which are not available on a self-select basis. We would recommend further exploration of this topic so as to rule in or rule out any possibility of wide scale mutualisation.

Non-insurance risk management strategies

This purpose of this report is to explore insurance based, or equivalent, financial contract based solutions. However, the desirability or otherwise of these solutions must be considered in the context of the status quo and, in particular, alternative strategies for managing risk at farm level as collectively form the current, do-nothing new option.

First, although this may not universally be true, it is assumed that a rational farmer would always prefer to adopt the least cost risk management strategies that are available as the first risk management strategy. This makes perfect sense as typically these include farming best practice and may even be the no cost option.

However where there is exogenous risk, beyond the control good farming practice, there remains residual risk which is characteristically severe and unpredictable. Even for these risks there are strategies. For example, the formalised and tax-efficient Farm Management Deposits Scheme (FMD) managed by the Federal Government. The FMD scheme aims to smooth out cash flow fluctuations and increase the self-reliance of farms, with the profits from a good year able to be spread across bad years. The pre-income profit that is deposited into a FMD is tax deductible, and only becomes taxable in the financial year when withdrawn.

Three recent changes recognised the realities of modern farming: from July 1, 2016, the FMD cap doubled from $400,000 to $800,000; the early access trigger during times of drought was re-established; and the law preventing FMDs being used as offset accounts against primary production business debt was removed.

FMDs can provide an opportunity for self-insurance, if used correctly and drawn down when the farm is in hardship. But, there is limitation to the FMD scheme, with FMDs only issued in an individual farmer's name, not in a farm company, partnership or trust account, and must be held in the account for more than 12 months (unless drought trigger is activated). The self-discipline of farmers also play an important role in the effectiveness of FMDs, with farmers needing to commit to deposit profits in good years, and draw down funds in bad years.

Federally, there is also the Farm Household Allowance (FHA). This provides farmers and their families experiencing financial hardship with financial support. This payment is managed through the Department of Human Services and is tailored to farmers.

For natural disasters, assistance is available through a joint funding model between the federal and state governments. The Natural Disaster Relief and Recovery Arrangements (NDRRA) provide disaster relief and recovery payments and infrastructure restoration to help communities recover from the effects of natural disasters. Most relief measures under NDRRA are funded 75% by the Commonwealth Government and 25% by the Queensland Government. The level of assistance available depends on the category of assistance triggered by the natural disaster, with farmers receiving direct assistance in categories C & D.

The Queensland Government Drought Relief Assistance Scheme (DRAS) is another level of assistance available to farmers, primarily around animal welfare. DRAS's purpose is to help drought declared properties manage the welfare of their breeding herd, and assist in restoring herds after drought. For this, DRAS provides three main assistance measures: freight subsidies for transporting water; freight subsidies for transporting fodder; the Emergency Water Infrastructure Rebate (EWIR) for the purchase and installation of water infrastructure for animal welfare needs.

A Worked Example: Cotton

In this example we examine the case of cotton grown in the Dalby area in the Darling Downs region of Queensland. Cotton is extensively grown around Dalby and two gins are located within a short distance of the town.

We obtained a historic yield series from USQ for the 24 year period from 1992 to 2015. The series is largely complete, with only two missing years (1994 and 2000) which are therefore ignored for the purposes of this illustration. We have also obtained the daily rainfall data series for Dalby from the Bureau of Meteorology.

Analysis of these data shows a strong correlation between the yield of cotton in a given season and the total rainfall recorded during January and February of that season. Figure 7-1 below enables a visual comparison between high/low and high/low yields.

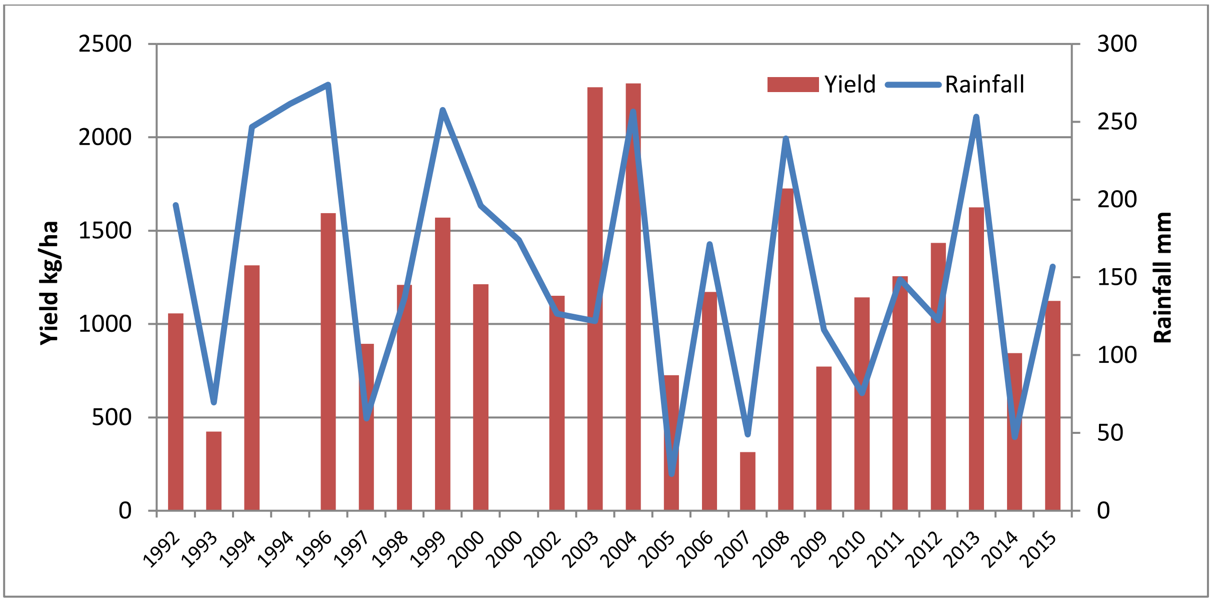


Figure 7-1 Cotton yield versus rainfall (Dalby)

In particular, it is clear that years in which the yield of cotton was markedly less than the long term average of 1,180 kg/ha were characterised by low Jan/Feb rainfall. These years were 1993, 1997, 2005, 2007, 2009, 2014: 6 years out of 24 (25%). Also, importantly, there were no years of low yields in which rainfall was not also low.

An average frequency of occurrence for poor crop yield of 1 year in 4 is rather high but is reflective of the natural variability of growing conditions in this region. A conclusion of this analysis and these observations however is that low yield can be attributed to low rainfall, regardless of other production factors and external influences.

On this basis it would be feasible to design an index-based insurance product that is referenced to the recorded rainfall during January and February as reported by the BOM at Dalby Airport. Figure 7.2 below shows the rainfall and a 'strike' level below which an index-based policy might payout. In this instance, for illustrative purposes, the strike level has been set at 50% of the long-term average rainfall for January and February which equates to approximately 80mm.

