

Developing potential adaptations to climate change for farming systems in Western Australia's Northern Agricultural Region using the economic analysis tool STEP

Megan Abrahams¹, Chad Reynolds¹, Dennis van Gool³, Kari-Lee Falconer², Caroline Peek¹, Ian Foster³ and Daniel Gardiner

¹Department of Agriculture and Food, Western Australia, 20 Gregory St, Geraldton; 6530 ²Department of Agriculture and Food, Western Australia, 20 Roberts St Moora; 6510 ³Department of Agriculture and Food, Western Australia, Baron-Hay Court, South Perth, 6151

Correspondence to kari-lee.falconer@agric.wa.gov.au 61 8 9651 0537

Abstract. Climate change is expected to have a significant effect on agricultural production but less is known about its projected impact on the farm business. This paper provides a first attempt at an economic analysis of the impacts of climate change for broadacre farming systems and provides an insight into agricultural production areas in Western Australia at risk over the next 50 years. These risks have been assessed using the Simulated Transitional Economic Planning (STEP) model to investigate the impact on the farm business. Modelled future climate scenarios were incorporated into crop and pasture production models to examine the economic impact on the whole farming system. Uncertainties associated with climate and production projections were captured through the development of scenarios and sensitivity analyses were performed to encompass a range of potential outcomes for the impact of climate change on the farming systems of the northern wheat-belt.

Testing of this process showed that the current farming systems of the region may decline in profitability under climate change to a point where some become financially unviable in the long term. This decline in profitability is driven not only by the decline in crop yields from climate change but also from a continuation in the trend of declining terms of trade. With innovation and adaptation it may be possible to overcome these impacts on the region's farming systems even under severe (CSIRO Mk2) climate change projections. Potential profitable adaptations under climate change included a combination farming system of trade cattle, opportunistic cropping and carbon sequestration from oil mallee trees in the low rainfall area; investment in technology and genetically modified crops in the medium rainfall area; and in the high rainfall area a combination of increased crop area on the better soil types and the use of perennial pastures on the poor soil types. The findings are dependent on the accuracy and validity of future climate projections, crop yield estimates and the economic conditions used in the STEP model. Use of this process has improved understanding of the potential impacts of climate change and facilitated regional planning, decision making and the setting of research and investment priorities. However, additional fine-tuning of the analysis and further exploration of alternatives is necessary before policy decisions are made on the future of agriculture in Western Australia's northern wheatbelt.

Key words: Farming systems, climate change, STEP, economics

Introduction

Australia's changing climate is part of a global trend. However, despite general consensus on the causes and likelihood of climate change, projections of our future climate vary across Australia (Whetton et al. 2005). In addition the impact of climate change on agricultural production is likely to vary across regions (Howden and Jones 2004). Crop, pasture and livestock production will be directly affected by changes in average temperatures and rainfall, and by changes in the distribution of rainfall throughout the year.

The Northern Agricultural Region (NAR) of Western Australia is one area that faces large uncertainties over the possible impacts of climate change, especially with regard to responses at a farming system level. Characterised by warmer seasons and lower rainfall than other broadacre agricultural regions in the state, the north-eastern low rainfall area of this region is expected to suffer the greatest changes in productivity as

a result of the shorter growing season and an unpredictable season start (late-April to mid-June). Combined with crop water deficits and high temperatures in the spring these conditions already limit wheat yield in the area (Kerr et al. 1992). While higher average temperatures and declining rainfall could transform traditional agricultural production in the NAR, we do not have a clear picture of;

- (i) whether the current farming systems will remain viable under new climatic regimes, or
- (ii) what adaptations can be made to our farming systems to ensure their sustainability and the cost of implementing these adaptations.

Mitigation strategies at a global and national level are aimed at reducing the extent of climate change but it is essential that local strategies are developed to adapt farming systems to the changing climate (Scheraga and Grambsch 1998). However, the ability of farming systems to adapt to climate change

is currently limited by a lack of decision support tools to evaluate the impacts of climate change on regional farming systems and the transitional costs of future farming systems. This report discusses the possible effects of climate change on farming systems at a farm level, explores possible adaptive strategies to deal with these impacts and examines the transitional costs associated with moving towards these strategies.

Materials and methods

Study area

The northern agricultural region of Western Australia (latitudes 27.7 to 31.3°C) has a typical Mediterranean climate with most of the rainfall occurring in the winter months. The region is divided into three distinct zones based on annual rainfall and soil types, each with a characteristic farming system (Figure 1). These high (450–750 mm), medium (325–450 mm) and low rainfall (<325 mm) zones extend in bands inland from the west coast. The low and medium rainfall zones focus mainly on broadacre agriculture heavily reliant on the production of wheat. In the high rainfall zone farming systems are more variable. They have traditionally been based on livestock for meat and wool production but cropping has increased over the past 10–15 years and there is also a small growing horticulture industry.

Overview of process

The process used to investigate the impact of climate change on farming systems was to:

- (i) Develop model farms representative of the major farming systems in the northern agricultural region of Western Australia
- (ii) Establish current climate and future projections for a set of climate scenarios
- (iii) Model the impacts of projected climate change on crop and pasture production
- (iv) Assess the effect of the production changes on the annual surplus or deficit of the model farms over 50 years using the STEP model and perform sensitivity analyses and
- (v) Assess the financial performance of potential alternative adaptations in response to climate change using STEP.

Different methods to assess the effect of climate-induced production changes were developed and tested on the three farming systems presented.

Model farms for the northern agricultural region

Three model farms were developed to represent the major farming systems in each of the three rainfall zones.

The low rainfall farm, developed using soil type data from the north-eastern area of the region represented an average farm business in the low rainfall zone (<325 mm annual rainfall) (Clarke 1995). The 4,315 ha farm comprised 60% cropping and 40% volunteer merino flock. The cropping and livestock rotations reflected the current land use of local farming systems. Yields and variable costs were based on a survey of local farmers with the yields based on long-term averages for each soil type. Soil types ranged from higher yielding red loamy sands (wheat 1.8 t/ha) through to low yielding shallow, acidic or saline soils (wheat 0.8–1.2 t/ha). Other financial data were obtained from agricultural benchmark surveys (Bankwest 2003, 2005) and general financial estimates for cropping and livestock enterprises of Western Australia's northern agricultural region (Department of Agriculture Western Australia 2002, 2005). As crop yields fell below breakeven they were replaced with low-cost volunteer pasture.

The medium rainfall farm was based on a grower case study of a high production sandplain farming system typical of the medium rainfall zone (325–450 mm annual rainfall). The 3,500 ha farm comprised 80% cropping, in a wheat–lupin rotation, and 20% volunteer pasture supporting a self-replacing merino flock. Cropping 80% of the farm was considered the optimal enterprise mix for maximising profit while achieving good weed control in an environment where herbicide resistance is a serious threat to the sustainability of the system (Grima 2007). The crop yields were the long-term average yield for the soil type (wheat 2.5 t/ha, lupins 2.0 t/ha).

In the high rainfall zone (450–750 mm annual rainfall), the model farm was based on a grower case study of a mixed enterprise farm. The 5,000 ha farm comprised 55% cropping in a wheat–lupin rotation and 45% pasture for running trade wethers. Soil types ranged from high yielding gravelly loams (wheat 4.5 t/ha) through to lower yielding white/yellow sands (wheat 3 t/ha). The cropping phase ran on a five-year rotation (three wheat years with a lupin crop between each wheat year) before being put back into pasture for three to six years depending on the soil type.

Farm gate crop prices for the three farms were modelled at \$250/t wheat and \$240/t lupins over a 50-year period. These prices were the best estimates of future long-term average farm-gate prices at the time of the analysis as determined by consultation with regional economists (Rob Grima, Department

of Agriculture and Food WA, pers comm. July 2008).

Modelling climate change in the test region

Climate scenarios were developed using the on-line OzClim program, available from <http://www.csiro.au/ozclim/home.do>.

