Broadacre farmers adapting to a changing climate

Final Report

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BROADACRE FARMERS ADAPTING TO A CHANGING CLIMATE

Australian Export Grains Innovation Centre

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The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

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ABSTRACT

Data on the financial performance of a diverse set of 249 farm businesses in south-western Australia over the period 2002 to 2011 was collated and analysed. These 10 years were a period of challenging weather years, underpinned by a warming and drying trend in the region's climate, frost events and marked price volatility.

Based on a range of metrics, almost two-thirds (64%) of the farms in the sample were classed as growing or strong. A less secure group of farms that are at some potential financial risk formed 15% of the farm sample. Over the study period farm profitability, on average, improved, supported by productivity growth, in spite of no underlying improvement in the farmers' terms of trade. Productivity improvement allowed most farm businesses, especially crop and mixed enterprise farm businesses, to prosper.

The pathway to their profitability was not so much by investing in new technologies that may have shifted outwards farms' production possibilities, but rather through better use of existing technologies, including technologies that offered scale economies. Also farmers' shift into greater dependence on cropping, especially wheat production, was shown to be a sensible and successful adaptation strategy in many regions of south-western Australia, particularly the northern grainbelt.

The unique and particular characteristics of each farm business were the main determinant of their business success. However, a few generalisations apply. Due to seasonal and market conditions during the study period more farms in the northern parts of the grainbelt in south-western Australia fared better. Also farmers whose businesses grew strongly over the study period on average displayed superior management capabilities and choices in many areas of farm management. In addition, these farmers were often more connected to their local community and achieved greater work-life balance.

We conclude that as long as broadacre farmers in south-western Australia have on-going access to improved crop varieties and technologies that support the profitable growing of crops, especially wheat; and that they have access to farm management and business education then farmers are likely to be able to adapt to projected climate change. Provided that farmers' terms of trade do not become unduly adverse, and that farmers sensibly manage farm debt, then it seems highly likely that farmers who continue to rely on crop production, mostly wheat-growing, will persist as financially sound businesses in most parts of the study region, even in the face of projected climate change.

EXECUTIVE SUMMARY

Unfolding change in climate, and its associated variability, poses challenges for broadacre dryland farm businesses in regions such as south-western Australia. The Western Australian grainbelt has experienced a 20 percent decline in rainfall over the last several decades, more than any other wheat-growing region in Australia. Average temperatures in the region have increased, with a disproportionate increase in the frequency of hot days during grain filling, and yet frost risk at flowering has increased. If these mostly drier, warmer conditions are the portend of southern Australia's future production environment, then learning about how Western Australian farm businesses are responding to their warmer, drier environment may have relevance for other regions projected to experience similar change in their climate.

This research traces the performance of 249 grainbelt farms in Western Australia over the period 2002 to 2011. This decade's worth of observations about farm performance is analysed to assess how successfully these businesses have managed a period of warmer and drier conditions amidst volatile market conditions. Traditional metrics of farm performance are reported; return on capital, operating surplus, business equity and the debt to income ratio. In addition, farms are classified into four performance categories; growing, strong, secure and less secure businesses. Farms are also grouped by enterprise type (crop specialists, mixed enterprise and sheep specialists) and sub-region. Drawing on the farm business datasets, each farm's productivity and its main components are estimated. Complementing the farm business datasets is a comprehensive set of socio-managerial data derived from responses to a detailed questionnaire.

Analysis of the data revealed the following key findings:

- Almost two-thirds (64%) of the sample farms are classed as businesses that are growing or strong. The less secure group of farms at some potential financial risk formed 15% of the sample of farms. The shares of farm types in the sample were 73%, 22% and 5% for mixed enterprise, crop dominant and livestock dominant farms respectively.

- A large proportion (38%) of crop farms and mixed enterprise farms are classed as growing. By contrast only 23% of livestock farms are classed as growing.

- The region with the smallest proportion of less secure farms is the northern agricultural region (L1&M1). The regions with the smallest proportion of farms that are growing or strong were the M4 and L3 regions (see Figure 1) that experienced many low-yielding years due to drought and frost during the study period.

- Although the study region is experiencing a warming, drying trend, the combination of seasonal and price conditions during the study period favoured crop production, especially in the northern region (L1&M1) and southern coastal region (M5).

- Farmers' dependence on wheat-growing as a principal source of farm income appears to be a sensible adaptation strategy in many regions. Moreover, the biological prospects for wheat yield in the region generally appear very sound in the face of its changing climate.

- Over the study period farm profitability improved, supported by productivity growth, in spite of no lasting improvement in the terms of trade. Productivity improvement has allowed a majority of farm businesses to prosper during this period of climatic challenge and market volatility.

- A concerning trend was a significant increase in the debt to income ratio, and an associated decline in farm equity (as a percentage) during the study period.

- Farms improved their productivity, not so much by investing in new technologies that may have shifted outwards their production possibilities, but rather through better use of existing technologies, including technologies that offered scale economies.

- The change in total factor productivity for growing farms is double that for less secure farms and farm profitability has increased greatly for growing farms whereas less secure farms have displayed no growth in profitability.

- Improvement in technical efficiency is far greater for growing farms than less secure farms. The practical implication of this finding is that throughout the study period, growing farms have improved their productivity through better use of existing technologies, including technologies that offer scale economies.

- Because growing farms rely on improving their technical efficiency and utilising scale efficiencies it is therefore not surprising that many growing farms are in northern regions where large crop-dominant farms operate; underpinned by economies of scale.

- The change in total factor productivity for crop farms is treble that for sheep farms and there is a strong positive change in farm profitability for crop farms, whereas sheep farms display no growth in profitability.

- Both crop farms and sheep farms have beneficial change in technical efficiency as their main driver of total factor productivity growth. For crop farms their main component of improved technical efficiency is best practice use of existing technology.

- Growing and strong farms, when compared to less secure farms, on average make greater use of leasing, contractors, superannuation funds, succession planning, Farm Management Deposits and off-farm assets. They also on average adopt and make greater use of farm business software, marketing strategies, decision support tools, precision technology, electronic paddock recording and GPS technology.

- Growing farms, when compared to less secure or secure farms, on average display a greater quality of commitment to the maintenance of their cropping

gear. They aslo on average are more involved in their local community and express more care regarding their work-life balance.

- Growing or strong businesses typically display a greater commitment to training and/or are additionally blessed with a breadth and depth of experience and family support to engage in farming. This finding implies a potentially beneficial role for continued productivity-enhancing research, complemented by education and extension activity to support farm management and boost farm performance.

Because the farm data come from businesses that employed a farm management consultant, there remains a question over how fully representative are these farms of all grainbelt farms. With that caveat, and after noting other research findings regarding wheat yield prospects in the study region, we broadly conclude that as long as farmers in south-western Australia firstly, have on-going access to improved crop varieties and technologies that support profitable grain production, and secondly that farmers continue to have access to farm management and business education, then most farmers are likely to be able to adapt to projected climate change in the next few decades, provided that the climate change is sufficiently gradual.

The forecast biologically robust performance of wheat in the study region, in particular, should help underpin the future profitability of crop production. Hence, provided that farmers' terms of trade does not become unduly adverse, and that farmers sensibly manage farm debt, then it seems highly likely that farmers who continue to rely mostly on wheat production, and practise sound farm management, will persist as financially sound businesses in many parts of the study region, even in the face of projected climate change.

1. INTRODUCTION

It is widely acknowledged that the physical operating environment for broadacre farm businesses in southern Australia has been challenging since the late 1990s (Howden and Hayman, 2005; Garnaut, 2011; Stretch et al., 2012). Also, many scientists consider the future environment will remain challenging due to continuing climate variability and long-term climate change (Sietchiping, 2007; Kingwell and Pannell, 2005; Kingwell, 2006; Gunasekera et al., 2007; Garnaut, 2011; Addai, 2013).

Higher average temperatures have been observed and are projected. Hughes (2003) notes that “Since 1951, mean temperatures have increased 0.1–0.2 °C per decade over most of Australia, with the greatest warming inland, particularly in Queensland and the southern half of Western Australia (WA).” (p. 424). More recent data (see Figure 6 later in this report) confirms the continuing warming trend in south-western Australia. Asseng and Pannell (2012) note that in south-western Australia average temperature has increased by 0.8°C over 50 years. They also note a disproportionate increase in the frequency of hot days during grain filling when cereal yields can be adversely affected (Asseng et al., 2011).

Drying trends are also being reported for southern Australia. For semi-arid regions like southern Australia, a poleward shift in winter storm tracks is thought to be a prominent driver of observed reductions in rainfall during the late 20th and early 21st century (Frederiksen et al., 2011; Cai and Cowan (in press)). Asseng and Pannell (2012) note that the Western Australian wheat-belt has experienced a 20% rainfall decline over the past 110 years, more than any other wheat-growing region in Australia. Hope et al. (2006) also comment that historical climate data for south-western Australia shows growing season rainfall (May to October) to have decreased since the 1970s by 15% to 20%. Similarly, Cai et al. (2012) report that since the late 1970s, south-eastern Australia has experienced a drying trend in autumn, predominantly during April and May. Cai et al. (2012) report that the total observed reduction in April to May rainfall during 1951 to 2010 is approximately 38% of the long-term climatological rainfall. Hence reductions in early growing season rainfall are being observed in south-western and south-eastern Australia.

The other main trend affecting climate is the increasing atmospheric concentration of greenhouse gases. Greater emissions of CO_2, although a cause of global warming, can nonetheless be beneficial for plant growth (Morgan et al., 2011).

Regarding the three main trends in climate change in southern Australia; warming, drying and greater concentrations of CO_2, there is far greater scientific confidence around the projected trends in warming and increased levels of greenhouse gas emissions than there is over rainfall changes (Hughes, 2003; Rebbeck et al., 2007; Hennessy et al., 2007; Addai, 2013).

South-western Australia that is subject to warming and drying, and higher CO_2 concentrations, is an agriculturally important region of Australia. The region generates up to almost 40% of Australia’s cereal production. It is Australia’s main source of wheat and lupin grain exports and is geographically positioned to help serve the emerging sources of Asian food demand. The unfolding change in climate, and its associated

variability, pose challenges for broadacre dryland farm businesses in this region. How financially successful these businesses can be will affect their adaptive capacity, and their ability to employ adaptation responses. If farm businesses in this region are financially weakened by the changing climate and have little prospects of financial viability then their capacity to adapt to the adversity or opportunity associated with climate change will be highly constrained and their exodus from farming will be accelerated.

Accordingly, for broadacre agriculture in south-western Australia it is worthwhile to determine:

(i) how climate change and climate variability over the last decade have affected farm businesses,
(ii) what characteristics of farm businesses and farm managers have made them vulnerable or not to climate impacts over that decade,
(iii) what adaptation strategies appear to have been successful in combating the changing climate,
(iv) how important has been the social setting for a business in affecting its performance,
(v) are there adaptation learnings that might be transferable to other farmers,
(vi) are there implications of findings for policy makers and researchers.

The research project described in the following pages of this report aims to address these questions. Longitudinal farm business datasets are complemented with novel socio-economic and management data and productivity assessments to provide a fulsome analysis of the adaptive capacity and adaptation responses of the broadacre farmers in south-western Australia. In this region climate change is acknowledged as almost certainly already occurring (Sadler, 2002; Foster, 2007).

2. LITERATURE REVIEW

2.1 Preamble

There is a considerable body of literature around the science of climate change and the projected impact on the earth's climate of continuing greenhouse gas emissions (Pittock, 2003; CSIRO & Bureau of Meteorology, 2007). This literature has fuelled significant public debate and encouraged various governments to respond, to varying degrees, by developing policies to mitigate emissions and facilitate adaptation (Nelson et al., 2009).

There is evidence that the physical operating environment for broadacre farm businesses in southern Australia, and particularly in Western Australia, will be challenging in the future due to continuing climate variability and long-term climate change (Sietchiping, 2007; Kingwell and Pannell, 2005; Kingwell, 2006; Gunasekera et al., 2007; Garnaut, 2011; Addai, 2013). Higher average temperatures are projected, along with higher atmospheric concentrations of greenhouse gases and a decrease in growing season rainfall over much of the wheat belt in Western Australia (Foster, 2007). There is greater scientific confidence around the projected trends in warming and increased levels of greenhouse gas emissions than there is over any decline in rainfall (Hughes, 2003; Rebbeck et al., 2007; Hennessy et al., 2007; Addai, 2013).

Already, broadacre farm businesses in the agricultural region of Western Australia have experienced pronounced climate variability and a warming and drying trend over the last two decades (Boston Consulting Group, 2010; Steffen and Hughes, 2011). In the 12 years since 1998 many farm businesses have reduced equity levels, despite substantial land value increases during the same period. The decline in average equity from 85 percent to 72 percent has been due to greater indebtedness caused by a combination of farm expansion and poor years, particularly warmer and drier years, that have forced increased borrowings due to poor yields and therefore low revenues (PlanFarm BankWest Benchmarks, 2011&2012; Stretch et al., 2012).

Historically Western Australian broadacre farmers have met previous climate and financial challenges by adapting to their changing circumstances. However, it could be argued that the decade of the 2000s included signs of structural adjustment associated with climate change (Foster, 2007). Indeed, as reported later in this review, there is a significant amount of research into the physical effects on agriculture of climate variability and possible long-term impacts of climate change. However, research on the financial impact of climate change and climate variability on farm businesses is relatively scarce. There is a need for longitudinal studies of farm business performance that may help identify emerging impacts of climate change and the adaptation responses to those impacts. This literature review examines this literature on climate change impacts and adaptation responses and identifies important gaps in the literature.

The structure of this literature review is that first, an overview of climate change and its scientific underpinnings are presented. Then literature on the anticipated impacts of climate change on Australian agriculture is presented, along with the adaptation responses used by farmers.

A key focus of this literature review is to describe our current understanding of how farmers are adapting or could adapt to the changing climate. Do they have the capacity to implement the necessary changes to remain viable into the future?

2.1.1 An overview of the understanding of climate change

Substantial research regarding the science of climate change has occurred both globally and within Australia in the last 30 years. Even though Svente Arrhenius in 1896 pointed out that burning of fossil fuels (oil, coal and natural gas) might cause an increase in atmospheric carbon dioxide, thereby warming the Earth, the climate ramifications of this suggestion have only recently risen to scientific prominence (Pittock, 2003).

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) as: “A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.”

More specifically, however, the UNFCCC, Article 1 defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” The UNFCCC thus makes a distinction between “climate change” attributable to human activities altering the atmospheric composition, and “climate variability” attributable to natural causes (Jarroud and Töpfer, 2004).

The IPCC was established in 1988 by the World Meteorological Organisation (WMO) Executive Council in collaboration with United Nations Environmental Program (UNEP) in response to the previous decade of concern expressed by WMO that “continued expansion of man’s activities on earth may cause significant extended regional and even global changes of climate”. The WMO and UNEP recognised the need for objective, balanced, and internationally coordinated scientific assessment of the understanding of the effects of increasing concentrations of greenhouse gases on the earth’s climate and on ways in which these changes may impact socio-economic patterns (Jarroud and Töpfer, 2004).

Three working groups comprising representatives from a number of different countries around the World were established and they prepared assessment reports on:

i. available scientific information on climate change,
ii. environmental and socio-economic impacts of climate change, and
iii. formulation of response strategies.

The IPCC reported to the Second World Climate Conference in November 1990, and to the United Nations General Assembly, on “the scientific information that is related to the various components of the climate change issue …” and on “formulating realistic response strategies for the management of the climate change issue.” (Pittock, 2003).

Two major Assessment Reports were released by the IPCC in 1996 and 2001 (IPCC, 2011; McCarthy et al., 2001; Metz et al., 2001), and a special report on The Regional Impacts of Climate Change (Watson et al., 1998) as well as a number of other reports, including the Special Report on Emission Scenarios (SRES) in 2000 (Nakicenovic and Swart, 2000), which produced a range of plausible scenarios for future greenhouse gas and aerosol emissions up to the year 2100.

Climate change research undertaken in Australia has been based on this international research. In recent years specific research programs on climate change have been funded such as the Australian Climate Change Science Program led by CSIRO and the Australian Bureau of Meteorology in partnership with the Australian Greenhouse Office. (CSIRO & Bureau of Meteorology, 2007). These programs include developing models of climate change.

The modelling of climate change is increasingly sophisticated, drawing on ever larger datasets to represent physical and dynamical processes and to provide finer spatial resolutions. The enlarged data sets and modelling capacity now allow 21 climate variables and 6 ocean variables to be projected and the enhanced international research effort has produced 23 climate models that can be compared, resulting in an increased confidence around the understanding of climate change and its impacts (CSIRO & Bureau of Meteorology, 2007).

The climate change projections for Australia based on the assumptions made and research done up until 2007 suggest that the best estimate of annual warming over Australia by 2030 relative to the climate in 1990 is approximately 1.0˚C, with warming around 0.7– 0.9˚C in coastal areas and 1 – 1.2˚C inland (CSIRO & Bureau of Meteorology, 2007). Current projections suggest an increase in global average temperatures of 1.1 to 6.4˚C by the end of the present century. These temperature rises may not seem particularly significant but a 1.0˚C rise in temperature for Melbourne will make it more like the climate currently experienced in Wagga Wagga; a 4˚C increase more like Moree and a 6˚C increase more like that north of Roma in Queensland (Stokes and Howden, 2010).

Recent climate observations show that modelling based on 1990 datasets have underestimated CO_2 emissions, sea levels and temperatures which are all at or above the worst-case scenario of the IPCC 2001 levels (Rahmstorf et al., 2007). However, despite there being more certainty and confidence in the modelling and the observations of climate change indicators like CO_2 emissions, sea levels and temperatures, there remains large uncertainty when discussing the implications of the modelling.

As noted by the CSIRO and Bureau of Meteorology (2007), "caution should be exercised when using the projections in any risk assessment". It is the high level of complexity surrounding the science and prediction of likely impacts that contributes to this high degree of uncertainty (CSIRO & Bureau of Meteorology, 2007; Stokes and Howden, 2010).

The IPCC has used emissions and climate scenarios as a central component of its work in assessing climate change and its impacts. These scenarios help identify

findings that are robust under a wide range of futures (Moss et al., 2010). This reliance on plausible scenarios also indicates that future climatic change is conditional on human activity which in turn is conditional on uncertain variables like rates of economic growth and changes in governments' carbon emission policies.

It is therefore not surprising that much of the literature on climate models and predictions of the future emphasize the need for caution in interpreting findings due to their inherent uncertainties. Moss et al. (2010) point out "that nearly a decade of new economic data, information about emerging technologies and observations of environmental factors such as land use and land cover change" is not considered in the currently reported predictions of climate change "and yet should be reflected in new scenarios". However, despite the high degree of uncertainty there remains a high degree of confidence that global climate will change in particular ways. For Australia, the exact nature and consequences of these changes are not known but the consensus among climate scientists is that the southern half of Australia is likely to become drier under the influence of higher global temperatures, and parts of northern Australia are likely to become wetter (CSIRO & Bureau of Meteorology, 2007; DAFWA, 2010; Heyhoe et al., 2007). CSIRO has produced national climate projections in 1990, 1992, 1996 and 2001 and, jointly with the Bureau of Meteorology in 2007. The next set of national climate projections are planned for release in 2014. The most recent projections point to a greater variability in the climate conditions is anticipated, with more heavy rain events and an increased number and severity of droughts (Addai, 2013; Loch, 2012; Hennessy et al., 2008).

In summary, the science community agrees that climate change is evident, that we are already seeing changes in climate, some of which are attributable to human activity; however the socio-economic impact of the change is uncertain. Among the important uncertain impacts of climate change is the impact on agriculture and food production. These impacts are discussed in the next section.

2.1.2 Understanding the impact of climate change on agriculture

Climate change has gradually been recognized as a factor affecting the form, scale, spatial distribution and rate of change in agricultural productivity. The general consensus is that changes in temperature and precipitation will result in changes in land and water regimes that will subsequently affect agricultural productivity (Kurukulasuriya and Rosenthal, 2003). Climate change is projected to bring further difficulties to millions of people for whom achieving food security is already problematic, and so climate change is perhaps humanity's most pressing challenge as the world seeks to nourish nine billion people by 2050 (Godfray et al., 2010). In recent decades global food production, has increased in line with and sometimes ahead of demand. However, FAO projects that demand for cereals will increase by 70% by 2050, and will double in many low-income countries (FAO, 2006). This increasing demand for food is an outcome of both larger populations and higher per capita consumption among communities with growing incomes, particularly in Asia. To meet this higher demand, food production obviously becomes crucially important (Vermeulen et al., 2010).

Research has shown that, specifically in tropical regions that encompass many of the world's poorest countries, the impacts on agricultural productivity are expected to be

particularly harmful. The vulnerability of these countries is also especially likely to be acute in light of their technological, resource, and institutional constraints. Although estimates suggest that global food production is likely to be robust, experts predict tropical regions will see both a reduction in agricultural yields and a rise in poverty levels as livelihood opportunities for many engaged in the agricultural sector become increasingly susceptible to expected climate pressures (Kurukulasuriya and Rosenthal, 2003).

The general consensus to emerge from the literature is that in the absence of adequate response strategies to long-term climate change as well as to climate variability, diverse and region-specific impacts will become more apparent (Kurukulasuriya and Rosenthal, 2003).

Numerous factors influence food production and the agricultural sector besides the uncertainties driven by climate variation. These include market fluctuations and changes in aspects such as: domestic and international agricultural policies (such as the form and extent of subsidies, incentives, tariffs, credit facilities, and insurance), management practices, terms of trade, the type and availability of technology and extension, land-use regulations and biophysical characteristics (availability of water resources, soil quality, carrying capacity, and pests and diseases) (Kurukulasuriya and Rosenthal, 2003).

Despite the increase in global food production over the last few decades, satisfying the Millennium Development Goal of reducing hunger by half by 2015 appears to be beyond reach. In fact, the number of people suffering from chronic hunger has increased from under 800 million in 1996 to over a billion according to FAO's most recent estimate in 2009 (FAO, 2009). Most of the world's hungry are in South Asia and sub-Saharan Africa. These regions have large rural populations, widespread poverty and extensive areas of low agricultural productivity due to steadily degrading resource bases, weak markets and high climatic risks. Farmers and landless labourers dependent on rainfed agriculture are particularly vulnerable due to seasonal variability in rainfall, and endemic poverty (Vermeulen et al., 2010).

Vermeulen et al (2010) report that in recent times, food insecurity has increased in several such regions due to competing claims for land, water, labour, and capital, leading to more pressure to improve production per unit of land. Rapid urbanization and industrialization in South Asia, for example, has taken away from agriculture some very productive lands and good quality irrigation water (Fazal, 2000). Climate change is therefore of particular significance for these countries, which already grapple with global and regional environmental changes (Aggarwal et al., 2004; Cook-Anderson, 2009; Toulmin, 2009) and significant inter-annual variability in climate (Arndt and Bacau, 2000; Haile, 2005). For example, changes in the mean and variability of climate will affect the hydrological cycle and crop production (Easterling et al., 2007) and land degradation (Sivakumar and Ndiang'ui, 2007).

For the Australian agricultural environment its climate is projected to become warmer and subject to more frequent extreme events, yet changes in rainfall amounts and patterns are highly uncertain and differ across regions. Even in a relatively small region like Gippsland in Victoria, Hood et al. (2002) reported that climate change will affect its

different agricultural activities in diverse ways over time, favouring some activities while adversely affecting others (Kingwell, 2006).

In summarising the main impacts of various projections of climate change on Australian agriculture Kingwell (2006) explains “in its most simplistic form climate change is reported (UNEP 1999, AAG 2001) as the shift of climatic zones and their associated agricultural activity toward the poles and to higher elevations.” Kingwell (2006) and many other researchers (Howden and Jones 2001 & 2004; Howden and Meinke, 2003; Harrison, 2001; Pittock, 2003; White et al., 2003; Kokic et al., 2005) all show that the agricultural impacts of projected climate change in Australia is a complex spatial story.

The following section focuses on how climate variability and climate change is likely to impact on Australian broadacre farm businesses. It first looks at the livestock and cropping enterprises and the predicted impact on these, before taking a wider view on whole farm business.

2.1.3 The impact of climate on Australian farm businesses

Australian farmers are no strangers to dealing with the challenge of seasonal variability. Anyone who has spent time on a farm or with farming family members will appreciate the importance placed on listening to or watching the latest weather forecast and in more recent years, using smart phones and computers to access the latest weather to make decisions around farm activities. Although key management activities are conditional on weather, often it is the enterprise mix and strategic management of a farm business that is governed by climate rather than weather.

Australian farmers face two major climate risks: climate variability and climate change. Climate variability refers to the short-term fluctuations in temperature, rainfall and other climatic conditions over a season or across years. In contrast climate change describes the longer term trends (decadal or longer) in the underlying average climate and climate variability (Loch et al., 2012).

Australia’s climate is recognised as one of the most variable in the world (CSIRO & Bureau of Meteorology, 2007; Hennessy, 2008) and as a result it is one of the greatest sources of risks for Australian agriculture (Loch, 2012; Kimura and Antón, 2011). Against this backdrop of on-going and possibly enhanced climate variability, long-term climate change is projected to involve several environmental changes. Anwar et al. (2012) list these changes as increases in atmospheric concentrations of CO_2 and ozone; increases in temperatures, extreme events and se levels and increases or decreases in rainfall and frost, depending on the geographical region.

Much of Australia is projected to experience an increase in temperatures. Depending on the extent of the temperature increase and the times during the year when high temperatures occur, farm production will be affected. For example, mortality in dairy and beef cattle are likely to increase due to heat stress (Mayer et al., 1999).

- ***The impact on livestock enterprises***

Future impacts of climate change on livestock production are likely to be both direct, for example productivity losses (physiological stress) owing to temperature increases, and indirect, for example changes in the availability, quality and prices of inputs such as

fodder, energy, disease management, housing and water (Thornton, 2010). Animal production systems have the added complication that they could be significantly affected by climate change policy and national targets to address greenhouse gas emissions, since livestock are estimated to contribute ~10% of Australia's total emissions and additional farm emissions are associated with activities such as feed production. More than two-thirds of agricultural emissions are attributed to ruminant animals (Henry et al., 2012).

Rötter and Van de Geijn (1999) suggested that any shifts in climatic conditions could affect animal production in four primary ways: (i) feed grain production, availability, and price; (ii) pasture and forage crop production and quality; (iii) animal health, growth, and reproduction; and (iv) disease and pest distribution.

The effects of climate change, in particular higher temperatures on animal growth and mortality have been investigated. A number of early studies have examined the impact of heat stress on dairy production. For example, Mayer et al. (1999) assessed the response of dairy cattle to heat stress in Australia and catalogued a range of adverse impacts; both milk yields and milk constituents declined with increases in temperature. Prior to this Davison et al (1996) produced a book about 'Managing hot cows in Australia' which is a widely cited resource.

The impacts of increased heat stress in cattle include reduced grazing time (partly as a result of animals seeking shade), reduced feed intake, increased body temperature, increased respiration rate, and weight loss. In dairy cows, heat stress reduces milk yield, reduces milk fat and protein content, and decreases reproduction rates (Davison, 1996; Jones and Hennessy, 2000). High-producing dairy cows are the most susceptible to increases in the temperature-humidity index (THI), a measure of the heat stress on cattle, and hence a measure of their productive performance. Heat stress days with THI > 80 lead to a substantial effect on reproduction of dairy cows, particularly for Holstein-Friesian cows (Cowie and Martin, 2009).

Howden and Turnpenny (1997) and Howden et al. (1999) report on impacts of heat stress and climate change on northern beef cattle in Australia. According to Petty et al. (1998) heat stress already affects the productivity of northern cattle. Growth rates; a key profit driver for meat production, are likely to be adversely affected due to heat stress.(Henry et al., 2012; Kassahn et al., 2009). Moreover, Norris et al. (2003) reviewed all cattle deaths on voyages from Australia to all destinations between 1995 and 2000 and found that Bos Indicus cattle coped with hot, humid conditions on board ships better than Bos Taurus, the main cattle species in southern Australia. Even as early as the late 1990s, Howden and Turnpenny (1997) were advocating selection of cattle lines with greater thermoregulatory control, but they pointed out that this would be difficult because it was unlikely to be consistent with high production potential (Finch et al., 1982 & 1984).

There are some studies on the impact of climate change and climate variability on pastures and stock. McKeon et al. (2004) have examined the rangelands and Heyhoe et al. (2007) discuss the impact on livestock enterprises. Cullen et al (2009) examine the climate change impacts on Australian pasture systems. Modelling the potential impacts of climate change on dryland cropping tends to be more advanced than

pasture related enterprises. Pearson (2008) observes that there is considerably less research and capability regarding the modelling and quantification of potential impacts of climate change on the grazing, dairy, viticulture and horticulture industries. In many instances, simple historical analogues or 'expert opinion' is the basis for estimating productivity impacts (Pearson, 2008). This is possibly due to the modelling showing that changes in rainfall resulting from climate change are estimated to have a proportionately greater impact on crop yields that they have on livestock production.

This gap in the literature is starting to be alleviated by some more recent work. For example, MLA have recently released a report (Moore, 2012) prepared by CSIRO to develop information about the likely extent of climate change and options for adaptation for livestock producers in southern Australia. Another recent publication by Henry et al. (2012) acknowledges some adaptation strategies are already being implemented, such as the management of heat stress in dairy cattle, but recommends that ongoing adaptive adjustments will be needed to maintain sustainability and productivity due to increasing temperatures, changing rainfall patterns, and increasing climate variability. In addition to continued improvement in climate adaptation, there is also a need to develop cost effective strategies for managing emissions from animal agriculture.

Henry et al. (2012) conclude that for livestock industries there is a specific and urgent need for greater understanding of how the biology (behavioural, immunological, physiological, and metabolic functions) of animals will be affected by the direct effects of climate change, and greater understanding of the indirect effects on disease/parasite exposure and feed quality through effects on plant and soil systems (Gaughan et al., 2009). Our understanding of the impact of climate change on the feedbase is more advanced, and new models, such as mosaic agriculture, are emerging that will increase the resilience of livestock farming across Australia (Stokes et al., 2010). Whole farm systems modelling needs to shift from modelling climate change impacts for current plants, animals, and management practices, to evaluating adaptation options identified by the researchers and agro-ecosystem managers who will develop and implement those options (Henry et al., 2012).

- ***The impact on grain production***

The implications of climate variability and climate change on food supplies for the world has attracted considerable interest and effort in understanding the consequences for crop production (Challinor, 2010). Considerable progress has been achieved in recent years to combine climate models with crop models in order to understand the implications for food production (Vermeulen, 2010; Challinor, 2009).

For example, global climate models predict for Europe a decrease of precipitation during summer and a substantial increase in temperature, and increases in the frequency and magnitude of extreme weather events. For example, heat waves in the UK are predicted to increase in frequency (by an order of magnitude), length and severity (peak temperature) by the end of the century. The impact of this type of weather has implications for crop yields. Even isolated incidents of extreme high temperature around a sensitive stage of crop development, such as flowering, could reduce grain yield considerably, while a continuous period of extreme high temperature could result in almost total yield loss (Semenov and Shewry, 2010).

There are many complex processes and interactions that determine crop yield under climate change. These include the response of crops to changes in temperature, particularly extremes of temperature, the interaction between water stress and CO_2, and the interaction between ozone and a range of environmental variables (Challinor, 2009).

Much of the work done in Australia on the impact of climate change looks at the implications for wheat production, which is understandable, considering it is the major crop in Australia. There are between 11 to 13 million hectares of wheat planted annually and it is the main source of revenue for many broadacre businesses. It has a gross value around $4.2 billion and a production volume around 22MT (Howden and Jones, 2001; Pittock, 2003; Howden and Crimp, 2005). Annual total wheat production for Australia can range from 10 to 26 million tonnes, depending on seasonal conditions and yields are generally low and variable in comparison to international grain growing areas (Mauldon and Schapper, 1974; Anderson and White 1991; Makeham and Malcolm 1993; Productivity Commission, 2005; Howden and Crimp 2005; Rayner et al., 2010; Kingwell, 2011). This is mainly due to Australia's low rainfall and low physical and chemical soil fertility. Therefore, understanding the impact of climate change and climate variability on wheat production is a significant issue for Australia, particularly southern regional Australia where most wheat is grown.

A review by Challinor et al. (2009) examines the progress in methodologies used to understand the impact of climate change on crop production. They outline that there are two types of approaches; the first is primarily based on climate models, which use spatial grids with resolutions typically of the order of a hundred kilometres, or sometimes done at a regional scale with grids of a few hundred kilometres. The second approach involves location-specific methods to account for the variety of climatic and non-climatic stresses on crop productivity. Typically these types of models were originally designed as decision support tools. In Australia both approaches are used. Many studies report the impact of climate change and climate variability on broadacre agriculture, most of which use broad scale climate models to analyse the anticipated production and physical outcomes of a change in climate or its variability (Nicholls, 1999; Kokic, 2005; Hennessy, 2008; Loch, 2012).

Nelson (2010) comments that "most climate-related research and extension in Australian agriculture has focused on impact modelling using seasonal climate forecasts to manage the production impacts of climate variability within the existing farming systems". He points to studies such as those by Hammer (2000), McKeon et al. (2004) and Meinke and Stone (2005). The results from these studies are derived from impact modelling that draws on assumptions and climate scenarios generated by the IPCC research (Pittock, 2003; Howden and Jones, 2004; Kokic, 2005).

Kingwell (2006) in his review of climate change literature discusses possible impacts on Australian agriculture of climate change. He notes that "Not all the studies of climate change impacts have consistent findings, in part due to the climate scenarios they consider, and the types of modelling assumptions and methodologies and time frames they employ." This comment is supported by Hennessey (2008) who points out that the uncertainties in projected regional climate to 2030 are mostly due to differences between the results of the climate models. The uncertainties lead to a range of possible

impacts. For example, projected changes in wheat yields and land values are that they will decline by between 7 and 16 per cent respectively or increase between 2 and 9 percent respectively (Kokic, 2005).

What is agreed upon in the literature is that impacts on the cropping industries as a result of climate change will be the net effect of the interaction between increased CO_2 concentrations, temperature changes and rainfall changes. The increase in CO_2 will increase crop water-use efficiency but reduce grain quality, the likely decrease and variability in rainfall will have a negative impact and the predicted increase in temperatures will have both negative and positive effects (Pittock, 2003; Howden and Jones, 2004; Kokic, 2005; Morgan et al., 2011; Potgieter et al., 2012; Nuttall et al., 2012).

Howden and Hayman (2005) examined the impact of projected climate change on the Goyder line in South Australia. This line historically has represented the border of cropping viability. They found a high probability of this line moving southwards, thereby reducing the area viable for cropping in South Australia. The impact of climate change on cropping area was also investigated in an earlier study by Reyenga et al. (2001). They noted that climate change would likely alter the distribution of cropping in Australia, given the importance of climate and soil characteristics in determining average yields and the frequency of failed sowings. They suggested that the viability of some cropping regions across Australia would decrease if the number or sequence of poor seasons increased.

Aside from warmer temperatures, it is the magnitude and variability of rainfall that most affects dryland agricultural production. Extended periods of dryness severely limit grain and pasture yields and critical stages of plant growth and development are adversely affected (CSIRO, 2007; Loch, 2012).

Recent studies have emphasised how the impact of climate change and predicted climate variability will differ for different regions of Australia (Crimp and Howden, 2008a; Potgieter, 2008; Ludwig et al., 2009; Asseng and Pannell, 2012; Potgieter et al., 2012). The most recent study by Potgieter et al. (2012) modelled the impacts of climate change on shire wheat yields across Australia. They found that projected climate change caused slightly negative, yet a spatially highly heterogeneously pattern of yield responses for temperature and rainfall regimes that tended to be offset by CO_2 fertilisation effects. For example, their 2050-high emissions scenario caused modelled wheat yields, relative to a 1901 to 2007 baseline, to range from −5 % to +6 % across most of Western Australia, parts of Victoria and southern New South Wales, and from −5 to −30 % in northern NSW, Queensland and the drier environments of Victoria, South Australia and in-land. After accounting for CO_2 fertilisation effects much of the yield reductions were cancelled out.

For the agricultural region of Western Australia, previous climate modelling at a shire scale often indicated a negative impact of climate change was anticipated (Van Gool and Vernon, 2005; Howden and Jones, 2004; Allen Consulting Group, 2005; Van Ittersum et al., 2003). More recent studies by Potgieter et al. (2012) and Asseng and Pannell (2012), however, indicate that the recent decades of climate have not adversely affected wheat yields, relative to historical climate, even though regional

climate has displayed some challenging trends for crop production. Historical climate data for the south west of Western Australia already shows the growing season rainfall (May to October) has decreased since the 1970s by 15 to 20 percent (Hope et al., 2006). Asseng and Pannell (2012) note that the Western Australian wheat-belt has had a 20 percent rainfall decline over the past 110 years, more than any other wheat-growing region in Australia.

Ludwig et al. (2009) examined the impacts of climate change on wheat production systems at various locations in Western Australia. They report that contrary to the 11 percent reduction in growing season rainfall (on average across nine sites) since the mid 1970s, wheat grain yield in the Western Australian wheatbelt actually increased during this period. From 1930 to 1980 wheat yields increased from about 0.7 t/ha to 1.1 t/ha. Yet between 1980 and 2000 yields increased from 1.1 to 1.7 t/ha. However, he did not include yield changes since 2000 in his analysis, and other data sources for this period indicate an increase in variability of yield and virtually no trend increase in yield (Kingwell, 2011; Stretch et al., 2012).

The explanation for the low impact on yield is a combination of the timing of the rainfall, a reduction in salinity issues (George et al., 1997; McFarlane and Ruprecht, 2005) and the introduction of minimum-till seeding. The latter has proven to be a very effective adaptation technique, although not a direct response to climate variability (Sadler, 2002).

Ludwig et al. (2009) argue that their results indicate a reduction in yield cannot be assumed to be proportional to the reduction in rainfall, even though analyses of farm yield potential show a strong correlation with growing season rainfall (French and Schultz, 1984). They suggest that previous studies (Van Ittersum et al., 2003; John et al., 2005; Ludwig and Asseng, 2006) that apply a proportional reduction in rainfall across the whole season are too crude and probably overestimate the impact of climate change on yield and farm productivity.

Issues such as the distribution of rainfall across the growing season, size and distribution of rainfall events will all have an impact on the yield outcome (Ludwig, 2009). For some locations in Western Australia this will increase yield potential due to reduced water logging but for other locations yield potential will decrease (John et al., 2005; Kingwell and Farré, 2009).

However, as stated above, there are a number of complexities that affect potential grain yield, and research is showing that the impact of heat stress on grain growing at flowering can also adversely affect grain yield and grain quality. A study by Semenov and Shewry (2011) shows that heat stress, not drought will increase vulnerability of wheat in Europe. Grain size and number can be substantially reduced if a cultivar, sensitive to heat stress, is exposed to a short period of high temperature around flowering, limiting the capacity of grains to store newly produced biomass. A number of experiments show that temperatures of 27 C or higher applied at anthesis reduce grain size resulting in yield losses. Studies done by Tashiro and Wardlaw (1989) showed several Australian wheat cultivars to be susceptible (Semonov and Shewry, 2011).

2.1.3.1 *Impacts on viticulture, forestry and biodiversity*

McInnes et al. (2003) have commented on possible impacts of climate change scenarios on Australia's viticultural regions. Warmer, drier conditions particularly in winter and spring are likely to accelerate phenological development, causing earlier ripening and possible reductions in quality. However, in cooler climates such as the Mornington Peninsula in Victoria, and in Tasmania, warming may allow new varieties to be grown. In all viticulture regions there will be greater competition for increasingly limited supplies of irrigation water. As vineyards have a life of 30 years or more, vines planted now are likely to experience climate change, so varietal selection and management would need to account for these likely future impacts.

Warmer conditions are also likely to alter the risk of bushfire. Beer and Williams (1995), Williams et al. (2001) and Cary (2002) report the potential impact of climate change on bushfire danger in Australia. These studies each found that associated with projected climate change was a general increase in fire danger, as measured by the McArthur forest fire danger index. Extreme fire danger already is highly correlated with periodic drought conditions that cause the drying of fuel; and extremely hot summer and autumn days are conducive to fire spread. Both these conditions are expected to increase with global warming under all plausible scenarios, at least in southern Australia (Pittock, 2003a).

The IPCC (2007) report estimates that production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. It is anticipated that In New Zealand there will be some initial benefit in western and southern areas and close to major rivers, due to a longer growing season, less frost and increased rainfall. The report does note how the region has substantial adaptive capacity due to well developed economies and scientific and technical capabilities but also notes there are considerable constraints to implementation and major challenges from changes in extreme events as natural systems have limited adaptive capacity (IPCC, 2007).

Western Australia is home to eight of Australia's fifteen national biodiversity hotspots and Australia's only international biodiversity hotspot, recognised by Conservation International. The Southwest Australia eco-region is one of only five Mediterranean climate systems to be listed as globally significant. The ecological value of the southwest region lies in the diversity of plants and animals found nowhere else in the world. The region has the highest concentration of rare and endangered species on the continent. Climate change, together with existing stresses from land clearing and human inhabitants, is likely to have a substantial negative impact on the extraordinary diversity of the southwest (Steffen and Hughes, 2011).

2.1.3.2 *Impact on profitability of broadacre farm businesses*

Although there is widespread recognition that research has provided important information on the likely impacts of climate change, there are also a number of recognised limitations such as the spatial scale being too broad to estimate localised impacts. However this can be resolved through use of specific localised models. Another limitation less easily resolved, and identified by a number of authors, is how to model farmers' behavioural responses to climate change. In short, how might farmers adapt to climate change? Efficient adaptation responses are theoretically possible, but

farmers need to react given a range of uncertainties about climate change and the efficacies of different adaptation options (Kurukulasuriya and Rosenthal, 2003).

Many analyses of the impacts of climate change are yet to fully explore the variability surrounding climate change (Kurukulasuriya and Rosenthal, 2003). Often analyses consider average anticipated annual changes in rainfall and temperature, rather than the inter-annual or inter-seasonal variability upon which the productivity of agricultural systems depends (Nelson et al., 2010a).

Perhaps the most common limitation of studies of the impacts of climate change is their failure to simultaneously include likely adaptation responses of farmers. Hennessey (2008), Antle and Capalbo (2010), Nelson et al. (2010a) and Pearson et al. (2008) all observe that most existing research has focused on modelling the potential impacts of climate change on agricultural production without considering the adaptive management responses of farmers that would potentially reduce the climate change impacts on agricultural production. Mendelsohn and Dinar (1999) also outlined several criticisms of the agronomic or production function approach that tends to overestimate damages and fails to consider adaptations in the form of modified farming methods or effects of government interventions.

Also, early work implicitly assumed that farmers would continue growing the same crops regardless of the climatic conditions. But subsequent work has adopted more sophisticated optimisation approaches whereby land is allocated to particular crops by profit maximizing farmers, subject to agro-climatic suitability constraints. Such spatial optimisation models enable researchers to predict movements in agro-climatic zones and the resulting impacts on world prices, patterns of trade and production, and consumer and producer surpluses. However, despite their complexity these models are nevertheless incapable of incorporating into the analysis all possible farmer adaptation strategies to changing climate (Mendelsohn and Dinar, 1999; Maddison et al., 2007).

An example of a recent attempt to address this issue is the work done by Malcolm et al. (2012), using a mathematical optimisation model known as the Regional Environment and Agriculture Programming (REAP) model. They predict how the USA crop sector might respond to climate change, and in particular how land use and land management decisions will be adjusted in the USA corn belt. However they still acknowledge weaknesses in these analyses, including the lack of understanding around the impacts on supply costs of agriculture inputs; land energy, fertiliser, water and labour. Their model also did not consider animal productivity and other aspects of livestock management costs although they did consider some livestock sector impacts through changes in feed grain markets.

Henry (2012) identifies that research in Australia is needed to better understand the direct and indirect effects of climate change on animal production systems for development of regionally applicable, longer term adaptation strategies as identified by Garnaut (2011).

The climate and impacts modelling community acknowledge many of these weaknesses and are seeking ways to address these issues (Mendelsohn and Dinar, 1999; Maddison, 2007; Challinor, 2009; Head et al., 2011). The role of socio-economic

drivers and the influence of human action on crop productivity are topics of growing interest, and a number of approaches are being used. Challinor (2009) claims that the intellectual foundations of much of this work is from Amartya Sen and the 'food entitlement theory' that examines the causes of 20th century famines. Sen (1981) argued that socio-economic factors that constrain an individual's production decisions strongly contribute to famine along with the obvious impacts of climate anomalies . The socio-economic research uses quantitative and qualitative methodologies based on farmer interviews, focus groups and questionnaires to show how households and villages adapt to weather-related challenges (Challinor, 2009; Head et al., 2011; Hogan et al., 2011). Many of these studies show that productivity relies on capital and labour inputs and a range of other factors (Mendelsohn, 2007) that make up a complex and unpredictable interactions between society and the environment (O'Brien and Leichenko, 2000).

There are efforts to increase the reliability and relevance of predictions by using the results from qualitative work in conjunction with a Ricardian approach where cross-sectional evidence is used to predict how farmers would adapt to a change in environmental conditions by regressing measures of agricultural outcomes on various climate and other variables. An example of this type of approach is work by Mendelsohn et al. (1999) and more recent work by Maddison et al. (2007), Kingwell and Lawes (2012) and Hogan et al. (2011).

Australian studies of the impact of climate variability on Australian farm income and business viability include work by Heyhoe et al. (2007), John et al. (2005) and Lawes and Kingwell (2012). Heyhoe et al. (2007) provide a broad perspective and they use the climate change scenarios discussed earlier that entails a high degree of uncertainty. They qualify their results by stating that they illustrate the potential impacts of two climate change scenarios with a high degree of uncertainty and that their results "should not be considered definitive".