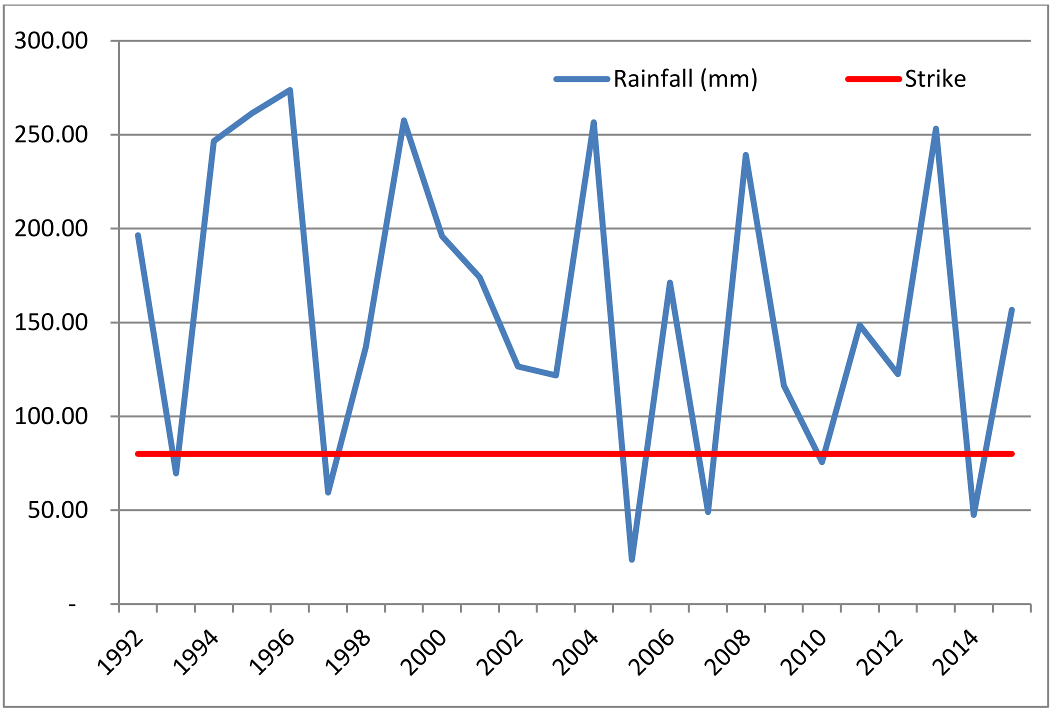


Figure 7-2 An illustration of rainfall and the selection of a trigger point

At this level of strike, it can be seen that the contract would have made payments in each of the low yield years with the exception of 2009.

In practice, it is likely that a policy that pays one year in four is likely to be more costly than is commercially attractive. So in the design of the index policy an attachment point needs to be found that balances the risk management objectives of the buyer with its premium price point. Table 7-1 below show how, for this rainfall series at Dalby Airport, a changing strike point alters the how the policy would have paid in the 24 years in question.

Table 7-1 The effect of changing the contract 'strike' point

Strike (mm):	40	50	60	70	80
1993	-	-	-	0.4	10.4
1997	-	-	0.6	10.6	20.6
2005	16.4	26.4	36.4	46.4	56.4
2007	-	1.0	11.0	21.0	31.0
2010	-	-	-	-	4.4
2014	-	2.6	12.6	22.6	32.6
No years	1	3	4	5	6
Probability	4%	13%	17%	21%	25%

For example, setting the strike point of the policy at 40mm from 80mm reduces the frequency of payment to a single year during the period. Arguably 1 year in 24 is not sufficiently frequent to provide protection in a range of years with poor yield, so a higher strike point might be preferable. We shall choose a strike point of 50mm for this illustration.

There are two further contract assumptions which are integral to the function of all index-based contacts. First is the basis on which the contract pays after the trigger point has been reached: the so-called 'tick' value is the amount paid for every millimetre recorded that is less than the strike point. In this case we have chosen a tick value of $120 per millimetre. Secondly, there is a contract limit which is the maximum payable under the contract regardless of the rainfall, here $3,000 per hectare. For the purposes of this example we make the assumption that all values apply 'per hectare' which is a simple and practical basis of operation and in line with traditional insurance procedure.

Figure 7-3 below shows how the selected trigger, tick and limit values determine the payment outcomes of the contract according to the level of rainfall recorded.

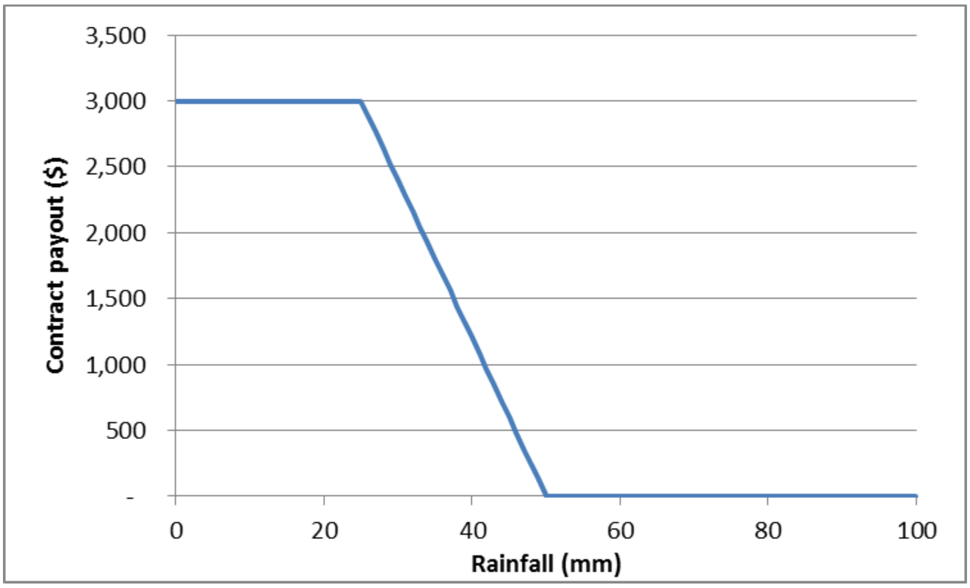


Figure 7-3 The relationship between rainfall and contract payments

On this basis Table 7-2, below, shows the payments that would have been received in each of the three years for which a payment would have been triggered.

Table 7-2 Illustration of an index-based contract payout

	Strike (mm)	**Tick** ($/mm)	**Limit** ($/ha)
	50	120	3,000
2005	26.4	3,168	3,000
2007	1.0	120	120
2014	2.6	312	312

In this case, as there would have been no payments made in any of the other years since 1992, the average payment for the entire time series would have been $143 per hectare (being $3,432 ÷24). It is this average payment which forms the basis of calculating the premium. In practice this simplifies the process that an insurer might typically use to model the expected loss under the contract. In addition, of course, the final premium charged would include a commercial margin to cover expenses, profit etc.

A Worked Example: Sugarcane

As a contrast to the previous worked example for cotton low yield resulting from a shortage of rain, a situation which develops over a moderate period of time, weeks and months, we consider below a distinctly different cause of crop loss, namely damage to and loss of yield of sugar cane resulting from cyclones.