The rainfall and temperature data generated for climate scenarios in OzClim were used to model the impact on future crop yields using a modification of the rainfall-driven French and Schultz (1984) equation. The equation was modified to suit each of the crops being modelled using previous estimates of water use efficiency (French and Schultz 1984; Hall 2002 Tennant 2001) and to reflect maximum yields from trials under ideal conditions. It was then further adjusted for excessive rainfall, soil capability class, and minimum and maximum temperatures (Van Gool and Vernon 2005; 2006; Vernon and Van Gool 2006). Van Gool and Vernon's (2005) wheat yield equations have been updated since publication and are shown below:

$$[1] \text{ (If } GR \leq 300 \text{ mm)} \text{ MY} = WUE1 \times (GR - WL) \times WAc \times LCc \times Mintc \times Maxtc$$

$$[2] \text{ (If } GR > 300 \text{ mm)} \text{ MY} = WUE2 \times GR + YI \times WAc \times LCc \times Mintc \times Maxtc$$

MY = mean yield

WUE1 = water use efficiency of 11.6 kg/mm

WUE2 = water use efficiency of 0.6 kg/mm

GR = growing season rainfall 1 April to 31 October, plus 20% of rainfall for 1 November to 30 March (The 20% accounts for initial soil moisture available to the crop)

WL = water loss. WL = 115 when GR \geq 150 mm/year; WL = GR \times 0.77, when GR < 150 mm/year

YI = 1635 kg (Yield at the intercept of two linear regressions of mean wheat yield versus corresponding rainfall record)

WAc = waterlogging constant (has a value of 1.0 for northern agricultural region where annual rainfall is below 700mm)

LCc = land capability class constant (Table 1a)

Mintc = minimum temperature constant (Table 1b)

Maxtc = maximum temperature constant (Table 1c)

WUE1, WUE2 and YI were calculated from linear regression of mean wheat yields obtained from 1995-1999 Co-operative Bulk Handling Limited grain receival data and corresponding Australian Bureau of Meteorology rainfall records (unpublished data).

This model is a useful tool for combining complex data and expert knowledge. However, it does not consider increased atmospheric carbon dioxide levels which may

offset some of the negative effects of temperature on yield (Ludwig and Asseng 2006), climate variability or climate extremes which are likely to increase with climate change (IPCC 2007).

An alternative crop simulation model APSIM-Wheat incorporating atmospheric carbon dioxide levels and climate variability was also used as an additional scenario in the analysis of the low rainfall farming system. Farre and Foster (2008) used the APSIM-Wheat model to compare simulated crop yields at different locations in Western Australia for two 30-year periods representing the current (1975-2004) and future (2035-2064) climates. The yield changes predicted using APSIM-Wheat modelled for the low rainfall area were of the same direction but about one-third of the magnitude as those using the modified French-Schultz approach. Therefore, in the economic analysis of the low rainfall farm under climate change the effect of predicted crop yields modelled using both the APSIM-Wheat and modified French-Schultz methods were included (see description below).

Modelling the effect of climate on future pasture growth

Modelling pasture production under climate change is also critical for a clear picture of the likely impacts of higher temperatures and reduced rainfall on livestock operations. The growth and quality of pasture may be affected by changes in rainfall amounts and variability, temperature and carbon dioxide concentrations. It was assumed that there was minimal impact on livestock productivity from climate change.

For the low and medium rainfall farms management of livestock and pasture is secondary to crop management. Livestock were grazed on annual volunteer pastures and pasture growth was estimated using a simple modified French-Schultz equation developed for the area (Rob Grima, Department of Agriculture and Food WA, pers comm. February 2007):

$$PG = (GSR \text{ mm} - 100 \text{ mm}) \times 28 \text{ kg DM/ha}$$

PG = pasture growth

GSR = growing season rainfall from 1 April to 31 October

DM = dry matter (Pasture production is measured in tonnes of dry matter per hectare.)

Livestock numbers in the model farms were adjusted to match the pasture available.

For the high rainfall farm, which is more livestock-focused, it was more important to accurately match livestock numbers to the carrying capacity of its pastures under climate change. Therefore, the more

sophisticated Sustainable Grazing Systems model (Johnson et al. 2003; Johnson et al. 2008) was used to calculate the annual and perennial pasture growth in response to different climatic conditions. The climatic factors driving the processes within the model are primarily solar radiation, temperature, humidity, rainfall and wind speed. The current climate for the high rainfall area was simulated using historical climate reference data for the period 1901 to 2008 inclusive from the Australian Bureau of Meteorology's SILO database (www.bom.gov.au/silo). The predicted future climate was generated in the on-line OzClim program (Version 3.0) (www.csiro.au/ozclim/home.do) using the latest version CSIRO Mk3 global climate model. A range of low, medium and high emission scenarios (scenarios B1, A1B and A1F1 in IPCC 2000) were investigated to scope the future pasture production for the area. Total growth for annual (ryegrass) and perennial (Rhodes grass) pastures was simulated on different soil types for the current climate and for the predicted future climate in the years 2030 and 2070 (Johnson 2009).

The difference in modelled pasture production between the current base climate and predicted future climate under each climate change scenario was calculated as a percentage change per annum. Livestock numbers in the model farms were adjusted to match the pasture available. The pasture requirements of livestock were calculated by assuming a Dry Sheep Equivalent will consume 1 kg of pasture per day. Pasture utilisation of the livestock on the model farm was calculated as:

$$\frac{\text{(pasture required for feed)}}{\text{(total pasture available)}}$$

It is difficult to predict the potential impact of heat stress and climate extremes on livestock under climate change. For the purposes of this study, it was assumed that these effects were minimal through adaptations in management (e.g. provision of shelter and water), animal behaviour (animals seeking shade, feed) and species selection. Livestock were assumed to be more resistant to climate change than crops due to their mobility which allows them to seek shelter and access available feed (IISD/EARG, 1997). Using STEP to model the economic impact of climate change.

The economic impact of the production changes modelled for the farms under each climate scenario was investigated using the STEP model. STEP consists of Microsoft Excel spreadsheets that allow whole farm cash flow to be tracked through a transition from one

farming system to another over a period of up to 50 years (Peek and Abrahams 2005).

The impact of climate change on the annual surplus or deficit was assessed over 50 years and compared to the current farming system without climate change impacts. Annual surplus or deficit was calculated as gross farm income net of total costs where costs included all capital, fixed and variable costs, taxation and personal drawings. To reflect improved efficiencies through normal advances in breeding, management and technology, the current farming system was modelled without the impact of climate change with an annual increase in crop yield each year. As the average yield increase of all crops in Western Australia over the last 20 years was 2% per annum (Stephens 2002) this value was used for the medium and high rainfall farming systems. Given the rainfall limitations of the low rainfall system, continued future yield improvements at the rate of 2% pa over the next 50 years was considered unrealistic. A rate of 0.5% was estimated to reflect a more realistic trend in yield improvements.

Declining terms of trade were included in the model to reflect the fact that input costs have been increasing at a faster rate than returns for more than 25 years (Mullen 2011). Hence, costs were increased at a rate of 3% per annum while returns were increased at only 2%.

A modified French-Schultz crop yield model projected changes in crop yield between 2007 and 2056. These were expressed as an annual linear percentage decline in yield for each climate scenario for each farming system and inserted into the STEP model.

To reflect real-life management the predicted decline in yield of the low rainfall farm was matched by modelled changes in farm management. Land was removed from crop production and increasingly devoted to livestock once crop yields fell below breakeven. The carrying capacity of pasture also declined under climate change but stock numbers were increased as the area of pasture increased. In addition, total input costs were reduced as less area was sown to crop. For the medium and high rainfall farms, which had higher crop yields and were modelled with a 2% annual increase in yield, the enterprise mix of the model farm was kept constant throughout the analysis. In addition the modelled effect of climate change on pasture production was negligible so livestock numbers were also maintained. In the climate change scenarios where crop yield declined input costs were reduced proportionately.

Future scenarios

With uncertainties in the accuracy of future climate and yield predictions, the financial viability of the model farms were further tested to scope the sensitivity of other possible future impacts under climate change on the farming systems. Scenarios tested included an alternative crop yield model and additional annual yield change scenarios to investigate the impact that additional variation in crop yield penalties had on the farming systems.

APSIM-Wheat was used as an alternative crop yield model to calculate future crop yield predictions for the low rainfall system (Farre and Foster 2008). APSIM-Wheat incorporates atmospheric carbon dioxide levels into crop yield calculations and models seasonal variability. Wheat yields were based on climate projections from a downscaled version of the later-released CSIRO Mk 3 global circulation model.

For the medium and high rainfall areas two annual yield change scenarios, 0% and 1%, were used to represent a combination of yield decline due to climate change and a level of yield increase due to advances in technology and management. Costs for these potential improvements were not factored into this analysis. These future scenarios were compared to the current system with no climate change at the current rate of crop improvement. All data into the model were validated through consultation with growers, researchers and/or agribusiness.

Sensitivity analyses

The relevance and strength of the input variables were assessed using sensitivity analyses to determine their impact on the potential outcomes. The financial performance of each model farm, under the CSIRO Mk2 climate scenario, was tested for sensitivity to:

- (i) Crop price — a base long-term average farm-gate price of \$250/t wheat, \$240/t lupins was compared to future lower prices of \$210/t wheat, \$200/t lupin.
- (ii) Terms of trade. In recent years the trend of declining terms of trade has slowed. To determine how better terms of trade would affect the financial viability of the model farms under climate change, currently declining terms of trade, where costs increase at a faster rate (3%) than returns (2%), were compared to projected future neutral terms of trade, where costs and returns both increased at the same rate of 2%.