John et al. (2005) investigated the impact on a low rainfall broadacre farming system in a region of Western Australia of a number of climate change scenarios, but these authors also acknowledged the uncertainty of their findings. They pointed out that their results should be viewed with caution because the impacts of climate change would be overstated as the study did not consider technological innovation in response to climate change. In the more extreme scenario modelled farm profit was reduced by 80 percent compared to the scenario of a continuance of historical climate. If this more extreme climate scenario was to eventuate then the viability of the low rainfall wheat belt in its current form would be questionable.

The study by Lawes and Kingwell (2012) takes a different approach and uses historical evidence to determine the characteristics required for coping with climate variability. The economic performance of 123 farms in Western Australia wheatbelt was examined from 2004 to 2009, a period that included severe droughts in 2006 and 2007. The characteristics of farm businesses that caused those businesses to survive the years of consecutive drought were discovered. These authors reported on the financial performance of the business using measures of business equity, operating profit per hectare, return on capital and the debt to income ratio. This is a rare study that relates the whole of farm business performance to climatic conditions, instead of focusing on

specific agronomic or production functions. They used statistical analyses to identify the possible interactions and explanatory variables of the four business indicators. This study also used a longitudinal approach to examine the historical performance of the farm businesses.

Similar studies by Reidsma et al. (2007 and 2009) analysed relationships between farm characteristics and yield variability across regions in Europe. The impacts of trends and variability in climatic conditions from 1990 to 2003 were analysed with trends and variability in yields of five crops and farmers' income. They found that farm intensity, farm size and land use were important characteristics that explained a significant part of the spatial and temporal yield variability.

The Lawes and Kingwell (2012) study found farms that cropped more than 50 percent of their farm area, and that had some diversity in their enterprise mix and that generated farm production without incurring excessive operating costs were most likely to maintain their equity position. Mean wheat yield was identified as being highly important to the financial health of these farm businesses and that drought was a serious impediment to the strength of the farm business.

2.2 Adapting to climate variability and climate change

Global mean temperatures have risen since the mid 1800s (Stokes et al., 2010) and past emissions of green house gases have already committed the globe to a further warming of approximately 0.1˚C per decade for several decades (Solomon, 2007), making some level of impact and therefore necessary adaptation responses already unavoidable (Howden et al., 2007).

Mitigation and adaptation are the two fundamental response options to the risks of anthropogenic climate change. Mitigation refers to limiting the global climate change through reducing the emissions of greenhouse gases (GHG) and enhancing their sinks. Adaptation primarily aims at moderating the adverse effects of climate change through a wide range of actions targeted at the vulnerable system (Füssell, 2005).

Mitigation from both a policy and science perspective has traditionally received much greater attention, despite adaptation being identified in a number of studies as an appropriate response in the 1990s by authors such as Fankhauser (1996), Smith and Lenhart (1996) and Smit et al. (1999). This lack of attention particularly in the last decade has attracted criticism from a number of authors (Smit et al., 2001a; Kurukulasuriya and Rosenthal, 2003; Howden et al., 2007; Antle and Capalbo, 2010).

In a review of literature Smit (2001b) identified that adaptation as an international policy response was recognised by at least 1992. He quotes the United Nations Framework Convention on Climate Change (UNFCCC, 1992) where it states that parties are 'committed to formulate and implement national and, where appropriate, regional programs containing measures to mitigate climate change and measures to facilitate adequate adaptation of climate change". This indicates that international bodies and governments recognised the role for adaptation as an effective response to climate change. The Kyoto protocol further commits parties to promote and facilitate adaptation and deploy adaptation technologies to address climate change (Smit, 2001b).

There are a number of difficulties associated with policy development for climate change that have created the disproportionate attention towards mitigation instead of adaptation. Füssell (2005) provides an explanation of these issues which are summarised in the following points:

(i) Reducing GHG emissions is applying the polluter pays principle, whereas the need for adaptation measures will be greatest in developing countries, yet they have contributed relatively little to climate change.
(ii) Mitigating climate change helps to reduce the impact on climate-sensitive systems where adaptation strategies will be inappropriate. For example, adaptation to the rising sea levels that affect small Pacific islands will not be appropriate.
(iii) GHG emissions are relatively easy to monitor quantitatively and the effectiveness of adaptation is much more difficult to measure.

The improvement in understanding about climate change and its impacts is directing the types of responses being developed. It has become increasingly apparent that adaptation will have to be part of the response given the amount of past and current GHG emissions. We are already bound to some degree of climate change which can no longer be prevented, even by the most ambitious emissions reductions (Fussell, 2005; IPCC, 2007). Anwar et al. (2012) argue for a framework of adaptation responses based on short term, medium term and long term actions.

The uncertainty surrounding the impacts of climate change, as discussed earlier, is forcing a rethink of traditional risk management approaches to climate policy, especially in agriculture. Climate related policy has tended to focus on scientific systems for predicting extreme events such as droughts, floods and storms and their impacts on agriculture (Nelson et al., 2009). However, there is recognition that although the uncertainty about future climate cannot be resolved, investments can be made to reduce this uncertainty and develop systems that are more climate resilient (Antle and Capalbo, 2010).

The importance of developing effective strategies for adaptation is recognised by many governments around the world (Iglesias et al., 2007). Adaptation to climate change has become part of the contemporary discourse about the politics and economics of global climate change (Adger et al., 2008). In the past decade, unlike the 1990s and early 2000s where there was a preoccupation about the mitigation, there is a growing attention to adaptation – both its practice and politics (Parry et al., 1998; Peilke et al., 2007; Adger et al., 2008).It has been enshrined in the policy debate through its appearance in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) where the ultimate objective of the Convention concedes that adaptation to climate change in relation to food production, ecosystem health and economic development can and will occur.

In Australia there have been a number of government initiatives to address climate change issues such as the Garnaut Climate Change Review (Garnaut, 2011); the National Climate Change Adaptation Research Facility, whose goal was to improve understanding of the impacts of climate change and to develop adaptation responses;

and the CSIRO Climate Adaptation Flagship; a large multidisciplinary research partnership designed to enable Australia, including the agriculture sector, to adapt more effectively to the impacts of climate variability and change. (Nelson, 2010; Stokes and Howden, 2010).

The Commonwealth Government Department of Climate Change and Energy Efficiency established in 2007 is the lead agency for climate change adaptation strategy and coordination in the Australian government. It is responsible for climate change adaptation policy. This includes building adaptation capacity and information as well as implementing adaptation program activities (DCCEE, 2011).

Nelson (2010) comments that these policy initiatives have a common set of goals whereby vulnerable industries and regions are identified, the cause of their vulnerability is examined, and policies and programs to build their adaptive capacity are prioritised. Similar policy programs are being developed around the world. Antle and Capalbo (2010) report that the U.S. government announced major new research initiatives on climate change impact and adaptation in 2010 and the FAO (2007) report that Canada has identified 96 different adaptation measures.

However, Antle and Capalbo (2010) observe that despite decades of research and policy frameworks the ability of the international science community is still limited when it comes to answering with confidence questions such as:

i. What technological, social, institutional and policy adaptations are worthwhile public or private investments?
ii. What is the economic value of specific system adaptations that ensure more resilient systems to climate extremes?
iii. What are the environmental and social benefits and costs of systems that are more climate resilient?
iv. What are the impacts to agri-food systems?

A review of the most recent literature reaffirms Antle and Capalbo (2010)'s observations that there is still a limited ability to answer these questions, despite a rapidly growing body of knowledge around the subject. The emphasis in recent literature seems to be around assessing the adaptation capacity of farm businesses and communities, analysing their vulnerability and understanding the characteristics of their resilience. (e.g. Smit, 2001; Fussell, 2005; Reidsma, 2007) There are few studies looking at the cost of adaptations, for reasons discussed below.

2.3 Adaptation to a changing climate

Kurukulasuriya and Rosenthal (2003) identify three key themes from the literature on adaptations to climate change that can arguably still be applied a decade later.

I. Given the range of current vulnerability and diversity of expected impacts, there is no single recommended formula for adaptation.
II. Responsibility for adaptations will be in the hands of private individuals as well as government.
III. The temporal dimensions of policy responses are likely to have a significant role in effectiveness of adaptation to climate change.

Two consistent themes in the literature surrounding adaptation to climate change are resilience and vulnerability. There is a growing body of research around each of these themes.

A commonly quoted definition of adaptation is “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.” (Burton et al.,1996; Iglesias et al., 2007; Stokes et al., 2010). In simple terms adaptation refers to all those responses to climate change that may be used to reduce vulnerability or take advantage of new opportunities that may arise as a result (Burton et al., 1996).

Howden et al. (2007) used the definition from the IPCC which states “to include the action of adjusting practices, processes, and capital in response to the actuality or threat of climate change, as well as responses in the decision environment, such as changes in social and institutional structures or altered technical options that can affect the potential or capacity for these actions to be realised.”

The IPCC (2007) in its Fourth Assessment Report recognised that some adaptation was occurring but on a very limited scale and affirmed the need for nations and economic sectors to address impacts and reduce vulnerability. The FAO (2007) responded by developing a framework that outlined approaches to climate adaptation. Autonomous and planned adaptations were the two main types of adaptation. Autonomous adaptation referred to the short-term reactive responses by farmers to changing circumstances, for example a farmer’s response to changing precipitation patterns and therefore altering the time of seeding or harvest. (FAO, 2007). By contrast, planned adaptation measures were conscious policy options or response strategies, often multi-sectoral in nature that aimed at altering the adaptive capacity of the agricultural system or facilitating farmers’ adoption of specific adaptations. These long-term adaptations could have been major structural changes such as changes in land-use, application of new technologies, new land management techniques or water-use efficiency related techniques (FAO, 2007).

Reilly and Schimmelpfenning (1999) defined major classes of adaptation that were subsequently used by the FAO (2007) in their framework to identify priorities for adaptation to climate change.

I. Seasonal changes and sowing dates,
II. Different variety or species,
III. Water supply and irrigation systems,
IV. Other inputs (fertiliser, tillage methods, grain drying, other field operations),
V. New crop varieties,
VI. Forest fire management, promotion of agro forestry, adaptive management with suitable species and silvicultural practices (FAO, 2007).

Autonomous adaptation was identified by the Iglesias et al. (2007) as a particularly important category because farmers traditionally adapted their methods in response to felt changes. Historically, new techniques have diffused through the industry, with

innovative farmers being the first to introduce new techniques, and others adopting these approaches as they are seen to be successful. Farmers tend to be responsive in the short term by altering cropping patterns and management practices (Iglesias et al., 2007).

Kokic et al. (2005) noted that much literature focused on short-term adaptations associated with on-farm responses to climate variability rather than the longer term climate change issues. However, Kurkukalasuriya and Ronsenthal (2003) provided explanations for this focus and they discussed this issue in some depth. They suggested that the primary reason many countries have not invested in adapting to climate change is that it is premature because there are few examples of climate change which warrant a response today; hence the lack of long term adaptation plans. For example, it would be difficult to convince a farmer to undertake costly infrastructure investment such as implementing a new irrigation system in response to long term climate change for uncertain productivity gains in the future, compared to making incremental adjustments and much smaller investments in response to climate variability. This scenario can also be related to government actions (Kokic et al., 2005; Kurukulasuriya and Rosenthal, 2003).

A key finding from reviewing the literature on climate adaptation is that there is no single solution to address climate change as the impacts of climate change on agriculture are uncertain and will vary in their timing, location and magnitude (Kokic et al., 2005). It is clear that dynamic solutions will be required and that they will evolve with time, but it is recognised that large reductions in adverse impacts from climate change are possible when adaptation is implemented (Mendelsohn and Dinar, 1999; Stokes and Howden, 2010). In Australia the prospect of significant climate change triggered the formulation and adoption of climate-related policy for Australian agriculture whereby a policy priority in agriculture became the identification of vulnerable industries and regions (DAFF, 2006).

Ideally, appropriate adaptations will allow agriculture to both minimise losses by reducing the negative impacts of longer term climate change and maximise profits through capitalising on any benefits. However, considering the high degree of uncertainty associated with the extent and timing of climate change, there is no single recommended strategy for adaptation, beyond optimising rural Australia's capacity to respond to a changing environment (Kokic et al., 2005).

Adaptation options that are effective need to be economically viable but they also need to be acceptable within the personal, social and institutional contexts in which farm management decisions are made (Kokic et al., 2005). Overall it is generally recognised (Kokic et al., 2005) that the policy goal should be to increase the flexibility of agricultural systems to ensure they have the capacity to adapt to climate variability and, in the long term, the impacts of climate change. Therefore a term widely cited expression in the literature is "adaptive capacity" (Iglesias et al., 2007) which is discussed further in the next section.

2.3.1 Understanding adaptive capacity

Climate change adaptation and the building of adaptive capacity are promoted as essential for future sustainable and equitable development, particularly for places and

livelihoods that are sensitive to climate variability and climate change (Osbahr, 2010). World food production and food security is identified as a significant issue for developing countries (Osbahr, 2010; Nelson et al., 2009) and one of the major concerns is the increasing frequency of extreme events and the variability impacting on food production (Alcamo et al., 2007; Ortiz et al., 2008). Populations in the developing world which are already vulnerable, and food insecure, are likely to be the most seriously affected. In 2005, nearly half the economically active population in developing countries, 2.5 billion people, relied on agriculture for its livelihood and in 2009 seventy percent of the world's poor lived in rural areas (World Bank, 2008).

The resilience of social-ecological systems in the face of real but uncertain global climate change is critical if communities, particularly in the developing world, are to adapt to meet future challenges (Adger et al., 2003; Washington et al., 2004; Low, 2005; Cash et al., 2006; Walker et al., 2006; IPCC, 2007; Hulme et al., 2008; Toulmin, 2009). Understanding the resilience of social-ecological systems is predicated on knowledge of the impacts of climate variability and climate change on agricultural productivity (Head et al., 2011; Pearson and Langridge, 2008).

There is now widespread recognition that people do not respond deterministically to climate scenarios (Chiotti and Johnston, 1995). Instead there are a number of ways, influenced by social and cultural dimensions, that farmers and communities adapt to climate change (Risbey et al., 1999; Smit et al., 2000; O'Brien et al., 2006; Smit and Wandel, 2006; Gorman-Murray, 2008; Marshall et al., 2010; Nielsen and Reenberg, 2010; Head et al., 2011).

Adaptive capacity has been described in many different ways, but is widely seen as a key element in understanding levels of vulnerability and resilience and the potential for adaptation. As Milne (2010) notes: "The level of exposure of an individual or group to a risk and their sensitivity to its effects will be modified by their capacity to adapt." In recent years a number of authors (Head et al., 2011; Eitzinger et al., 2010; Hulme, 2008) have argued that the focus on the technical and agronomic dimensions of farm practice; such as altering species and varieties, altering timing or location of cropping, and changing crop management practices (FAO, 2006; Heyhoe et al 2007; Howden et al., 2007; Iglesias et al., 2007; Lobell et al., 2008; Howden et al., 2010) oversimplifies adaptation and ignores the capacity of the industry and the actors within it to make the adjustments required in the face of climate variability and long-term change.

Social dimensions of adaptation have received most attention in relation to the developing world, where communities and nations are recognised to be particularly vulnerable to climate change (Adger et al., 2003; Ziervogel et al., 2006; Mearns and Norton, 2010). A number of early publications (Downing, 1992; Rosenzweig et al., 1998; Desanker, 2002) focused on the "vulnerability" of African countries to climate-induced reductions in agricultural production, and on the impacts on individual farmers.

In their justification to use a bottom-up approach for their work, Head et al. (2011) argue that relatively wealthy, well-educated countries are often assumed to have strong adaptive capacity, deducible from macro-scale variables such as governance and market signals (Brooks et al., 2005). As a result of this assumption and the recognition of the high degree of vulnerability developing countries, research into climate

adaptation and agriculture have taken different trajectories. Agricultural adaptation studies in the developed world have tended to focus more on agronomic and top down approaches (Heyhoe et al., 2007; Howden et al., 2007; Lobell et al., 2008) whereas in the developing world there is a strong methodological focus on case study and ethnographic research at household scales (e.g. Kelly and Adger 2000; Birkenholtz, 2010).

O'Brien (2006) argues that from a Norwegian perspective the perception of high levels of adaptive capacity have led to a dangerous complacency about climate change and an over reliance on technological rather than social solutions. Head et al. (2011) comment that the high levels of climate change scepticism in the Howard (1996-2007) and Bush administrations have slowed the rate of research in Australia and the U.S. respectively, compared to other nations like Canada. They argue these former nations are less advanced in research and preparedness, which demonstrates the impact the political environment can have on the adaptation capacity and implementation of adaptation strategies.

Rotter (2010) summarises the complexity of the issues. He states:

"Agricultural systems are affected by global change with associated impacts on food production, the environment and farmers livelihoods; which are not well understood. The extent of these effects will depend on the adaptive capacity of agriculture, which is in turn determined by the natural and socioeconomic conditions associated with the particular community and therefore it differs considerably depending on the region and country."

This highlights the complexities involved, at all levels; a high degree of uncertainty makes it individually rational to delay action, even though collectively this may risk irreversible, possibly catastrophic damage. The potential magnitude of catastrophic costs, even given their low likelihood, lessens the rationale to delay adaptive action. Hence a rational response in most circumstances would be to adapt rather than indefinitely delay action until greater clarity of the 'true' nature of the change in climate was evident. The global nature of the problem of climate change transcends national political jurisdictions, and costs of actions are local whereas the benefits are global and in the future (Antle and Capalbo, 2010).

Although a global issue, many of the solutions are at a localised level because both costs and benefits of adaptation investment are local and in the present, however they involve a complex set of interactions between the environment, economic and social factors (Antle and Capalbo, 2010; Head et al., 2011; Pearson, 2008). All contribute to the level of vulnerability a community and the world will be exposed to due to climate variability and long-term climate change (Nelson et al., 2010).

In their assessment of climate change vulnerability Pearson and Langridge (2008) identified four categories of current research: biophysical productivity changes, economic impacts, industry and community planning, and research into the adaptive capacity of rural communities. The latter, adaptive capacity of rural communities, is attracting attention from researchers from a number of different disciplines. Hogan et al. (2011) claim that this work began in earnest in Australia with the development of

social as well as economic indicators that could be used to monitor natural resource management (Fenton, 2004).

Some indicators focus on the capacity of land managers and farmers to implement changes and adopt sustainable land management practices. Measuring the adaptive capacity of farmers became a logical extension to this work. It built on Ellis (2000)'s rural livelihoods approach which both Nelson et al. (2005) and also Brown et al. (2011) used to understand the capacity of Australian broadacre farmers to adapt to a changing and variable climate.

Nelson et al. (2005)'s concept of adaptive capacity was formed by developing an adaptive capacity index that drew on five measures of human, social, natural, physical and financial capital, based on Ellis's rural livelihoods approach. These measures contained details about: human (education, management capacity), social (partnership in the business, internet usage, landcare membership), natural (a land degradation index, a pasture growth index), physical (the diversity of income, the area operated) and financial (average income, income risk, off-farm income). When aggregated into an index, these measures defined adaptive capacity as comprising 'forms of human, social, natural, physical and financial capital from which rural livelihoods are derived' (Hogan et al., 2011).

Another example of an assessment of adaptive capacity is the work of Sietchiping (2006) who developed an index to assess the adaptive capacity of the Victorian wheatbelt in Australia, by using a self-assessment approach with the stakeholders. These stakeholders were defined as the farming community, government and industry who had a major interest in the grains industry in Victoria. The adaptive capacity index developed by Sietchiping (2006) differed from other similar indexes as it weighted the indicators and themes, unlike those developed by Nelson et al. (2005) for Australian farmers.

Other studies of adaptive capacity include that of Bhadwal et al. (2003) who studied rural communities in India and that of Brooks et al. (2005) who compared the adaptive capacity and vulnerability of countries across Europe with a particular focus on mortality. In all these studies the number of final indicators used to develop indices of adaptive capacity varied widely. For example Nelson et al. (2005)'s index of the vulnerability of broadacre agriculture in Australia used 12 indicators grouped within five major themes. Bhadwal et al. (2003) used 11 indicators and Brooks et al. (2005) used 45 indicators.

These indices can be a tool for policy makers and governments to firstly identify factors that most limit adaptive capacity and secondly guide the allocation of resources to boost adaptive capacity (Nelson et al., 2010). In addition, as shown in the Sietchiping (2006) study, engagement with stakeholders; can allow the stakeholders to develop the adaptive capacity index and appropriately weight its variables, thereby enabling the participants to identify areas where they can best act to improve their community and industry resilience to climate change. It also overcomes one of the weaknesses identified by Nelson et al. (2010) where developing and interpreting vulnerability involves a myriad of value judgements on the part of scientists.

Other related research supports and complements the understanding of vulnerability and resilience to climate change (Miller et al., 2010; Nelson et al., 2010; Pearson et al., 2008; Kokic et al., 2005; Osbahr, 2010). Vulnerability and resilience are now recognised as key components of the adaptive capacity of an individual, group, community or sector. The volume of literature around vulnerability and resilience warrant a more in-depth discussion about these two concepts.

2.3.2 Understanding resilience and vulnerability

The concepts of resilience, vulnerability, adaptation and transformation are all related but, are slightly different ways of framing analyses on social ecological change and the challenges of sustainability (Miller et al, 2010). O'Brien et al. (2007) contend that the definitions and therefore the interpretations of terms like 'vulnerability' are not merely a question of semantics. Interdisciplinary research by scientists from differing backgrounds often use terminology that is vaguely defined and lacks shared meanings. O'Brien et al (2007) argue that it is important to distinguish and acknowledge the different but complementary meanings. If this issue is not resolved misunderstandings will occur in multidisciplinary teams and between the research communities about how climate change research is conducted. A number of authors have continued to discuss the meaning of vulnerability and resilience (Nelson et al., 2010; Miller et al., 2010; Cabell and Oelofse, 2012).

Miller et al. (2010) identify that there are a number of fundamental linkages and complementarities that exist between resilience and vulnerability and assert that they have been kept artificially separate by conceptual constructs, scientific traditions and lack of interaction between two respective academic communities. Arguably they are inversely related i.e. the more resilient, the less vulnerable (Nelson et al., 2005; Handmer and Dovers, 1996).

The evolution of the two concepts draws on disciplinary contributions from different origins. Vulnerability assessments have a long history of development in other contexts, such as food security, livelihoods, natural disasters, and risk management, with social geography, political ecology, and other disciplines also contributing crucial knowledge and experience to the assessment of a society's socio-economic vulnerability to climate change (Fussel and Klein, 2005). By contrast, resilience theory has primarily come from the natural sciences in relation to social ecological systems (SES) and in particular ecology (Miller et al., 2010). The theory offers a useful framework for understanding the dynamic relationship between humans and the environment and provides models for increasing society's capacity to manage change.

An in-depth discussion of how these theories have evolved is outside the scope of this review. For further reading see O'Brien et al. (2007), Nelson et al. (2010a) and Miller et al. (2010).

Resilience is defined in terms of ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance (Resilience Alliance, 2009). The building of resilience is defined by the Department of Agriculture Fisheries and Forestry (DAFF, 2006) by increasing 'human capacity for anticipation and learning to minimise environmental, financial and social costs through enhanced adaptive capacity'.

Cabell and Oelofse (2012) argue that resilience is so complex it cannot be measured in any precise manner, but is measured in general terms by (1) the amount of change the system can undergo and still retain the same controls on function and structure, (2) the degree to which the system is capable of self organisation; and (3) the ability to build and increase the capacity for learning and adaptation.

A two year qualitative study conducted by Greenhill et al. (2009) on South Australian farm families to determine their 'resilience' in the face of adversity concluded and concurs with observations of Storer (2012) that resilience is a complex process which needs to be understood in the context of wider and social economic systems. Greenhill et al. (2009) identified eight themes that influenced the process of resilience, (1) Pre-existing viability of the business, (2) Income security, (3) Managing risk and decision-making, (4) More than a farmer, (5) Opportunities to disengage, (6) Health and well-being (7) Farm women (8) Age and generational change.

Vulnerability research arguably is linked to resilience research (Miller et al., 2010). It generally seeks to understand the underlying causes of vulnerability, the scale at which it occurs and the main actors involved. It also tries to identify opportunities for risk reduction as well as coping and adaptation strategies. What is often neglected in vulnerability assessment, unlike the case in resilience research, are the interactions between longer term and shorter term ecological and biophysical changes (Miller, 2010).

However, as Nelson (2010a) and Miller (2010) identify and discuss, vulnerability is a contested concept and there is little agreement about how to convert it into policy relevant measures for priority-setting. Nelson (2010a) and Fussell and Klein (2005) have contributed to the discussion around the concept of vulnerability as have many others (Chambers, 1989; Dow, 1992; Bohle et al., 1994; Liverman, 1994; Ribot, 1995; Bankoff et al., 2004; Cardona, 2004; O'Brien et al., 2004; Brooks et al., 2005; Adger, 2006; Eakin and Luers, 2006).

Fussel and Klein (2005) argue that the purpose of climate change vulnerability assessments is to:

1. Increase the scientific understanding of climate sensitive systems under changing climate conditions,
2. Inform the specification of targets for the mitigation of climate change,
3. Prioritise political and research efforts to particularly vulnerable sectors and regions,
4. Develop adaptation strategies that reduce climate sensitive risk independent of their attribution.

Other authors such as Kelly and Adger (2000) and O'Brien et al. (2007) have contributed to defining the different interpretations of vulnerability to assist policy makers and researchers be more specific about the use of terminology. They assert there are differences between 'outcome vulnerability' and 'contextual vulnerability'. Outcome vulnerability was characterised by the IPCC (2001) as 'the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes.' By contrast, contextual vulnerability was

defined as, 'the susceptibility of a system to disturbances determined by exposure to perturbations, sensitivity to perturbations, and the capacity to adapt.' (O'Brien et al., 2007; Pearson et al., 2008). These two concepts of vulnerability differ as discussed by O'Brien et al. (2008), the former works more effectively in a linear or bounded system whereas the latter is more relevant to social and environment- linked open systems.

More recent work by Safi et al. (2012) acknowledges the complexity of defining vulnerability due to the classical disciplinary approaches to vulnerability being challenged by the rise in profile of climate change and the complex multifaceted nature of the issue. Using the growing body of literature they define vulnerability as a function of three main components, (1) physical vulnerability, (2) sensitivity and (3) adaptive capacity. The physical vulnerability of a particular system (community, individual) is determined by the probability and severity of certain hazards (natural or technological) affecting the system. Both sensitivity and adaptive capacity are determined by the socioeconomic conditions of threatened communities or individuals.

In their analysis they set out to determine people's risk perception to climate change, hypothesising that physical vulnerability and sensitivity will increase risk perception but adaptive capacity will decrease it. Assuming those more exposed and susceptible to a certain risk, like climate change, would be more concerned about it. However, the statistical analysis of data collected on farms in Nevada shows vulnerability to climate change as a function of physical vulnerability, sensitivity and adaptive capacity does not impact climate change risk perception whereas both sensitivity and adaptive capacity increase risk perception. However, they did find beliefs regarding climate change and beliefs regarding the impacts of climate change are strong determinants to increased risk perception (Safi et al., 2012).

Milne (2008) states that "the level of exposure of an individual or a group to a risk and their sensitivity to its effects will be modified by their capacity to adapt. Adaptive capacity is the ability to carry out adaptation within the context of existing enablers and constrainers in the operating environment." Adaptation to climate change cannot ignore the human element and therefore understanding people's perceptions and behavioural responses to climate change is essential to provide better policy decisions. Accordingly, there is a need to review literature that specifically considers the perceptions and attitudes of farmers regarding climate change and the variability of climate. The following section reviews this literature.

2.3.3 What are farmers' perceptions of climate change?

It is argued that policy making will be enhanced by policy makers having insight into how farmers perceive climate change in relation to their farming practices (Milne, 2008; Hogan, 2011). But in order to understand farmers' attitudes, it is first worth noting the operating environment in which farmers and agriculture exists in Australia.

Agriculture has been a major contributor to Australia's economic development since European settlement in rural Australia. But over the years its contribution to gross domestic product has decreased from twenty percent to around three percent. Instead of sixty percent of the population living outside towns, as was the case a century ago, the vast majority live in an urbanised environment. A small domestic market means that

the sector is very dependent on exports and maintaining a competitive edge in the global economy.

Australian farmers have made extensive use of advances in agricultural science and technology to cope with declining terms of trade and to maintain profitability. They have continually restructured existing farms to capture economies of size and to increase the real income flows and are one of the least dependent on government support of any country in the world (Drought Policy Review Expert Social Panel, 2008).

Common issues Australian farmers face are declining terms of trade, community fragility, productivity challenges, drought, land quality problems and soil degradation and changing financial, infrastructure and institutional supports, for example deregulation of the grains industry (Sietchiping, 2006). Drought is recognised as a natural characteristic of Australia's variable and changing climate and Hennessey et al. (2008) claim successful management of climate risk is recognised as a definitive characteristic of farming excellence. Through the past century, major droughts have been associated with episodes of regional degradation in inland Australia and governments over the years have recognised the need to assist in times of exceptional circumstances (Hennessey et al., 2008).

Edwards and Gray (2009)'s analysis of the impact of drought, using the Rural and Regional Families Survey that interviewed 8,000 people living in rural Australia, found that drought had significant negative economic impacts, with large effects on financial hardship and the deterioration of household finances. An event was declared an 'exceptional circumstance' (EC) when the likelihood of it occurring was once in a 20 or 25 year period. This declaration triggered a number of short-term measures to help farmers prepare for, manage and recover from drought with the key objective of self-reliance. However, some regions were continuously drought-declared for 13 of the past 16 years, prompting reviews of this policy framework (Hennessey et al., 2008). In 2008 nearly two-thirds of Australian agriculture land was covered by seventy-four EC declarations (Head et al., 2011). In a submission to the Productivity Commission (2011) the Department of Climate Change and Energy Efficiency outlined how the Australian Government had a long standing role as the insurer of last resort and the provision of assistance had cost approximately $4.85 billion in EC between 2001/02 to 2010/11 (Productivity Commission, 2009). In Western Australia, as shown in Figure 4 in ABARES (2011b), most agricultural regions received little EC assistance, as only small areas were drought-declared for 1 to 3 years during the period 1992 to 2010. By contrast, over that same period, large areas in NSW and Victoria were drought declared for between 7 to 14 years.

The frequency, severity and length of drought periods in the future are anticipated to increase (CSIRO & Bureau of Meteorology, 2007) and consequently a review of the National Drought Policy (NDP) was undertaken to create an environment of self-reliance and preparedness and to encourage the adoption of appropriate climate change management practices (Hennessey et al, 2008). The 2009 Productivity Commission inquiry subsequently found that the existing NDP EC declarations and related drought assistance programs did not help farmers to improve their self-reliance, preparedness or climate management.

A study by Milne et al. (2008) opened up the possibility that a link existed 'between people's perceptions of climate variability, climate change and [farmer] preparedness and management of climate risk.' (Hogan et al., 2012). Milne et al. (2008) found that 'understanding the relationship between perceptions and responses is important because it shows ways that interventions, including communication, might influence the decisions of landholders and rural businesses to adapt to climate change.'

The Bureau of Rural Science conducted a survey of 3993 farmers to gauge their attitudes to climate risk and farm adaptation. The initial results from the survey were reported by Hogan et al. (2008) and they found that:

- Farmers suffering from adverse weather conditions had a higher risk index that those that don't.
- Farmers suffering from adverse weather conditions were only contemplating using risk management strategies rather than taking action.
- Dry land cropping farmers indicated they were affected by adverse weather conditions such as frost or drought.
- The results show the respondents believe in climate change and man-made climate change and there was a small but insignificant difference between those who were suffering adverse weather conditions and those who weren't. The ones who weren't tended to be less likely to believe in climate change.
- Those primary producers affected by adverse weather conditions were more likely to agree that the melting of icebergs and glaciers, local changes in weather, extreme weather events, shift in seasons and reduced availability of water on my property were caused by or made worse by climate change. They did not think rising sea levels were a result of climate change.

However, like the case studies by Milne et al. (2008), there is a full spectrum of beliefs as to whether climate change is happening. There are those who believed that climate change is happening, some who are uncertain and others who do not believe in climate change. This seems to be common to all studies (Milne et al., 2008; Evans et al., 2011, Head et al., 2011; Hogan et al., 2011). For example, Head et al. (2011) found that 'farming households are strongly engaged with climate variables but that levels of "belief" in climate change do not correlate in a straightforward way with adaptive actions.'

Climate change is not emerging onto a "blank state" but instead where primary producers already are exposed to multiple issues, challenges and threats or opportunities which climate change in turn interacts with and can exacerbate (Brooks and Loevinsohn, 2011). Puig et al. (2011) emphasise that climate change is just one of a complex set of environmental, social, political and economic drivers affecting rural populations. Head et al. (2011) state how there is a wide recognition in the literature that farmers juggle multiple temporalities, from intraseasonal to generational succession planning (Kingwell et al., 1993; Risbey et al., 1999; Meinke and Stone, 2005; Howden et al., 2010).

Hogan et al. (2011) provide a snapshot of factors influencing farmers' decision making in the face of climate change at a given time and place. They identify multiple cross-

sectional as well as longitudinal and intervention studies are required to further investigate and build upon the insights they have discovered.

Understanding the relationship between perceptions and responses is important because it shows ways that interventions, including communication, might influence the decisions of landholders and rural businesses to adapt to climate change (Milne, 2008).

The few Australian studies to date (Hogan et al, 2011a; Hogan et al, 2011b) designed to understand farmers' decision making in Australia and how they adapt to climate change are based around the data from a survey of 3993 farmers undertaken by the Bureau of Social Sciences in 2008. A study done by Edwards and Gray (2009) looked at the impact of drought on rural Australians and despite considerable uncertainty and lack of evidence about the extent and nature between climate change, drought and mental health, this study attracted media attention that claimed that drought and climate change were harming mental health. Berry (2011), by contrast, argued that the survey evidence in fact did not support this media claim that drought and climate change were harming mental health.

In somewhat of a contradiction, resilience has been found among farmers, alongside their feelings of hopelessness. The relationship between material hardship and poor mental health has long been documented and drought prone areas are chronically vulnerable to low socioeconomic status and educational attainment. Hogan et al. (2008) reported farmers and farm workers to have better well-being than nonfarmers on many aspects of life satisfaction, but they also reported that farmers displayed less hope for their future. A possible explanation for this dichotomy is offered by Patel (2007) who suggested that in the face of limited options, many farmers have little choice but to persist with and even invest further in their current farming endeavour, hoping to trade their way out of their current situation. Such persistence may be confused with resilience.

In much of the work of Hogan et al. (2008) and Edwards and Gray (2009) it is very difficult to separate the findings about farmers' perceptions around climate change and the impact of drought, possibly because at the time of the survey in 2008 eastern Australia was in the grip of terrible drought conditions. Other work by Evans et al. (2011) involved surveying 255 farmers in Western Australia to ascertain their perceptions about climate change. This study provides clearer and less confused findings about what farmers think of climate change. One third of those surveyed agreed climate change was occurring and nineteen percent believed it was human-induced. Over half (52%) were uncertain whether human-induced climate change was occurring and perhaps one of the most significant findings was that only thirty one percent thought climate change represented a threat to the future of their farm business.

The findings of Evans et al. (2011) reveal that there are fundamental issues in the diffusion of climate change information and knowledge transfer between science and rural Western Australians. The high degree of uncertainty about climate change and its impact was found to be underpinned by the incomprehensibility of the scientific information and the ambiguous credibility of scientists and researchers. They suggested that there was a need to communicate the risks and implications around

climate change and translate them into actions appropriate to local situations. Their findings are supported by Hogan et al. (2011a) who found that almost half of the farmers they surveyed were not engaged with key mechanisms and institutional processes which facilitate the translation of research and technology into practice. Despite interest in becoming more sustainable, a majority reported that they were focused on the shorter-term strategies for managing their immediate pressures rather than their longer-term, climate change orientated adaptations.

There is an established recognition that farmers' goals and values are complex, and so simply dividing them into behavioural types on the assumption of profit maximising behaviour is increasingly difficult to sustain (DEFRA, 2006). McGregor et al. (1996) identified that farmers' decisions are influenced by not only maximising profit, but also by objectives and goals in farming, attitudes towards the traditional/ethical approach to farming, stress and the ability to cope with stress, satisfaction with and optimism about farming, attitudes to legislation, risk taking, autonomy, management attitudes, conservation attitudes, quality and quantity of information, who is involved in decision making process, the individual's ability to solve problems, and aspects of their personality.

The results from Hogan et al. (2011b) analysis of the 3993 farmers surveyed support this construct, where they clearly found that a one-size-fits-all assessment is inappropriate. Like McGregor (1996) and Shadbolt (2008) they found that farmers' life goals and identity play an important role in the way farmers make decisions and about their farming practice and the viability of their farms. The adaptive capacity of individuals cannot be isolated from broader socio-economic and environment determinants. They found that human aspects of adaptive capacity are based on the capacity to cope with change, farmer health, social connectedness, and the ability and readiness to use information, which they claim uniquely and powerfully differentiated types of farmers from one another.

Hogan et al. (2011a) used cluster analytical techniques and factor analyses to statistically differentiate farmers into groups. The groups included:

1. Cash poor long-term adapters who were the largest group in the study. They were younger, healthy, socially well-connected, information seeking and believed in climate change and implemented longer-term adaptive strategies and participated in government assistance programs. However, only one third of this group had annual incomes over $40,000.
2. Comfortable non-adapters represented one quarter of the study group. They were older, socially well connected, enjoyed comparatively good farming conditions, received reasonable income and maintained off farm investments. They had good social support, good physical health and confidence to continue with their current farming practices. They did not believe in climate change and did not perceive any immediate pressure for change. Consequently they did not seek information about alternative practices nor considered leaving the industry.
3. Transitioners were the smallest group. They were under considerable pressure and reported low adaptive capacity. They were less certain about climate change and what they should do about it than the cash poor long-term adapters. They reported the lowest incomes and fewest resources, the worst

health and generally were isolated from information services. They faced major barriers to adaptation with a compromised financial ability to manage the cost of change and had low social capital.

Another finding by Hogan et al. (2011b) was that understanding farmers' readiness to adapt needed to go well beyond a narrow view of farmer assets. Along with financial capital, vital concepts such as connectedness, health and education, all needed to be considered part of the farmer's assets. The results almost contradicted those of Kokic (2005) and Anderson (1993) that farmers operating at, or near the edge of economic survival might be less willing to take on the risk of adopting new technologies. This does not seem to be the case with the cash poor long- term adopters. It seems that the worst affected by drought and drying were also those with the greatest desire, irrespective of their financial health and other assets, to engage with change (Hogan et al, 2011b).

Similar concepts to those found by Hogan et al. (2011a) are also identified and supported by Shadbolt, (2008) and the joint working party on agriculture and the environment (2011). Based on their work they have made the following policy recommendations:

1. A holistic approach is needed. Financial incentives are important for new farming systems to be adopted, but they are not the sole incentive.
2. Behavioural change should be understood at the local level. Each farm and farmer has specific characteristics. In order to deal with such heterogeneity, policy needs to be developed that recognizes that different policy tools work differently for different farmers. For example, large scale, commercially-oriented farm businesses are likely to display behavioural characteristics that differ from small-scale, family run businesses.
3. "Nudging" could be a useful approach to guide policy. A "nudge" implies a small change in the social context that alters behaviour without forcing anyone to do anything, for example "visualisation" policies such as labelling (carbon foot print). This approach encourages farmers to establish what they have to do, while their efforts can be conveyed to consumers through labelling and therefore can complement incentive measures to address climate change.
4. Forming networks of farmers working collectively can play an important role. Advisory systems, extension diffusion and innovation and training have a crucial role in shaping attitudes and motivations, as does information about other people's behaviour. If information about other people's behaviour is not available, people tend not to cooperate. For example farmers need to receive information not only about their behavioural choices (management practices or emissions) but also whether those choices are above or below the community standard (benchmarking).

It is apparent from the literature that climate change, climate variability and adaptation span across several disciplines (Smit, 2001, Kurukulasuriya and Rosenthal, 2003; Howden et al., 2007; FAO, 2007). Smit (2001) identified the different themes as, climate change impacts, natural hazards, agrarian political economy, innovation adoption, agricultural systems, farm decision-making, risk management and agricultural vulnerability and adaptation. In support of this approach Kurukulasuriya and Rosenthal

(2003) identified the need for adaptation options to incorporate economic, institutional, political and social policy changes in the context of sustainable development systems. The need for expertise from different disciplines requires interdisciplinary analyses to better understand the potential consequences of climate change (Rotham and Robinson 1997; Smit, 2001; Kurukulasuriya and Rosenthal, 2003; Fussell, 2005; Kokic et al., 2005: Howden, 2007; Twyman et al., 2011) and the need to improve the integration of the interdisciplinary approach is a common theme throughout the literature.

Twyman et al. (2011) conclude that, although there is a healthy tension between qualitative based approaches and quantitative and general approaches, the need for collaborations is paramount. They comment: “We encourage researchers from different disciplines with different disciplinary languages to talk, collaborate, and engage effectively with each other and with stakeholders at all levels”.

Understanding farmers’ decision-making processes and behaviour is identified as being critical for implementing climate change policies that effectively achieve adaptation in farming practices (Shadbolt, 2008). He found that overall it is difficult to find socio-economic variables that explain farmer behaviour in the studies he reviewed not only because of heterogeneity but also due to psychological and socio-economic factors that simultaneously influence farmers’ decisions. Understanding farmers’ attitudes and therefore their behaviour and removing the barriers to behavioural change is essential (Shadbolt, 2008). The behavioural economics approach combines psychology and economics. It is empirical and applies appropriate theory and evidence to each situation and combines psychology and economics in order to better understand and predict human decision making.

Farmers have a long record in adapting to changes in rainfall and temperature over time. Future changes in the climate could have significant impact on agriculture which will challenge farmers to adapt to changes in land use, commodity production and its location.

2.3.4 Adapting to change – adaptive management strategies

Farmers have always carried out adaptive changes to their businesses based on the weather. They respond in the short-term by altering cropping patterns and management practices (Iglesias, 2007; Anwar et al., 2012). Pannell (2010) argued that farmers faced with a changing climate will successfully adapt their systems by means of successive small, short-term changes in management practice, a concept supported by a number of authors including McCarl (2007). However, Moore (2012) stated that this depends on two assumptions; first, that the feasible rate of on-farm practice change is greater than the rate at which changing climate will alter the production environment; and second, that farmers’ perceptions of current conditions will be sufficiently accurate to allow them to adjust their management strategies. It seems highly unlikely that even well planned incremental innovation will suffice in response to some of the future projected climate changes (Ash et al., 2008).

Climate change adaptation options for mixed farmers are relatively well documented. (Smit and Skinner, 2001; Kingwell, 2006; Howden et al., 2010; Stokes et al., 2010; ACG, 2005; Iglesias, 2007; Crimp et al., 2008b; Moore, 2012). For example, options for

adapting to climate change at farm level in the broadacre sector include strategies such as, diversification of crop varieties, species change, shifting planting seasons, changing crop management practices, i.e. tillage spacings, rotations, nutrient and salinity management, moisture conservation, pest management and taking advantage of season forecasting (Kokic et al., 2005; Howden et al., 2006). Livestock adaptations at farm level include increasing soil fertility to increase water use efficiency for pasture growth, ongoing genetic improvement, using summer-active perennials and using confinement feeding. Management of new pests and diseases, linked to a changing climate, also will be required (Moore, 2012). Longer-term adaptation strategies include changing the enterprise mix, diversifying into off farm employment, investing in off-farm assets and migrating to new industries and regions (Kokic et al., 2005).

Adaptation decisions are continuous with individual decisions being influenced by internal stimuli to the farm household, such as risk of income loss, changed perceptions of the farm environment, and changes in macro-economic policies or industry policies such as grain market deregulation (Chiotti and Johnston, 1995). Adaptations can be characterised as on-farm production practice management and farm financial management i.e. insurance and risk management (Joint working party on agriculture and the environment, 2011).

Kurukulasuriya and Rosenthal (2003) characterised adaptation strategies into micro-level, market responses, institutional changes and technological developments. A similar approach was used by Ash et al. (2008) who presented a conceptual map of coordinated adaptation for Australian agriculture across nested scales. However, there seems to be little evidence of these types of frameworks being adopted in the literature. Perhaps this is because it is recognised that there are practical limitations for identifying and evaluating particular adaptation measures, given their huge variety, their peculiarities in particular applications and the importance of ongoing decision processes. The IPCC suggested that a useful alternative is to work towards enhancing adaptive capacity (Smit and Skinner, 2001; Kokic, 2005; McCarl et al., 2007).

An approach which is more common is to develop models to understand the impacts of climate change on the system, either at large scale or more localised specific systems. Examples of this approach have been discussed throughout this review (e.g. John et al., 2005; Crimp et al. 2008; Challinor et al., 2009; Moore, 2012; Rötter et al., 2011, Malcolm et al., 2012). These studies often examine climate change impacts by contrasting impacts ‘with’ and ‘without’ climate change.

Pearson et al. (2008) reviewed and documented the available climate model tools available for assessing vulnerability and they found the majority were biophysical agricultural models rather than bio-economic models. Rodriguez et al. (2011) criticised the predominant focus on biophysical modelling rather than bioeconomic modelling such as that by John et al. (2005).

Often biophysical studies are undertaken at an individual crop level where crop yield is used as the scale for reporting. The neglect of economic measures is a serious short-coming of these studies as farm managers and policy makers typically support their decisions with information on impacts on farm business profits and risks.

However, there is a range is of computer based tools emerging, developed by scientists to provide farmers with information and procedures to assist with management decisions, collectively known as decision support systems or tools. But despite the ease of accessing these models, their adoption by farmers has been very slow and low in most instances which is thought to be due to the models' complexity, their lack of extension and marketing support and the lack of confidence in the models' outputs (Loch et al, 2012).

Studies such as Hogan et al. (2011) and Greenhill et al. (2009) have found that financial viability is one of the key issues for farmers so the lack of uptake of biophysical-based decision models is not surprising. The role and value of decision support tools is discussed in much greater detail by McCown et al. (2006).