It is well recognised that tropical cyclones occur with some regularity in the Northern Territory, eastern and western states of Australia and their destructive impact on the sugar cane industry in Queensland can be very severe. Canegrowers who participated in the survey upon which this report is based responded that while valuable fire insurance was available they were not availed of any suitable coverage for cyclone related damage.

The effect of cyclone on sugarcane is largely twofold: (i) mechanical, whereby the stems are snapped and torn by the strength of the wind leaving the plant compromised and (ii) water logging as a result of the extreme rainfall associated the cyclone.

Figure 7.4, below, shows sugar cane yields in the shire of Burdekin recorded since 1970. It shows that 2 out of the 4 years with yields below the long term coincide with cyclone activity in the area. However low rainfall is also associated with yield short fall.

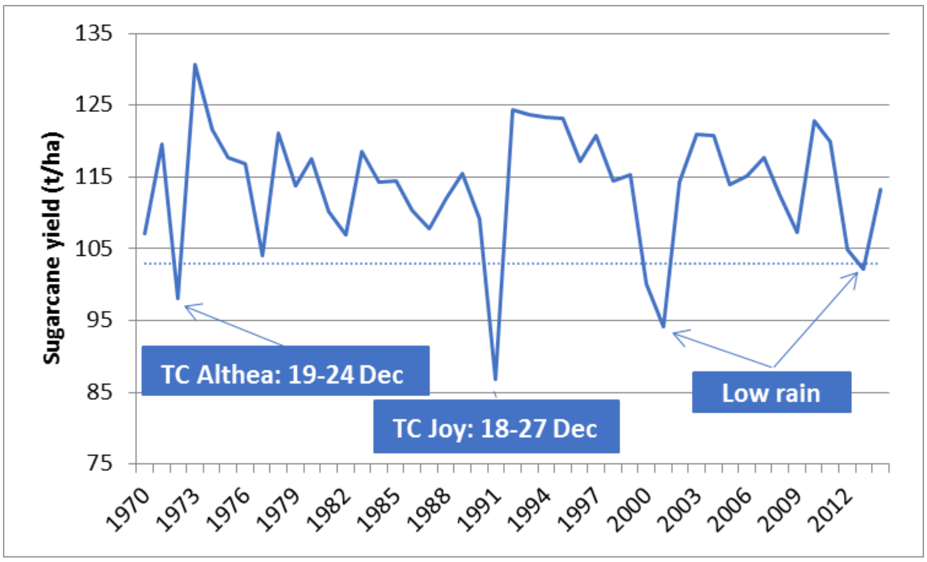


Figure 7-4 Sugarcane yields in Burdekin

However it seems that extreme rainfall on its own does not reflect years of low yield in the historical yield records. Table 3 shows the maximum daily and aggregate 3-day rainfall recorded at Mackay. There are some events of unprecedented magnitude reflected in this dataset and a comparison with more localised yield history than was available from this project's survey would be expected to reflect damage and yield loss associated with rainfall of this magnitude.

Table 7-3 Extreme rainfall events at Mackay

Daily Max (mm)	3-day max (mm)	Daily ave for month (mm)	Date of occurrence
388.6	796.1	9.3	01 March 1963
356.0	543.6	11.3	15 February 2008
326.0	414.0	3.1	17 November 2000
314.0	781.6	5.8	29 December 1990
302.8	467.6	11.3	06 February 1979
286.0	357.6	9.1	05 January 1996
255.8	513.2	9.1	03 January 1991
249.6	438.4	11.3	02 February 2007
249.0	484.8	9.3	29 March 1976

Conversely, we note some correlation associated with low rainfall seasons which are shown both in Figure 7.4, above and Figure 7.5, below which compares grower records of sugarcane yield at Mount Kanigan with the accumulated rainfall in September, October and November.

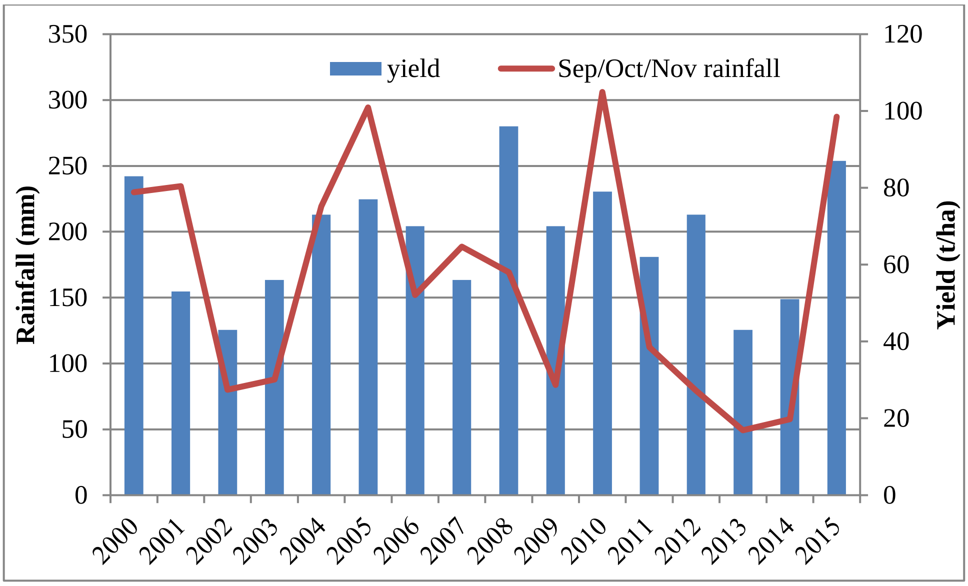


Figure 7-5 Sugarcane yield vs rainfall at Mount Kanigan

We note that there is not only a wide range of periodic rainfall such as that shown in Figure 7.5 above but also the variability of monthly rainfall can also be extreme. Figure

7.6 below shows the monthly profile of rainfall recorded at Mackay and that the maximum rainfall may be ten or more times the monthly average.