The financial performance of the medium rainfall model farm was also tested for sensitivity to:

- (iii) Crop yield — the current average yield (2.5t/ha wheat, 2t/ha lupins) was compared to a high potential yield (3.1t/ha wheat, 2t/ha lupins) and a low yield (2t/ha wheat, 1.5t/ha lupins), that is currently achieved by growers in the eastern edge of the medium rainfall zone.

In addition, the financial performance of the high rainfall model farm was tested for sensitivity to:

- (iv) Livestock numbers — current stock numbers, utilising 24% of the pasture available, were compared to increased livestock numbers resulting in pasture utilisation rates of 35% and 50%.
- (v) Cost of fertiliser inputs. In 2008, world fertiliser prices reached an unprecedented high. For the analysis of climate change impact on the high rainfall farm, fertiliser costs were based on June 2008 prices. Fertiliser prices continued to rise until the end of 2008 after which some fell to below the June 2008 levels. Hence current costs, based on June 2008 fertiliser prices, were compared to a 7.8% increase (using December 2008 prices) and a 1.6% decrease (February 2009 prices).

Testing potential adaptations to climate change using STEP

On-farm adaptations may play a role in reducing the impacts of climate change but their potential can be difficult to assess. STEP modelling provides a new approach to evaluate a potential adaptation by assessing the annual surplus or deficit of the model farm under a new or altered farming system. Using sensitivity analysis the production thresholds necessary for the farm to maintain an annual surplus can be determined. This process assists in highlighting the risks associated with implementing the new system and the knowledge gaps requiring research before trialling of the option can be considered. STEP was also used to compare the financial viability of different strategies of transition to a new system.

The current farming systems of the northern agricultural region were found to decline in profitability when modelled under the climate change projections of the CSIRO Mk2 scenario. Therefore, several potential adaptations to climate change were tested using STEP analysis.

Testing adaptations for the low rainfall farm

A combination farming system of a trade cattle pastoral alliance, oil mallee trees planted for carbon trading and opportunistic cropping was investigated as a potential adaptation for the low rainfall farming system. This adaptation used technologies and practices already in use by some farmers in the region.

Previous analysis identified a rapid transition phase strategy to a pastoral trade cattle alliance to be the most profitable (Megan Abrahams unpublished data). Under this scenario sheep were sold in the first year and replaced with trade cattle from pastoral regions. Opportunistic cropping operations occurred two in every ten years on the best cropping soil types achieving the current long-term average yields for each soil. Capital development and depreciation costs were reduced to reflect the lower frequency in use of cropping machinery.

Sensitivity to two crop prices (base long-term average farm-gate price of \$250/t wheat, \$240/t lupins and future lower prices of \$210/t wheat, \$200/t lupin) and two weight gains per head (120 kg and 180 kg) under conditions of declining and neutral terms of trade were tested. Two carbon prices (\$10/t CO₂ eq/ha and \$50/t CO₂ eq/ha) were also tested for each wheat price scenario and two fertiliser prices—base fertiliser input prices in July 2008 were compared with fertiliser prices reduced by 60% to 2007 prices. In this analysis cattle were stocked across the whole farm over winter with a stocking rate of 3 DSE/ha. This required an annual supply of up to 1,400 young steers at the start of winter or only 350 steers in a year where land was opportunistically cropped.

As the growth rate of the oil mallee trees and hence their potential to sequester carbon slows after about 30 years, this system was only tested over a 30-year period. During this period the oil mallee was assumed to maintain a constant growth rate (7 t CO₂ equivalent per annum per hectare). Additional future incomes from oil mallee products such as eucalyptus oil, wood pellets and activated carbon may also be possible but were not included in the analysis. The average annual surplus or deficit of the farm was expressed in today's dollar value by discounting at 8%.

Testing adaptations for the medium rainfall farm

Increasing crop area using genetically modified (GM) crops was investigated as a potential adaptation to overcome yield constraints on increased profitability of the medium rainfall farming system under

climate change. The crop rotation was modified by replacing pasture with GM lupins and canola. This increased the crop area in the farming system where the profitability was threatened by annual ryegrass and wild radish weeds developing resistance to selective herbicides.

Pasture paddocks were removed from the rotation and replaced with GM crops tolerant to the non-selective herbicide glyphosate. It was assumed that the GM crops, Round-up Ready canola and lupins, were available for use in 2011 and integrated weed management was used in addition to herbicide use (Diggle et al. 2009).

STEP analysis was conducted on both (i) an immediate transition, in which the new GM cropping rotation was introduced over two years beginning in 2011, and (ii) a delayed transition, where introduction of the new GM rotation was delayed until 2016. The annual surplus or deficit of the farm under the transition strategies was compared to the current system under climate change.

Annual ryegrass resistance to the glyphosate herbicide is likely to develop after 22 years using this GM cropping rotation and weed control strategy (Diggle et al. 2009). After this time a new strategy would need to be adopted to manage herbicide resistance. Hence, the annual surplus or deficit of the farm for the GM system under climate change was investigated over a 25-year period. Average crop yields were used with the farm-gate crop prices at \$250/t wheat, \$240/t lupins and \$560/t canola. (N.B. Where wheat in the rotation was grown after another wheat crop, the price was reduced to \$245/t).

Testing adaptations for the high rainfall farm

To improve the profitability and longevity of the high rainfall system a combination strategy of increased crop area on soil types that maximise profit and perennial pasture area for livestock production on soil types that minimise input costs was investigated. This adaptation aims to reduce the cost of the current high input system on poor performing crop paddocks and improve the profitability on the poorest soils through increased livestock production.

Crop area on the farm was increased from 55% to 66% of the farm by replacing two pasture years with crop on the better gravel and loam soils. Perennial pastures replaced crops and annual pastures on the poorest sand soil types with livestock numbers adjusted to match the improved feed production.

Three transition phase strategies were tested to determine the most profitable timeline to

convert the poorest sands to perennial pastures and increase livestock numbers:

- (i) A fast transition, in year one - all 1,500 hectares of the poorest soil planted to perennials
- (ii) A fast transition over the first two years, approximately half the area was planted in year one and half in year two while crop area was continued until perennials were planted.
- (iii) A delayed transition to the new farming system over the first eleven years – one paddock planted to perennials each year until completed.

For all transitions excess livestock were sold prior to the establishment year when the perennials cannot be grazed. Additional livestock were bought once the perennials were established to retain a pasture utilisation rate of 24% across the farm. The cost of establishing the perennial pasture was \$150/ha with an additional one-off cost of \$20/ha for infrastructure, such as fencing and more water points to accommodate higher stock numbers.

Results

Modelled impact of climate change on crop yields

Climate scenarios for the low, medium and high rainfall areas of Western Australia's northern agricultural region projected an increase in minimum and maximum spring temperatures and a decrease in annual and growing season rainfall (Table 2).

Due to the negative effects of higher maximum temperatures and reduced growing season rainfall, crop and pasture production were also projected to decline. The total reduction in crop yield predicted under the CSIRO Mk2 and Hadley climate change scenarios between 2007 and 2056 was expressed as an annual percentage decline in yield for each farming system (Table 3). Pasture modelling predicted a small reduction in pasture growth but this had little effect on livestock numbers on the farms. The economic impact of the modelled change in climate on crop and livestock production for each representative model farm is described below.

Economic impact on low rainfall farming system

The economic modelling showed that the predicted impact of climate change on crop yields could make the current low rainfall farm financially unviable within a few decades. Annual yield declines of 1.5% for the Hadley climate scenario and 1.3% for the CSIRO Mk2 climate scenario modelled using the modified French-Schultz crop yield

modelling approach caused the farm to fall into deficit within about 20 years (Figure 2). The reduction in the farm's annual surplus was driven by both the predicted yield decline under climate change and the current trend in declining terms of trade.

A lower annual yield decline of 0.4% has been predicted for the low rainfall area by the APSIM-Wheat crop model which incorporates yield impacts from atmospheric carbon dioxide and variability in interannual rainfall (Farre and Foster, 2008). Although the annual surplus of the farm under the APSIM-Wheat scenario is gradually reduced over time the farm is still profitable for almost the entire 50-year period (Figure 2).

When the current farming system was modelled without the yield effects of climate change the annual 0.5% yield increase from normal advances in breeding, management and technology maintained an annual surplus over the entire period (Figure 2). The graph shows this annual surplus to be increasing with time because the surplus has not been discounted to today's dollar value.

Stochastic effects were present in the graphs generated from the low rainfall farming system in difference to the smooth transitions graphed in the medium and high rainfall farming system. This reflects the higher risk profile of the low rainfall farming system and the greater sensitivity of low rainfall farm profitability to changes in crop yield and crop area which results from the yearly rotation of crop types on different land management units.