The lack of studies that relate climate change production impacts to their economic ramifications has been is identified by Antle and Capalbo (2000) and Agrawala (2011). No studies found, except Lawes and Kingwell (2012), take a longitudinal approach and certainly none integrate biophysical considerations with socio-economic and behavioural decision making, despite a number of authors identifying the need (Rotham and Robinson, 1997; Smit, 2001; Kurukulasuriya and Rosenthal, 2003; Füssel, 2005; Kokic et al., 2005; Howden, 2007; Twyman et al., 2011). Furthermore, there is an almost complete lack of literature on the cost side of the adaptation equation for agriculture, with the exception of the study by McCarl (2007) and Nelson et al. (2009) This review confirms this finding.

McCarl (2007) estimated that to respond to climate change, additional investments are required in research (such as drought resistant seed varieties), agricultural extension, and physical capital (such as irrigation infrastructure) for agriculture, forestry and fisheries. The cost is estimated to be USD 14.23 billion per year by 2030. Nelson et al. (2009) recommended an increase of at least $7 billion per year investment in community-based adaptation programs. However, Agrawala (2011) claimed that strong assumptions on adaptation responses raise questions about the reliability of the results in McCarl (2007).

However, one of the difficulties acknowledged by McCarl (2007) is that the agricultural sector regularly adapts to forces such as development of pest resistance to treatment methods, development of irrigation facilities, invasive species, consumer diet preferences, income effects on dietary choices, competition for water from municipal and industrial sectors, and changes in government policies among numerous others. Determining the costs associated with just those associated with climate change becomes problematic in such a complex and dynamic system with so many different interactions.

2.3.5 Concluding remarks

Australian agriculture businesses provide the food needs for 22 million Australians and at least 40 to 50 million people overseas. It is one of only 15 net food exporting nations globally and it ranks fourth in the world as a net exporter of agriculture commodities behind Brazil, Argentina and the Netherlands. The Australian agriculture sector is considered one of the world leaders for water, fertiliser and energy use efficiency and is renowned for its early adoption of technologies such as conservation tillage and

precision agriculture systems. It exports between 60 to 70% of its total production (Keogh, 2011). This is achieved by farm businesses that operate in one of the driest of all inhabited continents with one of the most variable rainfall patterns. Australian agriculture now faces the challenge of climate change and the introduction of climate policies that aim to reduce the nation's emissions of greenhouse gases (GHG).

Efforts to reduce GHG emissions and adapt to climate change are a classic collective action problem that is best addressed at multiple scales and levels (Joint working party on agriculture and the environment, 2011). Accompanying climate change is on-going climate variability that already is recognised as a major risk for agriculture production in Australia. Climate change is predicted to increase this risk and create further complexities around farm business performance. Investigating the way people cope with these complexities and how they will adapt to the increased variability associated with climate change attracts attention from a number of different disciplines i.e. social sciences, economic, agriculture science, meteorological, legal and health.

A number of analytical frameworks are being applied to further understand the interactions between human, social, natural, physical and financial capitals. Applying these multi-disciplinary frameworks will improve our understanding of the farming sector's capacity to adapt to climate change and increased climate variability, consequently improving policy frameworks and investment decisions for research and development.

The main objective of policy and investment decisions should be to improve farm business performance and profitability of the farm sector as this assists their adaptive capacity and builds their resilience to climate change. Yet much of the literature fails to discuss farm viability in terms of profitability or adaptation options in terms of whole-farm profit, with the few exceptions such as John et al. (2005), Lawes and Kingwell (2012) and Rodriguez et al. (2011).

Many of the analytical frameworks of climate change studies are applied at a point in time or consider climate scenarios yet fail to capture longitudinal farm financial performance. Most social studies, for example, report on how people think, feel and act at a particular point in time and so longitudinal behaviour and its impacts on long-term business performance is often overlooked.

Many studies are discipline-specific, such as solely reporting the physical science of climate change. Some connect two disciplines such as a physical science with a social science. Rarely in agricultural adaptation studies are several disciplines combined to holistically report on farmers' adaption behaviour, farmer characteristics, their social and physical environment, the type of climate change experienced and the longitudinal impacts on farm businesses of adaptation responses.

Therefore there is a need for a study that addresses the holistic gap in the literature on agricultural adaptation to climate change. The current NCCARF project, titled "Adaptive capacity and adaptation strategies of Australian farmers experiencing climate change and climate variability", adopts a three dimensional approach by reporting the longitudinal financial performance of farm businesses in response to changing climatic conditions, identifying successful (and unsuccessful) adaptation strategies employed

by these businesses and assessing the behavioural characteristics of farmers who successfully (or unsuccessfully) adapt to climate change and climate volatility. As such the NCCARF project is a unique and potentially worthwhile addition to the literature on adaptation to a changing climate.

3. DATA AND RESEARCH METHODS

3.1 Study region

The study region is the broadacre farming region of south-western Australia (Figure 1). The region comprises several agro-ecological zones categorised by annual average rainfall and length of growing season. In the northern parts of the broadacre farming region the growing season is typically shorter, lasting from April to September; whilst in the southern parts the growing season lasts from May through to November. Associated with movement inland, away from the coast, is a decline in annual and growing season rainfall, and greater extremes in daily minimum and maximum temperatures.

The region has a Mediterranean-type climate, characterised by long, hot and dry summers and cool, wet winters. During summer, a band of high pressure known as the sub-tropical ridge moves southwards and directs an easterly flow of dry, warm air over much of southern Australia. In winter this ridge moves northwards and directs a westerly flow of moist air over southern Australia. As indicated in Figure 1, average annual rainfall decreases rapidly in a north-easterly direction from the south-west corner of Western Australia.

In many central and northern parts of the study region around three-quarters of the average annual rainfall is received between April and October. Summer rainfall is highly variable, and is more common along the south coast parts of the study region. Compared to summer rainfall, winter rainfall is greater and is much more reliable, making the region mostly suited to annual crops and pastures. The region's farming systems are mixed enterprises, almost entirely rain fed. Most farms run crop-dominant farming systems with wheat being by far the principal crop grown and sheep are the main livestock enterprise.

Crops, primarily wheat (*Triticum aestivum L.*), barley (*Hordeum vulgare L.*) and canola (*Brassica napus L.*), are typically sown in late autumn through to early winter due to low levels of summer rainfall and mild winter conditions. The crops are harvested in November/December. In some parts of the study region frost risk can greatly affect grain production.

In recent decades, enhancements in technology and farm mechanisation have resulted in substantial increases in farm size and labour productivity. Due to greater reliance on farm mechanisation, farms in the region are typically owner-operated with no more than one other permanent labourer. However during seeding, harvesting and shearing periods, casual and/or contract labour is usually required (Doole et al., 2009). The main products from the farms are cereals, sheep and wool, all of which are mostly exported (Schilizzi and Kingwell, 1999; Doole et al., 2009).

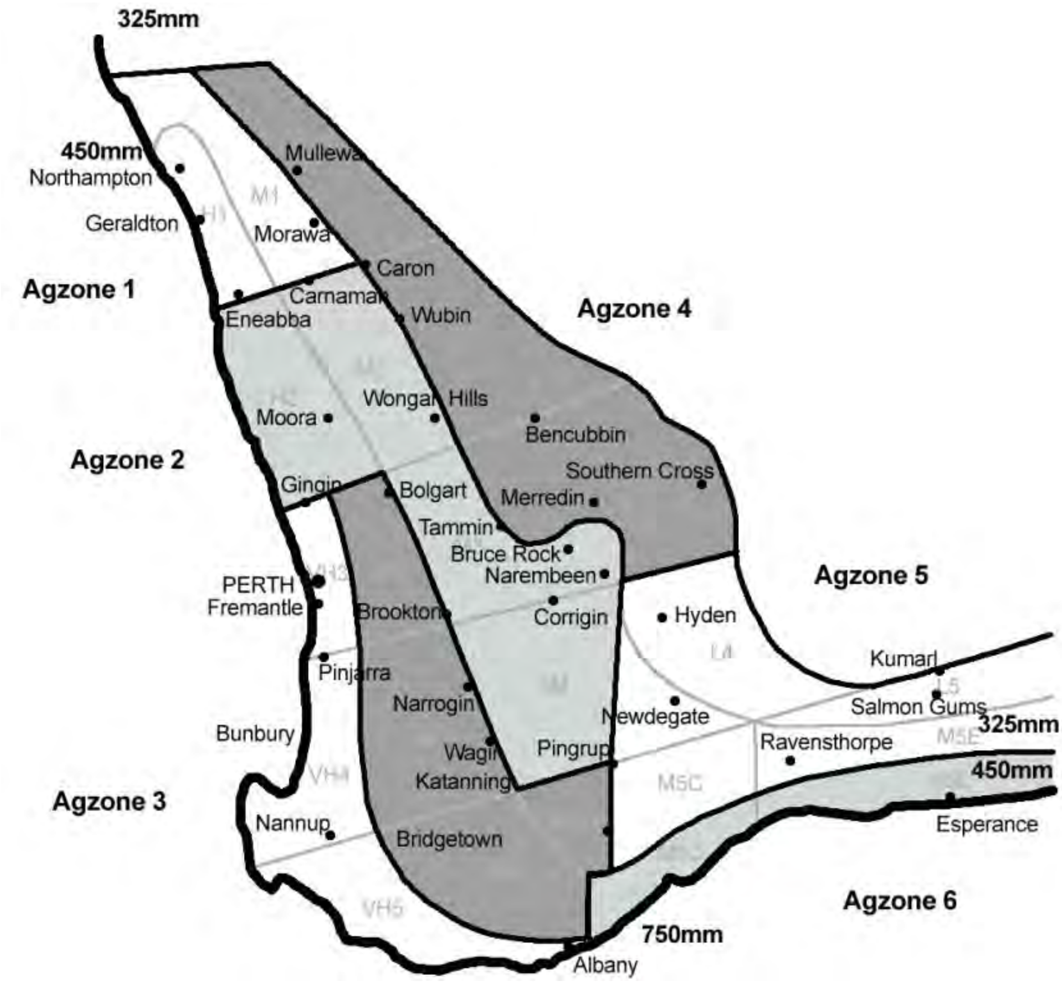

Figure 1: The study region of south-western Australia showing the 325mm, 400mm and 750mm isohyets (based on rainfall from 1900 to 1975), many rural towns and various agro-ecological zones Source: DAFWA (2001) The Crop Variety Sowing Guide 2002, Bulletin 4529, Department of Agriculture & Food, Western Australia

The crops and pastures are grown either separately or in rotation. The allocation of land to different products is altered each year in response to seasonal weather, commodity prices and weed and rotational considerations (Kingwell, 2006). Since the 1980s the region has undergone significant structural change in its crop farming system (John, 2004). On the northern sandy soils, lupins (*Lupinus angustifolius*) were introduced in the mid-1980s (Marsh et al., 2004). Following plant breeding improvements, lupins' importance increased in the 1990s, although dry years in the 2000s combined with poor relative prices and difficulties with herbicide-tolerant weeds has seen their planted area greatly diminish.

Canola was introduced into farming systems, especially in the moderate and higher rainfall parts of the study region, in the late 1990s. Its popularity has increased in the last few years due to its yield improvement and more attractive prices. Grain legumes like chick peas (*Cicer arietinum*) and faba beans (*Vicia faba*) have been trialled by a number of farmers (Siddique et al., 1993; Siddique and Sykes, 1997). These legumes,

however, are typically grown on only small areas (Bankwest, 2012) on clay or heavy loam soils in the region (John, 2004).

Crop yield is improved by the application of phosphate and nitrogenous fertilizers to most crops. Weeds are controlled primarily by chemical spraying using pre- and post-emergence herbicides. After grains have been harvested, they are usually transported by the farmer or contractors to on-farm and off-farm storage silos. A fraction of grain harvested is reserved for seed and as supplementary feed for use mostly by sheep in the autumn feed gap when pasture feed is in limited supply and usually of poor quality (John, 2004).

Pastures grown in the region vary by the soil type and quality. On the acid sands, the species grown are yellow serradella (*Ornithopus compressus*), volunteer annual grasses, herbs, and native legumes. On sandplain, gravelly sands and duplex soils, pasture species are pink and yellow serradella, volunteer annual grasses, herbs, native legumes and various varieties of subterranean clover (*Trifolium subterraneum*). On the sandy loams and clays, pastures are mainly based on burr medics (*Medicago polymorpha*). Some farmers and researchers in the 2000s took an interest in perennial options like lucerne and saltbush, or native grasses, but to date their use in most farming systems is limited. Over the last decade a growing proportion of farmers have introduced the practice of liming to reduce the soil problem of acidification that has limited pasture and crop pasture production (Andrew and Gazey, 2010).

The quantity and quality of pasture produced is mainly influenced by weather-year, rotation, soil type, grazing pressure and fertilizer effects. Pasture production is typically initiated with autumn or early winter rains. However, the leaf area index of germinated pastures limits livestock carrying capacity, with mid-winter and spring pastures being the most productive. Pastures senesce in October and November yet can remain a valuable source of feed for sheep for some months, provided they are not degraded by heavy rains in that period. Pasture production supplies feed for sheep and provides a disease break for crops. Pasture phases also facilitate control of herbicide-resistant weeds, and leguminous pastures biologically fix nitrogen for the benefit of subsequent crops.

Sheep are run on annual pastures during winter and spring. In summer months, livestock feed is mainly pasture residues and crop stubbles. In late summer through to early winter, there is often a feed gap when farmers provide grain (usually lupins) as a supplement to assist in maintaining the welfare of the sheep flock. The sheep systems mainly involve Merinos and include both wool- and meat-dominant systems. Merinos are large-framed animals which produce fleeces with fibre diameters in the range of 20 to 22 micron (Bell and Ralph, 1993). Adult sheep fleeces typically weigh between 4 and 6 kilograms.

A farm's stocking rate depends on a range of factors, including seasonal weather conditions, soils, rotations and flock structure. Typically stocking rates vary between one to seven dry stock equivalents (dse) per hectare of winter pasture, dependent on the rainfall environment and quantity and quality of available pasture. Wool production from Merino flocks has traditionally made up the majority of income from the sheep enterprise, but lamb production for meat has increased in the late 2000s due to

improved meat prices (ABARES, 2011) and many sheep are exported live to markets in the Middle East. During the 1990s with especially poor wool prices relative to grain prices many farms increasingly switched farm resources towards greater cropping.

Flock structure generally depends on relative prices of wool, sheep meat and live-trade prices for young wethers, and the husbandry costs associated with each class (John, 2004). Lambing is in late autumn or winter and shearing is in spring and autumn. All lambs have their tails removed and male lambs are castrated. Most sheep flocks are maintained to be self-replacing. Young castrated male sheep (wethers) are sold for export as live animals with ewes kept for wool and lamb production and finally sold as mutton.

A range of farm machinery and equipment is required for sowing, harvesting, grain storage, sheep handling and shearing. The replacement of this equipment usually depends on seasonal, liquidity and taxation considerations (John, 2004). Investment in cropping machinery is based on the size of annual cropping programmes. Infrastructure for sheep production includes fencing, sheep yards, shearing sheds, feed storage bins and water supply from dams and watering points.

3.1.1 Farm business data

Data describing the farm businesses in the study region were supplied by three agricultural consulting firms with farm business clients in the region. Farm business records of 249 farms were obtained, most for the period 2002 to 2011. The numbers of farms in the various agro-ecological zones (Figure 1) are listed in Table 1.

These unique longitudinal datasets describe the farm production and financial records of each farm over the decade. The list of key variables contained in or derived from the datasets are listed in Appendix 1. Because each consultancy firm reports different sets of physical and financial variables, and some variables are measured differently by each firm, care was taken to form a consistent unified dataset.

Table 1: Number of sample farms in each agro-ecological zone

Zone	Number of farms in sample
H4	5
H5C	12
H5E	4
H5W	10
L1	15
L2	36
L3	6
L4	2
M1	11
M2	47
M3	31
M4	30
M5C	19
M5E	15
M5W	6
Total	**249**

In order to test whether or not significant differences in farm characteristics and farm performance occurred between agro-ecological zones the farms were grouped into the following zones. Initially, this test required reducing the sample size to 236 farms and discarding farms in zones with small sample sizes. (see Table 2).

Table 2: Farms included in analyses to test for zonal differences

Zone	Number of farms in sample
L1&M1	26
L2	36
M2	47
M3	31
M4	30
M5	40
H5	26
Total	**236**

Zones excluded	
H4	5
L3	6
L4	2
Total	**13**

Although the sample size in the main zones represents around 15 percent of the farm population in those zones, since the data come from farms sufficiently viable to afford agricultural consultants, they may not necessarily be truly representative of the wider

farming community. The data may be upwardly biased if only above average farmers use consulting firms.

Also, some sub-regions are absent such as L5 and H1 to H3 or are clearly under-represented such as L3 and L4. Hence, there is spatial bias in the sample. However, the sample size is large and does capture a large cross-section and spatial spread of broadacre farms. Furthermore, after undertaking analyses that form the bulk of this study report, there was an opportunity to assess the impact of spatial bias by incorporating another 26 farms from L3 and L4. Inclusion of these farms, however, only reinforced all the main findings of the study.

Finally, because the sample comes from three major farm management consultancy firms it means that differences in reporting methods between the firms can be more easily reconciled that might have been the case if scores of firms provided data. Given the time constraints on data acquisition and analysis, this practical issue of ready access to data, and ensuring its uniformity and consistency, was a non-trivial consideration.

3.1.2 Socio-managerial data

Complementing the physical and financial datasets of farm businesses are socio-economic and managerial data. These are client questionnaire assessments provided by the consultants. Because the farmers have been clients of the particular consultancy firms for at least the period 2002 to 2011, and because the farmers tend to retain the same consultant, often a close professional relationship forms between the consultant and their client. Accordingly the consultant is often well-informed about the socio-managerial environment that underpins the operation of the farm business and consequently they are well-placed to provide independent assessments of that environment.

An example of the survey instrument is described in Appendix 2. The questionnaire was pilot-tested, then revised before sending out to the consultants who dealt with each particular farm business. Each questionnaire took about 15 to 20 minutes to complete and the consultants were mostly very thorough and clear in their completion of each questionnaire. Accordingly, a rich dataset was obtained about the socio-managerial characteristics of each business.

3.1.3 Climate of the study period: 2002 to 2011

Figures 2 to 4 show the spatial distribution of soil moisture in May each year from 2002 to 2012. May is the traditional month for the commencement of crop sowing in many parts of the study region and in most parts of the study region the bulk of sowing programmes is completed in May and June. Hence the amount of stored soil moisture in May is a key resource to support crop production. When little stored soil moisture is available then crop growth is entirely dependent on rainfall that occurs during the growing season. The set of soil moisture maps reveals that the period 2002 to 2011 was characterised by great spatial and temporal variability in the availability of stored soil moisture.

In years such as 2002, 2007, 2010 and 2011 there was widespread dryness such that the growing season began with crops and pastures having access to scant supplies of stored soil moisture.

By contrast, in the years 2005, 2006 and 2012 often widespread reserves of stored soil moisture were available to support subsequent plant growth. Often the south coastal regions and the higher rainfall parts of the far south-west had reasonable reserves of stored soil moisture as at May in many years.

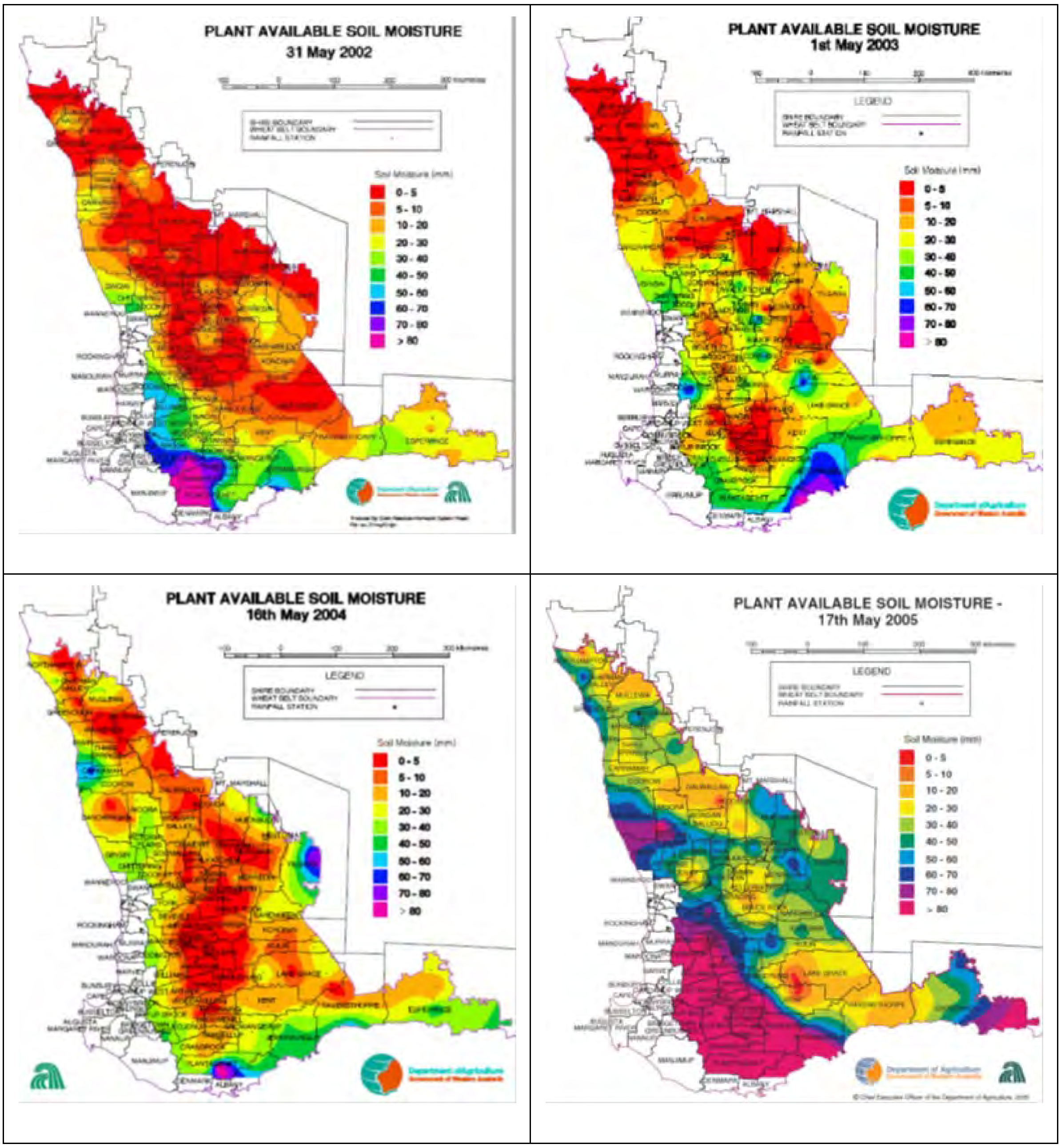

Figure 2: The spatial distribution of soil moisture in May each year from 2002 to 2005

Source: Department of Agriculture & Food, WA

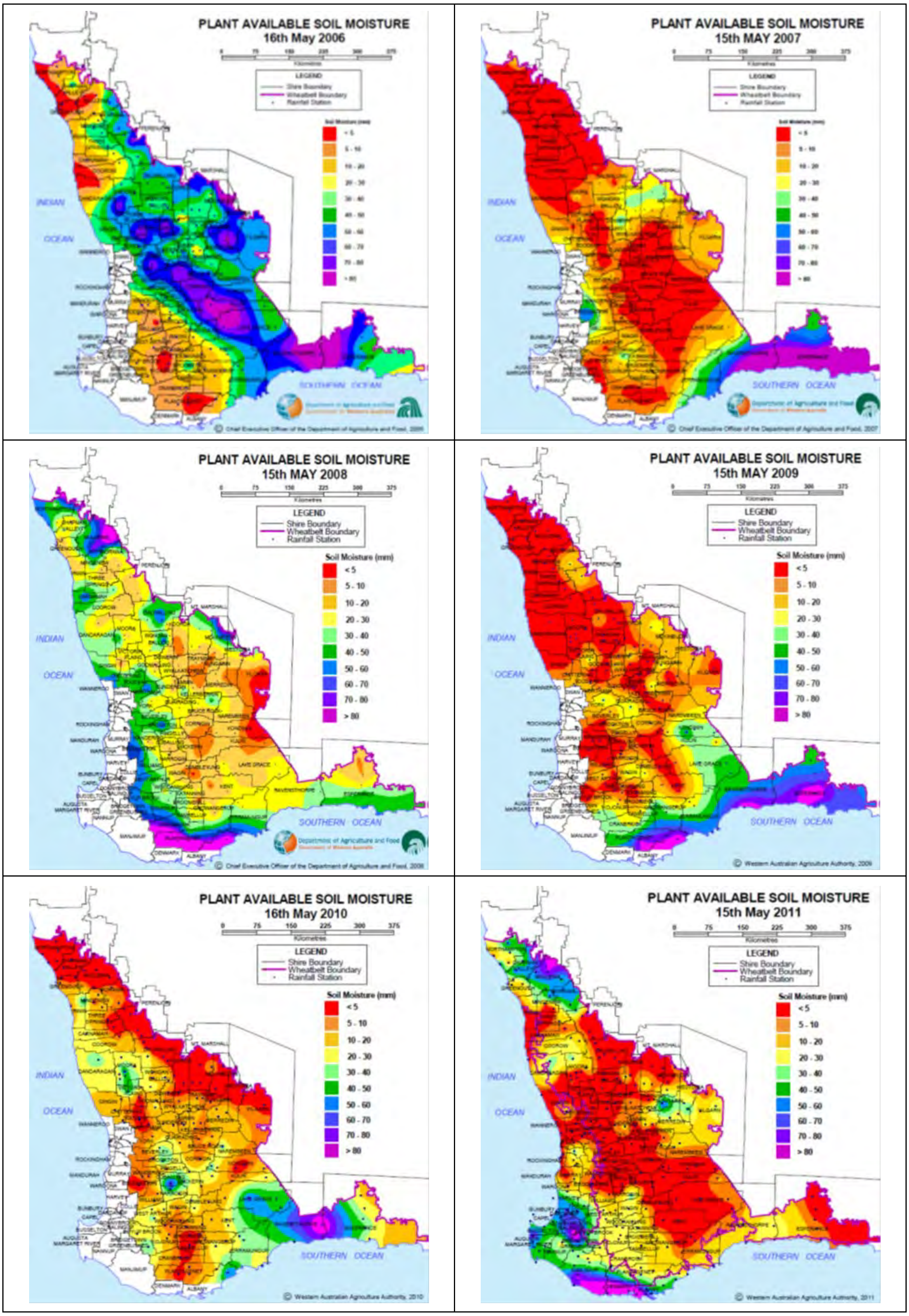

Figure 3: The spatial distribution of soil moisture in May each year from 2006 to 2011

Source: Department of Agriculture & Food, WA

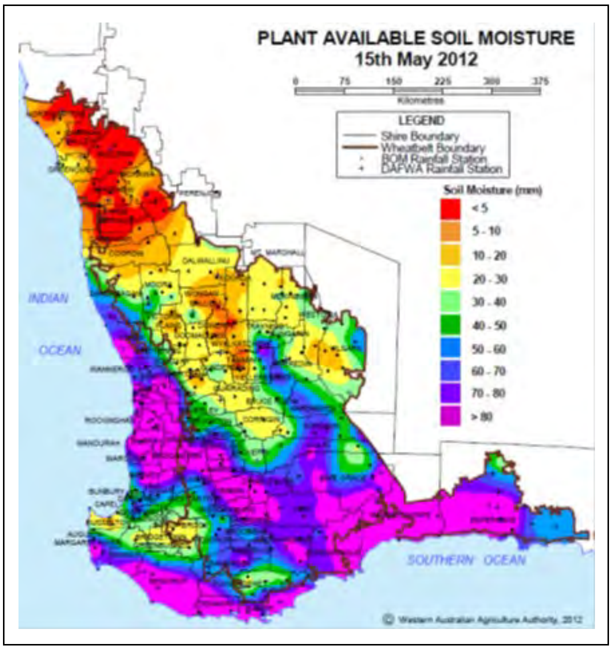

Figure 4: The spatial distribution of soil moisture in May 2012

Source: Department of Agriculture & Food, WA

Only in 2005, 2006 and 2012 was there widespread large reserves of soil moisture in May for the start of crop sowing. By contrast in many regions in 2002, 2004, 2007 and 2009 to 2001 there was little stored soil moisture.

Linked to the variability in both stored soil moisture and growing season rainfall is the resultant variability in crop and pasture yields. Because wheat production is by far the main farm enterprise for most broadacre farms, it serves as a useful indicator of how unfavourable or favourable have been growing conditions. Accordingly Figures 5 and 6 show estimated wheat yields by shire in November of each year from 2002 to 2012.

The set of wheat yield maps reveals that the period 2002 to 2011 was characterised by great spatial and temporal variability in wheat yield. Some years like 2002 and 2010 displayed fairly widespread very low yields. Other years like 2003, 2005, 2009 and 2011 displayed fairly widespread high yields. In some years particular regions fared particularly well or poorly. For example, the north and north-eastern parts experienced consecutive poor years in 2006 and 2007 2005 and 2011 high yields of wheat were widespread. Some parts of the study region, such as the northeast, experienced consecutive low yielding years in 2006 and 2007. Some far eastern parts have experienced very few favourable years for wheat production over the period 2002 to 2012, whilst by contrast the south coastal parts have experienced many more average and above average years for wheat production.

Figure 7 shows the annual mean temperature anomaly in south-western Australia over the period 1910 to 2012. Since the early 1960s a warming trend has emerged. Although not revealed by Figure 7, the cause of the warming is due to both increasing minimum and maximum daily temperatures.

Maximum daily temperatures have trended upwards in all seasons, but noticeably in winter. Minimum daily temperatures have trended upwards in all seasons, apart from winter.

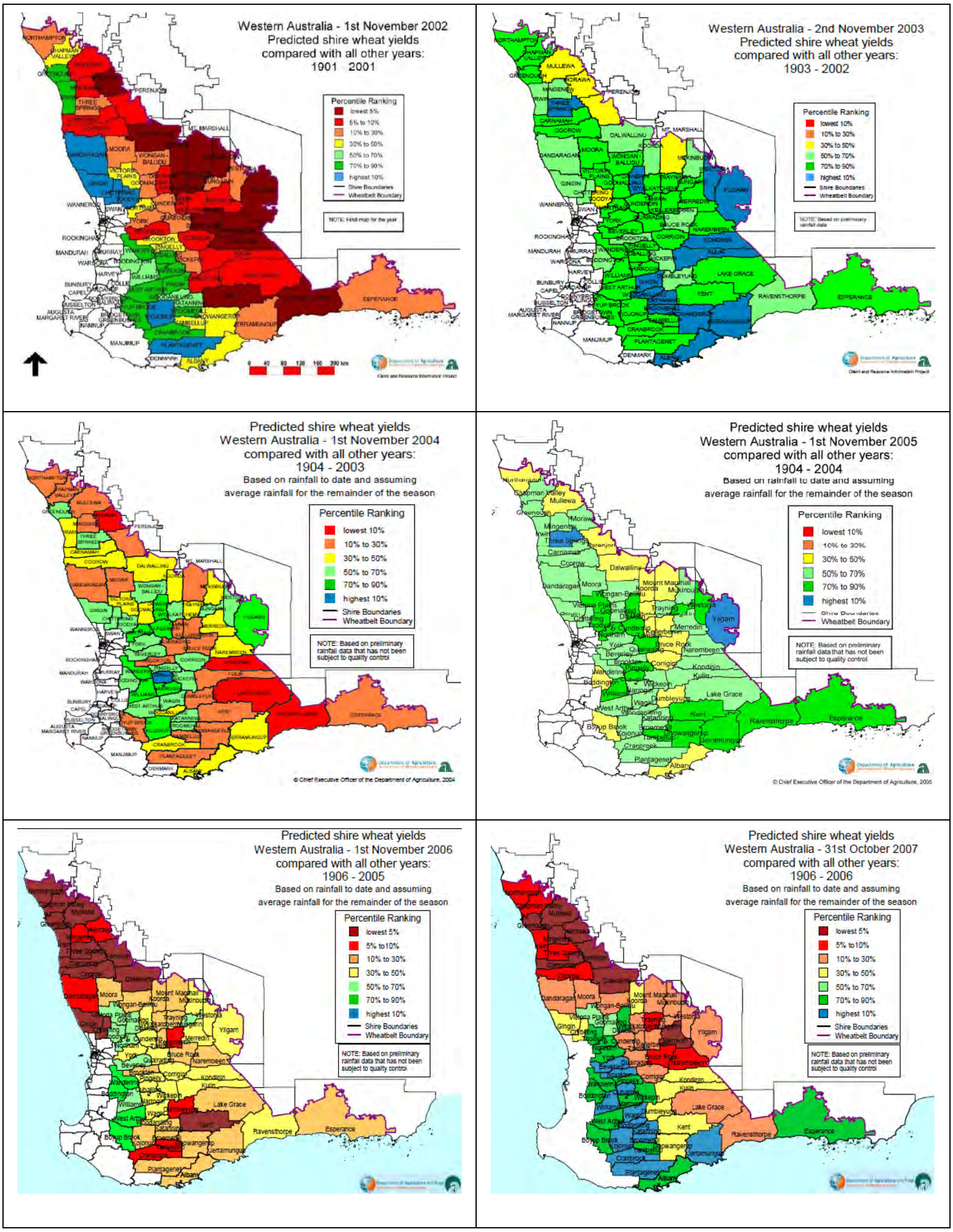

Figure 5: The spatial distribution of estimated wheat yield in November each year from 2002 to 2007 Source: Department of Agriculture & Food, WA

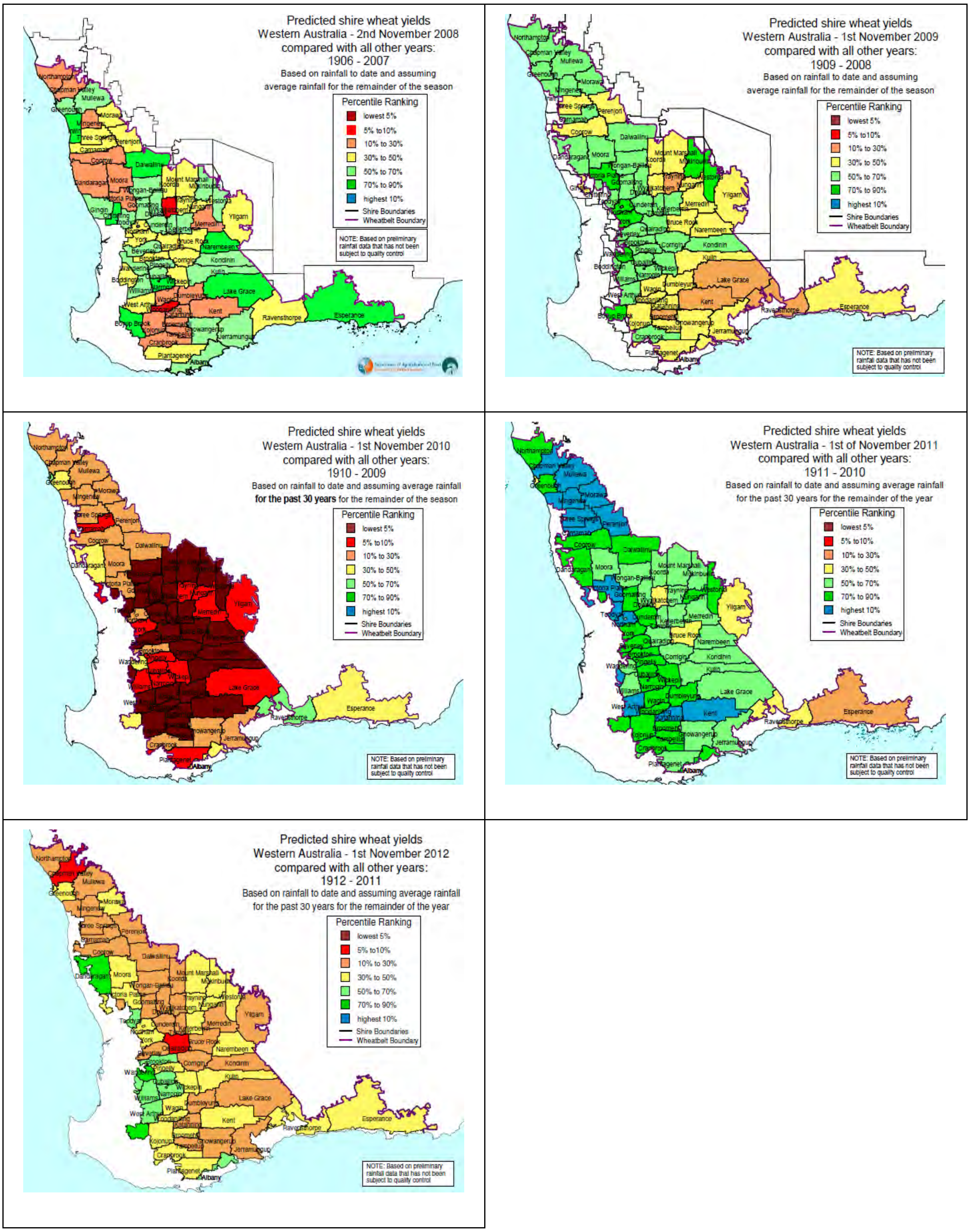

Figure 6: The spatial distribution of estimated wheat yield in November each year from 2008 to 2012 Source: Department of Agriculture & Food, WA

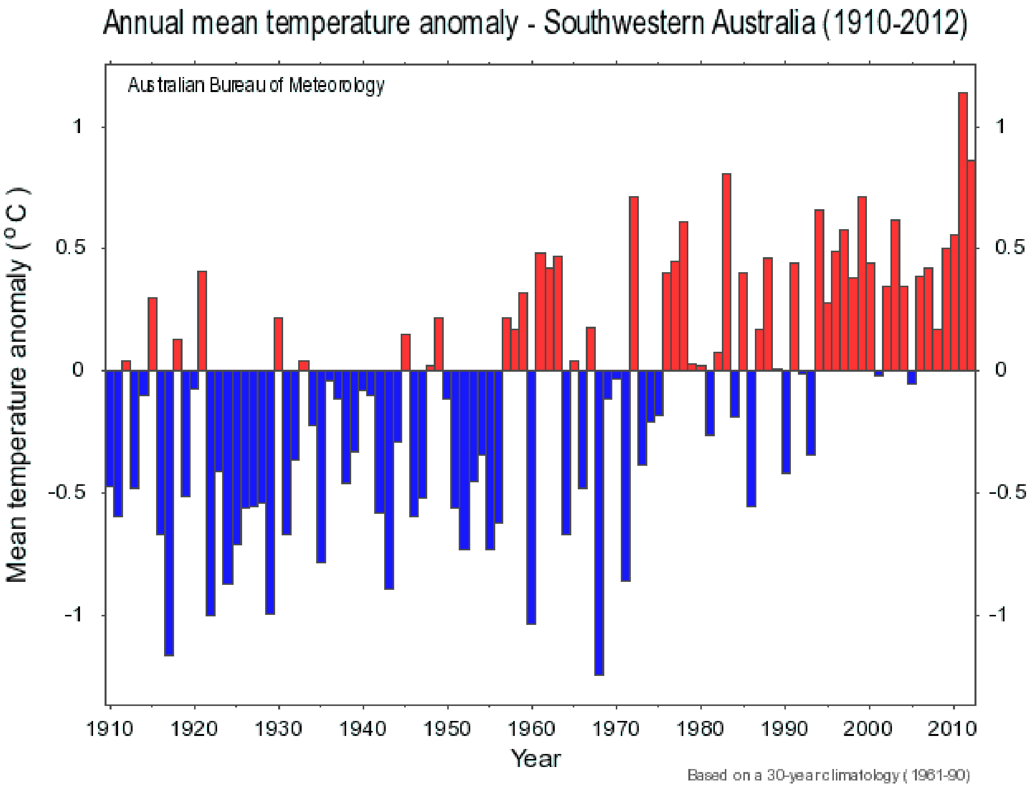

Figure 7: Annual mean temperature anomaly in south-western Australia.

Source BOM (2013) Available at http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=tmean&area=swaus&season=0112&ave_yr=A

Associated with the increase in average temperatures has been an increase in pan evaporation (see Figure 8). The black horizontal line in Figure 8 is the average pan evaporation in spring in south-western Australia over the period 1975 to 2012. As shown by the data, since the mid-1980s, the vast majority of years have recorded above average pan evaporation in spring. The greater levels of pan evaporation lessen the effectiveness of spring rainfall which is crucial for grain and pasture production, and further limits the prospects for high yields.

The current drying trend being experienced in south-western Australia is further revealed in Figures 9 and 10 that show respectively the annual percentage of the south-western area that experiences decile 10 rainfall and annual rainfall and its trend from 1900 to 2012. Since the 1970s most parts of the south-western region have not experienced extremely wet years (i.e. decile 10 rainfall years, see Figure 9). The absence of wet years makes runoff into farm dams problematic and lessens soil moisture reserves, making plant growth very dependent on growing season rainfall, and crop yields more vulnerable to spring conditions.

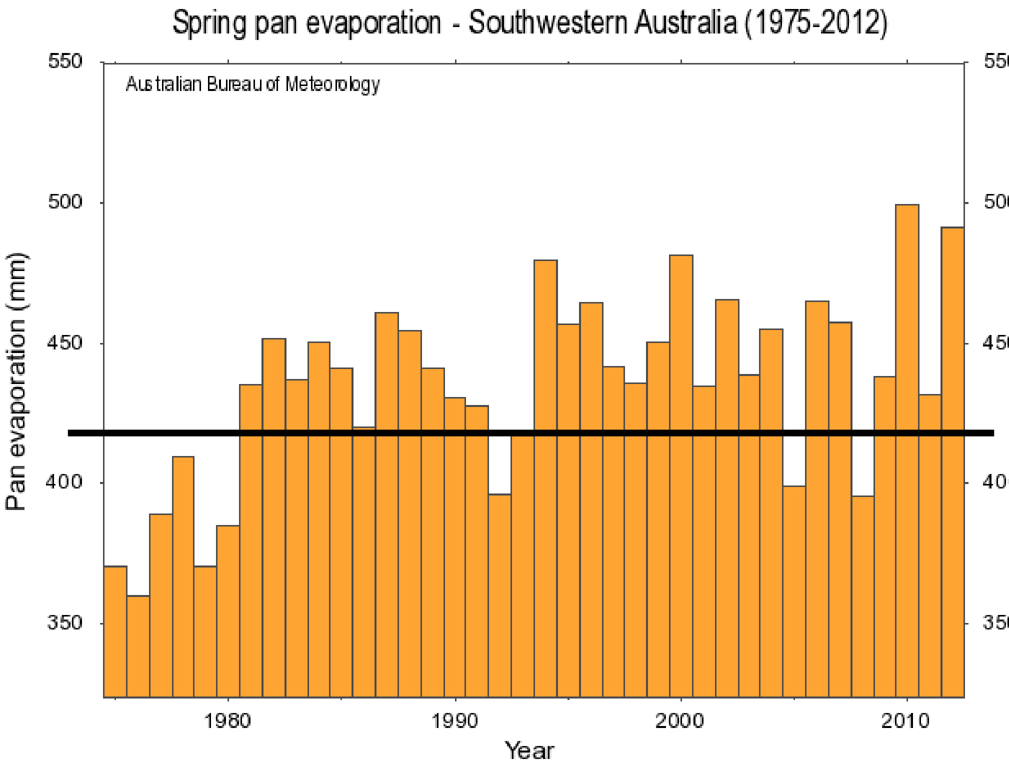

Figure 8: Spring pan evaporation in south-western Australia.

Source BOM (2013) Available at http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=evap&area=swaus&season=0911&ave_yr=0

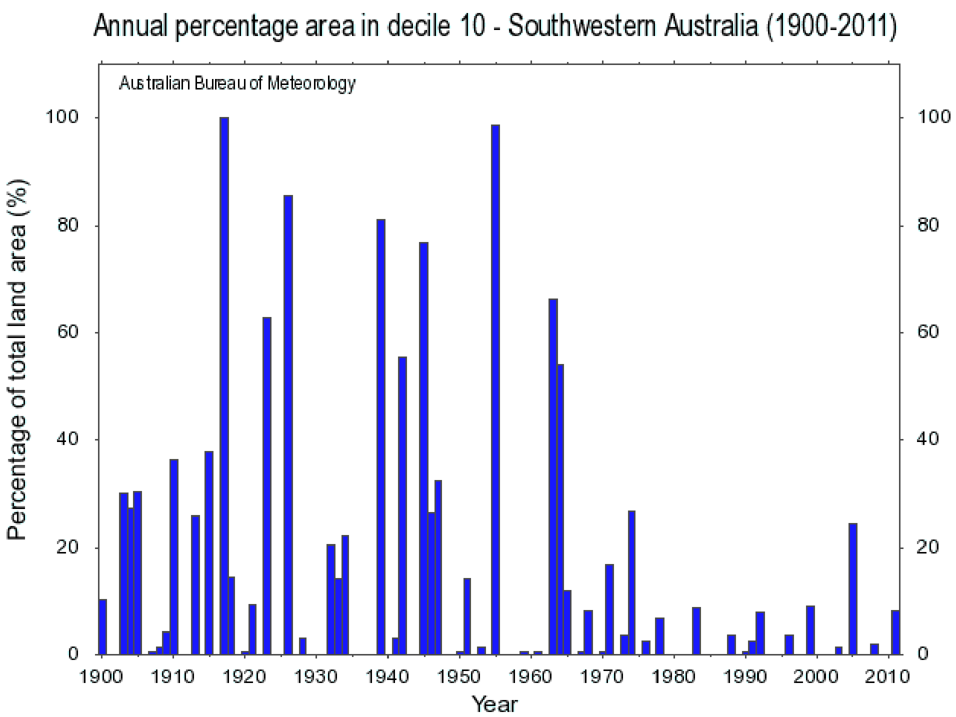

Figure 9: Annual percentage of the south-western area of Australia that experiences decile 10 rainfall Source BOM (2013) Available at http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=raindecile10&area=swaus&season=0112&ave_yr=A

The overall trend in annual rainfall is downwards for the southwest of Australia (see Figure 10). The region's expected annual rainfall at the start of the 1900s was around 750mm. Currently, the trend value for annual rainfall is around 620mm. This drying trend is observed throughout the southwest region, from inland to coastal parts. The degree of drying has been far greater than was projected in the late 1980s using the then best-available global climate models (Foster, 2013).