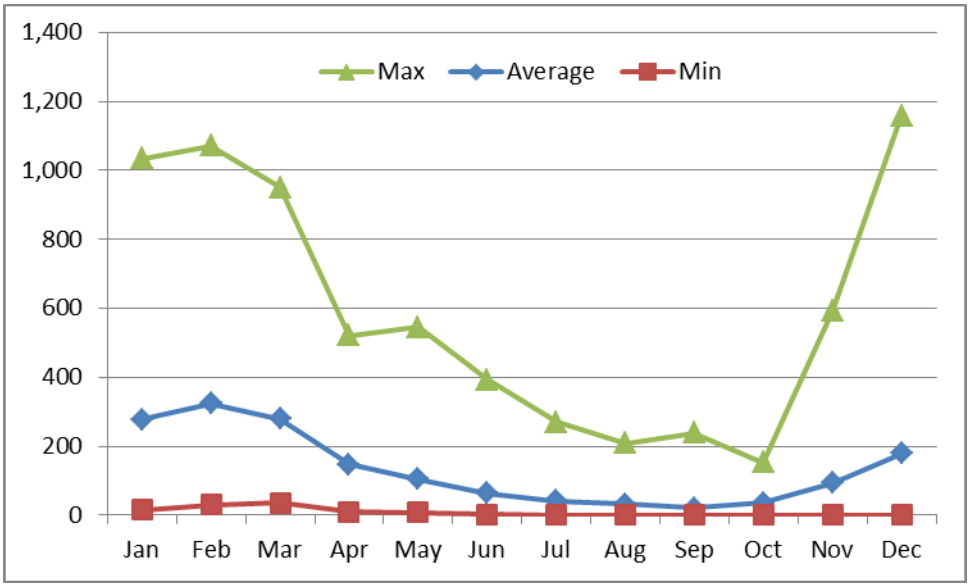


Figure 7-6 Profile of monthly rainfall at Mackay (1960-2016)

This report notes the potential suitability of a different design of index-based insurance product known as a "cat-in-a-box". This form of protection is suitable for event related loss such as that arising from the occurrence of a cyclone. The index definitions include: (a) a defined area, (b) the definition of the event occurring within that area and (c) the payment criteria associated with (a) and (b). Although this style of protection refers to a "box", the shape of the area may equally be a circle, rectangle or other defined polygon.

The definition of the event normally refers to the magnitude of the insured element, in this case the magnitude of the cyclone which may be defined by reference to one or more physical measurements or, perhaps, more simply being a 'named' cyclone. By definition, these have reached a set threshold of magnitude in terms of wind speed and therefore damage potential.

The payment under the contract is usually defined as being a function of either (a) binary i.e. any event within the 'box' or (b) a time-dependent payment whereby the longer the period of time event remains within the 'box' the greater the payment.

Under certain circumstances, the 'box' may have a series of boundaries, for example concentric circles for which events occurring in the inner circle(s) – closer to the assets at risk – receive a higher level of payment than events occurring in the outer circle(s). This design style is appropriate for elements such as windstorm and earthquake where the damage impact attenuates with distance.

So, with cyclone activity, events passing some distance from the sugarcane growing area may bring high wind and rainfall but neither sufficiently in excess to cause damage. Indeed, plentiful rainfall may have a beneficial impact on subsequent yield.

It is the observation of this report that the sugarcane industry in Queensland would benefit from the availability of cyclone coverage. For reasons set out elsewhere in this report – and as borne out by the lack of coverage currently available to growers – we believe that an innovative approach to the design of this coverage is needed to deliver an appropriate product that is as affordable as the variable climatic conditions allow. An index-based 'cat-in-a-box' style of coverage offers the potential to extend the present fire coverage to include an element of cyclone protection without the need for a costly insurance infrastructure. Such an index-based product may also be supplemented with either extreme low or high rainfall protection.

Index-based vs traditional or MPCI insurance

The conventional indemnity-based insurance policy offerings have certain apparent benefits, especially insofar as they are usually contracted on an individual farm basis with actual losses (or physical damage) being measured at the farm itself. Conversely, index-based contracts infer the relationship between actual on-farm performance and that of the index; with the attendant concern that there may be differences between the two.

However, aside from their simplicity of operation, index-based policies offer certain distinct advantages which – under circumstances where traditional insurance either does not exist or is not economically feasible – enable the implementation of valuable risk management where it would otherwise not be possible.

The challenge faced by insurers in issuing multi-peril crop insurance stems from the costly and complicated requirement to obtain farm-level risk information and provide loss adjustment services. Index-based policies require neither of these which immediately removes an element of cost from the process, enabling index-based programmes to be costed with lower overhead.

Importantly the vicious circle of anti-selection (as discussed in the context of compulsory vs voluntary schemes) does not apply. At farm-level, a concern that traditional crop insurances face is the selection of only parts of the farm that are more exposed than others. Whilst it is generally a requirement that the insured farmer should insure all of the eligible cropping, this may not always be the case.

Insurers offering an index-based programme need not have such concern as it the index location rather than the specifics of the farm location that determine the contract outcome. It follows that buyers can be offered flexibility as to how they purchase their policy. For example, if a farmer would prefer to take out index-based coverage for only a selected proportion of his farm, then this should be possible at no penalty or disadvantage. The index policy may simply be set up by reference to a certain number of hectares – which may, or may not, amount to all the hectares farmed.

In the case of farms which are extremely extensive or divided across many locations, it is likely that each distinct location would require its own appropriate geographical reference.

MPCI insurers also concern themselves with the quality of the farming that they insure; poor farming practices inevitable increase the chances of lower farm yields. It is very hard to make a judgement about the quality of farming practice without costly interventions such as farm surveys; this too adds to the cost burden of offering such a policy. Again, index-based policies perform without reference to the quality of the underlying farm, farmer or other human influence. As such, this component of risk does not need to be costed into the premium of an index-based policy.

Conventional, indemnity-based policies very typically (and logically) include conditionality to protect the insurer against adverse performance. These include 'warranties' (in which certain aspects of, say, risk management are deemed to be in place and remain so during the course of the policy) or 'exclusions' (in which losses or damage arising from specifically itemised risks are deemed not to be covered). There may also be time-related criteria which determine that only losses occurring during (or out of) a given time period are payable. All such conditionality must be properly stated in the policy contract and there are legal provisions to ensure that these are represented properly and fairly. However the consequence of such conditionality is that not all claims and losses become payable; sometimes this may be unexpected and disappointing. In any event, it represents a disparity between actual loss and the amount of the claim payable. So it is not only index-based policies that may introduce an element of such mismatch.

After the occurrence of a loss or damage, time is very often 'of the essence'; certainly speed of claims settlement is a key performance criterion by which an insurer may be judged. A simple, straightforward claim should be handled quickly and with little or no intervention by a competent insurer. However agricultural risk is seldom simple or straightforward; both yield-based insurances and named peril policies usually need on-farm intervention including one or more visits by a qualified loss adjuster.

Insured farms are generally dispersed quite extensively in rural areas and expert loss adjusters are thin on the ground, so the ability of an insurer to service a widespread loss event can be challenging and time-consuming. As crops (and indeed livestock) are distinctly perishable, especially following damage or death, it is sometimes the case that the claims 'evidence' has long since disappeared. Technological solutions including straightforward photographic evidence – but now including drone technology – have much to contribute to improve this situation.

Under circumstances where there are systemic losses – in which all or most farmers in a given area are similarly afflicted – it may actually be impossible to adjust all losses individually. In which case, an insurer may seek to agree a settlement value without adjusting each loss individually. Even with this relatively simplicity and such a pragmatic approach, the time taken to reach a settlement that is fair to all concerned, as it must be, is likely to be protracted.

A major performance advantage of index-based insurances is their speed of settlement. As the policy only references the index whose data components will have been very specifically detailed in the contract, the only obligation at the expiry of the contract is to obtain the index data and apply the prescribed calculation formula to establish whether a payment is due and, if so, how much.