Sensitivity analysis The profitability of the low rainfall farm was tested for sensitivity to lower crop prices and improved terms of trade. Lowering crop prices by only \$40/t markedly reduced the profitability of the low rainfall farming system which stayed in deficit after 7 years for the CSIRO Mk2 and Hadley scenarios and in 10 years for the APSIM-Wheat scenario (data not shown). Using the base crop prices, but with terms of trade increased to a neutral status, the farm remained profitable under the CSIRO Mk2 climate scenario for a further 10 years (data not shown).

Economic impact on medium rainfall farming system

Crop modelling for the medium rainfall farming system predicted an annual yield decline under climate change at the rate of 1% for the CSIRO Mk2 climate scenario and 1.1% for the Hadley climate scenario. The modelled effect of climate change on pasture production and consequently stocking rate was negligible. Therefore stocking rate was kept constant throughout the analysis. Where the annual yield declined at a rate of

1% under the CSIRO Mk2 scenario, the farm went into deficit in 2024 (Figure 3). In the event that climate change conditions are not as severe, or the annual yield decline was improved to 0% as a result of an improvement in technology and management the farm fell into deficit much later in 2047 (Figure 3). The annual surplus or deficit of the farm still declined even though long-term average yield remained constant due to declining terms of trade. At an annual yield increase of 2% and 1% the farm maintained an annual surplus over the entire 50-year period for average crop yields at the two prices tested and was able to overcome the negative impacts of declining terms of trade (Figure 3).

Sensitivity analysis The annual surplus or deficit of the medium rainfall farm under climate change was tested for sensitivity to changes in the key drivers of its profitability: crop price, yield and terms of trade.

The impact of lower long-term wheat and lupin prices caused the medium rainfall farm to go into deficit in 2008 under the CSIRO Mk2 (1% annual yield decline) scenario (data not shown). Analysis of breakeven yields showed that crop yields were at or just above breakeven in 2008 and the livestock enterprise was operating at a loss. With high input costs for fertiliser, fuel and herbicides this system was only just paying for itself at the crop prices of \$210 wheat and \$200 lupins. An annual reduction in crop yields of only 1% (i.e. 25kg/ha) immediately placed the farm in deficit. When a less severe scenario outlook was tested and the annual yield change improved to 0%, the farm still went into deficit in 2008 under lower farm-gate grain prices (data not shown).

The impact of higher potential wheat yields (3.1t/ha wheat, 2t/ha lupins) under the modelled 1% annual yield decline scenario (CSIRO Mk2) extended the financial viability of the medium rainfall farm by a further 14 years to 2038 (data not shown). Improvements in the terms of trade to neutral markedly improved the financial viability of the farm and it remained in surplus for a further 30 years under average yields (2.5t/ha wheat, 2t/ha lupin) (data not shown).

Economic impact on high rainfall farming system

Even with the small annual yield declines predicted under both the CSIRO Mk2 (0.04% annual yield decline) and Hadley (0.07% annual yield decline) climate scenarios the farm went into deficit within 25 years (Figure 4). Declining crop yields combined with declining terms of trade caused the

production of both lupins and wheat on the poorer soils to become unprofitable.

Sensitivity analysis The annual surplus or deficit of the high rainfall farm was tested for sensitivity to crop price, flock numbers, fertiliser input costs and terms of trade.

The high rainfall system was sensitive to reductions in the grain price. Due to the farm's high input costs a reduction in the price of wheat and lupins by \$40/t caused the farm to almost immediately go into deficit in 2011 unless annual yield increases of more than 1% could be achieved (data not shown). With low grain prices the farm must achieve higher yields at the current input prices or purchase at low input prices to remain profitable.

Profitability of the high rainfall farming system was improved by maximising stocking rates and increasing pasture usage. When livestock numbers were increased so that pasture utilisation improved to 35%, the high rainfall farm remained in surplus for a further ten years (data not shown). With a further increase to 50% utilisation, the farm remained in surplus for the entire 50-year period of the analysis. Current practice for farms in this region is to run livestock at a pasture utilisation of between 20–30%. However, with good management some farms in the area have increased this value to about 50%. In addition, the sheep on this high rainfall farm are a trading flock and most were sold before the summer-autumn feed gap period thereby reducing the grazing pressure when less pasture is available.

The annual surplus or deficit of the high rainfall farm under the CSIRO Mk2 scenario was also tested for sensitivity to the cost of fertiliser inputs. With an increase in the cost of fertiliser of 7.8% across the farm, the farm went into deficit eight years earlier (data not shown). Lowering the cost of fertiliser inputs by 1.6% had little effect only extending the financial viability of the farm by two years. Fertiliser prices have since fallen further and in November 2009 were 40% below June 2008 prices.

Similarly, the high input costs of the system made the farm very sensitive to changing terms of trade. When terms of trade were improved to 'neutral' the financial viability of the farm under both the CSIRO and Hadley climate scenarios increased markedly (Figure 5). Hence, the decline in profitability of the high rainfall farm is driven mainly by declining terms of trade rather than the predicted yield reductions under climate change.

Potential adaptation for the low rainfall farming system

A combination strategy of a trade cattle pastoral alliance with opportunistic cropping and oil mallees for carbon trading may sustain the viability of the low rainfall farm but it is sensitive to crop price, liveweight gain, terms of trade, carbon returns and fertiliser price. Weight gain per head is a particularly strong driver of profit in the system and its management involves lower input costs and less risk in a poor season than increasing stocking rate.

In the current situation of declining terms of trade the combination farming system only remains viable at the higher weight gain for cattle (180kg) while receiving high wheat and carbon prices unless the terms of trade improve to neutral (Table 4a).

Increasing the frequency of cropping years improves the profitability of the farm (data not shown) as does lowering the cost of fertiliser inputs (Table 4b). World fertiliser prices were volatile during the time of the analysis and had markedly increased from the previous average long term prices. Testing the profitability of the combination strategy with fertiliser prices reduced by 60% showed an improvement in profitability (Table 4b). Under lower fertiliser prices and declining terms of trade the combination farming system now succeeded under high cattle weight gains (180kg), at both the medium and high crop price levels and both levels of carbon pricing. If the terms of trade improved to neutral the farming system under high cattle weight gains succeeded under all prices but the system only succeeded under low cattle weight gains while receiving higher crop prices. The combination strategy however is only one possible scenario for adaptation and analysis of environmental and other impacts needs consideration.

Potential adaptation for the medium rainfall farming system

Increasing crop area in the rotation using genetically modified crops was more profitable than the current system under the CSIRO (1% annual yield decline) climate scenario. An immediate transition to the GM adaptation resulted in an average annual surplus of \$100,000 and extended the longevity of the system for a further ten years. Delaying the introduction of the GM crop rotation resulted in a loss of potential income with an average annual surplus of \$66,000 per annum (Figure 6). In contrast, the current farming system under climate change had an annual surplus of only \$36,000.

The sensitivity of the medium rainfall farm to profitability was increased during the transition to the GM crop rotation and this is illustrated by the stochastic effects present in the graph. This reflects the impact of yearly rotation changes of crop types and crop area on profitability during the transition to GM due to changes in crop input costs and crop price between the crop types.

While the GM crop adaptation aimed to lengthen the period of profitability of the farming system by delaying the development of resistance to selective herbicides it also allowed the farm to operate with a 100% cropping program. Increased wheat production together with the addition of canola in the rotation increased the potential income stream of the farm. As this cropping adaptation was more profitable than the current system delaying its introduction only reduced the profitability of the medium rainfall farm.

Potential adaptations for the high rainfall farming system

The combination of increased crop area on the good soils with increased perennial pastures and livestock on the poorer blackbutt sands significantly extended the viability of the farming system (Figure 7). The most profitable option for this strategy was to replace 100% of crop and annual pastures on the blackbutt sands with perennial pastures which resulted in an average annual surplus of \$286,000. Profitability in this strategy was maximised by allocating crop area to soil types that maximised profit, pasture area to soil types that minimised input costs and grazing numbers matched to the increased feed production. However, the establishment costs of perennial pastures were not included in this analysis which will impact on the profitability as will the speed of transition to the new farming system.

The fast transition strategies to convert the blackbutt sands to perennial pastures and increase livestock numbers were the most profitable, but the one and two-year transitions involved a large initial outlay of money (Figure 8). These strategies carry higher financial risk as pasture establishment failure could be detrimental to the economic position of the property. Although the two-year transition would spread this risk to a small extent the drop in the farm's annual income was more pronounced in comparison to the one-year transition strategy. This occurs because there is an extra year's delay before stock numbers reach their full complement while pastures are establishing.

The 11-year transition may be the lowest risk approach for the farmer and will reach the

same level of annual surplus as the quicker transition strategies in 2021 but returned the lowest average annual surplus (Figure 8). In this strategy the annual cost is reduced as only a small amount of land is being converted to perennial pasture each year. Stock numbers can be gradually built-up rather than purchasing large numbers at once. The risk of pasture establishment failure in a poor season will have less impact on the farm than for the quicker transition strategies.