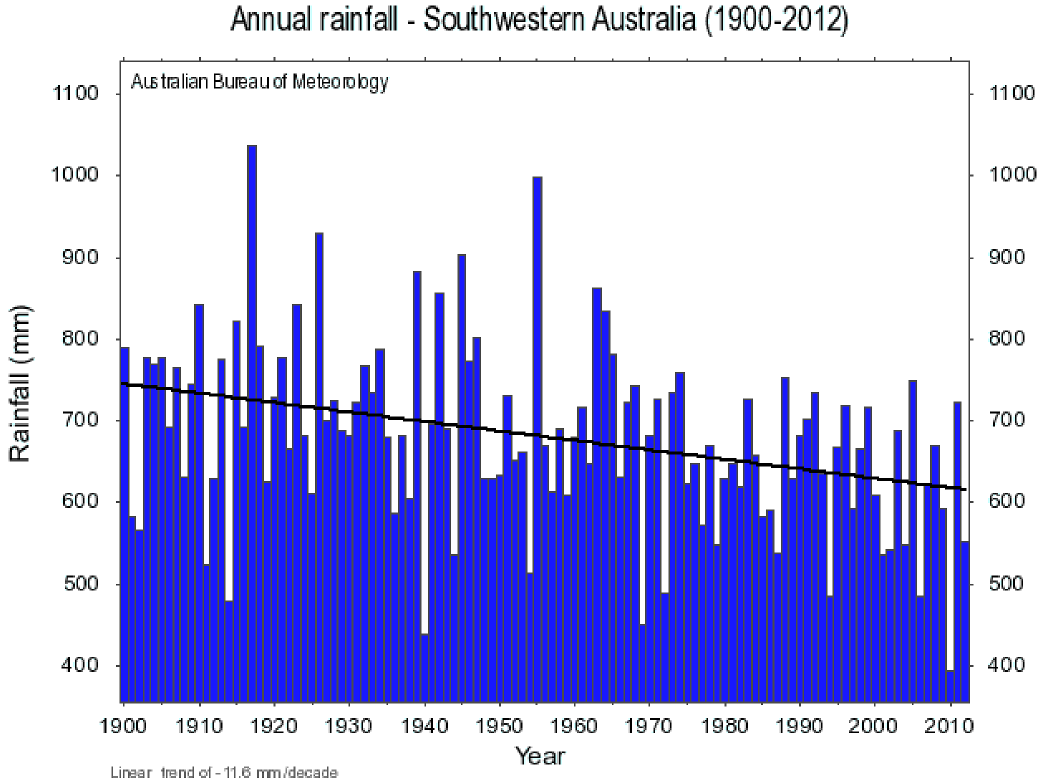

Figure 10: Annual rainfall and its trend in south-western Australia from 1900 to 2012

Source: BOM (2013) Available at http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rain&area=swaus&season=0112&ave_yr=T

Another important change in regional climate that has affected grain production in many central, eastern and southern parts of the study region has been the increased incidence of frost (GRDC, 2012). Research by CSIRO scientists has revealed and increased frequency of frosts late in the growing season over the period 1961 to 2010, especially in central and southern parts of the south-western grainbelt of Australia. In 2008, for example, extreme frosts in September in south-western Australia were estimated by Garren Knell (ConsultAg) to cost farmers up to $105 million in potential net farm income (DAFWA, 2011).

The risk of frost over the period 1975 to 2010 in south western Australia is shown in Figure 11. The sub-regions exposed to frost risk are the H3, M3, L3, H4, M4, L4 and L5 sub-regions in Figure 1. These are the central, eastern and some southern parts of the grainbelt of Western Australia. The absence of frost risk in the northern grainbelt is also one of the reasons why the northern grainbelt fared so well over the study period 2002 to 2011.

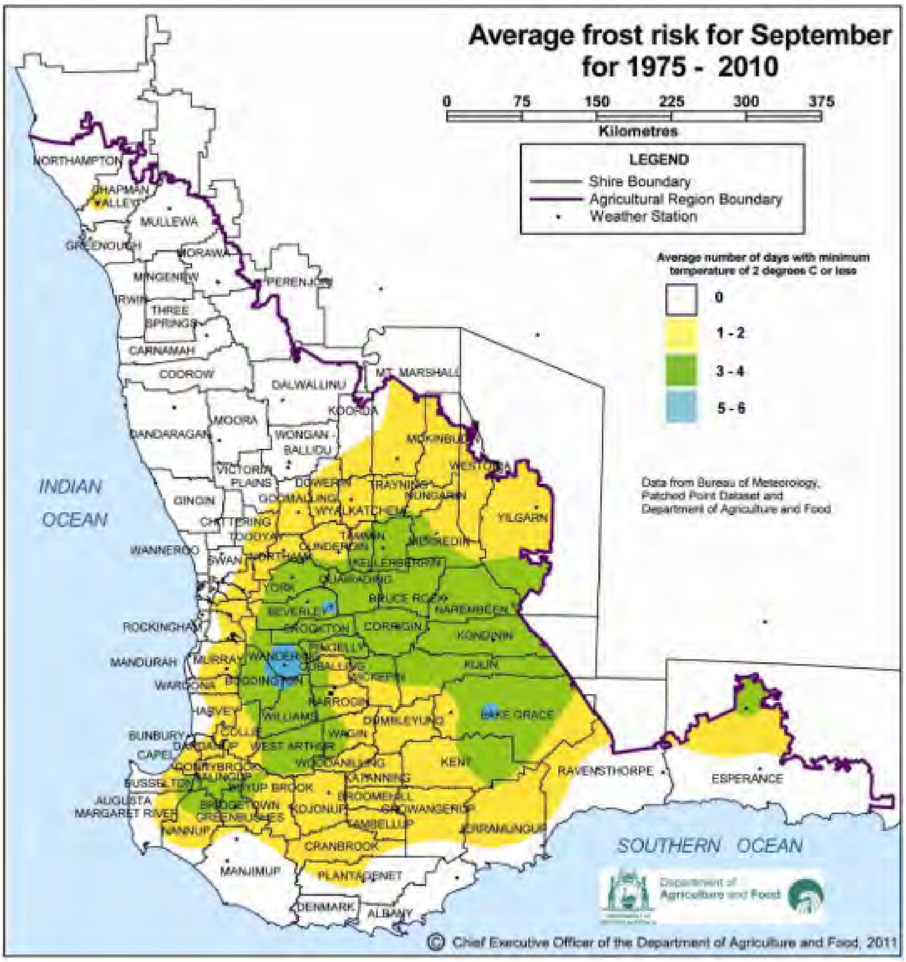

Figure 11: Frost risk in south-western Australia from 1975 to 2010

Source: DAFWA (2011) Available at http://grains.agric.wa.gov.au/node/frost-and-cropping

3.1.4 Price Volatility

Besides weather-year variation and its underlying warming, drying trend, farms in the study region also faced pronounced price volatility, especially for grains (see Figure 12). This volatility was a global phenomenon (Kingwell, 2012). As shown by the price data in Figure 12, in many recent production years there were very large changes in the grain price. For example, in the early months of 2008 the cash price for wheat peaked at $430 per tonne yet towards the end of 2008 the price was as low as $285 per tonne, a one third drop in price. By contrast in 2012 the cash price hovered around $250 per tonne until early May and subsequently rose to peak at $355 in early November, a 42% increase in price within 6 months.

Such volatility in price greatly affects the profitability of a grain enterprise and highlights the very important role that grain marketing and price risk management now plays in grain production since wheat market deregulation in 2008.

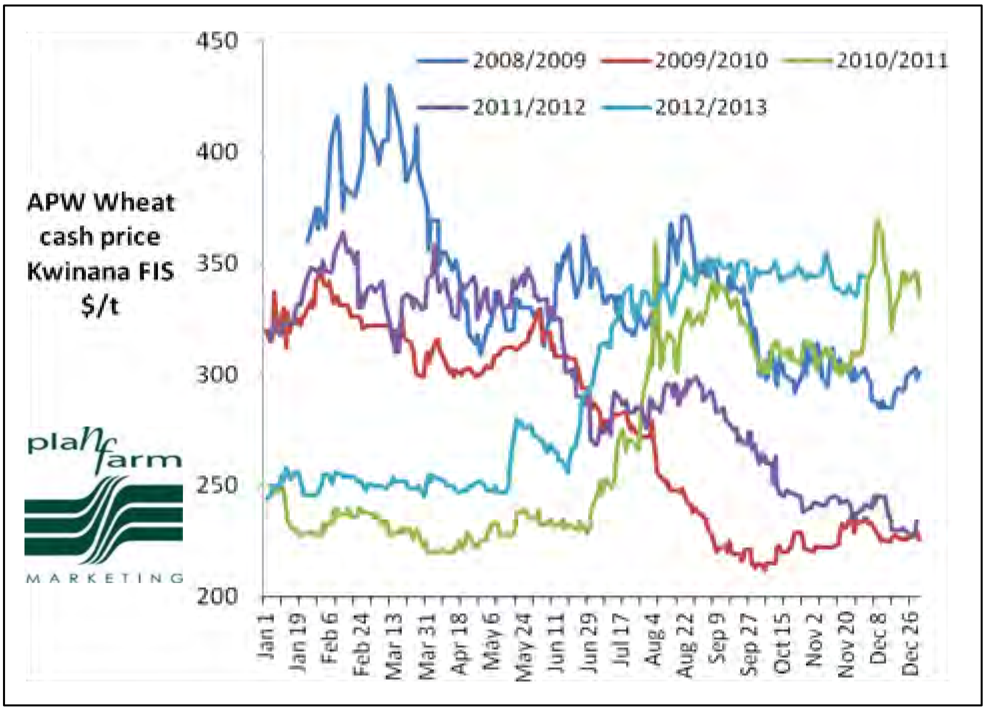

Figure 12: Daily cash FIS prices for APW wheat delivered to Kwinana ($/tonne): January 2008 to December 2012 Source: Daily Grain and Planfarm Marketing

3.1.5 Research Methods

3.1.5.1 Farm performance measures

Drawing on each farm's financial and physical records, a suite of farm performance financial measures were derived, including business equity, operating profit per hectare, return on capital, and the debt to income ratio. These were the same measures employed by Lawes and Kingwell (2012) in their study of broadacre farms in the low rainfall northern region of Western Australia's grainbelt. We adopted the same measure in this study so that our findings could be directly compared to those of Lawes and Kingwell.

Also, following the analytical approach outlined in Lawes and Kingwell (2012), generalised linear mixed effects models were used to fit a range of explanatory variables and interactions to these four business indicators. These analyses assisted to identify the characteristics of farms and management strategies that proved successful (or unsuccessful) through the study period.

Besides the four aforementioned measures of farm performance, a novel set of additional descriptors of farm performance were additionally created. These measures allowed farms to be classed as businesses that were either growing, strong, secure, less secure or unviable. The operational classification of farms was created as follows:

Firstly, two common metrics of farm business performance were listed for each farm in the sample. These measures are operating surplus and farm profit. Additionally, the increase in net wealth generated by the business over the ten years was measured as the difference in equity (at constant land values) at the start and end of the study period. Using this difference method avoided issues associated with equity expressed as a percentage or absolute value where inflation effects mask growth in real terms.

Relying on constant land valuation allows businesses which have been profitable and that have also achieved growth to be more easily identified.

The five categories of farm businesses performance, adapted from Blackburn and Ashby (1995), are:

1. Growing
2. Strong
3. Secure
4. Less secure, and
5. Non viable.

The derivation of these categories is shown in Table 3. The operating surplus/deficit is calculated as gross farm income (GFI) minus variable costs and fixed costs. Profit for each year was calculated by subtracting the cost of finance (interest), personal expenses of the business and depreciation (calculated as 10% of total machinery value for the year), from the operating surplus. Thus, depending on their resulting value of performance, as illustrated in Table 3, farms were given a score from 1 to 5.

Table 3: Categories of farm performance

	Growing	Strong	Secure	Less Secure	Non viable
Operating surplus	✓	✓	✓	✓	
MINUS					
Finance (interest)	✓	✓	✓	✓	
Personal expenses	✓	✓	✓	✓	
Depreciation	✓	✓	✓		
EQUALs Profit	+ve	+ve	-ve	-ve	-ve
EQUITY	Increasing	Maintaining	Maintaining or Declining	Declining	Declining

The change in equity was calculated as the difference between value of net assets in 2002 versus their value in 2011, using constant land values based on the values in the first year, 2002. A business which achieved a profit at least seven years in ten and showed an increase in equity from 2002 to 2011 was classified as a growing business. The distinction between a growing and strong business was that the strong business only maintained equity and achieved a profit in six of the ten years. Secure businesses could pay for their personal expenses, finance costs and depreciation but they made minimal profit and their equity was either maintained at a constant level or decreased over the period. Less secure businesses failed to achieve a profit after allowing for their finance cost, depreciation and unpaid family labour; and their equity declined as a consequence.

If an operating surplus was not achieved consistently over a period of time, the viability of the farm is eventually questionable. However it is possible to have a bad year or a number of bad years where an operating surplus is negative and equity declines, but the business can eventually recover if sufficient profit is subsequently achieved.

Besides considering the five classes of farm performance, as listed in Table 3, farms were also classified by their farming system. Three main types of farms were identified;

(i) Crop specialists, where more than 80% of the farm area was used for cropping,

(ii) Mixed enterprise farms, where 40% to 80% of the farm area is used for cropping, and

(iii) Livestock specialists, where less than 40% of farm area used for cropping and the usual livestock enterprise is sheep and wool production.

Additional to these classifications of farm type and farm performance, were the derivation of estimates of the total factor productivity of each farm in each year. The method for measurement of farm productivity is described in the next sub-section.

3.1.5.2 Farm productivity and its components

Farm productivity variations in agricultural production exist as farms face different production opportunities due to differences in factors such as: (i) physical resource endowments (e.g. quality of soils and climate), (ii) technology, capital and infrastructure and (iii) levels of costs and prices (Hayami, 1969; Hayami and Ruttan, 1971; Lau and Yotopoulos, 1989; Battese et al., 2004). On the other hand efficiency variations exist as a result of management decisions where farmers under-utilise certain inputs or misallocate inputs or select an inappropriate mix of enterprises or choose a crop type or crop variety that performs poorly. In this context measurement of efficiency has been a controversial analytical tool as it is a residual measure and thus is likely to involve measurement errors when functional forms or distributions are mis-specified. There is substantial evidence in the literature however, that inefficiency does exist and that it can be measured effectively using either data envelopment analysis or parametric methods (O'Donnell et al., 2008; O'Donnell, 2010a).

To measure farm productivity and efficiency, increasingly sophisticated methods have been developed to deal with issues such as data discrepancies, functional forms and behavioural assumption restrictions, *inter alia*. Ozkan et al. (2009) have reviewed literature on measuring efficiency in agricultural production. Existing approaches can be classified as parametric or non-parametric. The modified least-squares econometric production and stochastic frontier production function models (a maximum likelihood procedure based on a non-linear model) are examples of the first and the traditional Tornqvist-Theil or Christensen and Jorgenson total factor productivity index and data envelopment analysis are examples of the second. Detailed reviews of the productivity estimation methods can be found in Van Beveren (2010) and Van Biesebroeck (2007). Most of these studies deal with productivity and efficiency issues - not with profitability to which farm business viability is closely linked (Lovell, 2001). Productivity and profitability, however, are related in the sense that a more productive business typically is also more profitable, and a faster growth in productivity often translates into faster growth in profitability, *ceteris paribus* (O'Donnell, 2010a).

Economists have used numerous methods to demonstrate a relationship between profitability and productivity changes. Althin et al. (1996) show that the index of profitability is approximately equal to the efficiency change component of productivity change, which implies improvements in productivity are accompanied by improvements in profitability. Grifell-Tatjé and Lovell (1999) show that sources of profit change are driven by changes in quantities and prices. The changes in quantities can be further decomposed as illustrated in Figure 13 into five categories that affect quantities produced. Hadley and Irz (2008) have applied the hierarchy displayed in Figure 13 to farm-level production data for England and Wales.

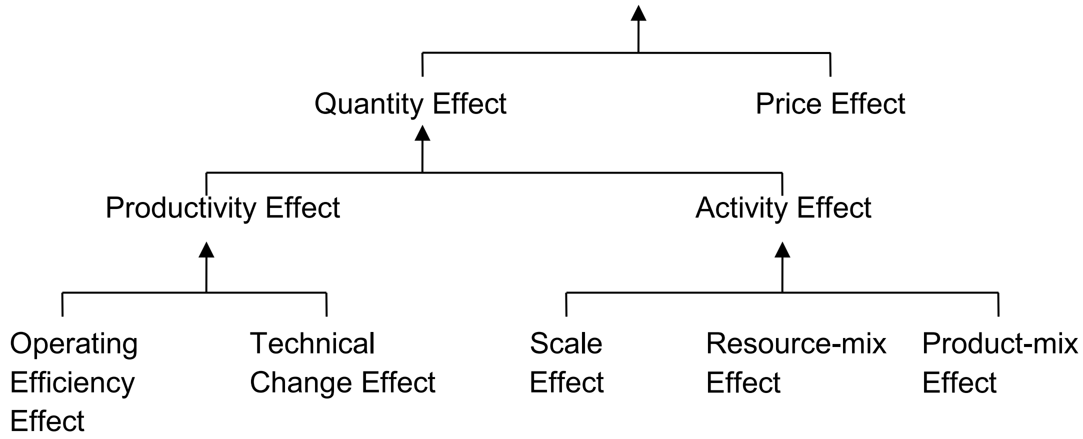

Figure 13: Profit decomposition (adapted from Grifell-Tatjé and Lovell (1999))

Advancing this decomposition approach, O'Donnell (2010a) distinguished a difference between 'profitability change' and 'profit change' and showed that the sources of profitability change are driven by the changes in the terms of trade, productivity and various measures of efficiency indexes. The distinction between 'profit change' and 'profitability change' is that the former is the change in revenue minus cost while the latter is the change in the ratio of revenue to cost in period *t* compared to period *0*.

According to O'Donnell (2010a), the sources of profitability change can be decomposed into three stages provided that: (a) the output and input quantity aggregates are associated with input and output price aggregates; (b) the quantity and price aggregates are non-negative and linear homogeneous in prices; and (c) any quantity-price aggregator function pair satisfy the product rules. The formulae for decomposing these profitability and productivity drivers are presented in simplified forms in the following equations (1) to (6).

The profitability index change (*d*PROF) between firms or periods, *0* and *t*, can be decomposed into the indexes of changes in the terms of trade (*d*TT) and total factor productivity (*d*TFP):

$$d\text{PROF} = d\text{TT} * d\text{TFP} \quad (1)$$

Following O'Donnell (2010a) we used a multiplicatively complete Färe-Primont index number. We computed the change of index numbers in Equations (1) to (6) between firms or periods *0* to *t*, using firm or period *0* as a base. For example, the change in profitability (*d*PROF) in Equation (1) can be computed as the ratio of profitability in time *t* over profitability in time *0* for firm *n*. This can be expressed as:

$$d\mathrm{PROF} = \mathrm{PROF}_{nt} / \mathrm{PROF}_{n0}$$ where,

$$\mathrm{PROF}_{nt} = P_{nt}Q_{nt} / W_{nt}X_{nt};$$

$$\mathrm{PROF}_{n0} = P_{n0}Q_{n0} / W_{n0}X_{n0};$$

P and *Q* are the price and quantity of outputs; and *W* and *X* are the price and quantity of inputs.

Similarly, the change in terms of trade (*d*TT) and the change in total factor productivity (*d*TFP) in equation (1) can be expressed respectively as:

$$TT_{n0,nt} = P_{n0,nt} / W_{n0,nt}$$ and

$$TFP_{n0,nt} = Q_{n0,nt} / X_{n0,nt}.$$

The total factor productivity change (*d*TFP) index in equation (1) can be further decomposed into the indexes of technical change (*d*TECH) and technical efficiency change (*d*EFF): See Appendix 3 for illustrative details of the TFP decomposition.

$$d\mathrm{TFP} = d\mathrm{TECH} * d\mathrm{EFF} \quad (2)$$

where,

$$d\mathrm{TFP} = TFP_{n0,nt} = \frac{TFP_{nt}}{TFP_{n0}}$$ or

$$d\mathrm{TFP} = TFP_{n0,nt} = \left(\frac{TFP_t^*}{TFP_0^*}\right) \times \left(\frac{EFF_t^*}{EFF_0^*}\right).$$

The term $\left(\frac{TFP_t^*}{TFP_0^*}\right)$ is *d*TECH which measures the difference between the maximum TFP that is possible using the technology available in period *t* and the maximum TFP that is possible using the technology available in period *0* and the term $\left(\frac{EFF_t^*}{EFF_0^*}\right)$ is *d*EFF which measures technical efficiency change in period *t* compared to period *0*.

The index of efficiency change (dEFF) can be decomposed into various indexes of efficiency change components as specified in Equations (3) to (6) (for simplicity, the subscripts are omitted):

$$d\text{Eff} = d\text{OTE}*d\text{OME}*d\text{ROSE} \quad (3)$$

$$d\text{Eff} = dO\text{TE}*d\text{OSE}*d\text{RME} \quad (4)$$

$$d\text{Eff} = d\text{ITE}*d\text{IME}*d\text{RISE} \quad (5)$$

$$d\text{Eff} = d\text{ITE}*d\text{ISE}*d\text{RME} \quad (6)$$

The above indexes are briefly defined below.

OTE (ITE) is output-oriented (input-oriented) technical efficiency that captures the potential change in TFP output (input) level by best practice use of existing technology. It is measured by the difference between observed TFP and the maximum TFP possible with existing technology, while holding the output (input) mix fixed and the input (output) level fixed.

OSE (ISE) is output-oriented (input-oriented) scale efficiency that captures the potential change in TFP, if output (input) level is changed to achieve the maximum TFP with existing technology. It is measured by the difference between TFP at a technically-efficient point and the maximum TFP based on existing technology, while holding the input and output mixes fixed but allowing the levels to vary.

OME (IME) is output-oriented (input-oriented) mix efficiency that captures the potential change in TFP if output (input) level is changed by altering the mix of enterprises in such a way that output is increased for a given set of inputs (output). It is measured by the difference between TFP at a technically-efficient point for use of existing technology or enterprise mix and the TFP that is possible holding the input (output) level fixed but allowing the output (input) level and mix to vary.

ROSE (RISE) is residual output-oriented (input-oriented) scale efficiency that measures the difference between TFP at a technically and mix efficient point and the maximum TFP that is possible through altering both input and output with existing technology.

RME is residual mix efficiency that measures the difference between TFP at a technically and scale efficient point and the maximum TFP that is possible through altering input and output mixes with existing technology.

More detail about the definitions and graphic illustrations of the index numbers specified in equations (1) to (6) can be found in O'Donnell (2010a and 2011) and Appendix 3 has further detail. To aid understanding the terms and concepts surrounding productivity analysis the following chart from Hughes et al (2011) is provided.

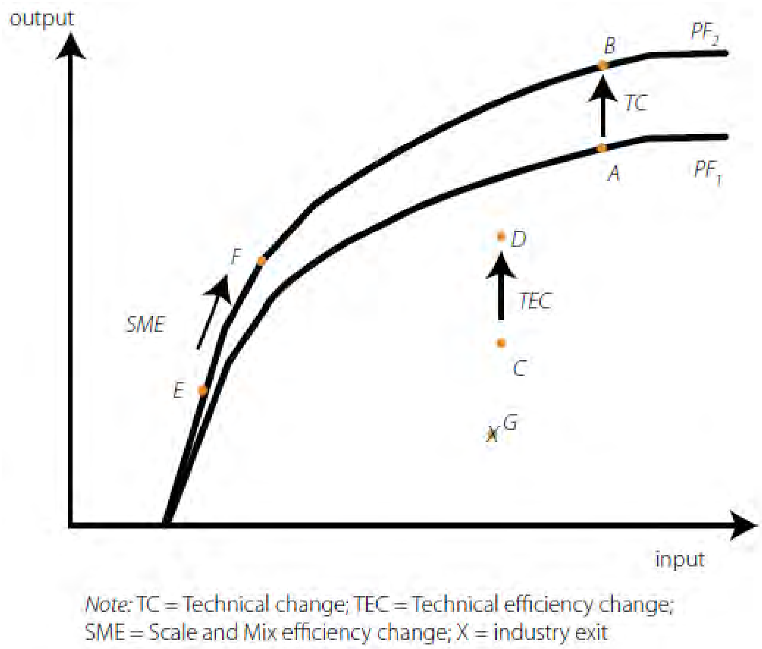

Figure 14: An illustration of productivity components Source: Figure 2 on page 8 of Hughes et al (2011)

Technical change is the upward shift in the production frontier (PF_1 to PF_2). Tecnical efficiency change (point C to D) is where a farm adopts currently available technology and moves closer to the current frontier (PF_1). Farms can also boost their productivity (point E to F) by scale and mix efficiency that involves growing the scale of their operations to reduce unit costs of production whilst also ensuring their mix of enterprises is tailored to market and production conditions.

3.1.5.3 Variables and index construction

The following is a list of key variables constructed or used in productivity analyses.

Crop output (q1) was constructed as the sum of production (tonnes) of all crops (wheat, barley, oats, lupin, canola and other) for each farm, noting that cereals (wheat in particular) were by far the dominant crop type.

Crop price index (p1) was generated by dividing the sum of all revenue from crop production by crop output ***(q1)***..

Animal output (q2) was generated by dividing the sum of all revenue from cattle, sheep and wool sales by animal price index (p2).

Animal price index (p2) was generated as an average of cattle, sheep and wool sale prices using revenue share as a weight. Their sale prices were generated by dividing their revenue from quantity sales. .

Land input (x1) was effective land area utilized for crop and animal production (in hectares).

Rental price of land (w1) was estimated by multiplying the land asset value which was available in the sample data and the 10 year real rate of Australian government bonds.

Labour input (x2) was in person weeks and was constructed as the annual sum of family, managerial and hired labour.

Labour wage index (w2) was constructed using ABARES's online farm survey data, as no labour payment data for family members existed in the sample data set. The cost and quantity of labour input from ABARES data were based on the average of the WA farm survey. We assumed that all farms in the sample faced the same per unit labour cost.

Capital input (x3) was constructed using asset values (livestock, machinery and equipment) divided by their average prices index series from ABARES (2011) using capital value share as a weighted.

User cost of capital (w3) was estimated using the same method used to derive ***(w1)***.

Fertilizers (x4) was constructed by dividing fertilizer expense by its price index ***(w4)***. ***Fertilizer price (w4)*** was the fertilizer prices index series from ABARES (2011).

Materials and services (M&S) inputs (x5) was constructed by summing annual farm expenditures over five input categories: chemicals, livestock materials, fuel and lubricants, and repairs and maintenance and dividing each item by the relevant price index from ABARES (2011).

Price of M&S inputs (w5) was constructed as an average of the prices of five items; chemicals, livestock materials, fuel and lubricants, repairs and maintenance, and contract expenses using their expenditure shares as a weight.

Growing Season Rainfall (GSR) input (x6) was actual rainfall recorded in millimetres for each farm in each growing season of the data period.

This current study examines whether or not farm total factor productivity is a key explanator of the variation in the four main measures of farm performance. To combat the adverse impacts of climate change and other sources of business risk, productivity growth is vital. In this study farm total factor productivity is decomposed into technical change and technical efficiency components in order to reveal which business strategies and management actions underpin high productivity and therefore assist in adaptation to climate change. The productivity levels and components are also related to the socio-economic and management traits of the farmer to see if farmers with certain traits achieve high levels of productivity and profitability.

Farm businesses can also be analysed through the lens of rural sociology. It may be that the particular demographic and managerial characteristics of a farm business are determinants of its financial performance. Accordingly, the socio-managerial characteristics of each business were assessed through administering the survey instrument (see Appendix 2).

4. RESULTS AND DISCUSSION

The presentation and discussion of results is based on applying the various methods outlined in the previous section. Accordingly, various sub-sections present and discuss results on farm performance, farm productivity and socio-managerial characterization.

4.1 Categories of farm performance

Applying the farm performance classification criteria outlined in Table 3 to the dataset generates the results in Table 4. The mean values of each main characteristic of farm businesses in each of the four categories of farm performance are listed.

Table 4: Characteristics of farms in the four categories of farm performance

		Growing	Strong	Secure	Less secure
	Unit				
Gross farm income	$	1,577,486	1,204,430	1,070,855	791,490
Operating costs	$	996,072	808,160	730,798	594,360
Operating surplus	$	581,414	396,270	340,057	197,130
Profit	$	273,090	138,128	114,573	- 43,983
Personal Expenses	$	111,752	105,847	83,202	84,701
Interest payments	$	81,477	52,699	58,261	81,524
Machinery replacement	$	115,259	99,596	84,021	74,439
Debt to income ratio	no.	0.99	1.05	1.35	1.64
Operating expenses as a % of gross farm income	%	69.5	73.1	79.3	91.9
Land owned	ha	3,875	3,422	3,093	2,739
Land operated	ha	3,935	3,502	3,269	2,660
Land value	$	4,685,816	4,496,043	3,557,352	3,276,747
Farm assets	$	6,987,197	6,202,225	4,864,321	4,608,275
Business assets	$	7,717,971	7,048,667	5,356,378	4,985,611
Liability	$	1,417,091	1,193,862	1,389,985	1,213,838
Equity	$	6,431,107	5,743,213	3,963,110	3,749,779
Equity as a %	%	82.4	82.2	75.6	76.7
Crop area	ha	2,826	2,313	2,188	1,770
Pasture area	ha	1,110	1,190	1,081	890

		Growing	Strong	Secure	Less secure
	Unit				
Crop Income as % of farm income	%	80	77	76	74
Crop income per ha	$/ha	464	427	403	379
Livestock income per ha	$/ha	250	201	295	255
Farm asset value per ha	$/ha	1,853	1,963	1,646	2,040
Business asset value per ha	$/ha	2,054	2,194	1,815	2,200
Debt per ha	$/ha	375	393	429	515
Equity per ha	$/ha	1,709	1,768	1,376	1,677
Return on equity	%	11	8	10	6
Return on capital	%	5	3	4	- 1
Growing season rainfall	mm	253	249	242	240

There is little difference in the mean values of growing season rainfall between the farm performance groups. The growing farms when compared to the less secure farms tend to have the following key differences. Growing farms are larger, generate a higher rate of return to capital and equity, carry less debt per hectare, are slightly more crop dominant, have higher personal and machinery replacement expenses yet similar debt repayments, have a much lower debt to income ratio, have slightly higher equity in percentage terms, generate similar livestock income per hectare but much higher crop income per hectare and overall generate much higher profits.

Due to the nature of their financial performance over the period 2002 to 2011, almost two-thirds (64%) of the sample farms were classed as growing or strong (see Figure 15). The group of farms at potential financial risk were classed as less secure, and they formed 15% of the sample of farms.

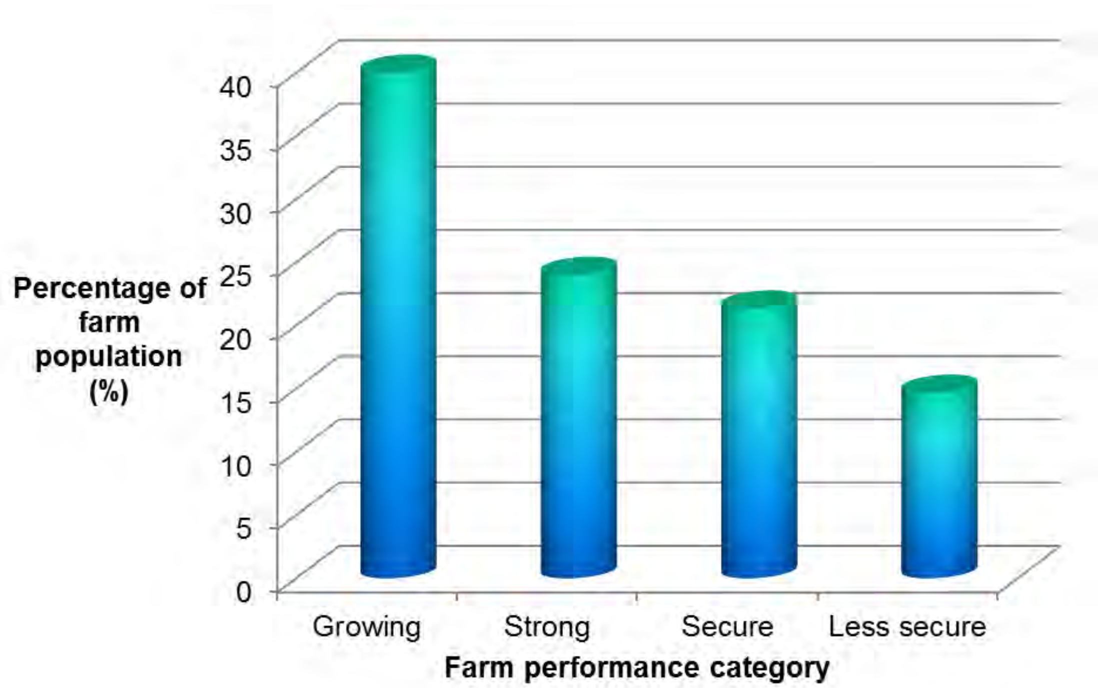

Figure 15: Proportions of farms in the various performance categories

When farms were also categorised on the basis of their farm type (crop dominant, mixed enterprise, livestock dominant) and performance category (see Figures 15 and 16) the main findings were that most farms that were growing were often crop farms or mixed farms and that especially among crop farms, most were growing or strong. By contrast, the few highly livestock dominant farms in the sample (only 13 farms) were more likely to be secure rather than growing or strong. The shares of farm types in the sample were 73%, 22% and 5% for mixed enterprise, crop dominant and livestock dominant farms respectively.

The distribution of farm performance among crop farms and to a lesser extent also for mixed farms was skewed. A large majority (45%) of crop farms, for example, were classed as growing. By contrast only 23% of livestock farms were classed as growing.

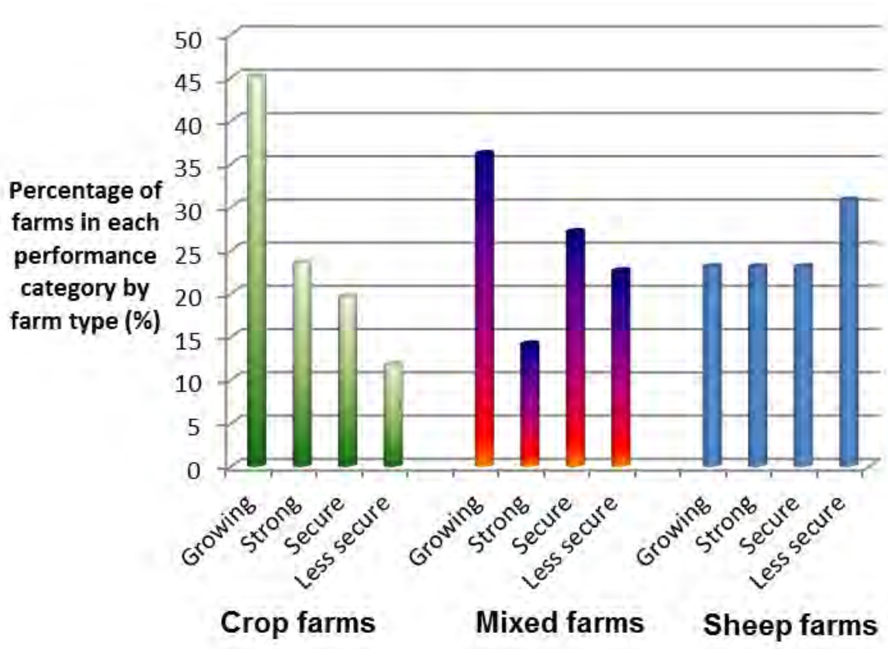

Figure 16: Percentage of farms in each performance category by enterprise type

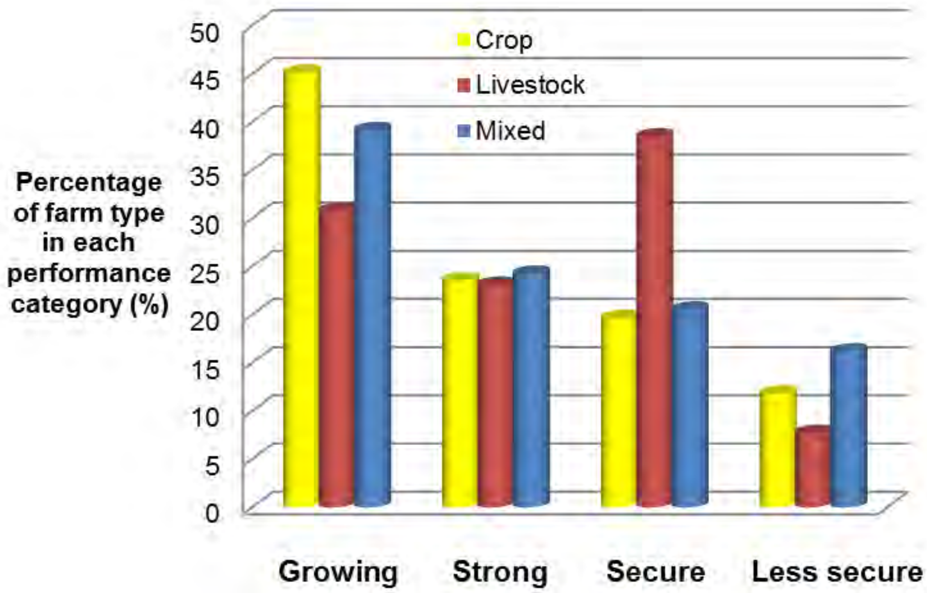

Figure 17: Percentage of farm types in each farm performance category

When farms were also categorised according to region (see Figure 18), the region with the smallest proportion of less secure farms was the northern agricultural region (L1&M1). The regions with the highest proportions of less secure farms tended to be the central grainbelt regions (M4,M2,M3&M5). The region with the smallest proportion of farms that were growing or strong was the M4 region. As shown by wheat yield outcomes in Figures 5&6, many low-yielding years characterised the period 2002 to 2011 in the M4 region. Furthermore, farms in that region and in some adjacent eastern and southern regions were also affected badly by frost in some years during the study period. Hence, farm revenues in that region over that period were often low and so few

farms were able to grow. By contrast, regions with the highest proportion of farms classed as either growing or strong were the northern agricultural region (L1&M1) and the southern near-coastal region (M5).

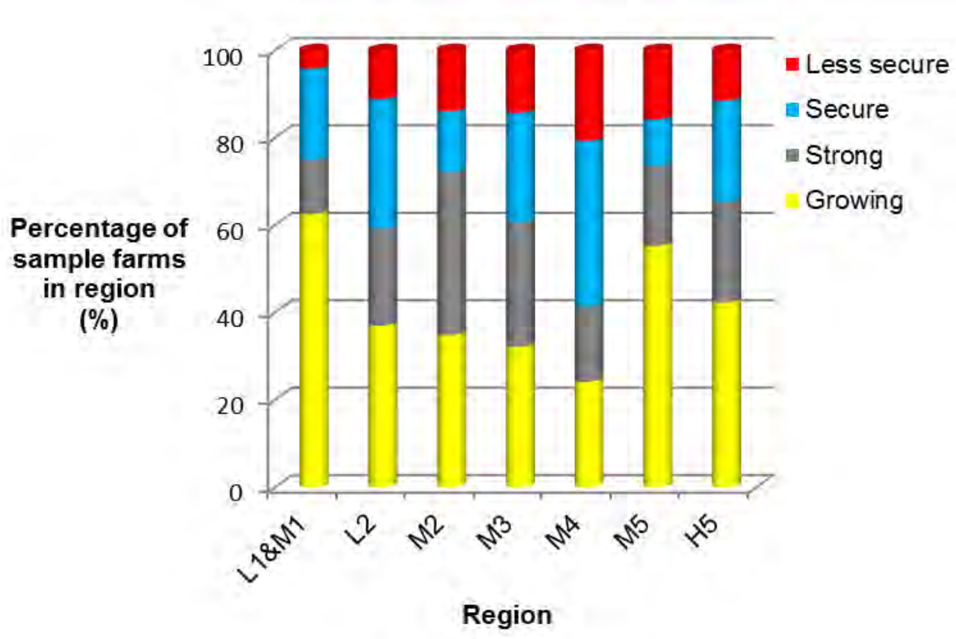

Figure 18: Percentage of sample farms in each performance category by region

Interestingly, in spite of the decade from 2002 to 2011 being a period of warmer and drier climate compared with previous decades (see Figures 7 to 10), it was not the high rainfall region that recorded the highest proportions of farms that were growing or strong. Rather it was the northern low and moderate rainfall zones (L1,M1,M2 and M5) that comprised mostly crop farms that displayed the highest proportions of farms that were growing or strong. Hence it appears that across the agricultural region of south-western Australia, where a warming, drying trend has been experienced, the combination of seasonal and price conditions have favoured profitable crop production, especially in the northern region (L1&M1) and southern coastal region (M5). This finding is consistent with that of Lawes and Kingwell (2012) who examined farm performance in the low rainfall north-eastern grainbelt of Western Australia over the years 2004 to 2009. It is also a finding consistent with recent wheat yield projections under a changing climate (Ludwig et al., 2009; Asseng and Pannell, 2012; Potgieter et al., 2012).

Ludwig et al. (2009) examined wheat yields at several locations in Western Australia's grainbelt, using crop simulation modelling based on historical and recent climate. They found virtually no change in wheat yield due to the apparent change in climate, despite reductions in rainfall at several sites. Hence, in spite of the warming and drying trend that Ludwig et al. observed at several locations in Western Australia's grainbelt, simulated wheat yields were relatively unchanged. An implication of the lack of change in wheat yields, attributable to a changing climate, is that wheat production serves as yield protection for these farm businesses, assuming the simulated yields match actual yields.

Potgieter et al. (2012) also modelled the impacts of climate change on shire wheat yields across Australia. For Western Australia they found that under a 2050-high

emissions scenario, the modelled wheat yields differed from −5 % to +6 % across most of Western Australia relative to a baseline climate of 1901 to 2007. Moreover, they found CO_2 fertilisation effects largely offset yield declines attributable to higher temperatures and drying. The surprisingly little impact of projected climate change on wheat yields in Western Australia implies that wheat is a species highly adapted to the range of projected climatic conditions for south-western Australia. Hence, farmers' dependence on wheat-growing as a principal source of farm income appears to be a sensible adaptation strategy, if only because the biological prospects for wheat yield appear very sound in the face of a changing climate in south-western Australia.

The farm performance classification that points to the merits of engaging in crop production, dominated by the growing of wheat, is a finding consistent with that of Lawes and Kingwell (2012). They found that wheat yield was the main explanator of farm performance in the northern low rainfall grainbelt of Western Australia over the 6 years, 2004 to 2009. Lawes and Kingwell found that wheat yield was more important in defining likelihood of farm business success than structural variables like the percentage of the farm area cropped or the enterprise diversity of the business. The prime importance of wheat yield, however, is not altogether surprising. Wheat revenue is the major source of income for almost all farm businesses in that region and so changes in wheat revenue, driven by yield change, translate into changes in the rate of return to capital.

The predominance of wheat in farming systems in that region and in other regions serves as a useful bulwark against recent and projected climate change. Certainly the evidence from the current study that examined more farms over a longer period, in more regions of Western Australia, confirms the findings of Lawes and Kingwell regarding the prime importance of wheat production. These findings suggest that so long as broadacre farmers in south-western Australia have on-going access to improved wheat varieties and technologies that support the profitable growing of wheat, that farmers will be able to adapt to projected climate change. The forecast biologically robust performance of wheat will help underpin the profitability of crop production. Moreover, the topography and climate over much of the study region suits wheat production and the wide adaptability of wheat further supports its preferred use by farmers. Lastly, major wheat breeding firms (e.g. Intergrain Pty Ltd, AGT Pty Ltd, LongReach Plant Breeders) are continuing to develop varieties suited to region'schanging climate. Hence, provided farmers' terms of trade (i.e. the ratio of prices received to prices paid) does not become unduly adverse, and that farmers sensibly manage farm debt, then it seems highly likely that farmers in the region who continue to rely on wheat production will persist as financially sound businesses.

However, there are some important caveats to the findings of this study and that by Lawes and Kingwell. As noted by Lawes and Kingwell, a sequence of favourable production years will allow crop dominant farmers to produce their way towards business growth. However, the converse is also applicable. An increased frequency of very poor production years will eventually lead crop dominant farm businesses towards insolvency. Hence, the crucial issue for climate change is not just the trend in environmental change but, more importantly, the nature of the variation about that trend. An increased frequency in very dry years, for example, will undermine farm profitability. Yet there remains uncertainty about even the nature of some climate-related environmental trends, let alone knowing how volatility about those trends may also change.

The analysis of farm performance reveals that the strategy of crop dominance has been profitable mostly in the northern agricultural region. However, it is open to debate as to whether this strategy in the longer term adds to the resilience of farm businesses. Specialisation in cropping, although often profitable does not remove the probability of periods of dry years and the business risks associated with such sequences. Whether or not greater enterprise diversity, including diversifying into off-farm investments, delivers greater resilience is a topic worthy of further research.