In a wide range of index-based contracts (such as apply, for example, in the power and energy sector) and where index data (daily temperature) are readily and reliably available, the contact may provide for settlement with 15 days. This is clearly very efficient by any standards.

There is no fundamental reason why index-based policies issued to farmers should not perform in the same way. It may be the case, however, that the agency (as nominated in the policy) responsible for compiling the 'settlement data' can only obtain (or release) the data after a prescribed period, say after month end. However this fact would be known in advance and factored into the payment procedure set out in the policy.

All index-based policies need to make provision for the inadvertent failure of the primary data provider, usually a nominated weather station. If that station fails or, for some reason, is unable to report the data as required, then secondary or back-up procedures are needed. It may be the case that an alternative station is sufficiently proximate or it may be necessary to make use of alternative sources or methodologies. In any event it is essential that recovery procedures are set out in the contract. Needless to say, the need to activate back-up procedures may add an element of delay to the process but as this is already quick, it is unlikely to become problematic.

Timing of contract inception

Crop insurances are usually bound well ahead of the crop planting period. In any case this needs to fit in with the farm planning calendar but also so that coverage can be in place during the critical early stages of plant growth. It may the case that certain crop insurance contracts have final application cut-off dates that are months prior to sowing. A farmer who fails to make an application in time will find himself without the protection he/she needs.

Index-based coverages are more flexible in this regard although it is the case that index-based insurers seek to ensure that the contract is executed well ahead of the period in which a reputable forecast might be able to predict the contract outcome, or at least an increased likelihood of trigger.

This added flexibility may allow the farmer to delay the decision to take out an index-based policy under circumstances which would deny him an opportunity to buy traditional crop insurance.

Index-based insurances are not necessarily concerned with pre-existing conditions, such as soil moisture which may be a factor that determines a farmer's last minute decision to plant, or not plant.

The Use of the Earth Observation Data and Vegetation Indices

This report has referenced indices that are generally based on a single weather element measured at a physical location close to the farming area. However there are sets of indices, specifically designed to measure plant health and crop growth that are derived from satellite, remote observation data and visual imagery rather than conventional meteorological data recordings.

It is not the purpose of this report to document these in detail but they merit reference and possible consideration in any future programme design. Foremost amongst these, at least in as far as practical application in index based programmes is concerned, are those based upon the Normalised Difference Vegetation Index (NDVI). This index is essentially a relative score of the 'greenness' or density of green on a defined area of land; the measurement is made by detectors that can record the wavelengths of visible and near infra-red light reflected by plants. Chlorophyll absorbs light within a characteristic band of wavelengths (0.4 – 0.7 µm) whereas the cell structure reflect near-infrared light (0.7 - 1.1 µm). Measurement in these bands and a formulaic calculation between their difference provides an index (between minus one and plus one) that is strongly indicative of the drought status of plants in the pixel. An improvement on NDVI is the Enhanced Vegetation Index (EVI) which is similar to NDVI but is based upon improved satellite technology that reports at a much higher spatial resolution (250m) and a greater number of wavelengths.

NDVI and EVI have been successfully deployed in index-based programmes where the density of green (as opposed to, say, crop yield) is of importance: notably in the coverage of pasture and grassland used to support grazing cattle.

Other Considerations

Group Buying Power

Queensland Farmers Federation members, Canegrowers and Cotton Australia, are in a position to use their size and scale of their membership base as a way of providing more cost-effective cover to growers. Mechanisms, such as a captive insurer or discretionary mutual fund (DMF), can be used to pool risk common to growers. Such arrangements can facilitate efficient risk sharing among growers by aggregating low value, high frequency losses and funding these from a dedicated pool of shared capital, meaning that external insurer capital would only be used – and paid for – to protect against an accumulation of smaller losses or one-off large losses in excess of Canegrowers' or Cotton Australia's risk appetite.

Captive Insurer

The establishment of a captive insurance company is one way for organisations to exercise an enhanced degree of control over the provision of risk transfer products. Additional benefits that could accrue from the creation of a captive include:

- Direct access to reinsurance (wholesale) markets which would streamline the delivery of the products discussed previously and therefore reduce frictional costs
- Quarantining of exposure to insurance products within a special purpose vehicle under the full control of the organisation
- The creation of a risk management framework and culture within the organisation which could link with Best Management Practice (BMP) framework already in place to accommodate growers' existing exposures.

Discretionary Mutual Fund

Another commercially proven mechanism to provide insurance-type protection to growers is by the establishment of a DMF. An industry DMF could be established in a shorter timeframe and at a lower cost than a captive. WTW has experience in establishing DMFs and has the requisite relationships with legal firms and taxation advisers to obtain clearance of all documentation and a tax opinion before submission of necessary paperwork to the Australian Securities and Investments Commission (ASIC).

WTW operates a global Captive Management Practice with operations in all key captive domiciles which has considerable experience in establishing and managing captives and DMFs for a range of client size and industry.

The author recommends that priority be given under the DCAP 2 Project to investigating the benefits for growers of group buying power.

Regulatory Issues

Various regulatory frameworks apply to the concepts raised in this proposal. WTW does not provide legal, tax or accounting advice but is nevertheless well versed in the insurance regulatory framework in Australia and other jurisdictions. We have a strong relationship with the Australian Securities and Investments Commission (ASIC), the Australian Prudential Regulatory Authority (APRA) and their counterparts around the world.

Regulatory due diligence would therefore be an integrated component of all the work undertaken with industry bodies.

Insurance Products Conclusion & Recommendations

It is our view that the Queensland agricultural sector has an excellent opportunity to provide its farmers with protection against uninsured seasonal risks to crop production. It has been observed in the responses to the farm-level questionnaires carried out during the course of compiling this report that there remains unfulfilled demand for such protection to be made available. The Australian agricultural sector in general and the cropping sector in Queensland in particular, is extremely highly exposed to production volatility as a result of weather risks.

Index-based weather risk management contracts can be extremely simple in terms of their operation, transparency and settlement process. The payments made from these contracts can be used to compensate for lost revenue or reimbursement of costs for almost any type of agribusiness weather peril. The analytical and structuring undertaking to arrive at the most appropriate index and pay-out levels, in the interests of minimising basis risk, is however somewhat time consuming and labour intensive. For this reason, we recommend extending the DCAP project to enable the development of the most appropriate offering to Queensland's farmers.

An important part of our analysis would also allow potential solutions to be presented to farmers and develop a range of products for a variety of crop exposures for different seasons and regions. The examples used in this paper are a snapshot of the many options that can be structured, and alternative pilot programmes should be considered for analysis and structuring.

Our recommendation is that we work together to develop a pilot programme for a discreet set of exposures for a single cropping season. This would not only allow Willis Towers Watson to more fully demonstrate the value and effectiveness of such products, but also minimise the up-front cost and complexity of the analysis. Should the pilot programme gain acceptance from Queensland Farmers Federation's member bodies, additional solutions can be tailored for other crops, perils and regions.