Discussion

The low rainfall farming system

The predicted impact of future climate change regimes on crop yields could make the current low rainfall farming system of Western Australia's northern agricultural region financially unsustainable within 20 years. The crop dominant mixed farming system becomes an unsuitable option for the low rainfall under declining crop yields and rising input costs. Even when practical management changes are made by removing land from crop into livestock production the system eventually fails as the cost of production exceeds the income due to the trend in declining terms of trade. A key adaptation approach could be to move the focus away from a crop dominant system that is dependant on a traditional start-of-season rainfall break for profitability and move towards a farming system that is more flexible in responding to variable season types.

The combined trade cattle, carbon trading and opportunistic cropping system may be a viable alternative to the current low rainfall farming system. This alternative system removes high input losses from cropping in poor seasons and focuses on lower cost production enterprises that are farmed to seasonal conditions. The system responds better to seasonal conditions as livestock are no longer carried year round and instead utilises trade cattle (through a pastoral alliance) which are finished on winter/spring pasture. This maximises pasture use in the most productive part of the growing season and allows an increase in stock numbers and turnover as pasture no longer needs to be managed as a feed source over summer.

Opportunistic cropping employs existing practices to maximise returns in good seasons through planting crops on the best land only when good seasonal start conditions permit and avoiding large losses in poor seasons. While there is some initial expenditure in site preparation and planting for oil mallees few inputs are required once established and oil mallees offer an income stream through poor agricultural seasons.

For oil mallees there is also a future potential for value-adding in the form of bio-energy and reconstituted wood products.

The biggest risk for the low rainfall adaptation is the cost of achieving the thresholds for success. The adaptation focused on incorporating existing practices and technologies which did not require a large degree of capital investment and avoided extra costs associated with training and adoption when changing to entirely new enterprises. For success in the trade cattle enterprise high weight grains of 120-180kg and stocking rates of 3 DSE need to be achieved in the low rainfall area. The risk in this adaptation is whether that weight gain and stocking rate can be achieved in the low rainfall area and the cost to the business in trying to achieve it. Achieving these levels will require more investment of time for labour in managing intensive grazing management practices and investing in new pasture types or animal genetics for higher levels of productivity.

With unpredictable starts to seasons any decline in crop yields will place further importance on the ability of the farm manager to make decisions to sow and interpret the season correctly. Correct interpretation of good seasons for planting will be a key area of importance to success. The cost of implementation is incorrect seasonal timing, poor commodity prices and high input costs. An opportunity cost is also created when oil mallee trees are permanently planted on highly productive crop land.

Management strategies which minimise risk in dry seasons are critical to ensure the long-term profitability of the low rainfall farm. With climate change forecasts predicting an increasing frequency of dry seasons (Pittock 2003), further research to develop and assess the viability of low input strategies for minimising losses in drought years is imperative and will facilitate the determination of appropriate policy and research agendas for this area. The STEP model has shown that there are possibilities for alternative farming systems in the low rainfall areas to overcome profitability declines whether or not they are climate change driven.

The medium rainfall farming system

The wheat-lupin rotation has been a profitable rotation on the sandplain soils of the northern agricultural region's medium rainfall area. However, if the effect of climate change on crop yield is as severe as the CSIRO Mk2 (1% annual yield decline) scenario suggests and input costs remain high, the medium rainfall farm may need to

adapt to a more sustainable enterprise within the next 15 years. If yield losses can be minimised through improvements in management or technology, terms of trade and/or higher wheat prices then the medium rainfall farming system could remain quite profitable. In fact other risks such as the development of herbicide resistance, rising fertiliser and fuel costs, and increasing climatic variability may be more immediate threats than climate change alone.

The potential adaptation tested for the medium rainfall focused on increasing the proportion of crop area in the farming system through the use of new GM technology to improve crop yields in low profit areas. The addition of GM lupin and canola to the farming system provides an option for cropping where current profitability is threatened by weeds developing resistance to selective herbicides. The use of GM crops tolerant to non-selective herbicides minimises the use of selective herbicides in the farming system and extends the time before resistance develops. An immediate transition to the GM adaptation was the most profitable transition strategy as delay resulted in a potential loss of income.

For longevity, it is imperative that the use of GM crops is accompanied by the implementation of the appropriate weed control package. Failure to implement a component of this package will reduce both the profitability of the medium rainfall farm and the length of time until the development of resistance to selective herbicides. In the absence of further adaption however, the overall trend of declining yield will still cause the farm to become financially unviable at some point in the future.

The high rainfall farming system

The high rainfall farming system may not remain financially viable beyond the next 30 years if declining terms of trade continue along with the modest reductions predicted in crop yield from climate change. Profitability of the high input crop enterprise on low productivity soils declines as a result of high input costs constricting margin returns as crop yields reduce further under climate change. If losses can be minimised and profitability improved on these soil types then the high rainfall farming system could remain quite profitable.

The potential adaptation tested for the high rainfall farming system focused on increasing crop area on soil types that maximise crop productivity and improving the profitability of poor soils by planting perennial pastures for increased livestock production. While high input costs in the farming system are driven by fertiliser for crops the margin returns for

the enterprise are also the largest. Increasing crop intensity and area on high yielding soil types is likely to increase the profitability and longevity in the farm.

Increased livestock production could be one of the key methods for farming systems to adapt to climate change. Livestock production is more resistant to climate change than crops because of mobility and access to feed (IISD/EARG 1997). SGS pasture modelling found that the quantity of pasture will only decrease slightly over the next 30 years which would leave stock numbers at current levels. Changing pasture type and management is likely to further increase pasture profitability through the ability to increase livestock production per hectare.

The most profitable transition strategy for this farming system was to increase crop area on productive soil types and embark on a slow transition of planting perennials on poorer soil types to improve livestock carrying capacity. This returned a slightly lower average annual surplus but carries lower risk as establishment and setup costs could be made gradually.

The potential costs of moving to this alternative farming system are small but include the risk of failure in perennial pasture establishment and the cost of purchasing additional livestock at market price each year that pastures are established. Further analysis of the high rainfall area however, should also include intensive agriculture options. Intensive agriculture enterprises, such as horticulture, currently exist in the southern part of the high rainfall area in close proximity to the state capital, Perth. As urban growth is currently pushing into traditional horticulture land it is expected that the horticulture precinct will push north into this area. The southern section of the high rainfall zone may become focused on intensive agriculture due to the availability of water and potential higher profitability compared to broadacre agriculture.

Conclusions

Climate change is expected to have some impact on the region's farm businesses. The farming systems that are currently in use are expected to decline in profitability to a point where some become financially unviable in the long term. However, the negative impact on farm profitability in the future is not only driven by a reduction in crop yields from climate change but also from a continuation in the trend of declining terms of trade.

The degree of impact on the future profitability of the region's farming systems is linked to rainfall. The low rainfall farming system is expected to be the most at risk

from the impact of climate change and declining terms of trade. The profitability of this farming system is already challenged by management decisions on climate risk. However, with innovation and adaptation it is possible for the region's farming systems to overcome these impacts. For the low rainfall farming system this could involve a change to a more flexible farming system that can respond better to season types. For the higher rainfall farming systems innovation and adaptation could focus on technologies and techniques that improve yields and profitability.

This paper has outlined a process developed to investigate the long-term economic effects of climate change on farming systems and evaluate strategies to cope with the impacts. The key feature of the process is the use of STEP which is a tool to examine the financial effect of production or system changes on a farm business over time. Here, the use of STEP modelling has been extended to include the effects of climate change, using three main steps – (i) predicting the change in the future climate, (ii) modelling its effects on agricultural production and (iii) using STEP to estimate impacts on the annual surplus or deficit of a representative farm.

As with any analyses of this type around the issue of climate change our findings depend on the accuracy and validity of future climate projections, crop yield estimates and the economic conditions used in the STEP model. Uncertainties include the future commodity price, the direction of the terms of trade and the effect that new technologies, new markets and other factors may have in alleviating the impact of reduced yields on farm profitability. Variability was also not included in scenarios, but instead long-term average conditions were used in the analysis.

In addition, if agriculture is included in the Government's Carbon Pollution Reduction Scheme the profitability of potential options discussed in this report will need further analysis incorporating the costs of greenhouse gas emissions. However, this report highlights that STEP can be used to investigate the long-term economic effects of climate change on farming systems and may be a useful research tool for the development of strategies to cope with the impacts.