The following regression model (LMM: linear mixed model) was fitted to investigate temporal trends for each zone and farms within zones:

$$Y_{ijk} = \mu + at + T_i + Z_j + F_{jk} + b_j t + TZ_{ij} + c_{jk} t + \varepsilon_{ijk} \quad (7)$$

where Y_{ijk} is an economic measure of interest (e.g. equity or operating profit per hectare); t is a variable for year of measurement (2002 – 2011); T_i are effects for each year; Z_j are effects for each zone; F_{jk} are effects for each farm within each zone; TZ_{ij} are effects for each year and zone; ξ_{ijk} are errors and the remaining parameters are regression coefficients. All terms are random apart from at, Z_j and $b_j t$. In addition the model included correlations between subsequent years which declined exponentially as the number of years between measurements increased.

The model for each economic measure of interest (e.g. rate of return to capital) was simplified by removing non-significant random terms. In addition, due to non-normality of the data (Arellano-Valle et al., 2005) the following transformations were applied to the economic variables of interest (see Appendix 1 for their description and units of measurement), so that their distributions were compatible with the assumptions necessary for regression analysis (see Appendix 2 and Appendix 7):

LOG_e(opPERha-MIN(opPERha)+0.5) {operating profit per hectare}

LOG_e(roc-MIN(roc)+0.1) {return on capital}

LOG_e((110-equityPC) {equity expressed as a percentage}

LOG_e(debt2incomeRatio+0.01) {debt to gross farm income ratio}

LOG_e(0.85-Diversity) {diversity of income sources}

The results in Table 5 show that there are significant differences in operating surplus per hectare between the zones considered in the analysis (see Table 5). There are also significant differences between the zones in their degree of enterprise diversity. The difference in operating surplus per hectare between the zones is mostly a product of differences in farm size and rainfall between the zones. In the high rainfall zones like H5 and H4 where farm size is typically small and crop and pasture yields are higher, then often operating surpluses per hectare are higher. By contrast in low rainfall zones like L1 and L2 where crop and pasture yields are typically smaller and farm sizes are larger, then operating surpluses per hectare are smaller. So the different environments in which these differently sized farm businesses operate lead to there being significant differences in operating surpluses per hectare.

The significant differences in the measure of enterprise diversity between the zones are due in part to important differences in the physical environments and farm sizes between the zones. In the low rainfall environments where farm sizes are greater, then often farms are crop-dominant and they rely on cropping machinery with high work

rates that provide economies of size. These farms have their income streams mostly dependent on wheat production. By contrast, farms in high rainfall environments where farm sizes are smaller are more likely to be mixed enterprise farms. Their topography is sometimes less suited to broadscale cropping and they often have a smaller proportion of their farm area devoted to crops. Moreover, there is often greater diversity in their mix of crops, with more canola and barley being featured in their cropping programs.

Table 5: Means and standard errors (in parentheses) of measures of farm performance

Variable	Ln_Operating surplus per ha	Ln_Return on capital	Ln_Equity as a %	Ln_Ratio of debt to gross farm income	Ln_Farm income diversity
H4&H5	-0.097±0.013	-0.829±0.048	3.315±0.062	-0.077±0.144	-1.680±0.060
	(0.407)	(0.337)	(82.5)	(0.916)	(0.664)
M1	-0.172±0.017	-0.733±0.053	3.392±0.109	-0.190±0.234	-1.390±0.104
	(0.342)	(0.380)	(80.3)	(0.817)	(0.601)
M2	-0.166±0.012	-0.817±0.047	3.180±0.052	-0.397±0.125	-1.492±0.051
	(0.347)	(0.342)	(86.0)	(0.662)	(0.625)
M3	-0.164±0.013	-0.816±0.048	3.253±0.063	-0.242±0.146	-1.657±0.061
	(0.349)	(0.342)	(84.1)	(0.775)	(0.659)
M4	-0.142±0.013	-0.784±0.048	3.391±0.063	-0.061±0.146	-1.742±0.061
	(0.368)	(0.357)	(80.3)	(0.931)	(0.675)
M5	-0.160±0.012	-0.802±0.048	3.382±0.055	0.021±0.131	-1.820±0.054
	(0.352)	(0.348)	(80.6)	(1.012)	(0.688)
L1&L3	-0.191±0.014	-0.783±0.049	3.446±0.076	-0.179±0.169	-1.300±0.073
	(0.326)	(0.357)	(78.6)	(0.826)	(0.577)
L2	-0.192±0.012	-0.779±0.048	3.292±0.059	-0.490±0.138	-1.201±0.057
	(0.325)	(0.359)	(83.1)	(0.603)	(0.549)
Linear (Year)	-0.0006 ±0.0037	-0.0108 ±0.0161	0.0293 ±0.0103	0.1115 ±0.0405	-0.0149 ±0.0113
	(-0.1%)[1]	(-1.1%)	(3.0%)[2]	(11.8%)	(-1.5%)

[1] Approximate growth factor each year; linear trends were only significant for Ln_ Equity as a % and Ln_ Ratio of debt to gross farm income.
[2] Approximate growth factor each year for (110-equityPC); translates to a loss in Equity as a % but not a constant.

The results in Table 5 also show a significant decline in equity (as a percentage) during the study period and a significant increase in the debt to income ratio. (i.e. the linear trends were significant for Ln_ Equity as a % and for Ln_ Ratio of debt to gross farm income). These results indicate that for the sample population, farm indebtedness increased and debt-servicing was becoming an issue for some farms, particularly as shown later for secure and less secure farms. The importance of these findings is also revealed in zonal differences; farms' ratio of debt to gross farm income (or more strictly, its logarithmic transformation), is significantly different between the zones as shown in

Table 6. The practical interpretation of these differences is that in some regions, due to the combination of seasonal conditions and farm expansion activity, some farm businesses in some regions experienced a worsening of their ratio of debt to gross farm income. The pattern of the zonal differences depends on the unique sequence of seasonal conditions and farm expansion activity within a zone. Table 6 displays for each zone the means, confidence intervals and standard errors of the key independent variables listed in the columns of Tables 5 and 6.

Using statistical model in equation (7) the variance of the five measures of farm performance is analysed and the results are shown in Table 6. The percentages of variance associated with each term in the regression model of equation (7) are listed for each of the five measures of farm performance.

The analysis of variance results in Table 6 indicate that the "Farm" effect is a main explanator of many of the farm performance measures, particularly for equity as a percentage. For this farm performance measure, the individual characteristics of each particular business are the main influence on its equity. There are some other significant explanators of the variance of particular performance measures. These explanators, such as “Year” or “Zone”, are significant for particular measures.

Table 6: Analysis of variance of measures of farm performance

Term	Ln_Operating surplus per ha	Ln_Return on capital	Ln_Equity as a %	Ln_Ratio of debt to gross farm income	Ln_Farm income diversity
Linear(Year)			6%	5%	
Year	10%	21%	0%	5%	1%
Zone	15%		3%	2%	21%
Linear(Year). Zone			0%	0%	
Year. Zone	7%	19%	1%	6%	2%
Farm	25%	10%	60%	48%	44%
Residual	43%	50%	29%	41%	33%

The main influence of the "Farm" effect on the various measures of farm performance indicates that often the financial performance of a farm has much to do with the unique characteristics of that particular farm business. An implication of this finding is that there are likely to be few generalisations about farm performance. It adds weight to observations made over 40 years ago by Mauldon and Schapper (1970) about the nature of inter-farm comparisons and benchmarking; observations reiterated more latterly by Ferris and Malcolm (1999). If farm performance is mostly a product of the unique characteristics of a farm business then drawing relevant generalisations from farm surveys and applying them to particular farm businesses is fraught with danger. It does lend support for the idea that the peculiar characteristics of a farm business might

first need to be properly understood before discerning ways to improve the financial performance of that business. It suggests that there is a legitimate role for personalised advice and support for individual farm businesses in order to further improve their performance.

The relationship between the standard deviation between years for each farm's Ln_Operating surplus per hectare and the mean of the same values is shown in Figure 19. Figure 19 displays positive relationships in all zones between the standard deviation of Ln_Operating surplus per hectare and its mean. So, higher average surpluses tend to be associated with greater variability in levels of surplus. This is the same result as found by Lawes and Kingwell (2012).

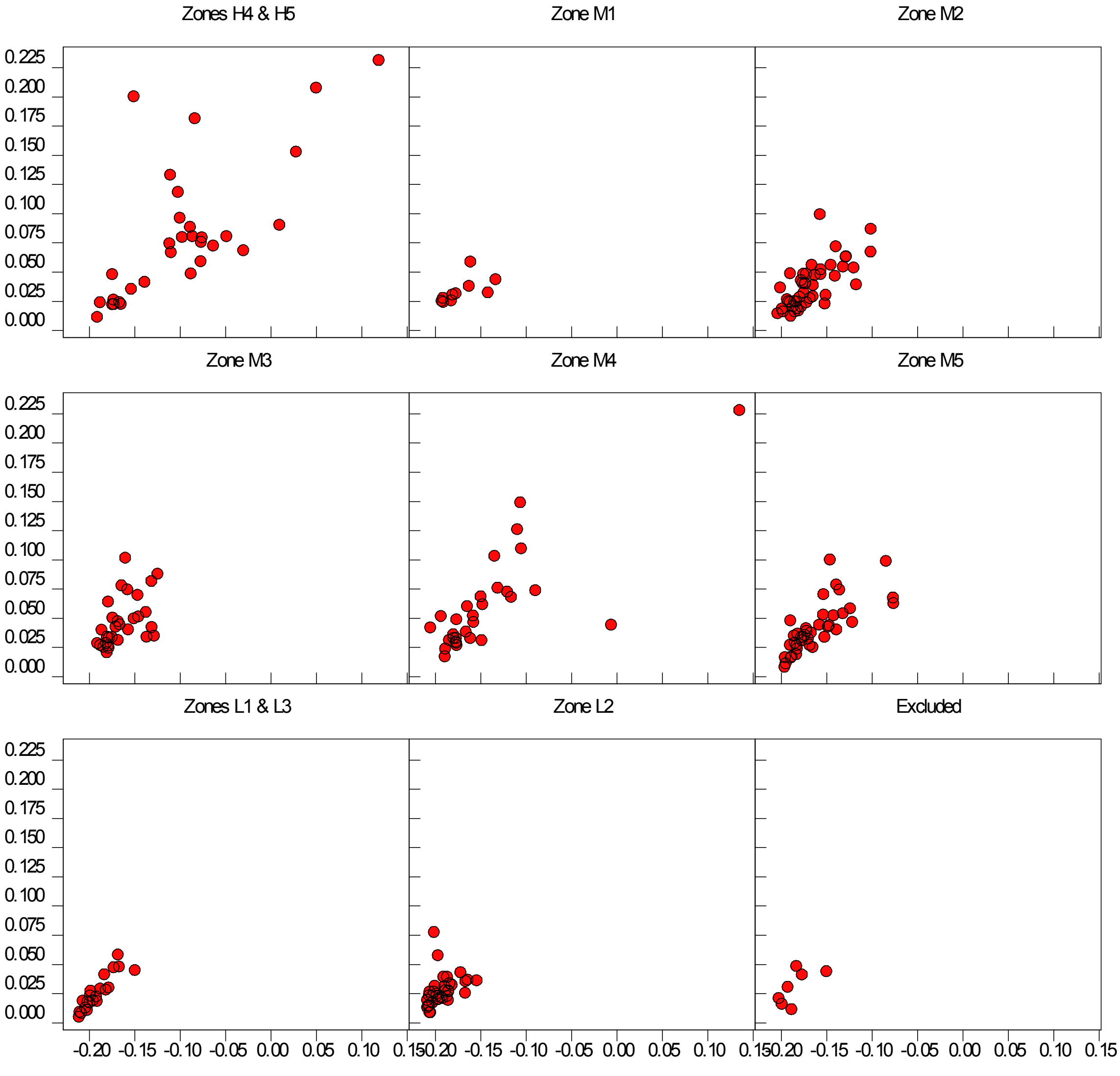

Figure 19: Relationship between the standard deviation of log_Operating surplus per hectare (vertical axis) and its mean (horizontal axis) in each zone

In some zones such as H4 and H5 there is a wide spread in the standard deviation of Ln_Operating surplus per hectare and its mean among the sample population. By contrast in some zones such as L2 and M1 there is a much narrower spread of these measures among the sample of farms. However, in all zones, despite the breadth or

narrowness of the spread of the measures, there remains a positive relationship between the standard deviation of Ln_Operating surplus per hectare and its mean. The practical implication of this finding is that it has not generally been possible for farm businesses to achieve a high mean in the Ln_Operating surplus per hectare whilst simultaneously achieving little variance in the Ln_Operating surplus per hectare. Hence, a farm business strategy of lifting the farm's mean Ln_Operating surplus per hectare has necessarily involved an increase in the variance of the Ln_Operating surplus per hectare.

Table 7: Independent variables in the second regression model

Variable	*Term and units*
landown	Area owned (ha)
land	Farm size (ha)
gsr	Growing season rainfall (mm)
%AreaCropped	Percentage area cropped (%)
TOC	Total operating costs/ha ($/ha)
ywheat	Wheat yield (t/ha)
ycanola	Canola yield (t/ha)
ISwheat	Is wheat grown? (0: no; 1: yes)
IScanola	Is canola grown? (0: no; 1: yes)
zone	Agroecological zones (see Figure 1 and Table 1)
farm	Farm

If a farm manager is highly risk-averse then this strategy will not be attractive. However, most studies of Australian farmers' risk attitudes reveal that they are only slightly risk-averse. Accordingly, as revealed by the data, this strategy is employed by many farmers to increase the profitability of their farm businesses.

A second regression model was fitted to each farm performance variable. This model included the linear trends in equation (7), if they were significant, an effect of zone and the variables in Table 8 and their interactions with zone.

When no wheat or canola was grown on a farm in a particular year, ywheat and ycanola were recorded as zero. Since this is not the same as a true zero yield, two additional factors, ISwheat and IScanola, were introduced which identified whether or not wheat and canola, respectively, were grown. Effects of ywheat and ycanola were nested within ISwheat and IScanola, respectively.

Correlations between the independent variables in listed in Table 7 are shown in Table 8. Correlations between land and landown across all farm/year combinations is very high (r=0.88) so only land is included in regression models. The correlation between gsr and ywheat is also high when only farm/year combinations which grew wheat were included (r=0.64) but both variables have been included initially. Correlation coefficients in bold font in Table 8 are statistically significantly different from zero.

The significance of each fixed term in the regression model that considered the suite of independent variables listed in Table 7 is shown in Table 10 and regression coefficients and confidence intervals are listed in Table 9. Most terms are highly significant but it is clear from the F statistics that some variables are contributing much more to the regressions than others. For instance, gsr, zone by Ln_land, lswheat and %AreaCropped are the major contributors to Ln_Operating surplus per ha. Zone and zone interactions are often significant but generally contribute little to the regressions.

The fact that so many independent variables listed in Table 7 are statistically significant explanators of the various measures of farm performance is illustrative of the role of the "Farm" effect where many factors influence farm performance such as zone, growing season rainfall, wheat yield and farm size; with some of these variables having significant interactions in addition.

Wheat yields, relative to canola yields, exert a greater influence on farm performance measures. Farm size and growing season rainfall are additionally important. The crucial role of rainfall is no surprise as all farm businesses are dryland enterprises and often are crop dominant. Therefore the amount of rainfall hugely affects crop yields, which in turn affects farm revenues and ultimately farm profits.

Table 8: Correlations between independent variables for (a) all data; (b) only farm/year combinations with ywheat>0; and (c) only farm/year combinations with ycanola>0

		gsr	land	landown	ycanola	ywheat	%Area Cropp ed	TOC perH A
All farms & years	gsr	-						
	land	**-0.19**	-					
	landown	**-0.15**	**0.88**	-				
	ycanola	**0.35**	-0.05	0.01	-			
	ywheat	**0.46**	-0.04	0.00	**0.40**	-		
	%AreaCropped	-0.06	**0.19**	**0.14**	**0.09**	**0.22**	-	
	TOCperHA	**0.35**	**-0.10**	**-0.07**	**0.42**	**0.36**	**0.33**	-
ywheat > 0	gsr	-						
	land	**-0.17**	-					
	landown	**-0.14**	**0.88**	-				
	ycanola	**0.37**	-0.05	0.01	-			
	ywheat	**0.64**	**-0.13**	**-0.07**	**0.46**	-		
	%AreaCropped	0.01	**0.16**	**0.12**	**0.09**	**0.12**	-	
	TOCperHA	**0.37**	**-0.08**	-0.06	**0.42**	**0.47**	**0.36**	-
ycanola > 0	gsr	-						
	land	**-0.17**	-					
	landown	**-0.13**	**0.88**	-				
	ycanola	**0.35**	-0.03	0.05	-			
	ywheat	**0.38**	-0.01	0.04	**0.41**	-		
	%AreaCropped	**-0.16**	**0.26**	**0.18**	-0.05	**0.12**	-	
	TOCperHA	**0.26**	-0.06	-0.03	**0.19**	**0.24**	**0.28**	-

Note: Correlation coefficients in bold font are statistically significantly different from zero.

Table 9: Regression coefficients for the regression model that considers the independent variables listed in Table 7

Variable	Ln_Operating surplus per ha	Ln_Return on capital	Ln_Equity as a %	Ln_Ratio of debt to gross farm income	Ln_Farm income diversity
gsr	0.00003260 ± 0.00001770	0.00015510 ± 0.00005825	0.00027010 ± 0.00013452	0.00004502 ± 0.00031158	0.00035200 ± 0.00013278
Ln_land	-0.05534000 ± 0.00219500	0.04306000 ± 0.00700900	-0.06285000 ± 0.01784900	-0.30630000 ± 0.04055000	0.00076360 ± 0.01602313
Iswheat	-0.07460000 ± 0.00596900	-0.07789000 ± 0.01899000	0.13846000 ± 0.04864000	0.40590000 ± 0.11050000	-0.42030000 ± 0.04340000
ywheat	0.03816000 ± 0.00218000	0.12245000 ± 0.00711000	-0.10328000 ± 0.01668000	-0.33720000 ± 0.03860000	-0.04246000 ± 0.01618000
Iscanola	-0.00211500 ± 0.00250100	-0.00368100 ± 0.00804300	0.05618000 ± 0.02019000	0.24790000 ± 0.04590000	-0.22160000 ± 0.01840000
%Area cropped	0.04043000 ± 0.00644500	0.25900000 ± 0.02076000	0.41510000 ± 0.05195000	-0.10360000 ± 0.11812000	-0.52960000 ± 0.04759000
TOC per ha	0.00000548 ± 0.00001643	-0.00054480 ± 0.00005298	0.00013770 ± 0.02986000	0.00065300 ± 0.00029895	-0.00072470 ± 0.00012063
Linear (Year)			0.02986000 ± 0.00586300	0.07616000 ± 0.01782900	

Table 10: Significance of each fixed term in the regression model that considers the independent variables listed in Table 7 for each measure of farm performance (continued next page)

Sequentially adding terms to fixed model											
		Ln_Operating surplus per ha		Ln_Return on capital		Ln_Equity as a %		Ln_Ratio of debt to gross farm income		Ln_Farm income diversity	
Fixed term	*d.f.*	*F statistic*	*F pr*	*F statistic*	*F pr*	*F statistic*	*F pr*	*F statistic*	*F pr*	*F statistic*	*F pr*
gsr	1	332.16	**<0.001**	24.39	**<0.001**	0.01	0.914	0.01	0.913	177.36	**<0.001**
Ln_land	1	1010.09	**<0.001**	78.87	**<0.001**	0.28	0.598	56.94	**<0.001**	10.11	**0.001**
ISwheat	1	69.86	**<0.001**	5.61	**0.018**	11.90	**<0.001**	3.02	0.082	277.15	**<0.001**
ISwheat.ywheat0	1	478.23	**<0.001**	291.13	**<0.001**	22.54	**<0.001**	62.45	**<0.001**	251.87	**<0.001**
Zone	7	2.80	**0.014**	9.89	**<0.001**	15.46	**<0.001**	17.30	**<0.001**	159.00	**<0.001**
Zone.gsr	7	1.82	0.079	18.05	**<0.001**	3.58	**<0.001**	5.53	**<0.001**	6.57	**<0.001**
Zone.Ln_land	7	26.58	**<0.001**	4.51	**<0.001**	12.16	**<0.001**	6.25	**<0.001**	16.64	**<0.001**
Zone.ISwheat	5	8.04	**<0.001**	1.50	0.187	3.45	**0.004**	4.12	**0.001**	10.73	**<0.001**
Zone.ISwheat.ywheat0	7	1.92	0.063	9.53	**<0.001**	4.30	**<0.001**	3.34	**0.002**	3.36	**0.002**
IScanola	1	0.09	0.764	0.00	0.974	29.63		29.89	**<0.001**	274.30	**<0.001**

Sequentially adding terms to fixed model											
		Ln_Operating surplus per ha		Ln_Return on capital		Ln_Equity as a %		Ln_Ratio of debt to gross farm income		Ln_Farm income diversity	
							<0.001				
IScanola.ycanola0	1	4.57	0.033	4.05	0.044	0.75	0.386	1.26	0.262	12.35	**<0.001**
%AreaCropped	1	62.27	**<0.001**	69.40	**<0.001**	84.93	**<0.001**	0.47	0.495	258.84	**<0.001**
TOCperHA	1	2.80	0.094	93.58	**<0.001**	9.14	**0.003**	11.87	**<0.001**	23.60	**<0.001**
Zone.IScanola	7	1.86	0.072	1.12	0.348	2.99	**0.004**	1.76	0.092	10.53	**<0.001**
Zone.%AreaCropped	7	2.76	**0.007**	0.82	0.568	5.39	**<0.001**	2.34	0.022	64.18	**<0.001**
Zone.TOCperHA	7	3.69	**<0.001**	4.42	**<0.001**	3.30	**0.002**	1.56	0.144	3.60	**<0.001**
Zone.IScanola.ycanola 0	7	13.73	**<0.001**	2.86	**0.006**	2.33	0.023	1.79	0.085	1.94	0.060
vYear	1					21.98	**0.001**	18.30	**0.002**		

Cells with an F statistic greater than 20 (an arbitrary value) are shaded.

4.1.1 Analysis of socio-managerial characteristics

Analysis of the socio-managerial datasets indicates there are some significant differences between farm performance groups regarding the socio-managerial characteristics of farms within those groups. As an illustration, Table 11 lists and compares some key socio-managerial characteristics of farms within each classification of farm performance. Because cropping enterprises have been revealed to play important roles in affecting farm performance, aspects of farm management that relate to crop management are initially investigated. As shown by the averaged results in Table 11, there are differences between the farm performance groups in some aspects of crop and business management.

Table 11: Management characteristics of farms grouped by performance

	Unit	Growing	Strong	Secure	Less Secure
No. of cropping innovations continuing to be used if adopted during the last 10 years	no.	8.2	7.7	7.5	7.4
Use of leasing, contractors, super funds, succession planning, FMDs, off-farm assets[1]	no.	4.0	3.6	3.4	3.0
Use of farm business software, marketing strategies, decision support tools, precision ag technology, electronic paddock recording, GPS technology[1]	no.	3.7	3.5	3.5	3.3
Current average age of primary male	yr	50.5	50.8	45.0	50.5
Quality of care for cropping gear[1]	no.	22.4	20.6	20.7	19.3
Community involvement and personal care[1]	no.	20.7	20.1	19.0	18.2

[1]The unit of measurement was the average score for farms in each performance group. A Likert scale (1 to 5) was used to assess the frequency of use of each particular aspect of farm management (e.g. use of leasing, use of GPS technology) by each farm business. Scores were summed and then averaged across the group of farms in each performance category.

An assessment of the statistical significance of the differences between the farm performance groups, stated in Table 11, is provided in Appendix 5. The key statistically significant differences are as follows:

(i) Growing farms, when compared to less secure or secure farms, have on average adopted more cropping management innovations over the last decade and continued to use them.

(ii) Growing farms, when compared to less secure or secure farms, have on average made greater use of leasing, contractors, superannuation funds, succession planning, Farm Management Deposits and off-farm assets.

(iii) Similarly strong farms, when compared to less secure farms, have on average made greater use of leasing, contractors, superannuation funds, succession planning, Farm Management Deposits and off-farm assets.

(iv) Growing farms, when compared to less secure farms, have on average adopted and made greater use of farm business software, marketing strategies, decision support tools, precision ag technology, electronic paddock recording and GPS technology.

(v) Secure farms, on average have a much younger primary male operating their farm business when compared to all other categories of farm businesses.

(vi) Growing farms, when compared to less secure, secure or strong farms, have on average a greater quality of commitment to the maintenance of their cropping gear.

(vii) Growing farms, when compared to less secure or secure farms, have on average expressed greater involvement in their local community and expressed more care regarding their work-life balance.

Rather than analyse farms through the lens of performance, it is also possible to analyse the socio-managerial dataset to gauge if there are particular groupings of farms solely based on their socio-managerial characteristics rather than their business performance. Figure 20 displays the results of that analysis, using the technique of cluster analysis as outlined in Appendix 6. The analysis shows there are 15 separate clusters (see Figure 20). However, 7 of the clusters comprise 4 or less farms. These small clusters are identified by black arrows on the far left side of Figure 21, and so ignoring those very small clusters reveals 8 main groups of farms.

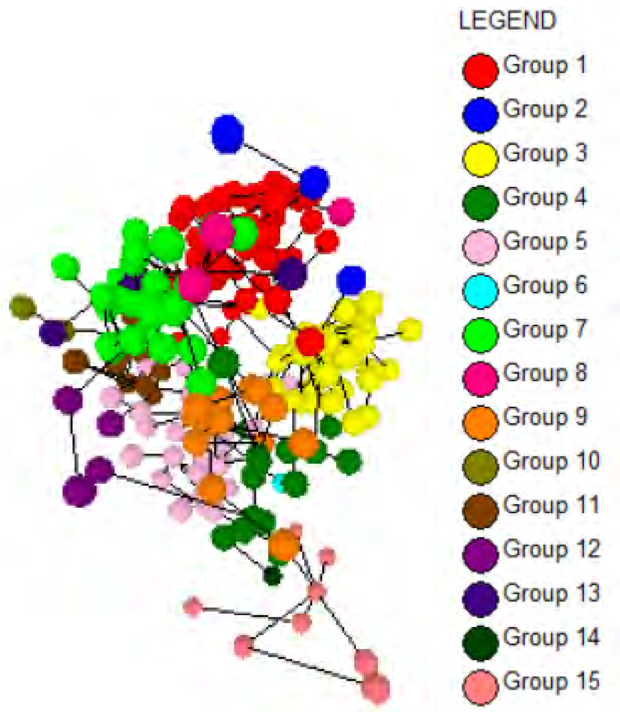

Figure 20: Clusters of farms based on their socio-managerial traits and farm characteristics

Figure 21 is a two-way table that shows the strength of relationships between each individual farm business and its characterising variables. Due to the number of farm businesses in the sample and the number of variables used to characterise each business it is not possible on a single A4 sheet to discern the labels of each farm characteristic listed in Figure 21. However, the colour and concentration of the colour pixels does indicate the overall pattern of association between socio-managerial characteristics of farms in each cluster. White pixels in Figure 21 are where there is no statistical correlation/ relationship, while blue pixels indicate some relationship and black pixels reveal a strong correlation.

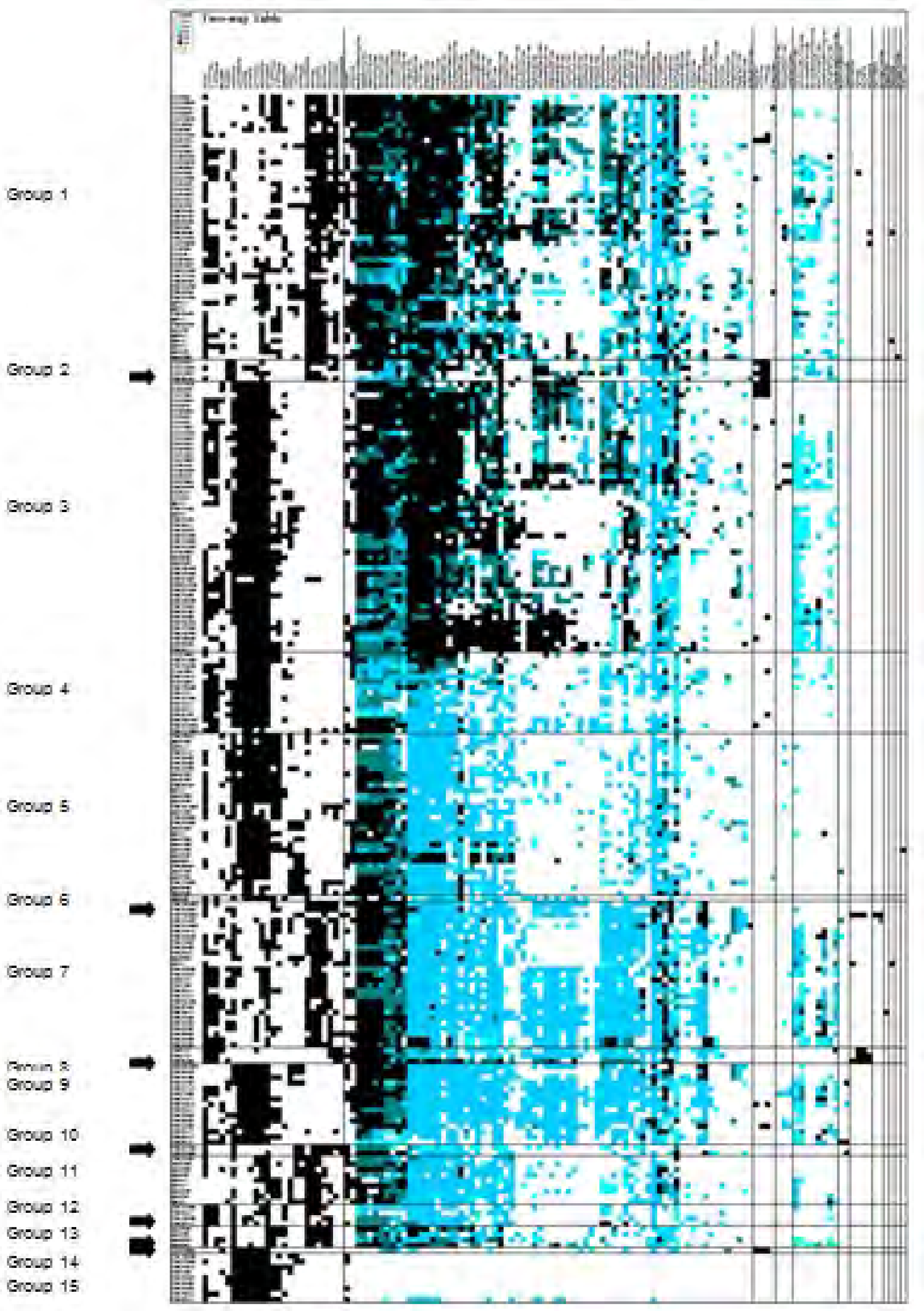

Figure 21: A cluster map of farms (black arrows indicate clusters with 4 or less farms)

The 8 main groups in Figure 20 and 21, in descending order of their proportion of the farm business sample, are group 3 (50 farms, yellow dots in Figure 19), group 1 (49 farms, red dots), group 5 (30 farms, light pink dots), group 7 (27 farms, light green dots), group 4 (15 farms, dark green dots), group 9 (15 farms, orange dots), group 11 (9 farms, purple dots) and group 15 (9 farms, mustard dots). Although the two way table of Figure 21 contains much detail about each business within each cluster, which makes discerning differences a difficult task, nonetheless detailed investigation of the results in Figure 21 reveal some key differences between the groups that are outlined below.

The key features of the main 8 clusters, as portrayed in Figure 21, are as follows:

Group 3: This large group comprises 21% of the farm sample. It includes farms from all the enterprise categories (mixed, croppers, livestock specialists), although two-thirds of the group are mixed enterprise farms. The group also includes a spread of farm performance with 36% classed as growing businesses and 18% are classed as less secure. Farms also display a range of productivity with most farms classed as displaying low to moderate productivity growth. What tends to characterise this group is their low human and social capital resource with most farms having very few dependents, and not having long experience in agriculture. However, this group displays an appetite for engaging in training and a majority use modern technologies (almost all use soil testing, liming and gypsum treatments; over half regularly test for herbicide resistance; over half examine yield maps; 59% use pregnancy scanning and 57% test of drench resistance, 20% use crop grazing, 30% rely on electric fencing and 40% use feed budgets). Within this group 63% use contractors and 38% lease land. Over three-quarters employ extra labour and this group has the highest rating of their work-life balance. Within this group 73% have prepared succession plans, 89% have developed marketing strategies and almost half have invested in Farm Management Deposits (FMDs).

Group 1: This large group also comprises 21% of the farm sample. It mostly includes mixed enterprise farms (80% of the group). The group has 73% of its members classed as growing or strong businesses. Farms also display a range of productivity with most farms classed as displaying moderate productivity growth. What tends to characterise this group is their moderate human and social capital resource with the group ranked as having the most numbers of dependents and having been in agriculture for many years. Given the experience within this group, it is not surprising that the group is also characterised by having regularly engaged in training and as users of modern technologies (almost all use soil testing, liming and gypsum treatments; almost half regularly test for herbicide resistance and 83% regularly engage various weed management strategies; 42% use yield mapping; 43% use pregnancy scanning and 44% test of drench resistance, 19% use crop grazing and half use deferred grazing, 26% rely on electric fencing and 27% use feed budgets). Within this group 63% use contractors and half lease land and 16% engage in share-farming. The group has one of the highest ratings of its care and maintenance of its harvest and seeding equipment. Over 60% employ extra labour and this group has the second highest rating of their work-life balance. Within this group 80% have prepared succession plans, 88% have developed marketing strategies and almost half have invested in Farm Management Deposits (FMDs).

Group 5: This group (13% of the sample) comprises almost equal numbers of croppers and mixed enterprise farms. Over two-thirds of all farms in this group are classed as growing or strong businesses. They have moderate to high levels of productivity growth and have low to moderate human and social capital resources and similar levels of dependents. Over half of the farms in this cluster come from the M2 region that had a higher frequency of favourable weather years compared to many other regions during the study period. Hence although the financial and productivity performance of farms in this group is reasonably high, there appears to be only loose connections between that outcome and the socio-managerial practices observed on these farms that ordinarily a priori would be linked to farm performance. By illustration most of the farmers do not have a wealth of experience. They are only moderate users of modern technologies and have invested little time in formal training regarding crop, livestock and financial management. Only 28% engage in testing for herbicide resistance and only a third use yield mapping and strategically manage weed problems. Only 6% use pregnancy scanning and a tiny proportion test for drench resistance. Crop grazing and feed budgeting do not feature in their farm management and only a third use contractors. They display a reasonable work-life balance but are not strongly linked to their local communities. However, almost despite these behaviours and choices, the period from 2002 to 2011 has been highly beneficial for many farmers in this group, where some favourable seasons have supported the revenue flows of many of these businesses.

Group 7: Of all the groups, this group has the highest proportion of mixed enterprise farms (85%) and comprises 12% of the sample population. The group has a range of farm productivity very similar to group 3. In addition, like group 1, this group has moderate levels of social capital, in spite of having few dependents. The group has a wealth of agricultural experience, yet has invested heavily in a variety of training in crop, livestock and especially financial management (26%) and this group has a very high proportion of farms (74%) that are classed as growing or strong. The group, compared to some others, is not a leader in the adoption of modern technologies. They do lease land (34%) and engage in share-farming. Due to their greater resource of farm family members they employ extra labour the least and rank the highest regarding their care and maintenance of seeding and harvest gear. They are ranked equal highest regarding their work-life balance and they are by far the most connected to their local communities.

This last observation points to a general finding; groups that display high proportions of growing and strong farms often have better work-life balances and are also often more connected to their local community. It is likely that because their farm businesses are so prosperous they then can choose to or afford to be more connected to their local communities. Their community is both a social resource and an obligation they are able and prepared to commit to.

Group 4: This small group of farms (6% of sample) comprises farms that are mostly mixed enterprise businesses of which 27% are classed as less secure and only 27% are growing. Most farms in this group (87%) display low productivity, low social capital, have few dependents, do not have long experience in farming and are yet to embrace fairly common farm practices (for example, only 8% test for herbicide resistance, only 20% use pregnancy scanning and none use precision agriculture, variable rate

technology or feed budgeting). Farmers in this group rarely engage in land leasing or use contractors. Only 15% invest in private superannuation and only 12% have developed succession plans. They have few off-farm assets and only half have a marketing strategy. They are poorly ranked regarding their care of harvest and tillage equipment and are worst-ranked regarding their work-life balance and connection to their rural community.

Group 9: This is a small group that is only 6% of the farm business sample. Two-thirds of the group are mixed enterprise farms and the remainder are mostly cropping farms. There is a diverse range in farm performance within the group with a third being classed as secure and there is also a wide range in productivity growth. Farm family labour and social capital is limited. This group is characterised by participation in many training activities and appear to emphasize sheep management. Within the group 47% engage in deferred grazing, 43% use feed budgeting, 37% rotationally graze and 17% use crop grazing. Perhaps a product of their commitment to sheep management this group has the second-worst ranking of their work-life balance and the poorest separation of their home life versus farm office work.

Group 11: This is a small group that is only 4% of the farm business sample and most of the farms in the group (56%) are cropping businesses with a rich experience in farming and a moderate size of family labour resource to draw upon. Most of the farms are large businesses in the L1, M1 and M2 regions and 89% of them are classed as growing or strong, marked by high productivity. There are no less secure farms in the group. Due to farm family labour availability, this group infrequently uses contractors, although extra casual labour is used during peak labour demand periods. Being crop specialists the group invests in little training or technologies regarding sheep management. The group frequently uses FMDs (53%) yet curiously is characterised by a low degree of care and maintenance for its farm machinery — the opposite of what might be expected of crop specialists.

Group 15: This is another small group that is only 4% of the farm business sample and farms in the group are either croppers or mixed enterprise farms. Two-thirds of farms in the group are classed as growing or strong farms that mostly display moderate growth in productivity. Farms in this group have limited availability of family labour. However, in many ways this group is an artefact of the surveying method as many details regarding the socio-managerial characteristics of these businesses are missing due to parts of the questionnaire being inadequately completed.

So in summary thus far, there are some significant socio-managerial differences between farms examined in this study. Broadly, there are 8 clusters or groups of farms within the sample population where those groups are defined by their social characteristics and farm management decisions, especially regarding use of certain technologies and farm practices. Because of the important role that farm productivity plays in supporting the profitability of farm businesses (see the next section), it is worthwhile to assess what innovations and technologies farmers use and whether or not farms can be grouped according to their use of particular innovations. Accordingly Figure 22 shows a cluster analysis of farms based on their use of particular farm practices and technologies. There are eight clusters. The two-way table, associated

with the cluster analysis, that portrays the strength of relationship between farm types and their use of particular farm practices and technologies is shown in Figure 23.

Although there are 8 clusters, three of them have 6 or less farms within their group. Hence, there are 5 main clusters. In descending order of their proportion of the farm business sample is group 5 (63 farms, pink dots in Figure 22), group 2 (41 farms, dark blue dots), group 1 (38 farms, red dots), group 7 (33 farms, light green dots) and group 3 (26 farms, yellow dots). The two way table of Figure 23 contains much detail about each business within each cluster, which makes discerning differences difficult. Nonetheless there are some differences between the groups that are outlined below; noting that in Figure 23, white pixels indicate no statistical correlation/ relationship; while blue pixels indicate some relationship and black pixels reveal a strong correlation.

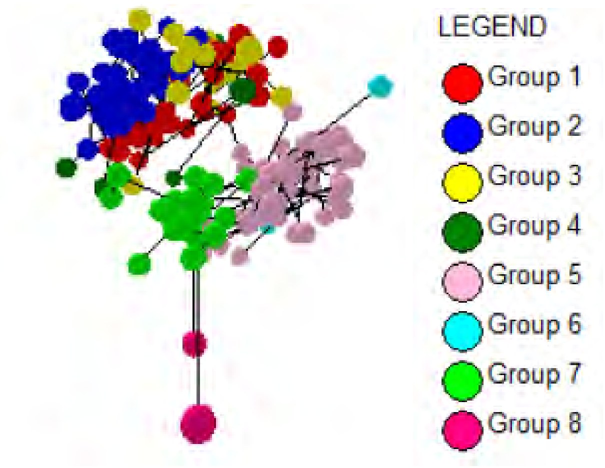

Figure 22: Enterprise clustering according to innovation practices

The clusters 1 to 3 (red, dark blue and yellow dots) represent farms especially characterized by their frequent use of soil innovation practices (soil testing, lime and gypsum application), cropping technologies (minimum tillage, GPS gear, yield mapping, use of press wheels) and their greater use of contractors and investment in superannuation. Group 3 has the highest proportion of farms that are strong or growing and the highest proportion (50%) of farms that are crop specialists. The group has the highest productivity growth among all groups. Not surprisingly, it ranks first in group participation in crop management training and is second highest rank in attendance at marketing and business management training. Group 3 is also the highest ranked regarding commitment to herbicide resistance testing, yield mapping, use of contractors, use of leased land and share-farming, investment in super, use of FMDs, investment in off-farm assets and use of GPS gear. This group, however, also has the second lowest rating of its work-life balance.

Group 5: (pink dots) comprises farms with the following general characteristics. These farms are mostly mixed farms and crop specialists, mostly in the medium rainfall northern grainbelt and are characterised by their little reliance on sheep management innovations. In spite of being mixed enterprise farms, few use pregnancy scanning, deferred grazing, feed budgeting, lot feeding nor is testing for worm resistance common. Even regarding crop management innovation, these farmers are late

adopters or laggards in the use of technology such as testing for herbicide resistance, double-row burning, use of decision support software, direct drill and min-till crop establishment. These farmers are viewed as having the lowest ranking of their work-life balance, are the least participants in local sports and the least connected to their community.

Group 7: (light green dots) comprises farms that are the most connected to their local community and the greatest participants in local sport. The vast majority of farms in this group are mixed enterprise farms and are among the greatest participants in training, particularly marketing and business training. Many farms are located in the low rainfall north-east. Is it likely that the twin years of decile one drought in this region in 2006 and 2007 triggered community support for farmers in the region.