A range of options, including multi-year and risk sharing versions, would be included in a detailed report produced from our analysis. The opportunity to build on this pilot programme would seem to be substantial given the range of weather perils faced by farmers.

Formal insurance market quotes for one or more of the options presented would then be sought from a range of highly-rated Australian and global insurers, reinsurers and specialist weather risk management underwriters. This would allow for sufficient competitive tension and counter-party security for such contracts. Capacity in excess of $200m per contract is available from specialist markets and their supporting carriers.

Internationally there are examples of Governments providing a partial insurance subsidy to reduce their financial exposure for any weather-related support. Whilst it is yet to be seen if this is a viable option for Australia, these types of initiatives should be thoroughly investigated to determine any potential savings for the Government.

8. Possible Policy Directions

Agricultural production in Australia, particularly in Queensland, is subject to volatile weather and climatic conditions such as drought, floods, storms, frost and cyclones. These risks will pose increasing challenges for farmers, as it is predicted that climate change will increase the frequency and impact of such events. Further, the Australian farm sector experiences a higher degree of production risk than other sectors of the economy.

It has been observed in the responses to the farm-level questionnaires completed while delivering this project that there is a demand for appropriate risk management tools (insurance) to be made available. Key messages from farmer surveys are that current insurance products available to Queensland farmers (specifically, cotton and sugar cane farmers) may not address critical risks to the production and/or profitability of these systems and that farmers would prefer to have a more options when deciding on insurance products that meet their business needs.

Government policy and investment can have large impacts on agricultural insurance. The South Australian, Victorian and New South Wales state governments have recently removed stamp duty from agricultural insurance, a positive and proactive step to drive agricultural insurance uptake. The Western Australian Government and New South Wales Government are also investing in weather station infrastructure to assist the agricultural insurance market.

The level of premium is still a major concern for farmers. Effective policy decisions, coupled with self-supporting low cost products may be able to deliver attractive and affordable insurance products for farmers.

Potential recommended products are climate index-based insurance for crops (e.g. sugarcane and cotton). The project has recommended index-based insurance products as it recognises the necessity for self-supporting low cost products.

The project has shown the potential for more affordable insurance projects. However, in order to ensure product affordability, innovative mechanisms need to be identified to roll out index-based insurance products. This may involve investigating options of new funds 'such as discretionary mutual funds' to roll out optimal insurance options.

It may also be possible that farmers with the appropriate Best Management Practice (BMP) accreditation benefit through a premium rate discount. The effects that viable agricultural insurance would have on risk profiling of rural lending is another area that needs to be researched with government support.

Large parts of the agricultural sector are unaware of the potential benefits of agricultural insurance and its use as a risk management tool. Therefore, there is a need to educate farmers about the value of insurance, through shed meetings and one on one facilitated meetings (e.g. phone or in person).

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10. Appendices

Appendix A Questionnaire

Drought and Climate Adaptation Programme

Producing Enhanced Multi-Peril Insurance Systems

Please note that all responses will be treated in confidence.
If you cannot or prefer not to answer any specific question, this will be understood but your fullest support would be gratefully appreciated and will provide most useful contribution to this valuable initiative.

GENERAL FARM INFORMATION

Address of Farm:					
Latitude:		**Longitude:**			
Nearest weather station to farm is:					
Farm Size:		**Irrigated:**	☐	**Dry Land:**	☐
Crop types grown:	Cotton: ☐	Sugarcane:	☐		
Other					

Crop Yields:	**Year:**	**Tonnes / Bales:**
Cost of Farm Production:	**Input:**	**Cost per Hectare:**
Gross Revenue* Per Year:	**Total:**	**Per Tonne / Bale:**

Gross Margin* Per Year: **Total:** **Per Tonne / Bale:**

REGION CLIMATE PATTERN AND RISK DESCRIPTION

Annual Rainfall: mm* at Farm (if known)

Vegetation Period Rainfall: mm* at Farm (if known)

How often have you experienced dry seasons?

Have you experienced severe drought? **Yes** ☐ **No** ☐

If Yes, specify years of occurrence:

Does drought influence significantly your production/profit? **Yes** ☐ **No** ☐

What other risks affect your production/profit:

Put risks in order of severity and importance and designate the most significant losses you have recently experienced (expressed as percentage of revenue):

Lack of Rain at planting:		
Lack of rain during season:		
Lack of rain before harvest:		
Hail:		

Fire:		
Frost (specify exact seasonal time):		
Overspray:		
Excess rain at harvest:		
Pests:		
Flood:		
Malicious damages:		
Prices:		
Marketing of crops:		
Mill or Gin breakdown:		

Other (please specify):

-

Designate the most significant losses you have recently experienced: (data cost as percentage of revenue)

Do you expect the future threat posed by droughts will increase in the future to:

Increase strongly ☐

Increase slightly ☐

Stay the same ☐

Decrease strongly ☐

How high on a scale of 1-5 do you rate the probability of incurring a loss from ...... in the near future:

1 = not at all / 5 = certain 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

RISK MANAGEMENT TOOLS APPLIED IN FARM

What risk management tools do you supply in your farm?

Irrigation: Yes ☐ No ☐

Special soil preparation technology: Yes ☐ No ☐

If yes, please specify: ____________________

Soil testing and agronomic advice: Yes ☐ No ☐

Soil moisture monitoring equipment Yes ☐ No ☐

Special varieties: Yes ☐ No ☐

Special damage reducing equipment (fences, net etc.): Yes ☐ No ☐

Insurance: Yes ☐ No ☐

Future contracts: Yes ☐ No ☐

Participation in any risk management system from government / bank / marketing company: Yes ☐ No ☐

Industry BMP: Yes ☐ No ☐

Sought information regarding current and future weather risks e.g. hail: Yes ☐ No ☐

Other (please specify): ____________________

Out of the measures you mentioned above, do you recall the costs of employing the tools identified?

Out of the measures mentioned above, on a scale of 1-5, how would you rate your capacity to implement such measures?

1 = not at all / 5 = certain 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Out of the measures mentioned above, on a scale of 1-5, how would you rate the measures ability to limit negative impacts?

1 = not at all / 5 = certain 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Did you employ one of the above mentioned measures after gaining insurance? Yes ☐ No ☐

Did you employ one of the above mentioned measures after experiencing a drought? Yes ☐ No ☐

Do you participate in Farm Management Deposit Scheme? Yes ☐ No ☐

Does it really help you? Yes ☐ No ☐

Which types of crop do you insure, if any?

The main reasons why you buy insurance?

What was the premium charged? And the coverage?

Which risks are covered by your insurance policy?

Which risks would you like to include additionally in your insurance policy?

What does not satisfy you in your insurance policy?

The size of the premium: Yes ☐ No ☐

Specific details:

The size of the deductible: Yes ☐ No ☐

Specific details:

The degree of coverage (i.e. max compensation of $10,000): Yes ☐ No ☐

Specific details:

The variety of coverage (i.e. wheat only vs. wheat and corn): Yes ☐ No ☐

Specific details:

Ease of access to insurance: Yes ☐ No ☐

Specific details:

Claim processing time: Yes ☐ No ☐

Specific details:

Other:

What price of any risk management tool is affordable for you?