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References

- Bankwest 2003, 'Bankwest benchmarks 2002/2003', Bankwest Agribusiness Centre, Perth Western Australia.
- Bankwest 2005, 'Bankwest benchmarks 2004/2005', Bankwest Agribusiness Centre, Perth Western Australia.
- Clarke M 1995, 'Pindar Tardun catchment management report', Department of Agriculture Western Australia, Unpublished report.
- Department of Agriculture 2002, 'Gross margins guide 2003', Department of Agriculture, Western Australia, Miscellaneous publication 18/2002.
- Department of Agriculture 2005, 'Gross margins guide 2005', Department of Agriculture Western Australia. (Replaces Miscellaneous publication 18/2002). http://www.agric.wa.gov.au/content/amt/agec/gross_margins_2005.htm (accessed 17 July 2012).
- Diggle A, Peek C, D'Emden F, Evans F, French B, Grima R, Harburg S, Hashem A, Holmes J, Lemon J, Newman P, Paterson J, Penny S and Portmann P 2009, 'The implications of GM glyphosate resistant lupin', in S Penny, G Shea, B French, A Douglas, and J Paterson (eds.), *2009 Crop updates*, Department of Agriculture and Food, Western Australia, pp.186-191.
- Farre I and Foster I 2008, 'Will wheat production in Western Australia be more risky in the future?' *Agribusiness Crop Updates*, Department of Agriculture and Food WA.
- French RJ and Schultz JE 1984, 'Water use efficiency or wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate'. *Australian Journal of Agricultural Research*, 35: 743-64.
- Grima R 2007, 'Economic analysis of a high production yellow sand farm in the Northern Agricultural Region', Department of Agriculture and Food, Western Australia, Unpublished report.
- Hall DM 2002, 'Impact of high yielding cropping systems on crop water use and recharge'. Final report summary prepared for the Grains and Research Development Corporation.
- Howden M and Jones RN 2004, 'Risk assessment of climate change impacts on Australia's wheat industry', in *New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress*, Sep 26 – Oct 1 2004, Brisbane, Australia.
- International Institute for Sustainable Development and the Environmental Adaptation Research Group 1997, *Agriculture and climate change: a prairie perspective*. Institute for Environmental Studies, University of Toronto.
- IPCC 2000, 'Special report on emissions scenarios', prepared for the Third Assessment Report of the Intergovernmental Panel on Climate Change, Geneva.
- IPCC 2007, 'Climate change 2007: synthesis report', contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,

- Pachauri RK and Reisinger A (eds.) IPCC, Geneva, Switzerland.
- Johnson I., Lodge GM and White RE, 2003, 'The sustainable grazing systems pasture model: description, philosophy and application to the SGS national experiment', *Australian Journal of Experimental Agriculture*, 43: 621-631.
- Johnson I, Chapman D, Snow V, Echard R, Parsons A, Lambert M and Cullen B 2008, 'DairyMod and EcoMod: biophysical pastoral simulation models for Australia and New Zealand', *Australian Journal of Experimental Agriculture*, 48: 711-728.
- Johnson I 2009, 'Pasture growth rates in the Geraldton region of WA: growth rate analysis and climate change scenarios using the SGS pasture model'. Prepared by IMJ consultants for the Department of Agriculture and Food, Western Australia, March 2009, unpublished report.
- Kerr NJ, Siddique KHM and Delane RJ 1992, 'Early sowing with wheat cultivars of suitable maturity increases grain yield of spring wheat in a short season environment'. *Australian Journal of Experimental Agriculture*. 32: 717-23.
- Ludwig F and Asseng S 2006, 'Climate change impacts on wheat production in a Mediterranean environment in Western Australia'. *Agricultural Systems*, 90; 159-179.
- Mullen, JD 2011, 'Public investment in agricultural research and development remains a sensible policy option'. *Australian Farm Business Management Journal*, 8 (2): 1-12.
- Peek C. and Abrahams M 2005, 'Farming systems analysis using the STEP tool', *Proceedings of the agribusiness crop updates 2005*, Department of Agriculture and Food Western Australia.
- Pittock B 2003, 'Climate change - an Australian guide to the science and potential impacts', Australian Greenhouse Office.
- Scheraga JD and Grambsch AE 1998, 'Risks, opportunities, and adaptations to climate change', *Climate Research*, 10: 85-95.
- Stephens, D 2002, 'National and regional assessments of crop yield trends and relative production efficiency: theme 5.1. land use change, productivity and diversification'. National Land and Water Resources Audit, Miscellaneous publication 12/2002, Department of Agriculture WA.
- Tennant D 2001, 'Software for climate management issues, in 'Crop updates 2001', Department of Agriculture, Western Australia.
- Van Gool D and Vernon L 2005, 'Potential impacts of climate change on agricultural land use suitability', Wheat resource management technical report 295, Department of Agriculture, Western Australia.
- Van Gool D and Vernon L 2006, 'Potential impacts of climate change on agricultural land use suitability: lupins', Resource management technical report 305, Department of Agriculture, Western Australia.
- Vernon L and Van Gool D 2006, 'Potential impacts of climate change on agricultural land use suitability: barley', Resource management technical report 302, Department of Agriculture, Western Australia.
- Whetton PH, McInnes KL, Jones RN, Hennessy KJ, Suppiah R, Page CM & Durack PJ 2005, 'Australian climate change projections for impact assessment and policy application: a review', CSIRO marine and atmospheric research paper, 001, Aspendale Victoria.

Appendix

Table 1a. Land Capability Class constants for adjusting yield potentials on each soil capability class

Land Capability Class	Land Capability Class Constant (LCc)	
1	1.8	Higher than average yields
2	1.4	Average yields
3	1.0	Lower than average yields
4	0.6	
5	0.4	

Table 1b. Minimum temperature constants for adjusting yield potentials

September average minimum temperatures (°C)	Temperature constant (Tc)
>5.6	1.00
5.4 – 5.6	0.95
5.2 – 5.4	0.90
5.0 – 5.2	0.85
Trend continues to 4.0 °C	

Table 1c. Maximum temperature constants for adjusting yield potentials

August-October average maximum temperatures (°C)	Temperature constant (Tc)
<22.8	1.00
22.8 – 23.0	0.95
23.0 – 23.2	0.90
23.2 – 23.4	0.85
23.4 – 23.6	0.80
Trend continues until 24.8 °C	

Table 2. Comparison of the modelled base climate (1990) to climate scenario projections (2056) for the three farming systems of Western Australia's northern agricultural region

Model farms	1990 base climate		2056 CSIRO Mk 2 projections		2056 Hadley projections	
	Growing Season Rainfall (mm)	Average September Maximum Temp.(°C)	Growing Season Rainfall (mm)	Average September Maximum Temp.(°C)	Growing Season Rainfall (mm)	Average September Maximum Temp.(°C)
1. Low rainfall	248	23.2	226	24.9	222	25.3
2. Medium rainfall	334	22.4	301	24.1	290	24.4
3. High rainfall	515	21.1	462	22.6	414	22.9

Table 3. Predicted annual crop yield decline over 50 years modelled using the French-Schultz and APSIM-Wheat methods under different climate scenario projections for three representative farms

Representative farm	Predicted annual yield decline		
	French-Schultz crop model		APSIM-Wheat crop model
	CSIRO Mk2 climate projections	Hadley climate projections	Downscaled CSIRO Mk3 climate projections
Low rainfall	1.3%	1.5%	0.4%
Medium rainfall	1%	1.1%	ND
High rainfall	0.04%	0.14%	ND

ND = not done

Table 4. The average annual surplus or deficit (today's value) of the farm over a 30 year period for different crop prices, carbon returns and weight gains per head at neutral and declining (\downarrow) terms of trade (T of T) for (a) base fertiliser input prices in July 2008 and (b) fertiliser prices reduced by 60% to 2007 prices

Table 4a.

Cattle weight gain/head		120kg		180kg	
Crop price* \$/t	Carbon returns \$/t CO ₂ e	T of T \downarrow	T of T Neutral	T of T \downarrow	T of T Neutral
\$210 wheat	\$10	<i>-\$61,000</i>	<i>-\$43,000</i>	<i>-\$27,000</i>	<i>-\$8,000</i>
\$200 lupin	\$50	<i>-\$51,000</i>	<i>-\$32,000</i>	<i>-\$16,000</i>	\$2,000
\$250 wheat	\$10	<i>-\$48,000</i>	<i>-\$29,000</i>	<i>-\$12,000</i>	\$7,000
\$240 lupin	\$50	<i>-\$37,000</i>	<i>-\$19,000</i>	\$3,000	\$22,000

Table 4b.