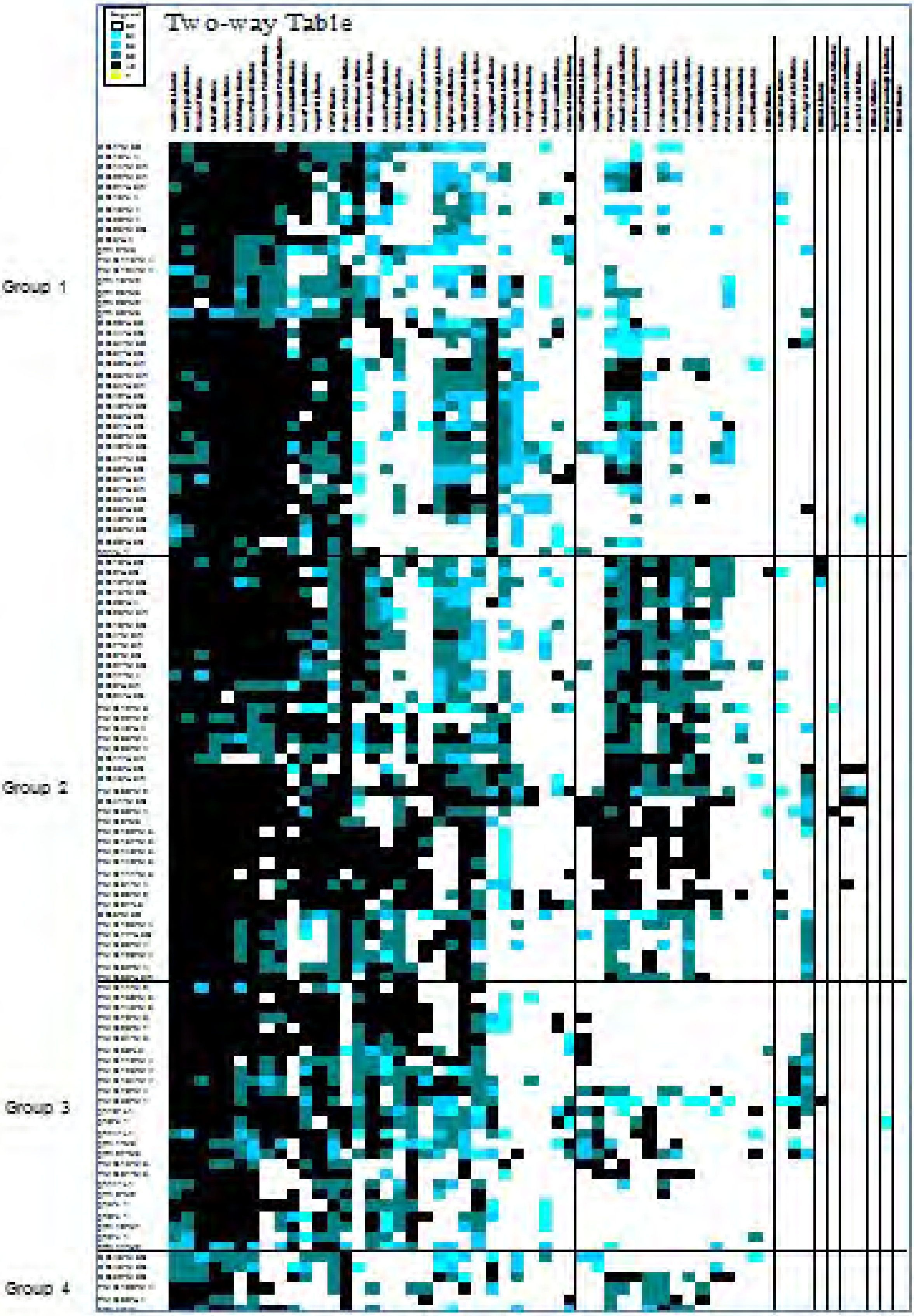

Figure 23: Farm clusters based on innovation and farm practice use

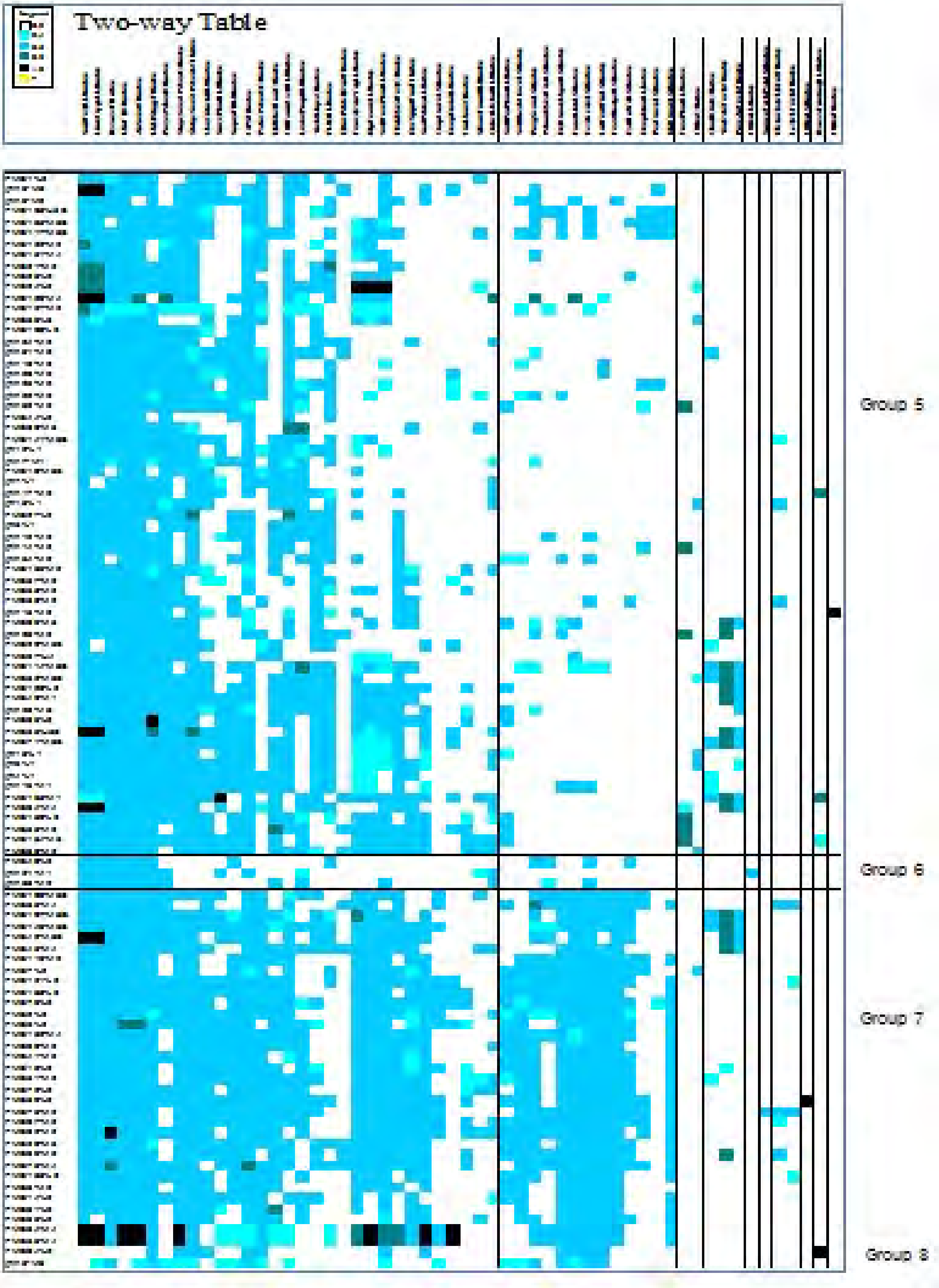

Figure 23 (cont): Farm clusters based on innovation and farm practice use

So in summary, significant socio-managerial differences exist between farms examined in this study. Overall, the socio-managerial analyses indicate socio-managerial characteristics of farm businesses are linked to farm performance. The management behaviours of farmers, whose farm businesses are growing and often are underpinned by high productivity growth, are typically significantly different from the management behaviours of farmers whose farm businesses are less secure farms and display low or little productivity growth. It is highly likely that management behaviours and family resources are a main reason for many observed differences in farm performance.

As already noted, groups that display high proportions of growing and strong farms often have better work-life balances and are also often more connected to their local community. Their productivity levels tend to be higher and often this appears due to a greater commitment to training, greater use of modern technologies and/or due to the breadth and depth of experience and family support available to the business.

A study by McDonald (2013) has reported on the use of best practices by 300 farmers in the medium and high rainfall zones (see Figure 1) of Western Australia. McDonald found that about 70% of the farmers were interested in changing practices to improve farm profitability or productivity. Over three-quarters of farmers in the survey indicated they already used about two-thirds of best practices. The two main barriers to adopting new practices and technologies that the farmers identified were their poor financial situation or time pressures on their management.

Important though management and the calibre of their socio-managerial environment might be to farm performance, nonetheless as a testament to the role of season variability in farming there are farmers who prosper (or suffer) due to acts of nature rather than due to the calibre of their socio-managerial environment and decisions. There are also farms that are growing or strong yet the farmers have a poor work-life balance.

4.1.2 Farm productivity and its components

Complementing the measures of farm performance is an assessment of changes in farm profitability and farm productivity for the sample of farms over the years 2002 to 2011. The measure of changes in farm profitability (*d*PROF) is the ratio of revenue to cost in each year compared to a previous year. This measure of changes in profitability can also be decomposed into its components of changes in the terms of trade (*d*TT), where the terms of trade is the ratio of prices received to prices paid, and changes in total factor productivity (*d*TFP), where:

$$d\mathrm{PROF} = d\mathrm{TT} * d\mathrm{TFP} \tag{8}$$

As shown in equation (8) a positive improvement in the terms of trade will increase the change in farm profitability, if there is no decline in farm productivity. Also an increase in farm productivity will beneficially influence farm profitability, if there is no adverse movement in the terms of trade.

When the sample of farms is examined, their averaged changes in profitability, productivity and terms of trade are as shown in Figure 24. The results in Figure 24 show that firstly, a slight downwards trend (not significant) in the terms of trade over the years 2002 to 2011. Favourable peaks in the terms of trade coincide with years in which international grain prices experienced spikes (e.g. 2007 and 2010). Secondly, the changes in farm total factor productivity were overall strongly positive. Thirdly, due to the positive combined effects of the terms of trade and productivity, the changes in farm profitability were also positive.

These are important results insofar as they show that, in spite of the warming, drying trend observed over those years, farm profitability improved, being supported by productivity growth, in spite of no lasting improvement in the terms of trade. So productivity improvement has allowed these farm businesses to mostly prosper during a period of climatic challenge.

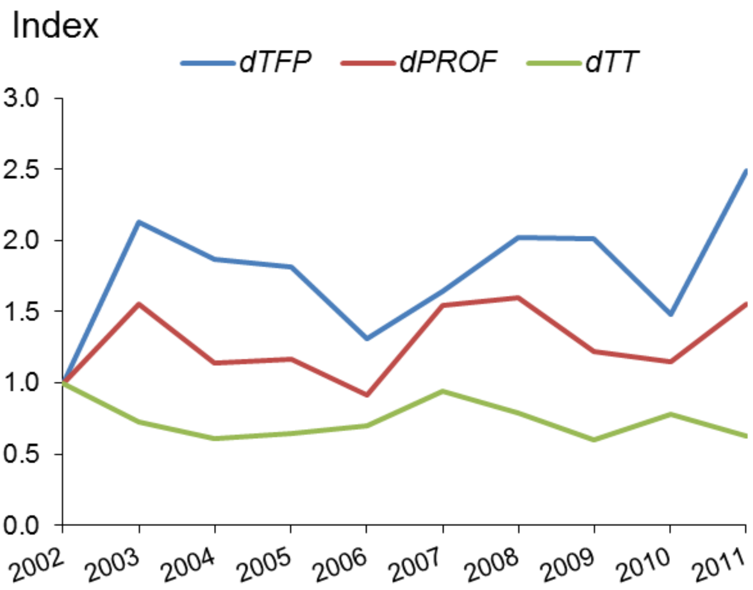

Figure 24: Changes in farm profitability, productivity and terms of trade

The fact that over the study period the terms of trade experienced a very slight decline would have offered a small encouragement to technically efficient optimizing firms to expand their operations into the region of increasing returns to scale (and scope), with the result that increases in profitability would be associated with increases in productivity.

The change total factor productivity change (*d*TFP) in equation (8) can be decomposed into components of technical change (*d*TECH) and technical efficiency change (*d*EFF), as shown in equation (9).

$$d\text{TFP} = d\text{TECH}*d\text{EFF} \tag{9}$$

*d*TECH measures the difference between the maximum TFP that is possible using the technology available in period *t* and the maximum TFP that is possible using the technology available in period 0. Also, *d*EFF measures technical efficiency change in period *t* compared to period 0.

The results in Figure 25 show that when the change in total factor productivity among farms is decomposed into technical change and technical efficiency components, then the increase in farm productivity is almost solely attributable to increases in technical efficiency. Although the index of technical change (*d*TECH) is slightly positive, the greater contribution to change in productivity (*d*TFP) is via change in technical efficiency (*d*EFF). The practical implication of this finding is that throughout the study period farms have improved their productivity, not so much by investing in new technologies that may have shifted outwards their production possibilities, but rather through better use of existing technologies, including technologies that offer scale economies.

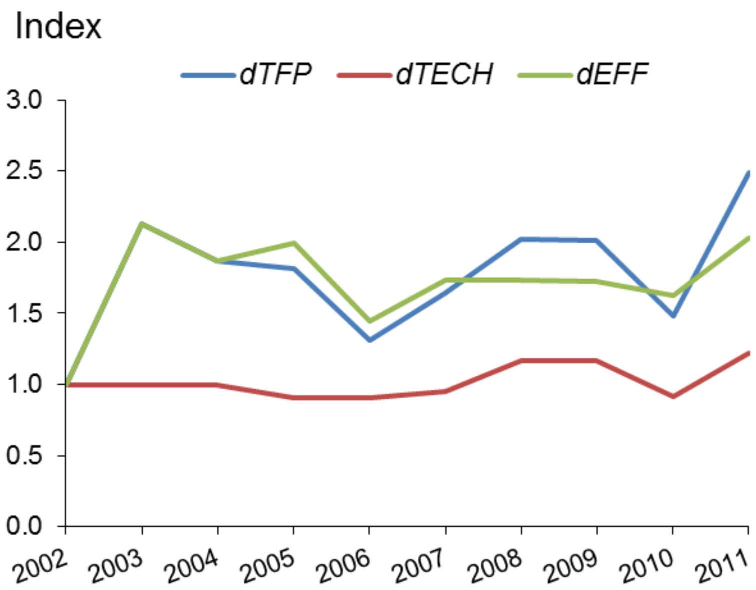

Figure 25: The technical change and technical efficiency components of farm productivity

The change in efficiency (*d*EFF) also can be decomposed into various indexes of efficiency change components as outlined earlier in this report in the *research methods* section. The key components to note are:

OTE (output-oriented technical efficiency) that describes the potential change in TFP attributable to best practice use of existing technology. It is measured by the difference between observed TFP and the maximum TFP possible with existing technology, while holding the output mix fixed and the input level fixed.

OSE (output-oriented scale efficiency) that is the potential change in TFP, if output is changed to achieve the maximum TFP with existing technology. It is measured by the difference between TFP at a technically-efficient point and the maximum TFP based on

existing technology, while holding the input and output mixes fixed but allowing the levels to vary.

OME (output-oriented mix efficiency) that is the potential change in TFP if output is changed by altering the mix of enterprises in such a way that output is increased for a given set of inputs. It is measured by the difference between TFP at a technically-efficient point for use of existing technology or enterprise mix and the TFP that is possible holding the input (output) level fixed but allowing the output (input) level and mix to vary.

ROSE (residual output-oriented scale efficiency) measures the difference between TFP at a technically and mix efficient point and the maximum TFP that is possible through altering both input and output with existing technology.

RME is residual mix efficiency that measures the difference between TFP at a technically and scale efficient point and the maximum TFP that is possible through altering input and output mixes with existing technology.

How all these components of the change in efficiency (*d*EFF) alter over the study period is shown in Figure 26. The results indicate that changes in technical efficiency (*d*OTE) that involve best practice use of existing technology and scale efficiency (*d*ROSE) are the dominant causes for the improved changes in efficiency (*d*EFF) and changes in total factor productivity (*d*TFP).

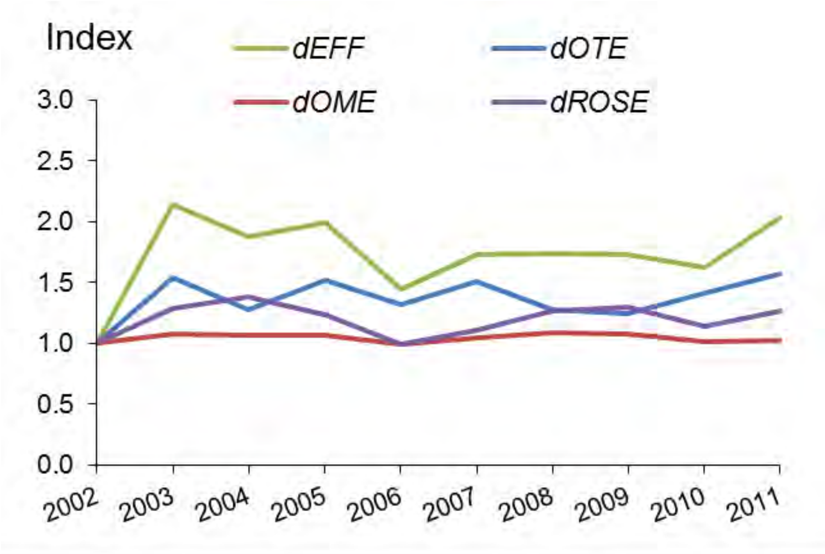

Figure 26: Components of the change in efficiency

The improvement in total factor productivity among broadacre farmers (see Figure 24) is not a new finding. Productivity growth has been a key factor driving agricultural output in Australia. Mullen and Crean (2007) identify that more than two-thirds of the current real value of Australian agricultural output can be attributed to productivity growth that has occurred since the early 1950s. These authors and Sheng et al. (2010) argue that an important source of productivity growth has been new technology from investment in research.

Sheng et al. (2011) point out, however, that agricultural productivity growth in Australia, as in some other developed countries, has been slowing. These authors suggest that a significant structural change, or turning point, occurred in the total factor productivity in Australia in the mid-1990s. They argue that the slowdown has been attributable to a combination of adverse seasonal conditions and stagnant public research and development expenditure since the late 1970s.

More particularly, Hughes et al. (2011) observe that a significant slowdown in productivity growth was observed over the past decade, even after controlling for deteriorating climate conditions. For cropping specialists across Australia they found that climate adjusted productivity growth averaged 1.06% a year post 2000, in comparison to 2.15% pre-2000. Importantly, Hughes et al. (2011) concluded that technical change was the key contributor to long-run productivity growth. They also found that growth in technical change was offset by a small decline in technical efficiency, where declining technical efficiency implied that the gap between the most efficient farms and the less efficient farms had widened. However, when the spatial details of Hughes et al.'s findings are examined it is clear that different results apply to farmers in Australia's south west.

Table 12 presents a sub-set of results from Table 6 in Hughes et al. (2011). What is interesting about the results is how different are the productivity change components in the western region compared to the southern region.

Table 12: Average annual growth in productivity components for ABARES' surveyed farms in the GRDC southern and western regions in 1999/2000 to 2007/8

		GRDC Southern region	GRDC Western region
Cropping specialists and mixed enterprise farms	Technical change	0.45	0.37
	Technical efficiency change	-0.35	-0.34
	Scale mix efficiency	-0.26	1.30
	Climate-adjusted TFP	-0.16	1.32
Cropping specialists only	Technical change	1.00	-0.42
	Technical efficiency change	-0.36	-0.09
	Scale mix efficiency	0.79	1.56
	Climate-adjusted TFP	1.43	1.04

Source: abstracted from Hughes et al. (2011)

The western region is the southwest of Australia while the southern region includes the agricultural regions of South Australia, Victoria, southern New South Wales and Tasmania. In the western region the principal component of growth in climate-adjusted TFP for all farm types is scale mix efficiency which refers to changes in farm scale and

input mix that influence productivity, typically in response to prevailing input and output prices. Importantly, in the western region for cropping specialists, technical change exerted a strong negative influence over climate-adjusted TFP during the years 1999/2000 to 2007/8, whilst technical efficiency exerted a small negative influence.

The important role played by scale efficiency (*d*ROSE) has previously been reported for studies of Australian broadacre agriculture (O'Donnell, 2010a). He found that during periods of significant declines in the terms of trade that scale (and mix) efficiency increased. In this current study of broadacre farming in south-western Australia, during a period of a slight reduction in the terms of trade, we also have found that scale efficiency and technical efficiency have played important roles in boosting change in total factor productivity (*d*TFP).

The productivity characteristics of the farm performance groupings (growing, strong, secure, less secure) can also be examined. In Figure 27 are shown the productivity components of farms classed as either 'growing' or 'less secure'. The key productivity differences between the farm groups are that:

(i) The change in total factor productivity (*d*TFP) for growing farms is double that for less secure farms, as shown by the year coefficients in the respective equations.

(ii) There is a strong positive change in farm profitability (*d*PROF) for growing farms whereas the less secure group displays no growth in profitability.

(iii) Both groups of farms have improving total factor productivity (*d*TFP) whose main component is beneficial change in technical efficiency (*d*EFF). Improvement in technical efficiency is far greater for growing farms than less secure farms, as shown by the time coefficients in the respective equations. The practical implication of this finding is that throughout the study period, growing farms have improved their productivity through consistently better use of existing technologies, including technologies that offer scale economies.

(iv) Growing farms achieve greater scale efficiencies (*d*ROSE). It is not surprising that many growing farms are in regions like L1 and M1 where large crop-dominant farms operate; underpinned by economies of scale.

Growing farms **Less Secure farms**

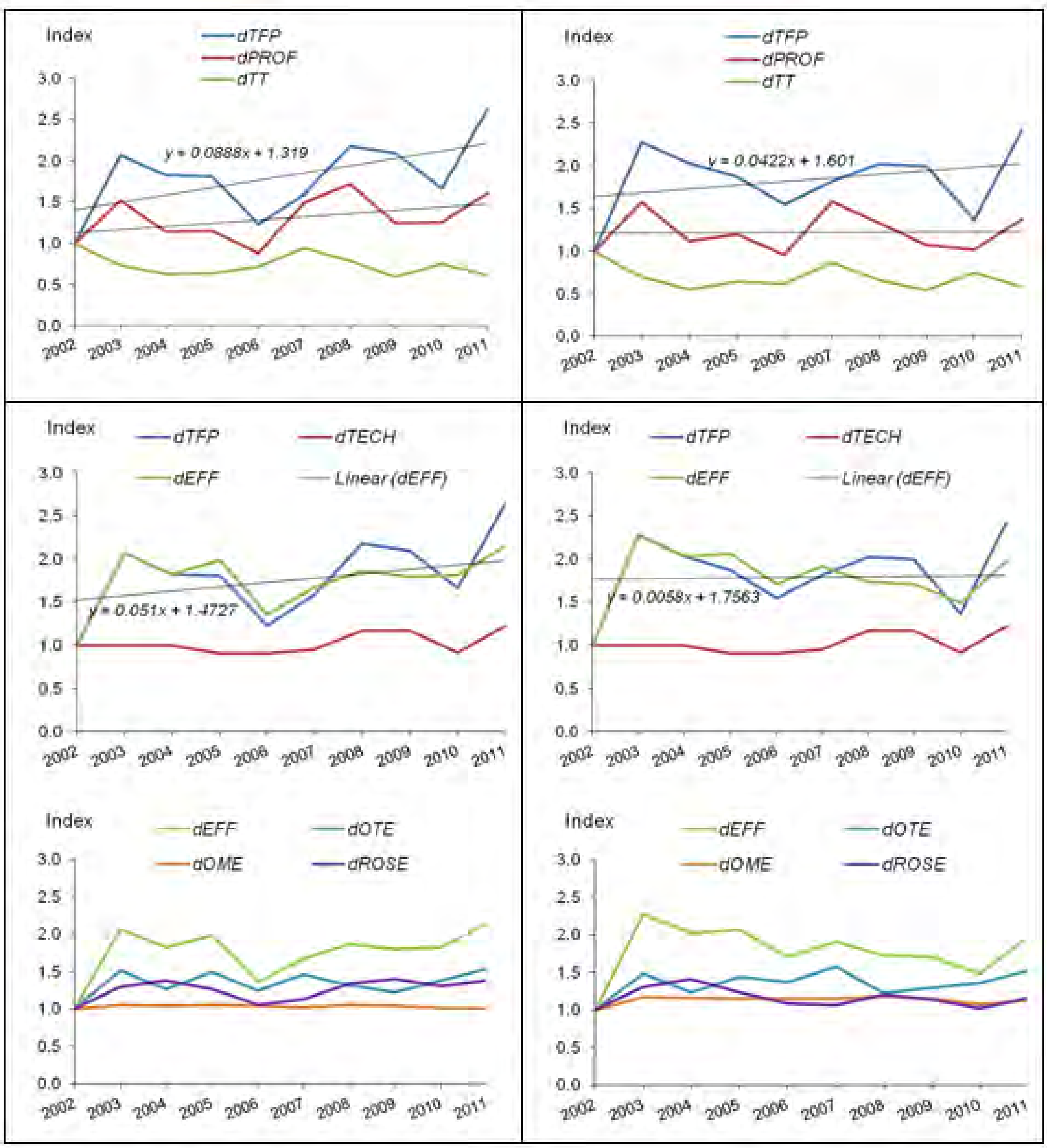

Figure 27: The productivity components of farms classed as either 'growing' or 'less secure'

The productivity characteristics of farm types (crop dominant, mixed enterprise, sheep dominant) can also be examined. In Figure 28 are shown the productivity components of two very different farm types, 'crop dominant' versus 'sheep dominant'.

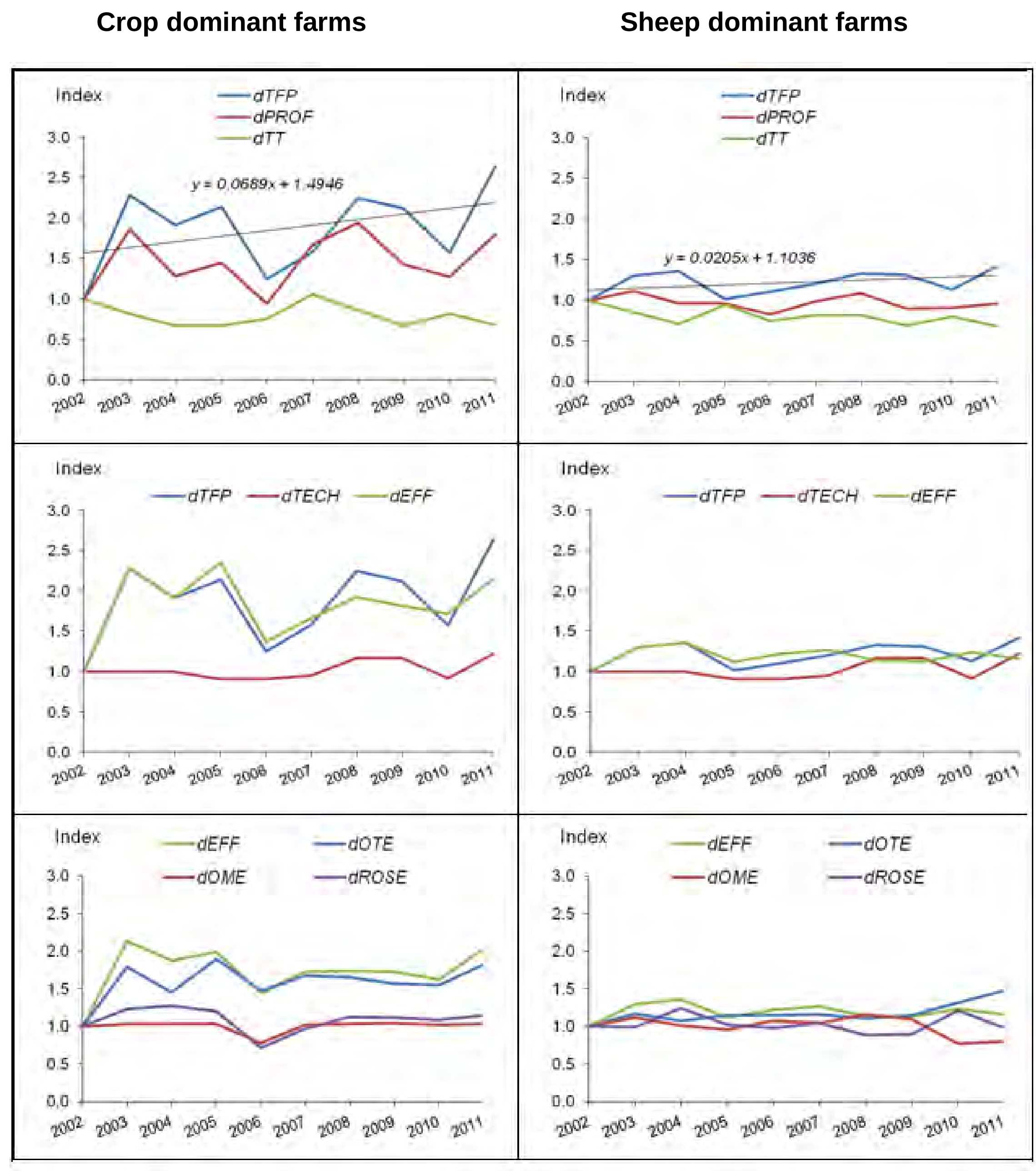

Figure 28: The productivity components of 'crop dominant' farms and 'livestock dominant' farms

There are productivity differences between the farm types:

(i) The change in total factor productivity (*d*TFP) for crop farms is treble that for sheep farms, as shown by the year coefficients in the respective equations.

(ii) There is a strong positive change in farm profitability (*d*PROF) for crop farms whereas sheep farms display no growth in profitability over the study period.

(iii) Both crop farms and sheep farms have beneficial change in technical efficiency (*d*EFF) as the main driver of total factor productivity (*d*TFP). For crop farms their main component of improved technical efficiency is OTE (output-oriented technical efficiency) that describes consistent best practice use of existing technology.

(iv) Sheep-dominant farms display far less variation between years in their total factor productivity (*d*TFP). This could be due to sheep production being concentrated in regions subject to less seasonal variation but principally is likely due to sheep numbers and production not changing rapidly between years, unlike crop yields.

The preceding productivity analyses are in broad agreement with those of Hughes et al (2011) for cropping specialists in south-western Australia. Hughes et al. and the current study both find that scale efficiency and technical efficiency, rather than technical change, have played important roles in generating productivity gain, particularly for crop farms and 'growing' farms in south-western Australia. The business and adaptation strategy that many farms have employed is to increase farm size and/or the size of cropping programs, and thereby reap the benefits of scale economies. In undertaking this often successful expansion strategy, farms have tended to rely on existing technologies and to improve their consistent use of best practice methods. Underpinning this strategy has been often a greater reliance on wheat production, and wheat growing has supported the growth and resilience of many farm businesses during the study period.

The current reliance on wheat production may also be a useful on-going farm business strategy. Support for this assertion comes from wheat yield modelling under future climate scenarios by Asseng and Pannell (2012), Potgieter et al. (2012), Nuttall et al (2012) and Addai (2013). For example, when assessing the impacts of the changes in climate on wheat yields in Western Australia, Asseng and Pannell conclude that:

> "In the wheat-belt of Western Australia, there is little or no need or scope in the short term for farmers to adapt to long-term climate change. Measurable climate change has occurred during the 20th century, but when the within-season timing of change is considered and combined with the benefits of higher CO_2 concentration, the overall impact on wheat yields has been minimal. Further, current practices that are being promoted to farmers as appropriate tools for adaptation to climate change are either already considered standard 'best practices' for reasons other than climate change, or else are not currently widely adoptable due to their adverse economic performance when implemented at large scale. In terms of public policy for adaptation to climate change in the region, the greatest benefits are likely to be generated by research and development. We highlight the need for research to develop improved agricultural technologies, such as new crop cultivars or new types of perennial plants that are tolerant of predicted climatic changes."

The views of Asseng and Pannell are interesting insofar as they recognise farmers' current sound use of best practice methods, yet they argue for the need to develop

technologies that will boost technical change (*d*TECH). It is true that future productivity enhancement cannot solely rely on improvements in technical efficiency (*d*EFF). Rather technical change is also essential so that at some stage farmers' production frontiers can move outwards. Hence, the call by Asseng and Pannell for further research and development that offers farmers beneficial technical change is a sound conclusion.

Other evidence that supports the greater dependence on cropping comes from Deards et al. (2012). Drawing on ABARES farm survey data they found that between 1977–78 and 2009–10, cropping specialists achieved average annual total factor productivity growth of 1.6%, compared with the broadacre industry average of 1.2% per cent. The greater productivity growth of cropping specialists would have supported their farm profitability.

4.1.3 Caveats

There are a range of caveats that apply to the findings in the current study. Firstly, it is unlikely that the sample of farms is truly fully representative of the broadacre farm population in south-western Australia. The farms in the sample are those that employ a farm management consultant. It is likely that over half of the value of broadacre farm products in south-western Australia comes from farms that employ a farm management consultant. However, this means there are many farms that do not employ a consultant and we cannot be certain that those farms have the same characteristics as farms that do use a consultant. Secondly, by virtue of having a sample population that we can track over a decade, it thus follows that these farms have survived financially. In that sense, we are looking at 'successful' farms, those that have grown or endured. It means we can perhaps discern their successful business adaptation strategies. However, we are not able to discern the 'unsuccessful' strategies that have led to insolvency or farmers' exodus from farming. We may discern less successful strategies such as a maintained principal commitment to sheep production, but not those strategies that proved so unsuccessful as to force adjustment out of farming. Thirdly, not every sub-region is equally represented. We are aware that there is likely to be a larger proportion of farm businesses in the L3 and L4 sub-regions (see Figure 1) that would be classed as less secure, due to high frequency of poor seasons experienced in those sub-regions over the study period. However, these sub-regions are poorly represented in our sample population, so our study findings are unlikely to apply to the farm population in those sub-regions. However, we have conducted supplementary analyses that do show a higher proportion of less secure farms, especially in L3. Farms records of an additional 26 businesses in sub-regions L3 and L4 were included in this supplementary analysis. However, inclusion of this additional data did not alter the State-wide findings.

Also, because we are only examining a decade of farm performance, we can only identify adaptation strategies that are applicable to the climate and market regime of that period. Projecting strategies into the future, given the uncertainties of climate, market conditions and technology offerings, is fraught with hazard. As pointed out by Kingwell and Pannell (2005) many respected agricultural scientists often have greatly erred in their projections of the future.

Lastly, although we classify farm businesses with value-laden terms such as ‘growing’ or ‘less secure’ it is important to remember that farming is both a business and a social activity. To amplify this point; Wilkinson et al (2012) note that farm performance is not just affected by seasonal conditions, but also by the managerial aspirations of farm owners. They surveyed 1300 farmers in Victoria in 2010 and found that 30 percent of those surveyed were either selling up or were phasing down. Only 16 percent of those surveyed planned to expand their farm businesses over the next 5 years through land leasing or land purchases.

Their findings point to the heterogeneous nature of the farmer population, with many farmers dependent to varying degrees on off-farm income and many farmers seeking to depart farming. They outline that baby-boomer farmers, many residing on small farms generating low incomes, are the largest segment of Australia’s farmer population; and they comment that: “It will not be farm policies or economic circumstances that encourage these farmers to finally leave their properties, it will be their stage of life and the resulting changes in personal and family circumstances.” (p. 35). An implication of their findings is that there is a proportion of farmers who although affected economically by climate volatility and climate change, nonetheless are adjusted out of farming by social considerations rather than simple economic drivers. Social factors play a principal role in affecting their length of stay in farming.

Hence, important though financial and productivity enhancement might be to the commercial success of farming, it is often social and demographic influences that play equally important roles in affecting activity and trajectories within farm businesses. Moreover, these influences are often entwined as Hogan et al. (2011b) have observed. In a large survey of farm families in Australia they found the group of farmers that faced the greatest challenges to climate adaptation were from the poorest farms and they had the poorest health. Their lack of income also affected their access to services and information, and social connectedness. Similarly, in the study of 1300 Victorian farmers Wilkinson et al (2011) found that 32% aspired to increase their productivity but not the scale of their farm; 14% were interested in increasing productivity but doubted they could achieve it; and 38% were not interested in productivity or were planning to sell all or part of their farm. Hence, the aspirations of a farmer are directly linked to their farm performance in many cases.

4.1.4 Implications for other regions, researchers and policy-makers

Doudle et al. (2009) evaluated a number of farm businesses in southern Australia that had survived a period of drought and concluded that successful businesses had sound farm management practices and targeted a high equity position. Lawes and Kingwell (2012) report a somewhat similar finding for farms in the northeast grainbelt of Western Australia. When periods of drought or poor seasons occur, often farm operating profits are reduced due to low yields, in spite of reductions farmers typically make in their operating costs per hectare. Reduced crop revenues worsen the debt to income ratio, lessen the operating profit per hectare and lead to increased borrowings that erode the business equity of the farm.

The current study revealed that most farms reduced their equity in percentage terms over the study period of 10 years, but farm equity in dollar terms improved. Most farms

had starting equities greater than 80 per cent, supporting the findings of Doudle et al. (2009). In short, in spite of the drying and warming trend that farmers experienced, overlain with weather-year and market volatility, most farmers improved their business performance by increasing their wealth. However, this finding may over-state the true situation as the sample of farms in this study necessarily only included businesses that were sufficiently financially sound to endure the decade. Also there are farms in the low rainfall east and south-east of the WA grainbelt that are under-represented in the farm sample and it is known that many farms in these particular regions are more likely to be currently in financial duress due to more frequent poor seasons. Also the finding of a significant increase in the debt to income ratio among the sample population is concerning as it suggests that debt-servicing is liable to become problematic, at least for some farmers and perhaps for farms in particular regions.

Kingwell (2002) commented on crop-dominant farming systems in Australia that: ". . .a switch into more cropping means a more capital-intensive business with greater demands for working capital. With such a business structure a few poor seasons, especially if coupled with poor prices, can rapidly cripple a farm business." (p. 10). Consistent with this view were findings by Lawes and Kingwell (2012). They found that the consecutive years of drought in 2006 and 2007 greatly challenged the profitability of farm businesses in the northeast part of the grainbelt of Western Australia. Almost two-thirds of farms experienced a decline in business equity over the period 2004 to 2009.

The current study suggests that over the decade 2002 to 2011, the frequency of poor seasons in the study region was insufficient to jeopardise greatly the profitability of most farm businesses. Rather, due to season and market conditions, most farms prospered. The degree to which any particular farm business prospered was likely to be due to the farm's location, enterprise mix and management. The particular characteristics of a farm business were the main explanator of farm performance, implying that few generalisations are possible. However, there are some; particularly regarding farm management that have possible relevance to other regions and that have implications for policy-makers.

We found that:

- Farmers' dependence on wheat-growing as a principal source of farm income appears to be a sensible adaptation strategy. Moreover, the biological prospects for wheat yield in the study region and in other regions of southern Australia generally appear very sound in the face of projected climate change.

- Over the study period farm profitability improved, supported by productivity growth, in spite of no lasting improvement in the terms of trade. Productivity improvement has allowed a majority of farm businesses to prosper during this period of climatic challenge and market volatility. The important role played by productivity growth in supporting farm profitability is a general finding applicable to other regions. Moreover, it points to the important role that policy-making can play in supporting and helping create environments that facilitate productivity growth.

- Farms improved their productivity, not so much by investing in new technologies that may have shifted outwards their production possibilities, but rather through better use of existing technologies, including technologies that offered scale economies. Farm businesses that grew substantially were often better managed and achieved greater productivity growth. These findings point to the beneficial role played by superior management and these findings are likely to be widely applicable. Hence, agricultural educators, administrators and policy-makers need to be aware of the value generated by improved farm management. Accordingly, provision of farm management and business training and education is likely to generate beneficial productivity and profitability outcomes (Keogh et al, 2011, George et al, 2007 & 2009). Growing and strong farms, when compared to less secure farms, on average made greater use of leasing, contractors, superannuation funds, succession planning, Farm Management Deposits and off-farm assets. Also, growing farms, when compared to less secure farms, on average adopted and made greater use of farm business software, marketing strategies, decision support tools, precision technology, electronic paddock recording and GPS technology.

- Growing farms, when compared to less secure or secure farms, on average were more involved in their local community involvement and expressed more care regarding their work-life balance. This important social dimension to farm performance is often over-looked in agricultural and climate change policy. Hence, supporting and encouraging community engagement generates not only social rewards but, as suggested by this study's findings, it is also positively linked to farm business performance.

- In addition, many growing and strong farm businesses were found to be underpinned by moderate to high productivity growth that in turn was fed by farmers' commitment to training and use of many modern technologies and management practices. The positive role of education, training and adoption of modern technologies indicates a potentially important role for extension in equipping farmers to enhance their knowledge and skill in farm management.

5. GAPS AND FUTURE RESEARCH DIRECTIONS

Because the dataset used in this analysis is effectively the records of farming's survivors, it is useful in assisting to identify strategies used by farm businesses to grow or to remain strong in the face of a challenging set of climate and market conditions. However, a clear deficiency of the dataset is that it necessarily excludes businesses that have failed or whose business strategy has been to quit farming and re-invest elsewhere. This latter strategy is certainly transformative for the farm families now successfully engaged in non-farm activity. How many farm families undertake a commercially successful transition from farming is not known to us, but it would be a worthy topic for further research.

A related useful topic for further research would be to examine farm businesses and farm families forced to quit agriculture. Understanding what strategies and socio-managerial characteristics may have made these businesses vulnerable would be useful, if only to reveal what perhaps should be avoided.

Another obvious gap is the generalisability of this study's findings. Strictly speaking, the findings are most applicable to other farm businesses in the study region. Extrapolating findings to other jurisdictions is fraught with challenge because other southern regions of Australia do have different climate regimes, farming systems and often different markets.

Extrapolating findings to other time periods is also fraught with challenge. There is little unanimity among market analysts over the future trajectories of the real prices of agricultural commodities and farm inputs. In addition, uncertainty surrounds how successful in future years might be technologies under development now or in coming years.

The analysis of farm performance has revealed that the strategy of crop dominance has been profitable, particularly in the northern agricultural region. However, it is open to debate as to whether this strategy in the longer term adds to the resilience of farm businesses. Specialisation in cropping, although often profitable does not remove the probability of periods of dry years and the business risks associated with such sequences. Whether or not greater enterprise diversity, including diversifying into off-farm investments, delivers greater resilience is a topic worthy of further research.

6. CONCLUSIONS

The main conclusion of this study is that as long as broadacre farmers in south-western Australia have on-going access to improved crop varieties and technologies that support profitable grain production, and that farmers have access to farm management and business training and education, then farmers are likely to be able to adapt to projected climate change. The forecast biologically robust performance of wheat in the study region, in particular, should also help underpin the future profitability of crop production. Provided that farmers' terms of trade does not become unduly adverse, and that farmers sensibly manage farm debt, then it seems highly likely that farmers who continue to rely mostly on wheat production, and who improve their farm management and business skills, will persist as financially sound businesses in the study region, even in the face of projected climate change.

We conclude that:

- Farmers' dependence on wheat-growing as a principal source of farm income appears to be a sensible adaptation strategy. Moreover, the biological prospects for wheat yield in the region generally appear very sound in the face of its changing climate.
- Productivity improvement has allowed a majority of farm businesses to prosper during the 10 years studied; a period of climatic challenge and market volatility. Productivity improvement is a key to improved farm performance.
- Farms improved their productivity, not so much by investing in new technologies that may have shifted outwards their production possibilities, but rather through better use of existing technologies, including technologies that offered scale economies.
- Because growing farms rely on improving their technical efficiency and utilising scale efficiencies it is therefore not surprising that many growing farms are in northern regions where large crop-dominant farms operate; underpinned by economies of scale, and where seasonal conditions during the study period have not been consistently unfavourable.
- The change in total factor productivity for crop farms is treble that for sheep farms and there is a strong positive change in farm profitability for crop farms, whereas sheep farms display no growth in profitability.
- Both crop farms and sheep farms have beneficial change in technical efficiency as their main driver of total factor productivity growth. For crop farms their main component of improved technical efficiency is best practice use of existing technology.
- Growing and strong farms, when compared to less secure farms, on average make greater use of leasing, contractors, superannuation funds, succession planning, Farm Management Deposits and off-farm assets. Growing farms, on average have also adopted and made greater use of farm business software, marketing strategies, decision support tools, precision technology, electronic

paddock recording and GPS technology. Growing farms, on average have a greater quality of commitment to the maintenance of their cropping gear.

- Farmers who manage growing farms, on average are more involved in their local community and express more care regarding their work-life balance.
- Farmers do need to sensibly manage debt. The significant increase in the debt to income ratio is a concerning trend, suggesting that servicing debt is or could be a problem for some farms.

This study shows there are a variety of influences and causes that have led a high proportion (64%) of farms in the sample population to be categorised as growing or strong farms. The managers of these farms have successfully steered their farm businesses through a drying and warming period of climate change in south-western Australia. They have achieved growth in farm equity, in dollar terms, have often expanded the size of their farm operations and have increased the crop dominance of their farming systems. These farmers, and most particularly those responsible for growing farm businesses, have displayed a range of managerial and social characteristics that have enhanced the productivity and profitability of their farm businesses during a period of challenging environmental and market conditions.

Typically, these farmers display a greater commitment to training, greater use of modern technologies and/or are additionally blessed with a breadth and depth of experience and family support to engage in farming. This finding implies a potentially beneficial role for continued extension activity that supports farm management and ultimately, farm performance. In addition, our finding that a farm's financial performance has much to do with its unique characteristics adds weight to observations made over 40 years ago by Mauldon and Schapper (1970) about the nature of inter-farm comparisons and benchmarking; observations reiterated more latterly by Ferris and Malcolm (1999). If farm performance is mostly a product of the unique characteristics of a farm business then understanding the peculiar characteristics of that farm business is likely to be a necessary prerequisite for discerning ways to improve its financial performance. It suggests that there is a legitimate role for personalised advice and support for individual farm businesses in order to further improve their performance, and thereby enhance their capacity to adapt to climate change. The significant increase in the debt to income ratio suggests that servicing debt is or could be a current problem for some farms and so debt management is likely to be a pressing and topical issue for these farmers.

REFERENCES

AAG (2001) The enhanced greenhouse effect and its impact on agriculture: an Australian perspective. Information paper, pp 11.

ABARES (2011) Agricultural Commodity Statistics 2011, Australian Bureau of Agricultural and Resource Economics and Sciences, Australian Government, Department of Agriculture, Fisheries and Forestry.

ABARES (2011b) Drought in Australia: Context, policy and management, Consultancy Report.

ACG (2005) Climate Change Risk and Vulnerability. A report by the Allen Consulting Group commissioned by the Australian Greenhouse Office, Department of Environment and Heritage, Canberra.

Addai, D. (2013) The economics of technological innovation for adaptation to climate change by broadacre farmers in Western Australia, Unpublished PhD thesis, School of Agricultural and Resource Economics, University of Western Australia.

Adger, W.N. (2003) Social capital, collective action and adaptation to climate change. Economic Geography 79 (4), 387- 404.

Adger, W.N. (2006) Vulnerability. Global Environmental Change 16, 268–281.

Adger, W.N., Hulme, M. and Naess, O. (2008) Are there social limits to adaptation to climate change? Climate Change 93, 335-354.

Agrarwal, K., Joshi, P., Ingram, I. and Gupta, R. (2004) Adapting food systems of the Indo-Gangetic plains to global environmental change: Key information needs to improve policy formulation. Environmental Science and Policy 7 (6), 487–498.

Agrawala, S., Bosello, F Carraro, C., de Cian, E. and Lanzi, E. (2011) Adapting to Climate Change: Costs, benefits, and modelling approaches. International Review of Environmental and Resource Economics 5, 245–284.

Alcamo, J., Dronin, N., Endejan, M., Golubev, G. and Kirilenko, A. (2007) A new assessment of climate change impacts on food production shortfalls and water availability in Russia. Global Environmental Change 17, 429-44.

Althin, R., Fare, R. and Grosskopf, S. (1996) Profitability and productivity changes: an application to Swedish pharmacies. Annals of Operations Research 66, 219-230.

Anderson, J.R. (1993) The economics of new technology adaptation and adoption. Review of Marketing and Agriculture Economics 61(2), 301-309.

Anderson, J.R. and White, D.H. (1991) Systems thinking as a perspective for the management of dryland farming. Chp 2 In (Eds: V.Squires and P.Tow) Dryland Farming: A Systems Approach. Sydney University Press, Sydney, pp 306.

Andrew, J. and Gazey, C. (2010) A preliminary examination of the spatial distribution of acidic soil and required rates of ameliorant in the Avon River Basin, Western Australia. 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia.

Antle, J. and Capalbo, S.M. (2010) Adaptation of Agricultural and Food Systems to Climate Change: An Economic and Policy Perspective. Applied Economic Perspectives and Policy 32, 386-416.