What would you prefer to insure – production cost, production value, income, nominated amount?

What is your criteria for choosing an insurer or broker?

What else do you insure on your farm (property, liability, etc.)?

When buying insurance what is your primary concern in a product? i.e. the size of premium, degree of coverage, size of deductible

What would you consider to be an unaffordable insurance policy?

IRRIGATION INFORMATION

What type of irrigation system do you have?

Where do you source your water? (e.g. ground, river, captured)				
Do you have an allocation amount?	Yes	☐	No	☐
Have you received a full allocation in the past 5 years?	Yes	☐	No	☐
If no, what it the allocation as a percentage of the full amount?				

WEATHER INDEX SOLUTIONS

This section to be completed after comprehensive presentation of interviewers.

Do you understand what weather index solutions are?	Yes	☐	No	☐
Do you understand what "basis risk" is?	Yes	☐	No	☐
Would you buy a weather index solution instead of or additionally to insurance?	Yes	☐	No	☐
Are you ready to buy a weather index solution 30 days before the start of season?	Yes	☐	No	☐
How would you prefer to receive an explanation about a weather index solution that is being offered?	Yes	☐	No	☐

Appendix B Measures of assessing risk

Utility in this project is measured in terms of the revenue of the representative farmer in each location. The revenue of the farmer for a particular year is the product of the yield and price. The farmer is also interested in minimizing the variability associated with the revenue. In essence, the farmer's utility is more complete when the variability of the revenue is also considered as in the usual mean-variance theory. That is, if an actuarially fair insurance contract reduces the risk of an expected utility maximizing farmer, the farmer will prefer the insurance. However, since the interest is in minimizing the downside risk, the standard deviation may not be appropriate (Estrada 2008). Estrada (2008) noted that, until recent years, scholars and practitioners have been using the variance minimization approach because they are more familiar with it when in actual fact the semi-variance is a better measure of risk.

2.1 **Mean Root Square Loss**

In the finance literature, Markowitz (Markowitz 1952, Markowitz 1959, Markowitz, 1991, Markowitz, et al. 1993) noted that analyses that are based on the semi variance minimization tend to produce better results than those based on the full variance because investors are interested in minimizing underperformance. According to Jin, Markowitz and Zhou (2006) the major limitation of the mean-variance measure is that it only measures volatility because it penalizes the upside deviations as much as the downside deviations. Hatt, Heyhoe and Whittle (2012) affirmed that the position of farmers as utility maximisers and downside risk minimisers is the same as those of other investors.

Jin, Markowitz and Zhou (2006) presented two forms of semi variance analysis. The first form is the expected squared negative deviation from the expected value, also known as, the below-mean semi variance. The second is the expected squared deviation from some fixed value. The fixed value could be benchmarked as a zero return or another target value like the median or a given level of return. Several authors have alluded to the attractive features of the mean-target semi variance model as noted in Fishburn (1977, p. 116). The models in a portfolio context as put forward by Jin et al (2006, p.55) are as follows:

The total return of the ith security during the period is a random variable ξi meaning that the payoff of one unit investment in security i is ξi units, i = 1, 2. . . , n. Suppose E(ξi) = ri and Var(ξi) < +∞.

$$\text{minimize} E[(\sum_{i=1}^{n} x_i \mathcal{E}_i - E\left(\sum_{i=1}^{n} x_i \mathcal{E}_i\right))^{-}]^2 \qquad (1)$$

Subject to the constraints $\sum_{i=1}^{n} x_i = a$ and $\sum_{i=1}^{n} x_i r_i = z$

where xi ∊ R represents the capital amount invested in the ith security, i = 1, 2, . ., n

(hence x := (x1, . . . , xn) is a portfolio), a ∊ R is the initial budget of the investor, and z ∊ R a pre-determined expected payoff. Here x−:= max (-x, 0) for any real number x. This problem is also referred to as below-mean semi variance model.

In contrast, the second problem, termed below-target semi variance model, is the following:

$$\textit{minimize } E[(\sum_{i=1}^{n} x_i \, \mathcal{E}_i - b)^{-}]^2 \qquad (2)$$

Subject to the constraint: $\sum_{i=1}^{n} x_i = a$

Where b ∈ R represents a pre-specified target.

The Mean Root Square Loss (MRSL) adopted by Vedenov and Barnett (2004) uses the first model presented above. Vedenov and Barnett (2004) used the MRSL as another measure of risk and it was found to be appropriate in this context because the minimization of the semi-variance rather than the full variance is of relevance since farmers are mainly interested in managing their downside losses like all rational investors. In this project, we intend to use the MRSL based on the mean since we expect farmers to be concerned with below average revenue. For different contracts (5th, 10th and 30th percentile contracts), the MRSL may be computed to observe the extent to which the downside risk below the mean is minimized. Hence, if the MRSL reduces with insurance, then the contract is efficient at that strike level or contract for that location.

The revenue without contract is given by:

$$I_t = pY_t \quad (3)$$

and with contract is:

$$I_{t\alpha} = pY_t + \beta - \theta \quad (4)$$

Where; I_t = revenue at time t without insurance, p = price of agricultural commodity, $I_{t\alpha}$ = revenue at time t with alpha percentile level of insurance, Yt = yield at time t, βαt = insurance payout for that level of insurance in that year and θα = the yearly premium for that level of insurance and is constant throughout the years in question, MRSL is the Mean Root Square Loss without insurance and MRSLα is the Mean Root Square Loss with an alpha level of insurance. These values differ by location but a location subscript is not included in the formula for simplicity.

$$\text{MRSL} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[\max(p\bar{Y} - I_t, 0)]^2} \quad (5)$$

$$\text{MRSL}\alpha = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[\max(p\bar{Y} - I_{t\alpha}, 0)]^2} \quad (6)$$

2.2 **Conditional Tail Expectation**

Another measure of risk is the Value at Risk (VaR). The VaR emphasizes the maximum reduction in revenue that will not be exceeded at a given level of probability. In finance literature, the VaR is typically used to analyse the risk to portfolio returns because volatility does not discriminate between the downside and upside of the revenue distribution whereas, the VaR captures the downside risk at a given alpha level. The VaR could be estimated by historical method, variance–covariance method or with monte-carlo simulation. The essence of calculating VaR is to assess the worst cases over a given period of time at a pre-specified level of probability. This method was adopted by Vedenov and Barnett (2004). However, VaR is not without its shortcomings.

The VaR is considered incoherent and does not satisfy the required axioms of an appropriate risk measure (Acerbi & Tasche 2001). Therefore, the Conditional Value at Risk (CVaR) is preferred. Alternative names for CVaR are Conditional Tail Expectation (CTE) and Expected Shortfall (ES). The CVaR improves on the VaR because it captures the expectation beyond the VaR. In essence, while the VaR tells us that the farmer's loss may not exceed a certain amount, the CVaR tells us about the expectation of the loss should the VaR be exceeded. Rockafellar and Uryasev (2002) also derived some fundamental properties of the CVaR that makes it a better measure of risk than the VaR. Some of these include coherence and stability.