Cattle weight gain/head		120kg		180kg	
Crop price* \$/t	Carbon returns \$/t CO ₂ e	T of T \downarrow	T of T Neutral	T of T \downarrow	T of T Neutral
\$210 wheat	\$10	<i>-\$33,000</i>	<i>-\$18,000</i>	\$4,300	\$21,000
\$200 lupin	\$50	<i>-\$23,000</i>	<i>-\$7,000</i>	\$21,000	\$38,000
\$250 wheat	\$10	<i>-\$13,000</i>	\$3,000	\$33,000	\$50,000
\$240 lupin	\$50	\$2,000	\$20,000	\$50,000	\$70,000

Note: Cattle at 3DSE/ha for 4–6 months. Pasture costs \$22/ha. Surpluses are shown in **bold**, deficits in *italics*. * Farm-gate price

Figure 1. Location of the representative model farms for the (1) low, (2) medium and (3) high rainfall areas of the northern agricultural region

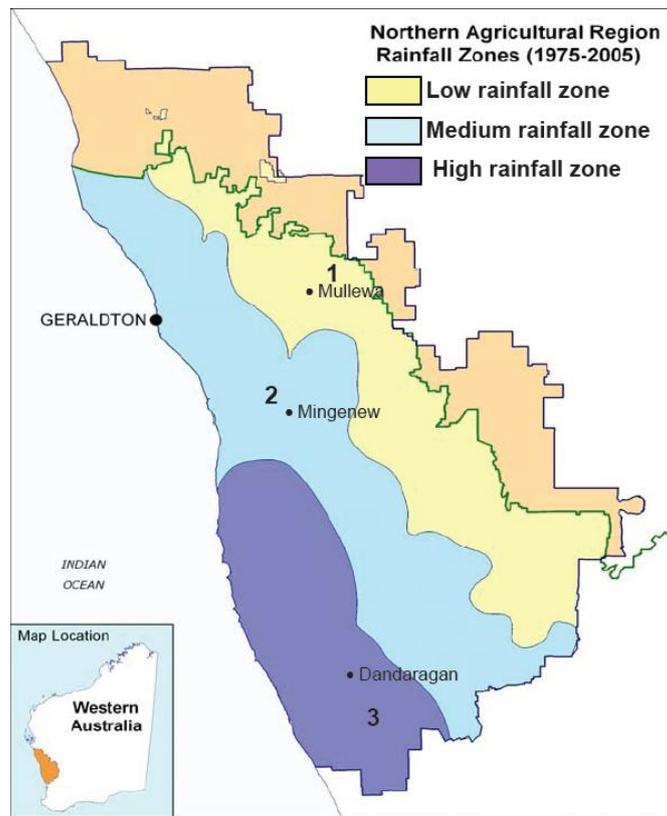


Figure 2. Annual surplus of the low rainfall farm for different climate change scenarios.

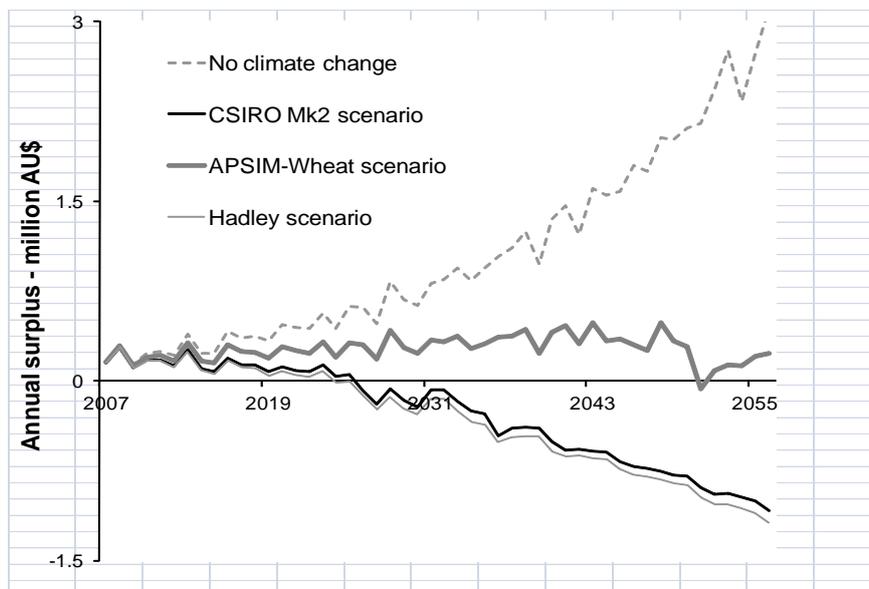


Figure 3. Annual surplus or deficit of the medium rainfall farm for different climate change scenarios

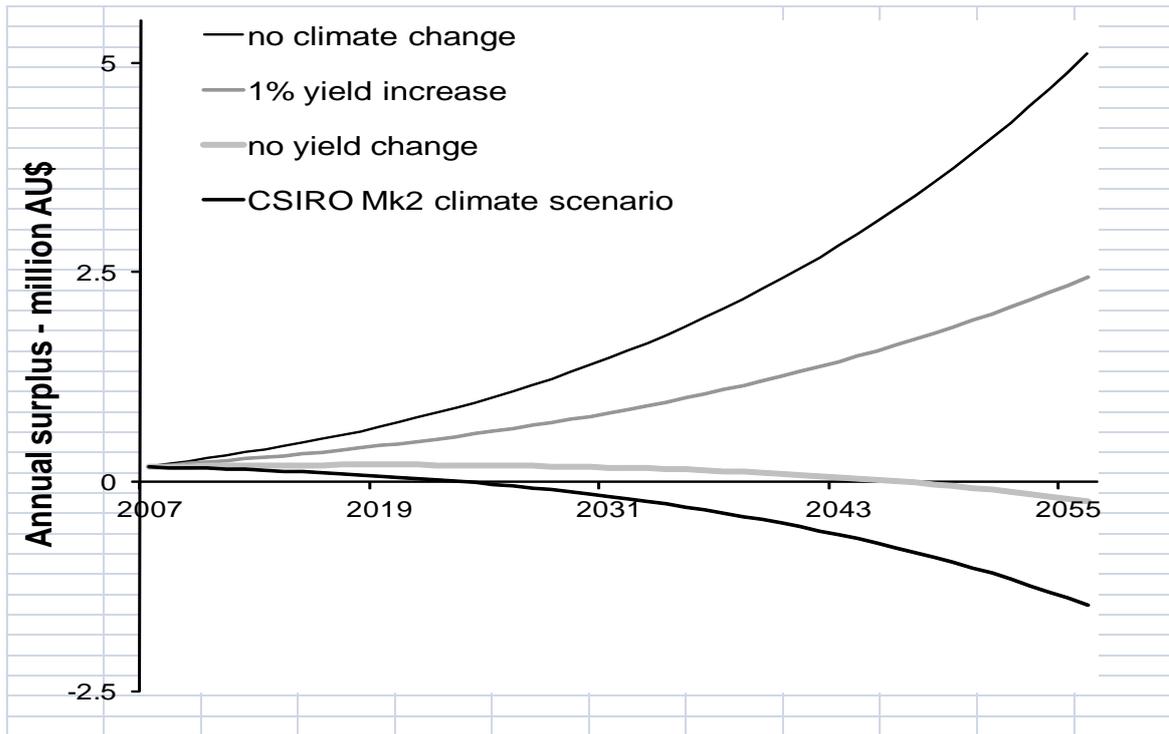


Figure 4. Annual surplus or deficit of the high rainfall farm for different climate change scenarios

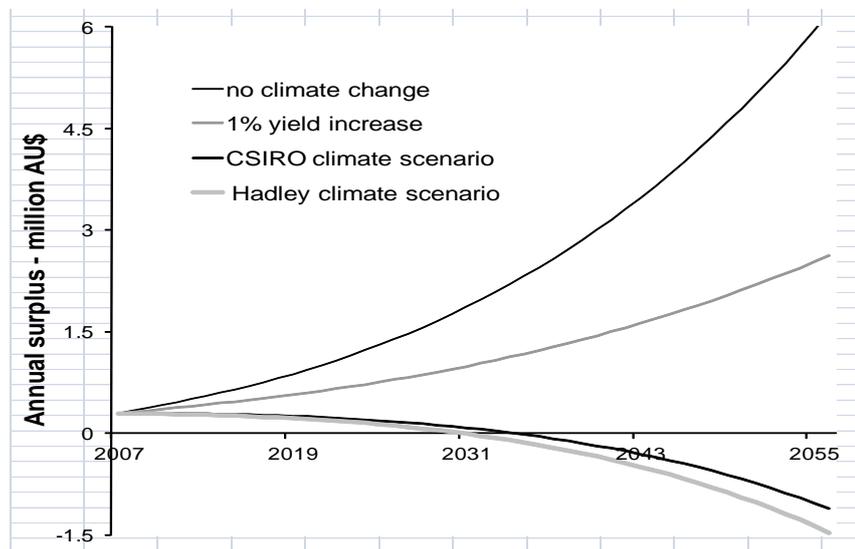


Figure 5. Sensitivity of the annual surplus deficit of the high rainfall farm under the CSIRO Mk2 (0.04% annual yield decline) scenario to terms of trade. Declining terms of trade (costs increasing at a higher rate than returns) were compared to neutral terms of trade (costs and returns increasing at same rate)