Anwar, M.R., Liu, D.L., Macadam, I. and Kelly, G. (2012) Adapting agriculture to climate change: a review. Theoretical and Applied Climatology DOI 10.1007/s00704-012-0780-1 DOI 10.1007/s00704-012-0780-1

Arellano-Valle, R.B., Bolfarine, H. and Lachos, V.H. (2005) Skew-normal linear mixed models. Journal of Data Science 3, 415-438.

Arndt, C. and Bacou, M. (2000) Economy wide effects of climate variability and prediction in Mozambique. American Journal of Agricultural Economics 82, 750-754.

Ash, A., Nelson, R., Howden, M. and Crimp, S. (2008) Australian agriculture adapting to climate change: Balancing incremental innovation and transformational change. In conference proceedings, ABARE Outlook, Canberra.

Asseng, S. and Pannell, D. (2012) Adapting dryland agriculture to climate change: Farming implications and research and development needs in Western Australia. Climatic Change DOI 10.1007/s10584-012-0623-1

Asseng, S., Foster, I. and Turner, N.C. (2011) The impact of temperature variability on wheat yields. Global Change Biology 17:997–1012.

Bankoff, G., Frerks, G. and Hilhorst, D. (eds). (2004) Mapping Vulnerability: Disasters, Development and People. Earthscan, London. ISBN 1-85383-9647

Battese, G., Rao, D. and O'Donnell, C. (2004) A metafrontier production function for estimation of technical efficiencies and technology potentials for firms operating under different technologies. Journal of Productivity Analysis, 21, 91-103.

Beer, T. and Williams, A. (1995) Estimating Australian forest fire danger under conditions of doubled carbon dioxide concentrations. Climatic Change 29, 169-188.

Belbin, L. (1995) PATN: Technical Reference, Canberra: CSIRO Division of Wildlife and Ecology.

Belbin, L., Faith, D.P. and Minchin, P.R. (1984) Some algorithms contained in the Numerical Taxonomy Package NTP, CSIRO Division of Water and Land Resources Technical Memorandum.

Bell, K.J. and Ralph, I.G. (1993) Current sheep management: Western Australia, pp.60-66 in Proceedings of a national workshop on: Management for wool quality in Mediterranean environments, Perth, Western Australia.

Berry, H., Hogan, A., Owen, J., Rickwood, D. and Frager, L. (2011) Climate change and farmers mental health: Risks and responses. Asia-Pacific Journal of Public Health supplement to 23(2): 119S-132S.

Bhadwal, S., Bhandari, P. Javed, A., Kelkar, U, O'Brien, K and Barg, S. (2003) Coping with global climate change: Vulnerability and adaptation in Indian agriculture. New Dehli, The Energy and Resources Institute.

Blackburn, A. and Ashby, R. (1995) Financing Your Farm - 3rd Edition, Australian Bankers Association, Melbourne.

Blennow, K., and Persson, J. (2009) Climate change: Motivation for taking measure to adapt. Global Environmental Change 19, 100-104.

Bohle, H.G., Downing, T.E. and Watts, M.J. (1994) Climate change and social vulnerability: toward a sociology and geography of food insecurity. Global Environmental Change 4(1), 37–48.

Booth, T.H. (1978) Numerical classification techniques applied to forest tree distribution data: A comparison of methods, Australian Journal of Ecology 3, 297-306.

Boston Consulting Group (2010) Observed climate change: Western Australia. Available at http://www.bcg.org.au/resources/WAMasters_Observed_climate_change.pdf

Bray, J.R. and Curtis, J.T. (1957) An ordination of the upland forest communities of southern Wisconsin, Ecological Monographs 27, 325-349.

Brooks, N., Adger, W.N. and Kelly, P.M. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change 15 (2), 151–163.

Brown, P., Bridle, K., Toms-Morgan, R. and Rodriguez, D. (2011) Capacity for broadacre mixed farmers to adapt to climate change in Queensland. In: World Congress on Conservation Agriculture 2011 Papers. 5th World Congress on Conservation Agriculture and Farming Systems Design, Brisbane, Australia, (1-4), 26-27.

Burton, I. (1996) The growth of adaptation capacity: practice and policy. In: Adapting to climate change: An international Perspective. (Smith, J., Bhatti, N., Menzhulin, G., Benioff, R., Budyko, M.I., Campos, M., Jallow, B. and Rijsberman, F. (eds)) Springer-Veralag, New York, USA, 55-67.

Cabell, J. and Oelofse, M. (2012) An indicator framework for assessing agroecosystems resilience. Ecology and Science 17(1), 18.

Cai, W. and Cowan, T. (in press) Southeast Australia autumn rainfall reduction: A climate-change-induced poleward shift of ocean-atmosphere circulation. .Journal of Climate.

Cai, W., Cowan, T. and Thatcher, M. (2012) Rainfall reductions over Southern Hemisphere semi-arid regions: the role of subtropical dry zone expansion. Nature (Scientific Reports) 2, Article number: 702, doi:10.1038/srep00702

Cardona, O.D. (2004) The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. In: G. Bankoff, G. Frerks, D. Hilhorst (eds), Mapping Vulnerability: Disasters, Development and People, Earthscan, London, 37–51.

Cary, G.J. (2002) Importance of changing climate for fire regimes in Australia. pp 26-46. In: (Bradstock, R.A., J.E. Williams and M.A. Gill, (eds.)), Flammable Australia: The Fire Regimes and Biodiversity of a Continent, Cambridge University Press, Cambridge UK, pp. 455.

Cash, D., Adger, W.N., Berkes, F., Garden, L., Lebel, L., Olsson, P., Pritchard, L. and Young, O. (2006) Scale and cross-scale dynamics: Governance and information in a multilevel world. Ecology and Society 11(2), 8.

Challinor, A., Ewert, F., Arnold, S., Simelton, E. and Fraser, E. (2009) Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. Journal of Experimental Botany 60 (10), 2775-2789.

Chambers, R. (1989) Vulnerability, coping and policy. Institute of Development Studies Bulletin 20, 1–7.

Chiotti, Q. and Johnston, T. (1995) Extending the boundaries of climate change research: A discussion on agriculture. Journal of Rural Studies 11, 335-50.

Cook-Anderson, G. (2009) NASA satellites unlock secret to northern India's vanishing water. NASA Earth Science News Team 2009.

Cowie, A. and Martin, R. (2009) Impacts and implications of climate change for the pastoral industries. Proceedings of the 24th Annual Conference of the Grassland Society of NSW. pp65.

Crimp, S., Gaydon, D., DeVoil, P and Howden, M. (2008) On-farm management in a changing climate: A participatory approach to adaptation. Birchip Cropping Group, cropping manual 2008.

Crimp, S., Howden, M., Power, B., Wang, E. and de Voil, P. (2008) Global climate change impacts on Australia's wheat crops. Report for Garnaut Change Review.

CSIRO and Bureau of Meteorology (2007) Climate change in Australia. Technical Report, CSIRO publishing , Melbourne.

DAFF. (2006) National Agriculture and Climate Change Action Plan 2006-2009. Department of Agriculture, Fisheries and Forestry, Canberra.

DAFWA (2001) The Crop Variety Sowing Guide 2002, Bulletin 4529, Department of Agriculture & Food, Western Australia, pp 212.

DAFWA. (2010) Climate change and impact on W.A agriculture. Farmnote 415/2010

DAFWA (2011) Frost and cropping. Available at http://grains.agric.wa.gov.au/node/frost-and-cropping

Davison, T., McGowan, M., Mayer, D., Young, B., Jonnson, N., Hall, A., Matschoss, A., Goodwin, P., Coughan, J. and Lake, M. (1996) Managing Hot Cows in Australia. Queensland Department of Primary Industries, Brisbane, Australia, pp.58.

Deards, B., Fell, J., Mobsby, D. and Davidson, A. (2012) Australian Grains 12.2: Grains outlook for 2012–13 and industry productivity, ABARES report prepared for the Grains Research and Development Corporation, Canberra, November.

DEFRA. (2006) Behaviour and motivations of farmers in responding to climate change in agriculture. DEFRA project EPES 0405/17, Final report by University of Reading Commissioned by DEFRA.

Desanker, P.V. (2002) The impact of climate change of life in Africa: climate change and vulnerability in Africa. WorldWide Fund for Nature, Washington, DC.

Doole, G.J., Bathgate, A.D., Robertson, M.J., (2009) Labour scarcity restricts the potential scale of grazed perennial plants in the Western Australian Wheatbelt. Animal Production Science 49, 883–893.

Doudle, S., Hayman, P., Wilhelm, N. and Alexander, B. (2009) Farmers' capacity to adapt to climate change-SA case studies. Agricultural Science 21, 13–19.

Dow, K. (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental Change. Geoforum 23, 417–436.

Downing, T.E. and Patwardhan, A. (2005) Assessing vulnerability for climate adaptation, adaptation policy frameworks for climate change: Developing strategies, polices and measures. Cambridge University Press, Cambridge and New York, 67-90.

Drought Policy Review Expert Social Panel (2008) It's About People: Changing Perspective. A Report to Government by an Expert Social Panel on Dryness, Report to the Minister for Agriculture, Fisheries and Forestry, Canberra, September. ISBN 978-0-9803714-7-5

Eakin, H. and Luers, A. (2006) Assessing the vulnerability of social–environmental systems. Annual Review of Environment and Resources 31(6), 1–6.

Easterling, W., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, S., Kirilenko, A., Morton, J-F., Soussana, J., Schmidhuber, J. and Tubiello, F. (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. (Eds. Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press Cambridge, UK, pp273-313.

Edwards, B. and Gray, M. (2009) A sunburnt country: The economic and financial impact of drought on rural and regional families in Australia in an era of climate change. Australian Journal of Labour Economics 12 (1), 109-131.

Ellis, F. (2000) Rural development and diversity in developing countries. Oxford, UK, Oxford University Press.

Etzinger, J.M., Stanstna, Z. and Dubrosky, M. (2003) A simulation study of the effect of soil water balance and water stress in winter wheat production under different climate change scenarios. Agriculture Water Management 61, 195-217.

Evans, C., Storer, C. and Wardell-Johnson, A. (2011) Rural farming community climate change acceptance: Impact of science and government credibility. International Journal of Sociology of Agriculture and Food 18 (3), 217-235.

Fankhauser, S., Smith, J.B. and Tol, S.J. (1996) Weathering climate change: Some simple rules to guide adaptation decisions. Ecological economics 30(1), 67-78.

FAO. (2006) World Agriculture: Towards 2030/2050. Food and Agriculture Organization of the United Nations, Rome.

FAO. (2007) Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities. Food and Agriculture Organisation for the United Nations, Rome. ftp://ftp.fao.org/docrep/fao/009/j9271e/j9271e.pdf

FAO. (2009) The State of Food Security in the World. Food and Agriculture Organization of the United Nations, Rome.

Fazal, S. (2000) Urban expansion and loss of agricultural land: A GIS based study of Saharanpur City, India. Environment and Urbanization 12(2), 133-149.

Fenton, M. (2004) Socio-Economic Indicators for Natural Resource Management (Project A1.1) Indicators of capacity, performance and change in Regional NRM bodies. National Land and Water Resources Audit, Canberra.

Ferris, A. and Malcolm, B. (1999) Sense and nonsense in dairy farm management economic analysis, 43rd Annual Australian Agricultural and Resource Economics Society Conference and 6th Annual New Zealand Agricultural Economics Society Conference, Christchurch, New Zealand.

Finch, V.A., Bennett, I.L. and Holmes, C.R. (1982) Sweating response in cattle and its relation to rectal temperature, tolerance of sun and metabolic rate. Journal of Agricultural Science 99, 479-487

Finch, V.A., Bennett, I.L. and Holmes, C.R. (1984) Coat colour in cattle: effect on thermal balance, behaviour and growth, and relationship with coat types. Journal of Agricultural Science 102, 141-147.

Foster, I. (2007) Climate change projections and impacts for Western Australia. Department of Agriculture and Food Western Australia. Farmnote 5/2002

Foster, I. (2013) Assessment of climate change projections for WA – new tools for adaptation. Selected paper for the 2013 Crop Updates, Crowne Complex, Burswood, 25-26 February, 2013.

Frederiksen, J.S., Frederiksen, C.S., Osbrough, S.L. and Sisson, J.M. (2011) Changes in Southern Hemisphere rainfall, circulation and weather systems. 19th International Congress on Modelling and Simulation.

French, R.J. and Schultz, J.E. (1984) Water use efficiency of wheat in Mediterranean-type environment..The relation between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Füssel, H. and Klein, T. (2005) Climate change vulnerability assessments: An evolution of conceptual thinking. Journal of Climate Change 75 (3), 301-329.

Garnaut, R. (2011) Climate change impacts on Australia. pp 121-152, Chapter 6 in the Garnaut Review 2011: Australia in the Global Response to Climate Change, Commonwealth of Australia and the Cambridge University Press.

Gaughan, J.B., Lacetera, N., Valtorta, S.E., Khalifa, H.H., Hahn, L., Mader, T. (2009) Response of domestic animals to animal challenges. In Biometeorology for adaptation to climate variability and change. (Eds K.L. Ebi, I. Burton and G.R. McGregor) Springer: The Netherlands.

George, D.A., Clewett, J.F., Birch, C.J, Wright A.H. and Allen, W.R. (2009), A professional development climate course for sustainable agriculture in Australia. Journal of Environmental Education Research. 15(4), 417-441.

George, D.A., Clewett, J.F., Wright, A. Birch, C., and Allen, W. (2007), Improving farmer knowledge and skills to better manage climate variability and climate change. Journal of International Agricultural and Extension Education. 14(2), 5-19.

George, R., McFarlane, D. and Nulsen, B. (1997) Salinity threatens the viability of agriculture and ecosystems in Western Australia. Hydrogeology Journal 5, 6-21.

Godfray, H., Beddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S. and Toulmin, C. (2010) Food Security: The challenge of feeding 9 billion people. Science 327(5967), 812-818.

Gorman-Murray, A. (2008) Before and after climate change: The snow country in Australian imaginaries. M/C – Media and Culture Journal 11 (5).

GRDC (2012) Researchers probe warming climate frost puzzle. GRDC Ground Cover Available at http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-101/Researchers-probe-warming-climate-frost-puzzle

Greenhill, J., King, D., Lane, A. and MacDougall, C. (2009) Understanding resilience in south Australian farm families. Rural Society. 19 (4), 318-325

Grifell-Tatjé, E., and Lovell, C. A. K. (1995) A note on the Malmquist productivity index. Economics Letters 47(2), 169-175.

Gunasekera, D., Kim, Y., Tulloh, C. and Ford, M. (2007) Climate change impacts on Australian agriculture. Australian Commodities 14, 657- 676.

Hadley, D. and Irz, X. (2008) Productivity and farm profit – A microeconomic analysis of the cereal sector in England and Wales, Applied Economics, 40(5), 613-624.

Haile, M. (2005) Weather patterns, food security and humanitarian response in sub-Saharan Africa. Philosophical Transactions of the Royal Society B, 360 (1463), 2169-2182.

Hammer, G. (2000) Applying seasonal climate forecasts in agricultural and natural ecosystems – a synthesis. In: Hammer, G., Nicholls, N., Mitchell, C. (Eds.), Applications of seasonal climate forecasting in agricultural and natural ecosystems – the Australian experience. Vol 21. Atmospheric and Oceanographic Sciences Library, Kluwer Academic publishers, Dordrecht.

Handmer, J.W., and Dover, S.R. (1996) A typology of resilience: Rethinking institutions for sustainable development. Industrial and Environmental Crisis Quarterly 9 (4), 482-511.

Harrison, A. (2001) Climate change and agriculture in NSW: The challenge for rural communities. A report prepared for the Nature Conservation Council of NSW and Greenpeace, Climate Action Network. pp.4.

Hayami, Y. (1969). Sources of agricultural productivity gap among selected countries. American Journal of Agricultural Economics 51, 564-75.

Hayami, Y. and Ruttan V. (1971). Agricultural Development: An International Perspective. Baltimore: Johns Hopkins University Press.

Head, L., Atchison, J., Gates, A. and Muir, P. (2011) A fine-grained study of the experience of drought, risk and climate change among Australian wheat farming households. Annals of the Association of American Geographers 101 (5), 1089-1108.

Hennessy, K., Fawcett, R., Kirono, D., Mpelasoka, F., Jones, D., Bathols, J., Whetton, P., Stafford-Smith, M., Howden, M., Mitchell, C., and Plummer, N. (2008): An assessment of the impact of climate change on the nature and frequency of exceptional climatic events. A consultancy report by CSIRO and the Australian Bureau of Meteorology for the Australian Bureau of Rural Sciences, 33pp, www.bom.gov.au/climate/droughtec/

Hennessy, K., Fitzharris, B., Bates, B., Harvey, N., Howden, S., Hughes, L., Salinger, J. and Warrick, R. (2007) Australia and New Zealand. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp. 507-540.

Henry, B, Charmley, E., Eckard, R., Gaughan, J. and Hegarty, R. (2012) Livestock production in a changing climate: adaptation and mitigation research in Australia. Crop & Pasture Science 63, 191–202.

Heyhoe, E., Crimp, S., Nelson, R., Yeon, K., Kokic, P., Levantis, C., Ahammad, H., Flood, N. and Carter, J. (2007) Adapting to climate change issues and challenges in the agriculture sector. Australian Commodities 14, 167-178.

Hogan, A., Berry, H. and Bode, A. (2011b) Farmer health and adaptive capacity in the face of climate change and variability. Part 2: Contexts, personal attributes and behaviours. International Journal of Environmental Research and Public Health 8, 4055-4068.

Hogan, A., Berry, H., Peng Ng, S. and Bode, A. (2011a) Decisions made by farmers that relate to climate change. Rural Industries Research and Development Corporation. No.10/208.

Hogan, A., Hanslip, M., Kancans, R., Russell, J and Maguire, B. (2008) Climate risk and adaptation among primary producers: Topline results focusing on primary producers reporting the effects of adverse seasonal conditions, Report prepared for the Drought Review Branch, Australian Government Department of Agriculture, Fisheries and Forestry. Canberra: Bureau of Rural Sciences.

Hood, A., Hossain, H., Sposito, V., Tiller, L., Cook, S., Jayawardana, C., Ryan, S., Skelton, A., Whetton, P., Cechet, B., Hennessey, K. and Page, C. (2002) Options for Victorian agriculture in a "new" climate – a pilot study linking climate change scenario modelling and land suitability modelling. Volume one – Concepts and Analysis. 62 pp. Volume Two – Modelling Outputs. 83 A3 pp Department of Natural Resource and Environment – Victoria.

Hope, P., Drosdowsky, W. and Nicholls, N. (2006) Shifts in the synoptic systems influencing southwest Western Australia. Climate Dynamics 26, 751-764.

Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P., Dai, X., Maskell, K. and Johnson, C. (2001) Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. and New York, NY, USA.

Howden, M. and Hayman, P. (2005) The distribution of cropping under climate change: Goyder's line. Contributed paper presented at the conference Greenhouse2005, Carlton Crest Hotel, Melbourne, 14-17 Nov, 2005.

Howden, M. and Jones, R. (2004) Risk assessment of climate change impacts on Australia's wheat industry. In Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004. Available at: www.cropscience.org.au

Howden, M. and Meinke, H. (2003) Climate change: challenges and opportunities for Australian agriculture. In: Proceedings of the Conference on Climate Impacts on Australia's Natural Resources: Current and Future Challenges, Queensland,

Australia, Canberra: Standing Committee on Natural Resource Management. Managing Climate Variability Program, pp. 53-55.

Howden, M., Ash, A., Barlow, S., Booth, T., Charles, S., Cechet, B., Crimp, S., Gifford, R., Hennessey, K., Jones, R., Kirschbaum, M., McKeon, G., Meinke, H., Park, S., Sutherst, B., Webb, L. and Whetton, P. (2006) An overview of the adaptive capacity of the Australian agricultural sector to climate change; Options, costs and benefits, CSIRO, Canberra.

Howden, M., Gifford, R. and Meinke, H. (2010) Grains, pp. 21-48, In Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future, (eds: C. Stokes and M. Howden), CSIRO Publishing, Canberra, Australia.

Howden, M., Soussana, J., Tubiello, F., Chhetri, N., Dunlop, M. and Meinke, H. (2007) Adapting Agriculture to climate change. Proceedings of the National Academy of Science 104 No.50 19691-19696

Howden, S. M., Hall, W.B. and Bruget, D. (1999) Heat stress and beef cattle in Australian rangelands: recent trends and climate change. In: People and Rangelands: Building the Future. Proceedings of VI International Rangelands Congress, Townsville, July, 1999. [Eldridge, D. and D. Freudenberger (eds.)]. 6th International Rangelands Congress Inc., Aitkenvale, Queensland, Australia, pp. 41-43.

Howden, S.M. and Crimp, S. (2005) Assessing dangerous climate change impacts on Australia's wheat industry. [In Zerger, A. and Argent, R.M. (eds)] MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, pp. 170-176. ISBN: 0-9758400-2-9.

Howden, S.M. and Turnpenny, J. (1997) Modelling heat stress and water loss of beef cattle in sub-tropical Queensland under current climates and climate change. In: Modsim ’97 International Congress on Modelling and Simulation, Proceedings, 8-11 December, University of Tasmania, Hobart [McDonald, D.A. and M. McAleer (eds.)] Modelling and Simulation Society of Australia, Canberra, Australia. 1103-1108 pp.

Hughes, L. (2003) Climate change and Australia: Trends, projections and impacts. Austral Ecology 28 (4), 423–443.

Hughes, N., Lawson, K., Davidson, A., Jackson, T. and Sheng, Y. (2011) Productivity pathways: climate adjusted production frontiers for the Australian broadacre cropping industry, ABARES research report 11.5, Canberra.

Hulme, M. (2008) Geographical work at the boundaries of climate change. Transactions of the Institute of British Geographers 33, 5–11.

Hulme, M., Doherty, R., Ngara, T. and New, M. (2005) Global warming and African climate change: a re-assessment. In Lim, P. (Editor) Climate and Africa. Pp 29-40 Cambridge University Press, Cambridge, UK.

Iglesias, A., Avis, K., Benzie, M., Fisher, P., Harley, M., Hodgson, N., Horrocks, L., Maoneo, M. and Webb, J. (2007) Adaptation to climate change in the agriculture sector. AGRI-2006-G4-05. AEA Energy and Environment and University of Madrid, Report to European commission Directorate General for Agriculture and Rural development.

IPCC (1996) The IPCC Second Assessment: Climate change 1995, Cambridge, Cambridge University Press.

IPCC (2001a) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

IPCC (2001b) Climate Change, 2001: Impacts, Adaptations and Vulnerability. A report of Working Group II of the IPCC Geneva, IPCC.

IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.)). Cambridge University Press, Cambridge, UK, 7-22.

Islam, N., Xayavong, V. And Kingwell, R. (forthcoming) Broadacre farm productivity and profitability in south western Australia. Australian Journal of Resource and Agricultural Economics.

Jarroud, M. and Töpfer, K. (2004) Sixteen years of scientific assessment in support of the climate convention. Intergovernmental panel on climate change. 10th Anniversary Brochure.

John, M. (2004) The Economics of Dryland Salinity Management in a Low-Rainfall Environment of Western Australia, PhD thesis, University of Western Australia.

John, M., Pannell, D. and Kingwell, R. (2005) Climate change and the economics of farm management in the face of land degradation: Dryland salinity in Western Australia. Canadian Journal of Agricultural Economics 53, 443-459.

Joint working party on agriculture and the environment. (2011) Farmer behaviour and management practices in relation to mitigation and adaptation to climate change. Trade and agriculture directorate, Environment directorate. JT03305024

Jones, R. and Hennessy, K. (2000) Climate change impacts in the Hunter Valley: a risk assessment of heat stress affecting dairy cattle, CSIRO Atmospheric Research, Aspendale, Victoria, Australia.

Jorgenson, D. W. and Griliches, Z. (1967) The explanation of productivity change. The Review of Economic Studies 34(3), 249-283.

Kassahn, K.S., Crozier, R.H., Pörtner, H.O., Caley, M.J. (2009) Animal performance and stress: responses and tolerance limits at different levels of biological organisation. Biological Reviews of the Cambridge Philosophical Society 84, 277–292.

Kelly, P. M. and Adger W. N. (2000) Theory and practice in assessing vulnerability to climate change and facilitation adaptation. Climatic Change 47, 325–52.

Keogh, M. (2011) Food Security, Food Reality and Australian Agriculture Opportunity. Farm Policy Journal 8, 1-15.

Keogh, M., Granger, R. and Middleton, S. (2011) Drought Pilot Review Panel: a review of the pilot of drought reform measures in Western Australia, Canberra, September, 2011.

Kimura, S. and Antón, J. (2011) Risk Management in Agriculture in Australia. OECD Food, Agriculture and Fisheries Working Papers, No. 39, OECD publishing.

Kingwell, R. (2006) Climate change in Australia: agricultural impacts and adaptation. Australian Agribusiness Review, Paper 1, 14, 1-30. ISSN 1442-6951

Kingwell, R. (2011) Revenue volatility faced by Australian wheat farmers. Contributed paper to the Australian Agricultural & Resource Economics Society's annual conference, Melbourne, Feb 9-11, 2011.

Kingwell, R. (2012) Revenue volatility faced by some of the world's major wheat producers. Farm Policy Journal 9:23-33.

Kingwell, R. and Farré, I. (2009) Climate change impacts on investment in crop sowing machinery. Australian Journal of Agricultural and Resource Economics 53, 265-284.

Kingwell, R., and Pannell, D. (2005) Economic trends and drivers affecting the wheatbelt of Western Australia to 2030. Australian journal of Agriculture Research 56, 553-561.

Kingwell, R., Pannell, D. and Robinson, S. (1993) Tactical responses to seasonal conditions in whole-farm planning in Western Australia. Agriculture Economics 8, 211-226.

Kokic, P., Heaney, A., Pechey, L., Crimp, S. and Fisher, B. (2005) Climate change: predicting the impacts on agriculture: a case study. Australian Commodities 12(1), 161-170.

Kokic, P., Nelson, R., Meinke, H., Potgieter, A. and Carter, J. (2007) From rainfall to farm incomes—transforming advice for Australian drought policy. I. Development and testing of a bioeconomic modelling system. Australian Journal of Agricultural Research 58, 993–1003.

Kurukulasuriya, P and Rosenthal, S. (2003) Climate change and agriculture: A review of impacts and adaptations. The World Bank. Paper no.91 published jointly with the Agriculture and Rural Development Department.

Lau, J. and Yotopoulos, P. (1989) The meta-production function approach to technological change in world Agriculture. Journal of Development Economics, 31, 241-69.

Lawes, R. and Kingwell, R. (2012) A longitudinal examination of business performance indicators for drought-affected farms. Agricultural Systems 106, 94-101.

Liverman, D.M. (1994) Vulnerability to global environmental change. In: S.L. Cutter (ed), Environmental Risks and Hazards, Prentice Hall, Upper Saddle River, NJ, 326–342.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., and Naylor, R. L. (2008) Prioritizing climate change adaptation needs for food security in 2030. Science 319, 607–10.

Loch, A., Hatt, M., Mamum, E., Xu, J., Bruce, S., Heyhoe, E., Nicholson, M. and Ritman, K. (2012) Farm risk management in a changing climate. ABARES conference paper 12.5, Canberra, March 2012.

Lovell, C.K. (2001) Future research opportunities in efficiency and productivity analysis, Efficiency Series Paper 1/2001, University of Oviedo, Department of Economics, Permanent Seminar on Efficiency and Productivity.

Lovell, C. K. (2003) The decomposition of Malmquist productivity indexes. Journal of Productivity Analysis 20(3), 437-458.

Low, P.S. (Ed). (2005) Climate change and Africa. Cambridge University Press, Cambridge, UK.

Ludwig, F. and Asseng, S. (2006) Climate change impacts on wheat production in a Mediterranean environment in Western Australia. Agriculture systems.90, 159-179.

Ludwig, F., Milroy, S. and Asseng, S. (2009) Impacts of recent climate change on wheat production systems in Western Australia. Climate Change 92 (3), 495 - 115.

Maddison, D., Manley, M. and Kurukulasuriya, P. (2007) The impact of climate change on African agriculture: a Ricardian approach. Policy research working paper 4306, The World Bank.

Makeham J.P. and Malcolm, L.R. (1993) The Farming Game Now, Cambridge University Press, pp 399.

Malcolm, S., Marshall, E., Ailley, M., Heisey, P., Livingston, M and Day-Rubenstein, K. (2012) Agriculture adaptation to a changing climate: Economic and environmental implications vary by U.S region. ERR- 136. U.S. Department of Agriculture, Economics Research Service.

Marsh, S.P., Pannell, D.J. and Lindner, R.K. (2004) Does agricultural extension pay? Agricultural Economics 30, 17-30.

Marshall, N. A., Stokes, C. J., Howden, S. M., and Nelson, R. N. (2010) Enhancing adaptive capacity. In Adapting agriculture to climate change, ed. C. J. Stokes and M. Howden, 245–56. Canberra, Australia: CSIRO.

Maslow, A.H. (1943) A Theory of Human Motivation, Psychological Review 50(4), 370-96.

Mauldon, R. and Schapper, H.P. (1970) Random numbers for farmers, The Journal of the Australian Institute of Agricultural Science 36, 279-284.

Mauldon, R.G. and Schapper, H.P. (1974) Australian Farmers Under Stress in Prosperity and Recession, University of Western Australia Press, Perth, pp 232.

Mayer, D., Davison, T., McGowan, M., Young, B., Matschoss, A., Hall, A., Goodwin, P., Jonsson, N. and Gaughan, J. (1999) Extent and economic effect of heat loads on dairy cattle production in Australia. Australian Veterinary Journal 77, 804–808.

McCarl, B.A. (2007) Adaptation Options for Agriculture, Forestry and Fisheries. A Report to the UNFCCC Secretariat Financial and Technical Support Division. http://agecon2.tamu.edu/people/faculty/mccarl-bruce/climchgadapt.html.

McCarthy, J., Canziani, O., Leary, N., Dokken, D. and White, K. (2001) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of working group II to Third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press. ISBN 0 521 80768 9

McCown, R.L., Brennan, L.E. and Parton, K.A. (2006) Learning from the historical failure of farm management models to aid management practice. Part 1. The rise and demise of theoretical models of farm economics. Australian Journal of Agricultural Research 57, 143–156.

McDonald, G. (2013) Hard-thinking growers show best practice a serious goal. Ground Cover March-April 2013, pp 24.

McFarlane, D.J. and Ruprecht, J. (2005) How salinity has changed Indian Ocean climate initiative climate note. 11/05. http://www.ioci.org.au/publications/pdf/IOCIclimatenotes_11.pdf

McGregor, M. (1996) Links between psychological factors and farmer decision making. Farm Management 9 (5), 228-239.

McInnes, K.L., Whetton, P.H., Webb, L. and Hennessy, K.J. (2003) Climate change projections for Australian viticultural regions. The Australian and New Zealand Grapegrower and Winemaker, February 2003, 40-47.

McKeon, G., Hall, W., Henry, B., Stone, G. and Watson, I. (2004) Pasture degradation and recovery in Australia's Rangelands: Learning from history. Queensland Department of Natural Resources, Mines and Energy, Brisbane.

Mearns, R., and Norton, A., eds. (2010) Social dimensions of climate change: Equity and vulnerability in a warming world. Washington, DC: The World Bank.

Meinke, H. and Stone, R. (2005) Seasonal and interannual climate forecasting: The new tool for increasing preparedness to climate variability and change in agriculture planning and operations. Climate Change 70, 221-253.

Mendelsohn, R. (1999) Measuring the effect of climate change on developing country agriculture. Paper prepared for FAO.

Mendelsohn, R. (2007) Measuring climate impacts with cross sectional analysis. Climate Change 81, 1-7.

Mendelsohn, R. and Dinar, A. (1999) Climate Change, Agriculture and developing countries: Does adaptation matter? World Bank Research Observer (14), 277-293.

Metz, B., Davidson, O., Swart, R. and Pan, J. (2001) Climate Change 2001: Mitigation Contribution to working group III for Third assessment report Intergovernmental panel on climate change, Cambridge University Press, UK.

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Zierovogel, G., Walker, B., Birkmann, J., van der Leeuw, S., Rockström, J., Hinkel, J., Downing, T., Folke, C. and Nelson, D. (2010) Resilience and Vulnerability: Contemporary or conflicting concepts. Ecological and Society 15(3), 11.

Milne, M., Stenekes, N. and Russell, J. (2008) Climate risk and industry adaptation. Bureau of Rural Sciences (BRS). Canberra.

Moore, D. (2012) Climate change adaptation in the Southern Australian livestock industries. CSIRO and Meat and Livestock Australia Limited, North Sydney NSW.

Morgan, J.A., LeCain, D.R., Pendall, E., Blumenthal, D.M., Kimball, B.A., Carrillo, Y., Williams, D.G., Heisler-White, J., Dijkstra, F.A. and West, M. (2011) C(4) grasses prosper as carbon dioxide eliminates desiccation in warmed semi-arid grassland. Nature 476:202–U101.

Mortreaux, C., and Barnett, J. (2008) Climate change, migration and adaptation in Funafuti, Tuvulu. Global Environmental Change 19, 105-12.

Moss, R., Edmonds, J., Hibbard, K., Manning, M., Rose, S., Vuuren, D., Carter, D., Emori, S., Kainuma, S., Kram, T., Meehl, G., Mitchell, F., Nakicenovic, N., Riahi, K., Smith, S Stouffer, R., Thomson, A., Weyant, P. and Wilbanks, T. (2010) The next generation of scenarios for climate change research and assessment. Nature 463, 747-756.

Nakicenovic, N. and Swart, R. (2000) Emissions scenarios. Special report for Intergovernmental panel on climate change. Cambridge University Press, UK.

Nelson, G., Rosegrant, M., Jawoo, K., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M. and Lee, D. (2009) Climate Change; Impact on Agriculture and Costs of Adaptation. Food policy report. International Food Policy Research Institute. www.ifpri.org

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H. and Howden, S.M. (2010b) The vulnerability of Australian rural communities to climate variability and change: Part I – Conceptualising and measuring vulnerability. Environmental Science & Policy 13, 8-17.

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S.M., de Voil, P., and Nidumolu, U., (2010a) The vulnerability of Australian rural communities to climate variability and change: Part II – Integrating impacts with adaptive capacity. Environmental Science & Policy 13, 18-27.

Nelson, R., Kokic, P., Ellistone, L., King, J-A. (2005) Structural adjustment, A vulnerability index for Australian broadacre agriculture. Australian Commodities 12 (1), 171-179.

Nicholls, N., Chambers, L., Haylock, M., Frederiksen, C., Jones, D., and Drosdowsky, W. (1999) Climate variability and predictability for south-west Western Australia. pp 1-52 in Towards Understanding Climate Variability in south Western Australia, Research report on the First Phase of the Indian Ocean Climate Initiative, October 1999.

Nielsen, J. O. and Reenberg, A. (2010) Cultural barriers to climate change adaptation: A case study from northern Burkina Faso. Global Environmental Change 20, 142–52.

Norris, R., Richards, R., Creeper, J., Jubb, T., Madin, B. and Kerr, J. (2003) Cattle deaths during sea transport from Australia. Australian Veterinary Journal 81(3), 156-161.

Nuttall, J., O'Leary, G., Khimashia, N., Asseng, S., Fitzgerald, G. and Norton, R. (2012) 'Haying-off' in wheat is predicted to increase under a future climate in south-eastern Australia. Crop & Pasture Science 63, 593–605.

O'Brien, K. and Leichenko, R. (2000) Double exposure: assessing the impacts of climate change with the context of economic globalisation. Global Environmental Change 10, 221-232.

O'Brien, K., Eriksen, S., Nygaard, L. and Schjolden, A. (2007) Why different interpretations of vulnerability matter in climate change discourses. Climate Policy 7, 73-88.

O'Brien, K., Eriksen, S., Schjolden, A. and Nygaard, L. (2004) What's in a word? Conflicting interpretations of vulnerability in climate change research. CICERO Working Paper 2004, 04, Oslo, Norway.

O'Brien, K., Eriksen, S., Sygna, L. and Naess, L. O. (2006) Questioning complacency: Climate change impacts, vulnerability, and adaptation in Norway. AMBIO A journal of the human environment 35, 50–56.

O'Donnell, C. (2010a) Measuring and decomposing agricultural productivity and profitability changes, Australian Journal of Agricultural and Resource Economics 54(4), 527-560.

O'Donnell, C. (2010b) DPIN Version 1.0: A program for decomposing productivity index numbers, Centre for Efficiency and Productivity Analysis Working Paper Series No. WP01/2010., School of Economics, University of Queensland.

O'Donnell, C. J. (2011) The sources of productivity change in the manufacturing sectors of the U.S. Economy. Centre for Efficiency and Productivity Analysis Working Paper WP07/2011.University of Queensland.

O'Donnell, C. J. (2012a) An aggregate quantity framework for measuring and decomposing productivity change. Journal of Productivity Analysis DOI: 10.1007/s11123-012-0275-1.

O'Donnell, C. J. (2012b) Nonparametric estimates of the components of productivity and profitability change in U.S. agriculture. American Journal of Agricultural Economics 94(4), 873-890.

O'Donnell, C.J., Rao, D.S.P. and G.E. Battese (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empirical Economics 34:231-255.

Ortiz,R., Sayre, D., Govaerts, B., Gupta, R., Subbaroa, V., Ban, T., Hodson, D., Dixon, J., Oritz-Monasterio, I. and Reynolds, M. (2008) Climate change; Can wheat beat the heat? Agriculture, Ecosystems and Environment 126, 46-58.

Osbahr, H., Twyman, C., Adger, W. N. and Thomas, D. S. (2010) Evaluating successful livelihood adaptation to climate variability and change in southern Africa. Ecology and Society 15(2), 27. URL: http://www.ecologyandsociety.org/vol15/iss2/art27/

Ozkan, B. and Ceylan, R.F. and Kizilay, H. (2009) A review of literature on productive efficiency in agricultural production. Journal of Applied Science Research 5(7), 796-801.

Pannell, D.J., (2010) Policy for climate change adaptation in agriculture. In 54th Australian Agricultural and Resource Economics Society Conference, Adelaide.

Parry, M., Arnell, N.W., Hulme, M., Nichols, R. and Livermore, M. (1998) Adapting the inevitable. Nature 395, 741.

Patel, R. (2007) Stuffed and Starved: Markets, power and the hidden battle for the world's food system. London, England: Portobello Books.

Patt, A.G., and Schröter, D. (2008) Perceptions of climate risk in Mozambique: Implications for the success of adaptation strategies. Global Environmental Change 18, 458-67.

Pearson, L. and Langridge, J. (2008) Climate change vulnerability assessment: Review of agricultural productivity. CSIRO Climate Adaptation Flagship Working Paper No.1 hhttp://www.csiro.au/resources/CAF-Working –Papers

Peilke,R., Prins, G., Rayner, S. and Sarewitz, D. (2007) Climate change 2007: Lifting the taboo on adaptation. Nature 445, 597-598.

Petty, S.R., Poppi, D.P and Triglone, T. (1998) Effect of maize supplementation, seasonal temperature and humidity on the liveweight gain of steers grazing irrigated Leucaena leucocephala/Digitaria erinta pastures in north-west Australia. Journal of Agricultural Science 130, 95-105.

Pittock B, (2003) Climate Change: An Australian guide to the science and potential Impacts. Report compiled for the Australian Green House Office. Canberra, Australia. Available at www.greenhouse.gov.au/science/guide/index.html

Planfarm Bankwest. (2011) Planfarm Bankwest Benchmarks 2010-2011. Planfarm Pty Ltd and Bankwest Agribusiness Centre, Perth.

Planfarm Bankwest. (2012) Planfarm Bankwest Benchmarks 2011-2012. Planfarm Pty Ltd and Bankwest Agribusiness Centre, Perth.

Potgieter, A., Doherty, A., Crimp, S., Rodgriguez, D., Hammer, G., Meinke, H. and Fairweather, H. (2008) Shire scale impacts and adaptation options for Australian cereal crops affected by climate change. In: 14th Australian Agronomy Conference, Adelaide.

Potgieter, A., Meinke, H., Doherty, A., Sadras, V.O., Hammer, G., Crimp, S. and Rodriguez, D. (2012) Spatial impact of projected changes in rainfall and temperature on wheat yields in Australia. Climatic Change DOI 10.1007/s10584-012-0543-0

Productivity Commission (2005) Trends in Australian Agriculture, Research Paper, Canberra, pp170.

Quiggin, J. and Horowitz, J. (2003) Costs of adjustment to climate change. Australian Journal of Agricultural and Resource Economics 47: 429-446.

Rahmstorf, S., Cazenave, A., Church, J., Hansen, J.., Keeling, R., Parker, D. and Somerville, R. (2007) Recent Climate Observations Compared to Projections. Science 316, 5825 709.

Rebbeck, M., Dwyer, E., Bartetzko, M. and Williams, A. (2007) A guide to climate change and adaptation in agriculture in South Australia. ISBN 978-0-7590-1397-1.

Reidsma, P., Ewert, F. and Lansink, A.O. (2007) Analysis of farm performance in Europe under different climate and management conditions to improve understanding of adaptive capacity. Climate Change 84, 403-422.

Reidsma, P., Ewert, F., Lansink, A.O. and Leemans, R. (2009) Vulnerability and adaptation of European farmers: a multi-level analysis of yield and income responses to climate variability. Regional Environmental Change 9, 25-40.

Reilly, J.M. and Schimmelpfenning, D. (1999) Agricultural impact assessment, vulnerability, and the scope for adaptation. Climate Change 43, 745-788.

Resilience Alliance. (2009) Assessing and managing resilience in social-ecological systems: a practitioner's workbook, version 1.0. http://wiki.resalliance.org/index.php/Main_Page.

Reyenga, P.J., Howden, S.M., Meinke, H. and Hall, W.B. (2001) Global impacts on wheat production along an environmental gradient in south Australia. Environment International 27, 195-200.

Ribot, J. (1995) The causal structure of vulnerability: its application to climate impact analysis. GeoJournal 35(2),119–122.

Risbey, J., Kandlikar, M., Dowlatabadi, H. and Graetz, D. (1999) Scale, context, and decision making in agricultural adaptation to climate variability and change. Mitigation and Adaptation Strategies for Global Change 4, 137–65.

Rodriguez, D., de Voil, P., Power, B., H. Cox, Crimp, S. and Meinke, H (2011) The intrinsic plasticity of farm businesses and their resilience to change. An Australian example. Field Crops Research 124 (2), 157-170.

Rosenzweig, C. and Hillel, D (1998) Climate change and the global harvest: Potential impacts of the greeenhouse gas effect on agriculture. Oxford University Press, New York, pp336.

Rötter, R. and Van de Geijn, S. (1999) Climate change effects on plant growth, crop yield and livestock. Climatic Change 43, 651–681. doi:10.1023/A:1005541132734

Rötter, R., Lehtonen, H., Kahiluoto, H., Helin, J., Palosuo, T., Salo, T., Pavlova, Y., Wolf, J., Carter, T.R. and Ewert, F. (2011) Assessing adaptive management options to cope with climate change at the farm level. Agrifood research Finland.

Sadler, B. (2002) Informed adaptation to a changed climate state. Is South-Western Australia a national canary? Informed Adaptation. Indian Ocean Climatic Initiative report. http://www.ioci.org.au/publications/reports.html

Safi, A.S., Williams, J.S.Jr. and Zhnongwei, L. (2012) Rural Nevada and Climate Change: Vulnerability, beliefs, and risk perception. Risk Analysis 32, 6.

Schilizzi, G.M. and Kingwell, R.S. (1999) Effects of climatic and price uncertainty on the value of legume crops in a Mediterranean-type environment. Agricultural Systems 60, 55-69.

Semenov, M. and Shewry, P. (2011) Modelling predicts that heat stress, not drought, will increase vulnerability of wheat in Europe. Scientific Reports 1, 66 DOI: 10.1038/srep00066

Sen, A. (1981) Poverty and famines. Oxford, Clarendon Press.

Shadbolt, N. (2008) Farm management indicators: An exploration of the linkages between external drivers, farm management decisions, farm practices and selected environmental outcomes in agriculture. Report to the Joint working party on Agriculture and the Environment, Paris.

Sheng, Y., Mullen, J.D. and Zhao, S. (2011) A turning point in agricultural productivity: consideration of the causes, ABARES research report 11.4 for the Grains Research and Research and Development Corporation, Canberra, May.

Siddique, K.H.M. and Sykes, J. (1997) Pulse production in Australia: past, present and future. Australian Journal of Experimental Agriculture 37, 103-111.

Siddique, K.H.M., Walton, G.H., Seymour, M. (1993) A comparison of winter grain legumes in Western Australia. Australian Journal of Agricultural Research 33, 915-922.

Sietchiping, R. (2007) Applying an index of adaptive capacity to climate change in North-Western Victoria, Australia. Applied GIS 2 (3), 16.1-16.28.

Sivakumar, M. and N. Ndiang´ui, eds. (2007) Climate and Land Degradation. Environmental Science and Engineering, Berlin, Springer.

Smit, B. and Pilifosova, O. (2001) Adaptation to climate change in the context of sustainable development and equity. In McCarthy, J., Canziani, O., Leary, N., Dokken, D. and White, K. (2001) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of working group II to Third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press. ISBN 0 521 80768 9

Smit, B. and Skinner, M. (2001) Adaptation options in Agriculture to climate change: A typology. Mitigation and Adaptation Strategies for Global Change 7, 85-114.

Smit, B., and Wandel, J. (2006) Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282–92.

Smit, B., I. Burton, R. J. T. Klein, and J. Wandel. (2000) An anatomy of adaptation to climate change and variability. Climatic Change 45, 223–51.

Smith, J. and Lenhart, S. (1996) Climate change adaptation policy options. Climate Research 7(3), 251-264.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (2007) Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge. UK.

Steffen, W. and Hughes, L. (2011) The critical decade: Western Australia climate change impacts. Climate Commission. Canberra.