The CVaR analysis in this project is to be measured at the 5th, 10th and 30th percentiles. In essence, the expected revenue in the worst 2, 4 and 12 years in a 40–year period under both constant and variable commodity price assumptions are proposed to be analysed. The purpose of this analysis is to know whether or not insurance will increase the revenue of farmers in the worst two years of rainfall, the worst four years of rainfall and the worst 12 years of rainfall in a 40-year period. If the contract is efficient, then the utility of the farmer, measured in terms of revenue, should increase in years when droughts are experienced. Should the contracts be triggered in years that did not match with the years of drought, the CTE decreases due to the deduction of the premium. Should the payout be equal to the premium every year when the contract was triggered, the farmer will be indifferent and if the payouts outweigh the premiums for those years, the farmer would have derived value from the insurance contract.

Based on the work of Brazauskas et al. (2008, p. 3591), the CTE risk measure, or function, can be defined as follows: given a loss variable X (which is a real-valued random variable) with finite mean **E**[X], let F_X denote its distribution function. Next, let F_X^{-1} be the left-continuous inverse of F_X called the quantile function in the statistical literature. That is, for every $t \in [0, 1]$, we have:

$$F_X^{-1}(t) = inf\{x: F_X(x) \geq t\} \quad (7)$$

With the above notation, the CTE function is defined by;

$$CTE_X(t) = \boldsymbol{E}[X/X > F_X^{-1}(t)] \quad (8)$$

Some scholars have used these methodologies in the analysis of the efficiency of weather index insurance. In particular, Kapphan (2012) adopted both the VaR and the CTE in the analysis of optimal insurance contracts in Schaffhausen Switzerland. Vedenov and Barnett (2004) adopted the VaR, MRSL and Certainty Equivalence of Revenue (CER) in the analysis of a range of contracts designed for different crops at diverse locations in the US.

2.3 **Certainty Equivalence of Revenue**

The next risk measure we propose to use is Certainty Equivalence of Revenue (CER). Since the value and cost of shifting risk is derived from the tendency to be risk averse (Arrow 1996) researchers have attempted to quantify this value in utility terms (Arrow 1964, Arrow 1971, Henderson & Hobson 2002). The value of the insurance therefore explains why an individual will be willing to pay an actuarially unfair price to have the insurance. By paying the actuarially unfair price, the individual has paid an additional premium for covering the risk. Hence, the individual may be able to pay the actuarially fair premium if the insurance is only reasonably valuable but may not be able to pay the actuarially unfair price if it is not much more valuable in terms of utility maximization and downside risk minimization.

Based on experience, individuals who accept a price under a voluntary insurance scheme without subsidy creates interests not only for themselves but also for the insurer (Arrow 1996). Therefore, a necessary condition for insurability is the willingness of the representative farmer to pay for an actuarially fair contract because the willingness to pay for a fair contract is a necessary but insufficient condition to pay for an unfair contract. A useful concept in the analysis of the utility of risky alternatives is an expression of the willingness to pay for a certain equivalence of the risky alternative. In this project, the CER of actuarially fair contracts was analysed. If the CER increases with the insurance contracts, then, the insurance contracts have made the farmer to opt for an additional value as a certain equivalence implying that the contracts have added value to the revenue distribution of the farmer.

There are different models that could be adopted in the context of individual's risk aversion under the assumption that an individual is non-satiated. By non-satiation, the utility of X+1 > X. This implies that more revenue is preferred to less revenue. However, it should be noted that marginal utility of a unit increase in wealth may differ. In essence, an increase of a dollar for someone who owns no money is different from the same unit increase for someone who already owns $100. The individual with an initial wealth of $100 may select a fair gamble on the $1 increase whereas the individual with a zero initial wealth may not be able to take as much risk but would prefer to have a certain equivalence of the increment. In this project, the implication of initial wealth is ignored by selecting a utility model that expresses certainty equivalence of revenue with assumptions that are compatible with the context of this project.

Since the farmer prefers higher revenue and lower risk as modelled using the Conditional Tail Expectations and mean-semi variance, the logarithmic utility model of CER was adopted. This model assumes that the farmer is risk averse, prefers more to less and that the percentage of wealth invested into production is constant irrespective of changes in wealth (Elton et al 2003). The risk aversion of Australian farmers and the differences in their risk attitude have been well affirmed in literature (Bardsley & Harris 1991; Ghadim & Pannell 2003; Khuu & Weber 2013). It was assumed that the representative farmer in each shire exhibits a constant relative risk aversion (CRRA) (Henderson & Hobson 2002). Kapphan (2012) similarly assumed CRRA in the analysis of optimal weather insurance contracts for a region in Switzerland. However, the model adopted in this project is less complicated than Kapphan (2012). Quiggin and Chambers (2004, p. 249) has shown that;

> *In some applications, the additive functional form associated with the expected-utility model proves useful as a simplifying assumption, but for most purposes the assumption of risk-aversion is sufficient to permit a simple and informative analysis.*

The Constant Relative Risk Aversion, based on the model of Elton et al. (2003) (p. 219):

$$\frac{1}{T}\sum_{i=1}^{T} \text{Ln}\, I_{t\alpha} \tag{9}$$

Where all variables are as defined earlier.

The three models, Conditional Tail Expectations (CTE), Mean Root Square Loss (MRSL) and Certainty Equivalence of Revenue (CER) are used to assess the efficiency of the crop insurance contracts. The impact of the insurance will be analysed by finding the percentage difference between the revenue of the farmer without insurance and with insurance at different strike levels. The percentage difference if positive for CTE and CER implies that the contract will be efficient whereas a negative difference implies efficiency for MRSL since the objective of the contract is to reduce the downside risk of the farmer's revenue.

1.4 Measurement of diversifiability of a portfolio of crop insurance premia

The Loss Ratio (Lt) is the ratio of the indemnity paid to premiums collected. Pooling the premiums and indemnities across different shires and over time helps to examine the spatial and temporal covariate structure of the risk. The L_t is calculated as follows:

$$L_t = \frac{\sum_{l \in L} \Pi_{lt}}{\sum_{l \in L} P_{lt}} \tag{14}$$

and when pooled over time, it becomes;

$$L_t = \frac{\sum_{t \in \tau} \sum_{l \in L} \Pi_{lt}}{\sum_{t \in \tau} \sum_{l \in L} P_{lt}} \tag{15}$$

Π=Indemnities, P = Premium, L = locations, τ = time (the pooling could be based on 1, 2, 5 and 10 years).

If L_t is lower than 1 (L_t<1) , it indicates that the premium collected is more than the indemnities paid and therefore the insurer makes a profit, when it is 1 (L_t = 1), it implies a breakeven in that the indemnities paid is exactly equal to the premium and when it is above 1 (L_t >1), it means that the insurer experienced a loss for that period in that indemnities paid is more than the premium collected (See Chantarat 2009 pp. 108 – 110).