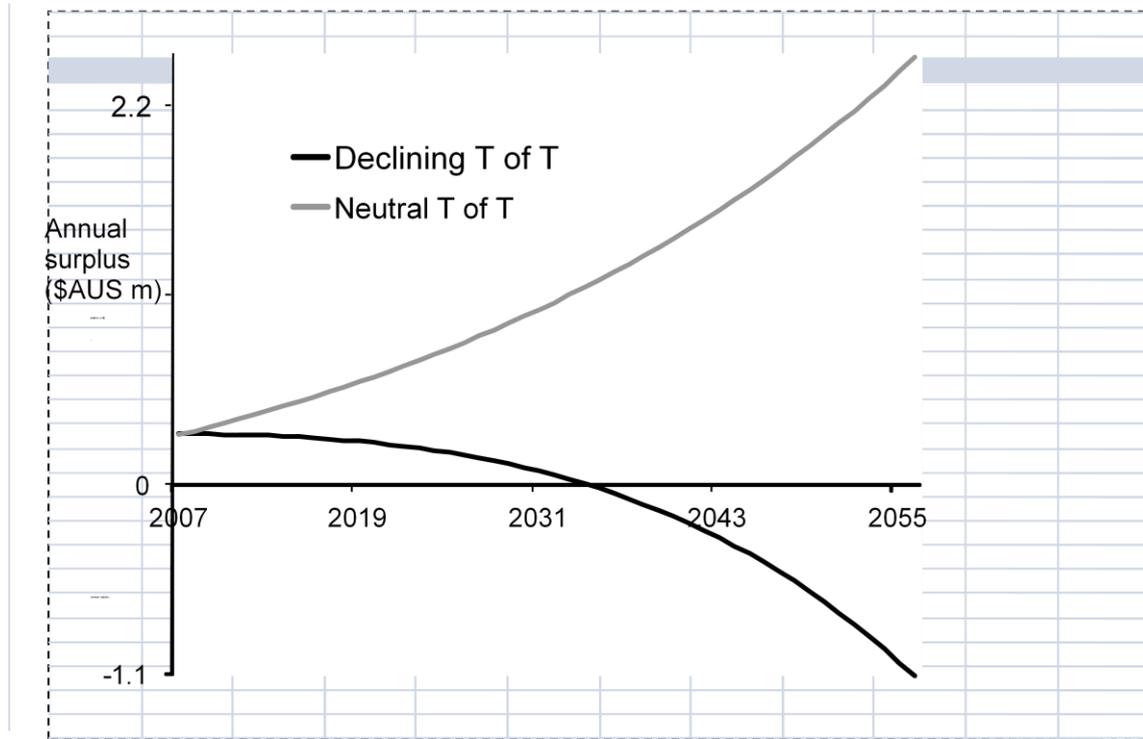


Figure 6. Annual surplus or deficit (today's value) of the medium rainfall farm for the current system and two GM crop transition strategies under the CSIRO (1% annual yield decline) climate change scenario. The average annual surplus over the entire 25-year period is also shown in bold type. (Crop prices were \$250/t wheat, \$240/t lupins, \$560/t canola farm-gate)

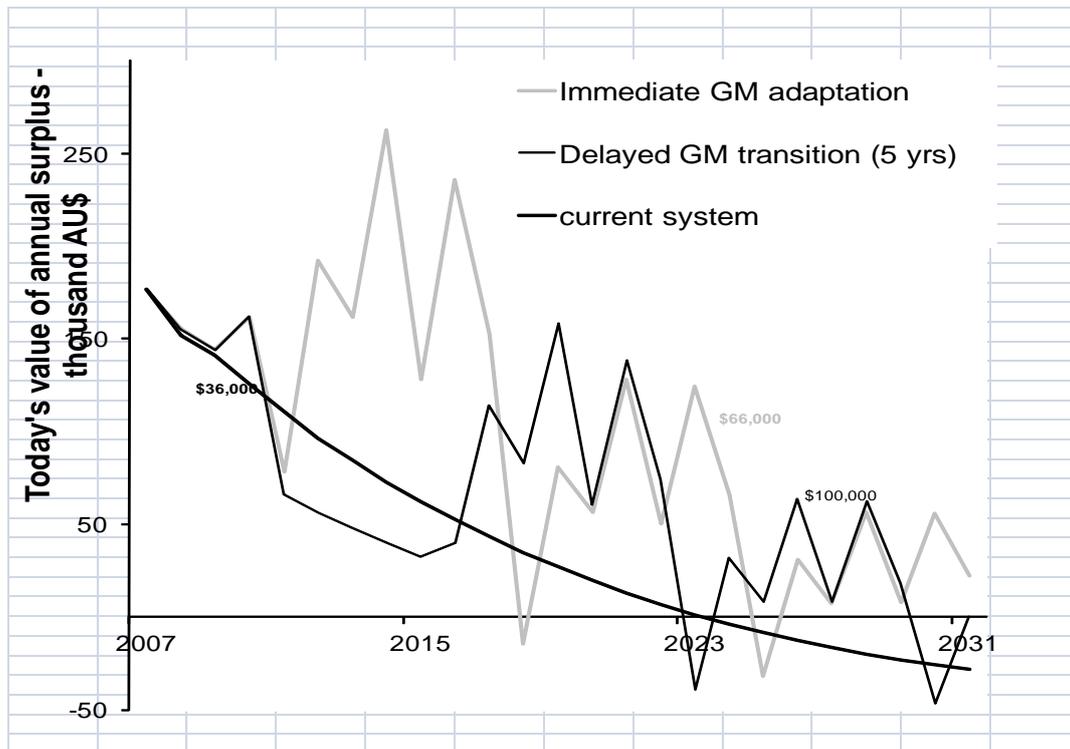


Figure 7. Annual surplus or deficit of the high rainfall farm with increased cropping on the good soils with or without increased perennials and livestock on the lower yielding soils. All scenarios are compared to the CSIRO Mk2 climate change scenario

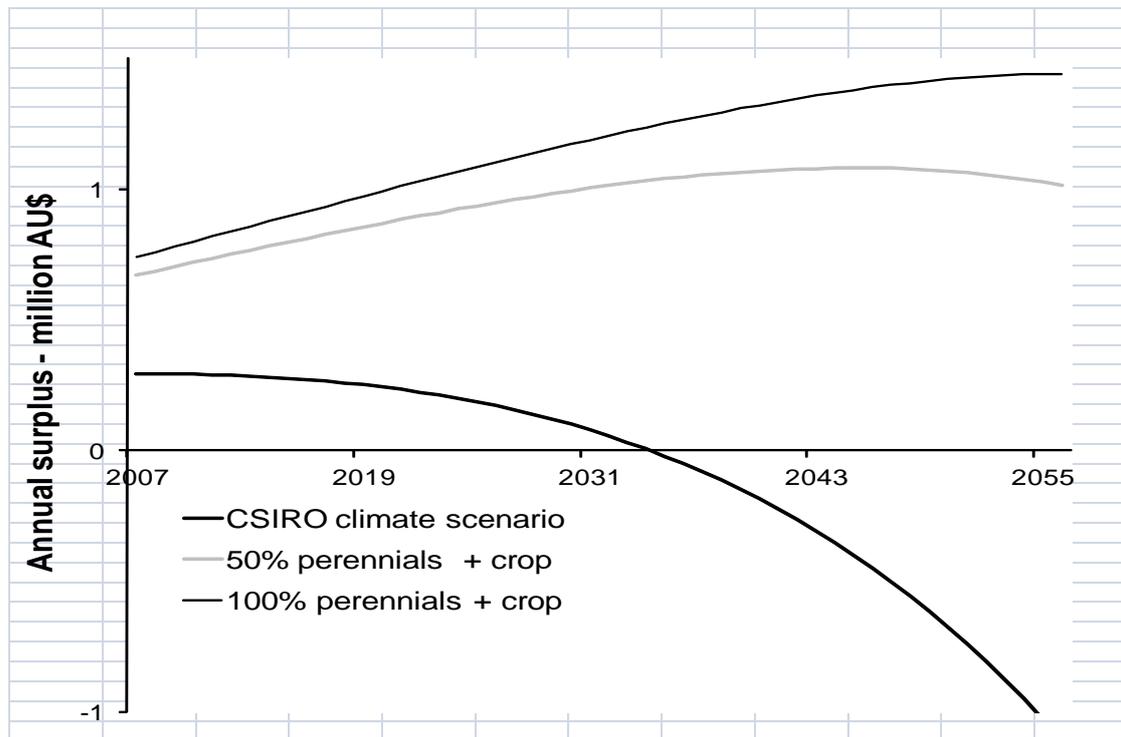


Figure 8. Annual surplus or deficit of the high rainfall farm during transition to increased cropping on the good soils and increased perennials and livestock on the lower yielding soils