Stokes, C. and Howden, M. (2010) Adapting agriculture to climate change: Preparing Australian agriculture, forestry and fisheries for the future. CSIRO publishing Melbourne: Publishing. ISBN: 9780643095953

Storer, C. (2012) Measuring Farmer Resilience. Unpublished report. Curtin University of Technology Western Australia.

Stretch, T., Kingwell, R. and Carter, C. (2012) Grains Profitability: A Regional Analysis, AEGIC research report, South Perth, pp. 57.

Tashiro, T. and Wardlaw, I. F. (1989) A comparison of the effect of high-temperature on grain development in wheat and rice. Annals of Botany. 64, 59–65 (1989).

Thornton, P.K. (2010) Livestock production: Recent trends, future prospects. Philosophical Transactions of the Royal Society 365, 2853-2867.

Toulmin, C.(2009) Climate Change in Africa. Zed Books, London, UK.

Twyman, C., Fraser, D.G., Stringer, L., Quinn, C., Dougill, A., Ravera, F., Crane. and Sallu, S. (2011) Climate science, development practice, and policy interactions in dryland agroecological systems. Ecology and Society 16 (3), 14.

UNEP (1999) A beginners guide to the UN framework convention and its Kyoto protocol, United Nation Environment Programme, Division of Environment Conventions, pp40. Available at hhttp://www.unep.org/dec/information/public_information.html

Van Beveren, I. (2010) Total factor productivity estimation: A practical review. Journal of Economic Surveys 1-38. doi 10.1111/j.1467-6419.2010.00631.x.

Van Biesebroeck, J. (2007) Robustness of productivity estimates. Journal of Industrial Economics 55(3), 529-569.

Van Gool, D. and Vernon, L. (2005) Potential impacts of climate change on agricultural land use suitability: Wheat. DAFWA Resource Management Technical Report 295, Perth, Western Australia

Van Ittersum, M.K., Howden, S.M. and Asseng, S. (2003) Sensitivity of productivity and deep drainage of wheat cropping systems in a Mediterranean environment to changes in CO2, temperature and precipitation. Agriculture, Ecosystems and Environment 97, 255-273.

Vermeulen, S., Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B., Challinor, A., Hansen, J., Ingram, I., Jarvis, A., Kristjanson, P,. Lau, C., Thornton, P. and Wollenberg, E. (2010) Agriculture, food security and climate change: Outlook for knowledge, tools and action. CCAFS Report 3. Copenhagen, Denmark: CGIAR-ESSP Program on Climate Change, Agriculture and Food Security.

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S. and Shultz, L. (2006) A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecology and Society 11(1), 13.

Wardell-Johnson, Angela. 2005. Social relationships in landscape systems: Identifying values and variables that drive social interactions, in Richardson, K. and Gregory W. and Midgley, G. (ed), Systems Thinking and Complexity Science: Insight for Action, 11th Annual ANZSYS Conference/Managing the complex V., Dec 5-7 2005, Christchurch, New Zealand: ISCE Publishing.

Washington, R., M, Harrison, and Conway, D. (2004) African climate report. Department for Environment, Food and Rural Affairs (DEFRA) and the Department for International Development (DFID), London, UK.

Watson, R., Zinyowera, M. and Moss, R. (1998) The regional impacts of climate change: An assessment of vulnerability. Contribution to working group II Intergovernmental Panel on Climate Change, Cambridge University Press.

White, N., Sutherst, R.W., Hall, N. and Whish-Wilson, P. (2003) The vulnerability of the Australian beef industry to impacts of the cattle tick (Boophilus microplus) under climate change. Climate Change 61(1-2), 157-190.

Wilkinson, R., Barr, N. and Hollier, C. (2011) Segmenting Victoria's farmers. A report of the Farm Services Victoria Division, Department of Primary Industries, 63 pp.

Wilkinson, R., Barr, N. and Hollier, C. (2012) The choices farm families make. Farm Policy Journal 9, 27-37.

World Bank. (2008) World Development Report 2008: Agriculture for Development, Washington D.C. The World Bank.

Ziervogel, G., Bharwani, S. and Downing, T. E. (2006) Adapting to climate variability: Pumpkins, people and policy. Natural Resources Forum 30, 294–305.

APPENDICES

Appendix 1: List of key variables contained in or generated from consultants' data

Variable Code	Unit	Description
year		Year
farmid		PF = planfarm; EG = Evans&Grieve' FMC = Farmanco
shire		Shire name
zone		DAFWA's agro-ecological zones based on rainfall and length of growing season
gsr	mm	Growing season rainfall
landown	ha	Area of farmland owned
land	ha	Effective area
lab	weeks	Total weeks of labour
plab	weeks	Permanent labour
clab	weeks	Casual labour
livestockCap	$	Capital value of livestock
PMCap	$	Capital value of plant and machinery
ywheat	t/ha	Wheat yield
ybarley	t/ha	Barley yield
ylupin	t/ha	Lupin yield
ycanola	t/ha	Canola yield
qwheat	tonnes	Quantity of wheat produced
qbarley	tonnes	Quantity of barley produced
qlupin	tonnes	Quantity of lupin produced
qoats	tonnes	Quantity of oats produced
qcanola	tonnes	Quantity of canola produced
qocrop	tonnes	Quantity of other grains produced (field peas, triticale, faba beans, lentils)
qcrop	tonnes	quantity of all grains produced
qsheep	hd	number of sheep sold
qwools	kg	amount of wool produced and sold
qcattle	hd	number of cattle sold
vcrop	$	Income from grain sales
vcattle	$	Income from cattle sales
vsheep	$	Income from sheep sales
vwool	$	Income from wool sales
vlivestock	$	Income from grain sales
vofffarm	$	Income from sales of all types of livestock (including pigs)
GFI	$	Gross farm income
GFI1	$	Gross farm income (excluding other income)
checkGFI	$	Other farm income

fertiliserEx	$	Expenditure on fertilisers
chemicalsEx	$	Expenditure on chemicals
livestockEx	$	Expenditure on livestock
fuelEx	$	Expenditure on fuel
RMEx	$	Expenditure on repairs and maintenance
livestockPurEx	$	Expenditure on livestock purchases
cartageEx	$	Expenditure on cartage
seedsEx	$	Expenditure on seed
contractEx	$	Expenditure on contractors
cwage	$	Expenditure on wages staff
shearingEx	$	Expenditure on shearing
levyEx	$	Expenditure on levies
VCEx	$	Variable costs of production (note this data is missing for Evans&Grieve clients)
VCEx1	$	Estimated variable costs of production (note this data includes estimates for Evans&Grieve clients)
pwage	$	Cost of permanent labour
RLW	$	Expenditure on rates, licences and water
adminEx	$	Expenditure on administration
energyEx	$	Expenditure on electricity and gas
insuranceEx	$	Expenditure on general insurance
otherEx	$	Expenditure on other items and sundries
FCEx	$	Expenditure on fixed costs and overheads (note this data is missing for Evans&Grieve clients)
FCEx1	$	Estimated expenditure on fixed costs and overheads (note this data is missing for Evans&Grieve clients)
TOC	$	Total operating cost
TOC1	$	Estimated total operating cost based on cost items
financialEx	$	Interest repayments
taxEx	$	Tax payments
PSEx	$	Personal expenses
repayment	$	Loan repayments
OS	$	Operating surplus
OS1	$	Estimated operating surplus based on financial items
machineryReplace	$	Cost of machinery replacement (based on 10% of machinery asset value)
Rprofit	$	Retained profit
landVALUE	$	Value of farmland assets
farmASSET	$	Value of farmland, machinery, buildings and livestock assets
businessASSET	$	Value of farm and off-farm assets owned
debt2incomeRatio	no.	Debt to income ratio

liability	$	Business liabilities (farm and off-farm debt)
equity	$	Business assets minus liabilities
equityPC	%	(Business assets minus liabilities)*100/business assets
cropArea	ha	Area of crop
pastureArea	ha	Area of pasture
pcCropIncome	%	Crop income as a percentage of all farm income
cropIncomeHa	$/ha of crop	Crop income per hectare of crop
livestockIncomeHa	$/ha of pasture	Livestock income per hectare of pasture
pcOPEX2GFI	%	Operating expenses as a percentage of gross farm income
assetHa1	$/ha	Value of farmland ($/ha)
debtHa	$/ha	Value of debt ($/ha)
equityHa	$/ha	Value of equity ($/ha)

Appendix 2: The socio-managerial questionnaire

Department of Agriculture and Food — NCCARF National Climate Change Adaptation Research Facility — University of the Sunshine Coast Sustainability Research Centre — Curtin University

"Adaptive capacity and adaptive strategies in broadacre farming"

is social science research being conducted in Western Australia by

Ross Kingwell, Angela Wardell-Johnson and Lucy Anderton

DAFWA and the University of the Sunshine Coast

in association with (**ag consultant company names**).

This research is trying to find out how people farming in the Great Southern manage their enterprises.

Climate change projections indicate that this agricultural region of Western Australia will be particularly adversely affected by climate change, and evidence has already emerged that the region has experienced a warming and drying trend since the mid-1970s. It has been said that the region potentially acts as a climate canary for broadacre agriculture in southern Australia. Agriculturally the region is economically important, generating up to almost 40 percent of Australia's cereal production.

Assessing the adaptive capacity of these broadacre farms will involve drawing on unique, detailed longitudinal farm datasets. Agricultural consulting firms with farm business clients in the region will provide relevant longitudinal farm business data. These datasets, allowing the adaptive capacity of each farm business to be tracked through time and for their adaptation strategies to be noted and compared. Productivity and profitability measures for each farm will also be determined.

Complementing these physical and financial datasets of farm businesses will be socio-economic and managerial assessments that, identify socio-economic and managerial traits linked to farm performance and adaptive capacity. Data provides farmer demographics, their information sources and business attitudes, their goals and motivations, and their control over and management of their farm business.

All information provided through this research will remain **confidential** to the research team. All information provided by consultants will be coded with only general information on sectors.

Recommendations that arise from this research will be presented in the form of **aggregated** information that cannot be traced back to individuals or businesses. This provides participants with the opportunity to be clear in their responses without fear of exposure.

A **summary** of the research results will be made available to all interested study participants.

Reporting to the wider community will be as a joint effort between members of the NCCARF Broadacre and Adaptation Research team. In addition, academic papers will provide the results from this work to the wider academic community.

This study has been cleared by human **ethics committees** of the University of Sunshine Coast in accordance with the Australian National Health and Medical Research Council's guidelines. Participation in this study can be discussed with project staff contactable on the phone numbers provided here.

Participation in each survey will require up to 15 minutes of your time. **Please note:**

- Taking part is voluntary and you can withdraw at any time without any consequences.
- Your withdrawal will not affect you in any way. Should you wish us to destroy the records we will do so.
- This interview and questionnaire are confidential and your privacy is respected at all times.
- Any information that could identify you will be removed.
- The researcher has signed a confidentiality form and cannot share information about you with any person outside the research team.
- All information will be stored then for the period of analysis then destroyed.

Program contact is: *Dr Angela Wardell-Johnson*

University of the Sunshine Coast (mob) +61 (0)401 364 817 or Awardell@usc.edu.au.

Prof Ross Kingwell, DAFWA 08 93683225; *Lucy Anderton*, DAFWA 08 98928449.

Client Number:

"Adaptive capacity and adaptive strategies in broadacre farming": a survey.

1. CLIENT'S PROFILE (THE FARMING ENTERPRISE) CIRCLE category

Members	Relationship	Age	Country Of Origin	Level of formal education	No Of Dependents	Age Of Dependents	Years In Agriculture	Years On Property	Days per week WORK on property	Days per week LIVE on property
PRIMARY MALE		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		
PRIMARY FEMALE		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		
SECONDARY MALE (FATHER/ SON/ BROTHER ETC)		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		
SECONDARY FEMALE (MOTHER/ SISTER/ DAUGHTER ETC)		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		
OTHER FAMILY MEMBERS		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		
OTHER FAMILY MEMBERS		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		
OTHER PARTNERS		18-30 30-45 45-60 60-70 70+		TertiaryUni TertiaryTech Secondary Primary		0–5 5–13 13–18 18–25 25–70 70+	0-5 5-10 10-20 20+	0-5 5-10 10-20 20+		

Client Number:

2. ENTERPRISE TRAINING THROUGH PRIVATE AND INDUSTRY SECTOR

Please circle relevant categories; if more than one training instance per category write number next to circled category: i.e.: (PM) 2

CODING:

PRIMARY MALE	PM
PRIMARY FEMALE	PF
SECONDARY MALE (FATHER/ SON/ BROTHER ETC)	SM
SECONDARY FEMALE (MOTHER/ SISTER/ DAUGHTER ETC)	SF
FAMILY MEMBERS	FM
OTHER FAMILY MEMBERS	OFM
OTHER PARTNERS	OP

INDUSTRY BASED TRAINING/ EDUCATION	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	OTHER	NAME TRAINING
CROP SPECIFIC	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
LIVESTOCK SPECIFIC	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
COMMODITY MARKETING	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
FINANCE OR BUSINESS MANAGEMENT	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
RELEVANT TO LANDCARE & NRM	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
OTHER INDUSTRY TRAINING	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	

Client Number:

Department of Agriculture and Food · NCCARF National Climate Change Adaptation Research Facility · University of the Sunshine Coast Sustainability Research Centre · Curtin University

3. ENTERPRISE TRAINING THROUGH GOVERNMENT SECTOR

(local, state or federal government department, government supported/ initiated, TAFE or other)

Please circle relevant categories; if more than one training instance per category write number next to circled category: i.e.: (PM) 2

CODING:

PRIMARY MALE	PM
PRIMARY FEMALE	PF
SECONDARY MALE (FATHER/ SON/ BROTHER ETC)	SM
SECONDARY FEMALE (MOTHER/ SISTER/ DAUGHTER ETC)	SF
FAMILY MEMBERS	FM
OTHER FAMILY MEMBERS	OFM
OTHER PARTNERS	OP

GOV BASED TRAINING/ EDUCATION	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	OTHER	NAME TRAINING
GOV BASED STRATEGIC PLANNING	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
GOV BASED MARKETING	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
GOV BASED BUSINESS	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
GOV BASED NRM & LANDCARE	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
GOV BASED CROP / LIVESTOCK MANAGEMENT	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	
OTHER GOV BASED TRAINING	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	PM PF SM SF FM OFM OP	

Client Number:

4. INNOVATIONS IN LAND MANAGEMENT ENTERPRISE

What **LAND MANAGEMENT** innovation has your client undertaken in recent years?

INNOVATION	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	CONTINUES TO USE
Soil testing				YES NO
Applying lime/gypsum				YES NO
Salt bush/perennial plantings (not for grazing)				YES NO
Use of deep rooted perennials (lucerne) for water table management				YES NO
Fencing remnant vegetation				YES NO
Planting trees (income stream)				YES NO
Planting trees (management of salinity)				YES NO
Fencing creek lines/waterways				YES NO
Surface water management strategies				YES NO
Deep drains				YES NO
Other				YES NO

5. INNOVATIONS IN CROPPING ENTERPRISE

What **CROPPING** innovation has your client undertaken in recent years?

INNOVATION	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	CONTINUES TO USE
Use of Minimum Till techniques				YES NO
Air seeder				YES NO
Herbicide resistance testing				YES NO
Strategic seeding for weed control/frost management				YES NO
Press wheels				YES NO
Double row burning				YES NO
Chaff carts				YES NO
Strategic seeding to minimise weed burden				YES NO
Pasture phases to reduce weed burden				YES NO
Green manuring				YES NO
Variable rate technology (automated)				YES NO
Yield monitor maps				YES NO
Other				YES NO

5

Client Number:

6. INNOVATIONS IN LIVESTOCK ENTERPRISE

What **LIVESTOCK** innovation has your client undertaken in recent years?

INNOVATION	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	CONTINUES TO USE
Pregnancy scanning				YES NO
Worm resistance testing				YES NO
Deferred grazing management				YES NO
Monitoring of Food on Offer (FOO)				YES NO
Using pastures from space technology				YES NO
Rotational grazing (moving stock 3 to 5 days)				YES NO
Grazing crops				YES NO
Feed budgeting				YES NO
Condition scoring ewes to manage feed requirements				YES NO
Finishing animals in lot feed (lambs or cattle)				YES NO
Use of estimated breeding values (EBV)				YES NO
Planting/using perennial grasses				YES NO
Planting salt bush for grazing				YES NO
Other				YES NO

7. INNOVATIONS IN BUSINESS ENTERPRISE

What **BUSINESS MANAGEMENT** innovation has your client undertaken in recent years?

INNOVATION	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	CONTINUES TO USE
Leasing additional properties				YES NO
Share farming				YES NO
Contractors (Using contractors)				YES NO
Contracting machinery (contracting their services to others)				YES NO
Funding (such as AACL)				YES NO
Succession planning				YES NO
Superfunds etc				YES NO
FMD's				YES NO
Off –farm assets				YES NO

6

8. TECHNOLOGY IN ENTERPRISE

What **TECHNOLOGY** has your client adopted in recent years?

	PAST 1 YEAR	PAST 5 YEARS	PAST 10 YEARS	CONTINUED TO USE	NAME TECHNOLOGICAL APPLICATION
Business management computer package (eg Agrimaster, Quickbooks, MYOB)				YES NO	
Marketing strategies (eg forward selling in grain)				YES NO	
Decision support tools (eg. seasonal forecasting; weed seed wizard; APSIM; Lambplanner)				YES NO	
Precision agriculture technology (e.g. Variable rate technology maps and managing inputs or EM38 mapping of salinity)				YES NO	
Electronic Paddock recording system				YES NO	
Electronic Livestock recording system				YES NO	
Using GPS				YES NO	
Livestock management technology (e.g. electronic ear tags)				YES NO	
Other				YES NO	

9. What level of business acumen do they apply? And what risk management strategies do they implement?

			IMPLEMENTED WITHIN PAST 5 YEARS	
External labour used: NUMBER?	YES	NO	YES	NO
Contracted crops/ livestock/ production	YES	NO	YES	NO
Occupational Health and Safety Plan (documented)	YES	NO	YES	NO
Safety equipment provided/ in use? (eye protection, ear muffs, sunscreen etc)	YES	NO	YES	NO
Fire management plan/ emergency management plan (documented)	YES	NO	YES	NO
Succession management plan	YES	NO	YES	NO
Family or Farm house in other regional centre or location	YES	NO	YES	NO
Other	YES	NO	YES	NO

Client Number:

10. Please rank your client's **ORGANISATIONAL AND TIME MANAGEMENT** capacity where 1 is low and 5 is high.

	RANKING	IMPROVEMENT OVER PAST 10 YEARS	
Is their seeding equipment ready to go at the break of the season?	1=low 2 3 4 5=high	YES NO	Unknown
Is the header serviced and ready to go at harvest?	1=low 2 3 4 5=high	YES NO	Unknown
Is the header cleaned and put away as soon as harvest is finished?	1=low 2 3 4 5=high	YES NO	Unknown
Do they regularly service their tractors?	1=low 2 3 4 5=high	YES NO	Unknown
How do you rate their plant and machinery care?	1=low 2 3 4 5=high	YES NO	Unknown
Do they take an annual holiday and/or regular breaks	1=low 2 3 4 5=high	YES NO	Unknown
Labour management?	1=low 2 3 4 5=high	YES NO	Unknown
Work-life balance?	1=low 2 3 4 5=high	YES NO	Unknown
Separate home from office?	1=low 2 3 4 5=high	YES NO	Unknown
Is your client involved in the local community?	1=low 2 3 4 5=high	YES NO	Unknown
Does your client play sport locally?	1=low 2 3 4 5=high	YES NO	Unknown
Other (please comment)	1=low 2 3 4 5=high	YES NO	Unknown

That completes the survey, thanks for your input.

If you would like a summary of the research once it is completed please complete the attached form.

Program contact is:

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Appendix 3: Productivity concepts and measurement

Total Factor Productivity Indexes

This study uses the Färe-Primont index to compute and decompose total factor productivity (TFP) into a measure of technical change and several measures of efficiency change over the study period 2002 to 2011. Consider a dataset on N firms over T time periods where:

$x_{it} = (x_{1it}, \ldots, x_{Kit})'$ and

$q_{it} = (q_{1it}, \ldots, q_{Jit})'$ are the input and output quantity vectors for firm *i* in period *t*.

Then the TFP can be defined as:

$$\mathrm{TFP}_{it} = \mathrm{Q}_{it}/\mathrm{X}_{it} \qquad \text{(A3.1)}$$

where $\mathrm{Q}_{it} = \mathrm{Q}(\mathrm{q}_{it})$ and $\mathrm{X}_{it} = \mathrm{X}(\mathrm{x}_{it})$ are aggregate output and aggregate input, respectively, and $\mathrm{Q}(.)$ and $\mathrm{X}(.)$ are non-negative, non-decreasing and linearly-homogenous aggregator functions. With these definitions, the productivity index that compares the TFP of firm *i* in period *t* with the TFP of firm *h* in period *s* is:

$$\mathrm{TFP}_{hs,it} = \frac{\mathrm{TFP}_{it}}{\mathrm{TFP}_{hs}} = \frac{\mathrm{Q}_{it}/\mathrm{X}_{it}}{\mathrm{Q}_{hs}/\mathrm{X}_{hs}} = \frac{\mathrm{Q}_{hs,it}}{\mathrm{X}_{hs,it}} \qquad \text{(A3.2)}$$

where $\mathrm{Q}_{hs,it} = \mathrm{Q}_{it}/\mathrm{Q}_{hs}$ and $\mathrm{X}_{hs,it} = \mathrm{X}_{it}/\mathrm{X}_{hs}$ are output quantity index and input quantity index respectively. Thus, equation (A3.2) shows that changes in TFP can be obtained by dividing an index of output by an index of input, which is said to be multiplicatively complete (O'Donnell, 2012a) and, which is how most economists define relative productivity (Jorgenson and Griliches, 1967).

Now, different choices of functional forms for the aggregator functions, $Q(.)$ and $X(.)$, produces different multiplicatively complete indexes. For example, the Färe-Primont index is a member of a class of "multiplicatively complete" productivity indexes where:

$$\mathrm{TFP}_{hs,it} = \frac{\mathrm{D_O}(\mathrm{x_0}, \mathrm{q}_{it}, \mathrm{t_0})}{\mathrm{D_O}(\mathrm{x_0}, \mathrm{q}_{hs}, \mathrm{t_0})} \frac{\mathrm{D_I}(\mathrm{x}_{hs}, \mathrm{q_o}, \mathrm{t_0})}{\mathrm{D_I}(\mathrm{x}_{it}, \mathrm{q_o}, \mathrm{t_0})}. \qquad \text{(A3.3)}$$

where $\mathrm{D_O}(\mathrm{x_0}, \mathrm{q}, \mathrm{t_0})$ and $\mathrm{D_I}(\mathrm{x}, \mathrm{q_o}, \mathrm{t_0})$ are the Shephard output and input distance functions representing the production technology available in period *t*, respectively.

Efficiency Measures

Following O'Donnell (2012a) several measures of efficiency in terms of aggregate outputs are defined. These efficiency measures are also illustrated using three simple diagrams in Figures 29, 30 and 31. The efficiency measures that feature in an output-oriented decomposition of TFP change are:

Output-oriented technical efficiency (OTE), $\mathrm{OTE}_{it} = \frac{\mathrm{Q}_{it}}{\bar{\mathrm{Q}}_{it}},$ (A3.4.1)

Output-oriented scale efficiency (OSE), $\mathrm{OSE}_{it} = \frac{\bar{Q}_{it}/X_{it}}{\tilde{Q}_{it}/\tilde{X}_{it}}$, (A3.4.2)

Output-oriented mix efficiency (OME), $\mathrm{OME}_{it}=\frac{\bar{Q}_{it}}{\hat{Q}_{it}}$, (A3.4.3)

Residual output-oriented scale efficiency (ROSE), $\mathrm{ROSE}_{it}=\frac{\hat{Q}_{it}/X_{it}}{Q^{*}_{it}/X^{*}_{it}}$ an(A3.4.4)

Residual mix efficiency, (RME), $\mathrm{RME}_{it} = \frac{\tilde{Q}_{it}/\tilde{X}_{it}}{Q^{*}_{it}/X^{*}_{it}}$ (A3.4.5)

where $\bar{\mathbf{Q}}_{\mathbf{it}}$ is the maximum aggregate output that is technically feasible to produce a scalar multiple of $q_{\mathbf{it}}$ using $x_{\mathbf{it}}$; $\hat{\mathbf{Q}}_{\mathbf{it}}$ is the maximum possible aggregate output using $x_{\mathbf{it}}$ to produce any output vector; and $\tilde{Q}_{it}$ and $\tilde{X}_{it}$ denote the aggregate output and input quantities at the point where TFP is maximised subject to the constraint that the output and input vectors are scalar multiples of $q_{\mathbf{it}}$ and $x_{\mathbf{it}}$.

Figure 29 provides useful insights into technical efficiency measurement in the two-output case. The curve passing through point C is a familiar production possibilities frontier representing all technically efficient output combinations that can be produced using $x_{\mathbf{it}}$ .The dashed line passing through point A is an isoquant line that represents the same aggregate output at each point as at point A.

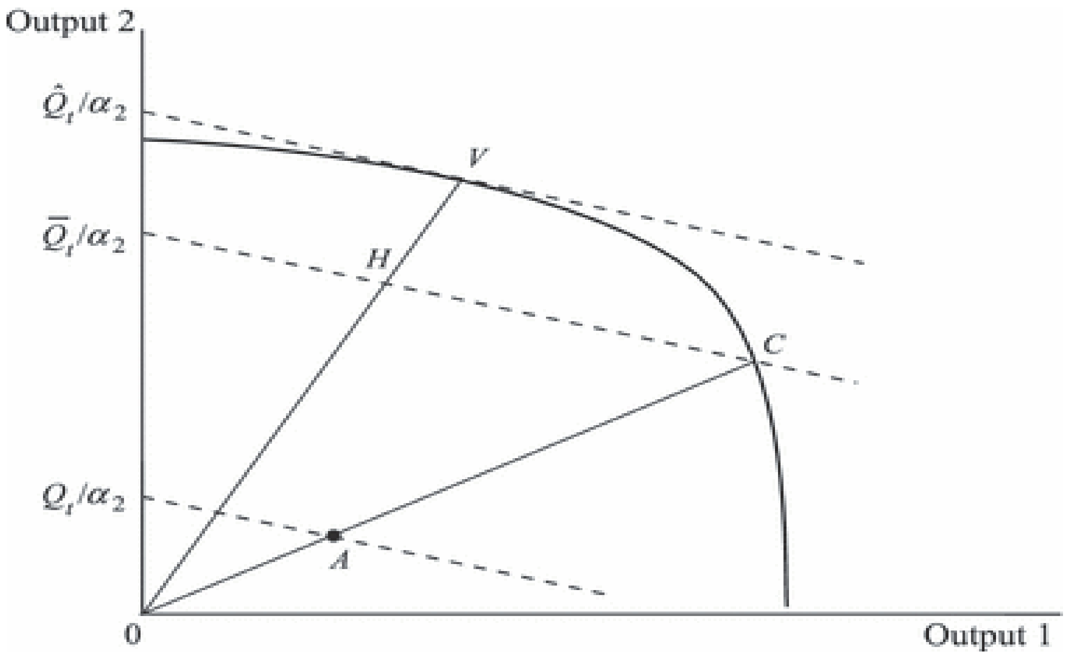

Figure A3.1: Output-oriented mix efficiency for a two-output firm Source: Adopted from O'Donnell (2010)

O'Donnell further provides an alternative graphical representation in the multiple-output multiple-input case which is drawn in Figure 30 to illustrate the relationships between measures of efficiency. In Figure 30 the curve passing through point C represents a mix-restricted frontier as the input and output vectors are scalar multiples of $\mathbf{x}_{\mathbf{nt}}$ and $\mathbf{q}_{\mathbf{nt}}$.

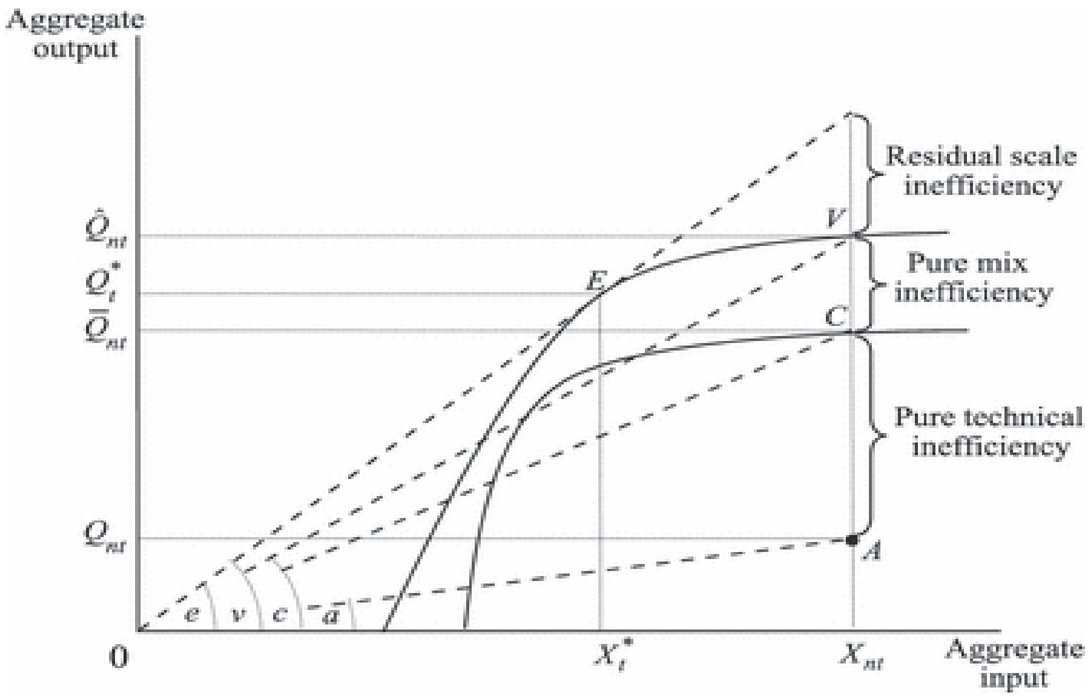

Figure A3.229: Output-oriented measures of efficiency Source: Adopted from O'Donnell (2010)

The OTE is proposed by Farrell (1957) that measures movements towards or away from the frontier. If the output mix and input vector are held fixed, then the ratio of the distance 0A and 0C in Figure 29 is the measure of OTE. Similarly, in Figure 30 the measure OTE represents the proportionate increase in TFP when the firm moves from point A to point C on the restricted frontier. If restrictions on output mix are relaxed firm can further increase aggregate output by moving to point V in Figure 29 which corresponds to a vertical movement from point C to point V in Figure 30. This potential change in productivity is termed as the OME which can be defined as the ratio of the distance 0H to the distance 0V in Figure 29. Thus, the measure OME shows the increase in TFP while holding inputs fixed and relaxing restrictions on output mix. However, improvements in technical and mix efficiency do not maximise productivity of firm. Firm can maximise productivity by moving around the unrestricted frontier from point V to point E in Figure 30. The point E is referred as point of maximum productivity. O'Donnell termed this potential productivity gains as ROSE that can be achieved through economies of scale.

Further, O'Donnell presents two more output-oriented measures of efficiency OSE and RME which is depicted in Figure 31. If the input and output mixes are kept unchanged, firm can maximise its productivity by moving to point D in Figure 31. Point D is the point of mix-invariant optimal scale (MIOS). The measure of OSE is a measure of the proportionate increase in productivity that occurs as firm moves from a technically efficient point C to a MIOS point D. The measure of RME is the ratio of productivity at a MIOS point to productivity at a point of maximum productivity (MP). In Figure 31 RME is the ratio of productivity at point D on the mix-restricted frontier to TFP at point E on the unrestricted frontier.

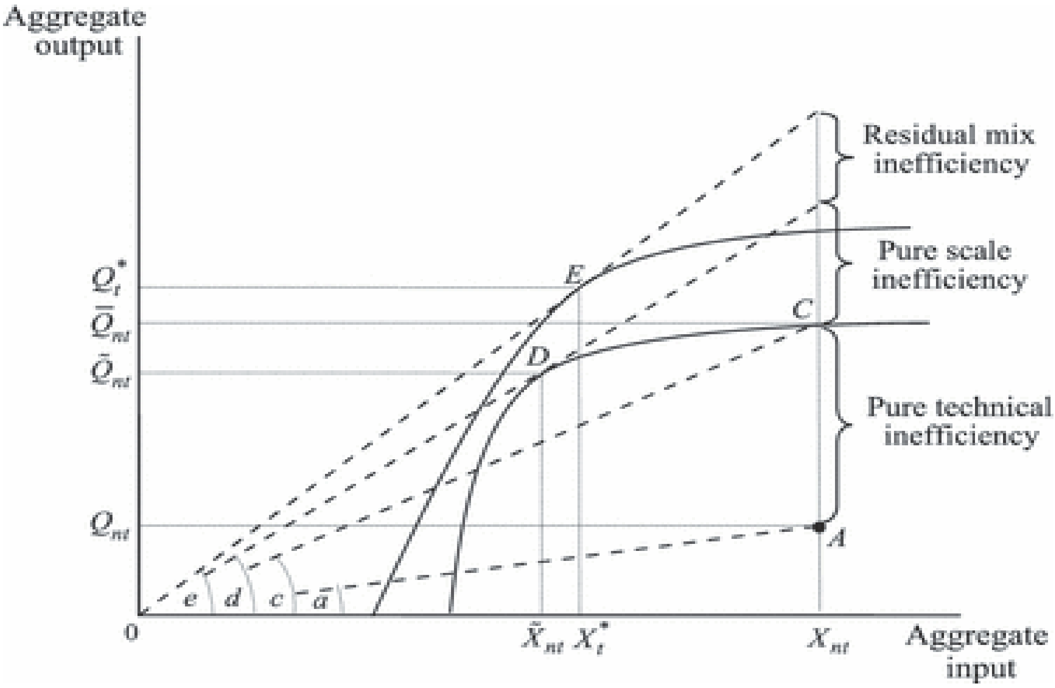

Figure A3.3: Output-oriented measures of efficiency Source: Adopted from O'Donnell (2010)

TFP efficiency

As an overall measure of firm performance, O'Donnell measures TFP efficiency (TFPE) as the ratio of observed TFP to the maximum TFP given the available technology. Mathematically, TFP efficiency of firm *i* in period *t* is:

$$\mathrm{TFPE_{it}} = \frac{\mathrm{TFP_{it}}}{\mathrm{TFP_t}^*} = \frac{\mathrm{Q_{it}/X_{it}}}{\mathrm{Q_{it}^*/X_{it}^*}} \qquad \text{(A3.5)}$$

where $\mathrm{TFP_t}^*$ indicates maximum TFP possible given technology in period t and $\mathrm{Q_t^*}$ and $\mathrm{X_t^*}$ are the TFP-maximizing aggregate output and aggregate input, respectively. This measure is represented both in Figure 30 and Figure 31 that provides two of many meaningful decompositions of TFP efficiency as the firm moves all the way from point A to point E. Then, the proportionate increase in TFP can be decomposed as:

$$\mathrm{TFPE_{it}} = \frac{\mathrm{TFP_{it}}}{\mathrm{TFP_t}^*} = \frac{\mathrm{slope0A}}{\mathrm{slope0E}} = \frac{\mathrm{slope0A}}{\mathrm{slope0C}} \times \frac{\mathrm{slope0C}}{\mathrm{slope0V}} \times \frac{\mathrm{slope0V}}{\mathrm{slope0E}} = (\mathrm{OTE_{it}} \times \mathrm{OME_{it}} \times \mathrm{ROSE_{it}}) \text{ (A3.6.a)}$$

$$\mathrm{TFPE_{it}} = \frac{\mathrm{TFP_{it}}}{\mathrm{TFP_t}^*} = \frac{\mathrm{slope0A}}{\mathrm{slope0E}} = \frac{\mathrm{slope0A}}{\mathrm{slope0C}} \times \frac{\mathrm{slope0C}}{\mathrm{slope0D}} \times \frac{\mathrm{slope0D}}{\mathrm{slope0E}} = (\mathrm{OTE_{it}} \times \mathrm{OSE_{it}} \times \mathrm{RME_{it}}). \text{ (A3.6.b)}$$

Decomposing Productivity Change

On the basis of above mentioned measures of output-oriented efficiency a multiplicatively complete TFP index can be decomposed into several meaningful components. Rewriting equation (A3.6) we can see the decomposition of output-oriented TFP index:

$$\mathrm{TFP_{it}} = \mathrm{TFP_t}^* \times (\mathrm{OTE_{it}} \times \mathrm{OME_{it}} \times \mathrm{ROSE_{it}}) = \mathrm{TFP_t}^* \times (\mathrm{OTE_{it}} \times \mathrm{OSE_{it}} \times \mathrm{RME_{it}}). \qquad \text{(A3.7)}$$

A similar decomposition holds for firm *h* in period *s*. Then, the relative TFP index comparing of TFP of firm *i* in period *t* with the TFP of firm *h* in period *s* can be decomposed exhaustively as:

$$\mathrm{TFP}_{\mathrm{hs,it}} = \frac{\mathrm{TFP}_{\mathrm{it}}}{\mathrm{TFP}_{\mathrm{hs}}} = \left(\frac{\mathrm{TFP}_{\mathrm{t}}{}^{*}}{\mathrm{TFP}_{\mathrm{s}}{}^{*}}\right) \times \left(\frac{\mathrm{OTE}_{\mathrm{it}}}{\mathrm{OTE}_{\mathrm{hs}}} \times \frac{\mathrm{OME}_{\mathrm{it}}}{\mathrm{OME}_{\mathrm{hs}}} \times \frac{\mathrm{ROSE}_{\mathrm{it}}}{\mathrm{ROSE}_{\mathrm{hs}}}\right) \qquad \text{(A3.8.a)}$$

$$\mathrm{TFP}_{\mathrm{hs,it}} = \frac{\mathrm{TFP}_{\mathrm{it}}}{\mathrm{TFP}_{\mathrm{hs}}} = \left(\frac{\mathrm{TFP}_{\mathrm{t}}{}^{*}}{\mathrm{TFP}_{\mathrm{s}}{}^{*}}\right) \times \left(\frac{\mathrm{OTE}_{\mathrm{it}}}{\mathrm{OTE}_{\mathrm{hs}}} \times \frac{\mathrm{OSE}_{\mathrm{it}}}{\mathrm{OSE}_{\mathrm{hs}}} \times \frac{\mathrm{RME}_{\mathrm{it}}}{\mathrm{RME}_{\mathrm{hs}}}\right). \qquad \text{(A3.8.b)}$$

The first term in parentheses on the right-hand side of (A3.8) is a measure of technical change, which compares the maximum TFP possible in period *t* with the maximum TFP possible in period *s*. The other terms on the right hand side of the equation (A3.8) are the different measures of output-oriented measures of efficiency such as: technical efficiency change; mix efficiency change; and residual scale efficiency change. Other two alternative components are output oriented scale efficiency and residual mix efficiency.

Appendix 4: Histograms for each transformed farm performance variable and key explanatory variables

(a)

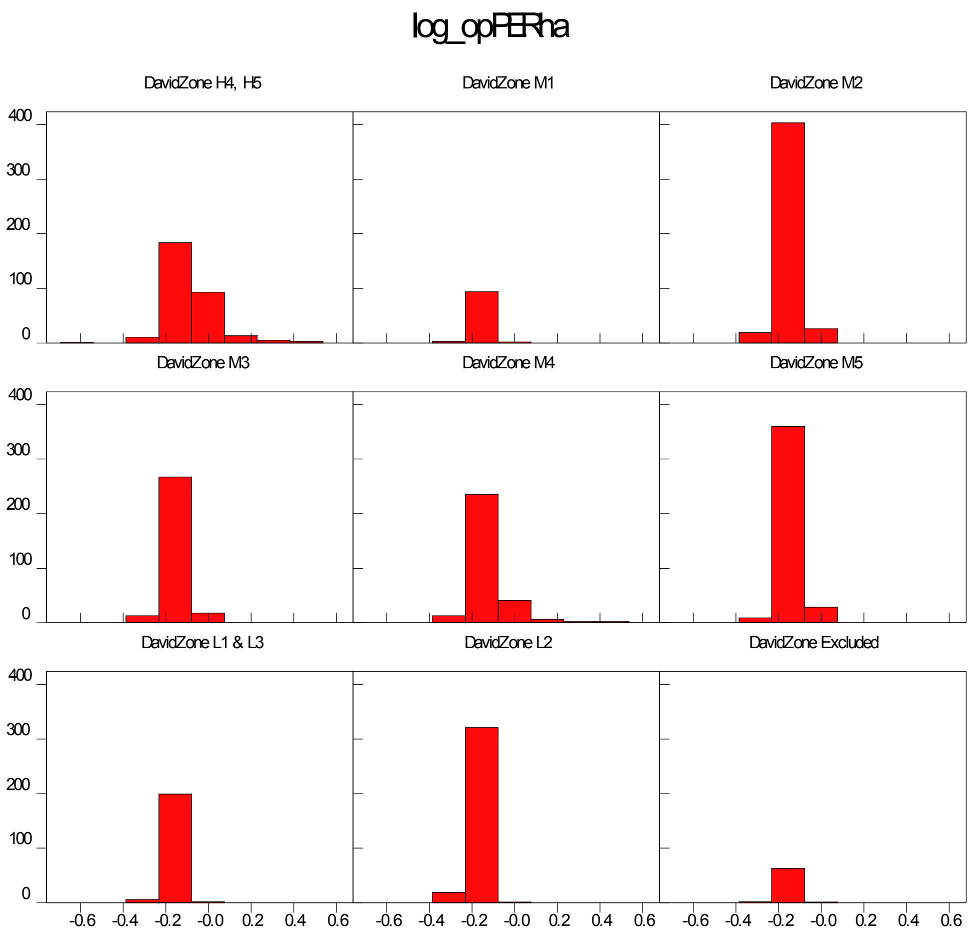

Figure A4.1: Histogram (a) log_PERha

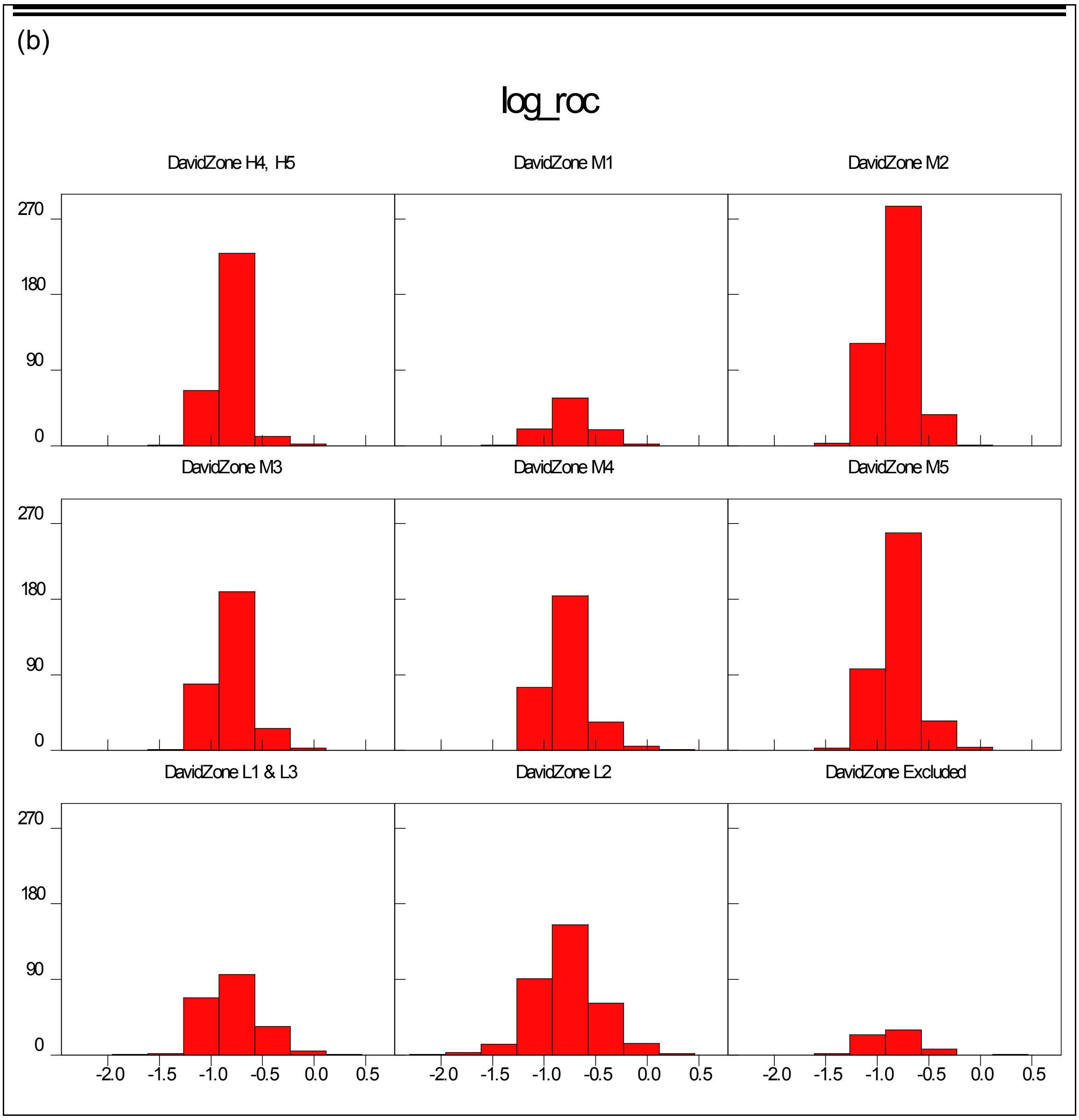

Figure A4.2: Histogram (b) log_roc

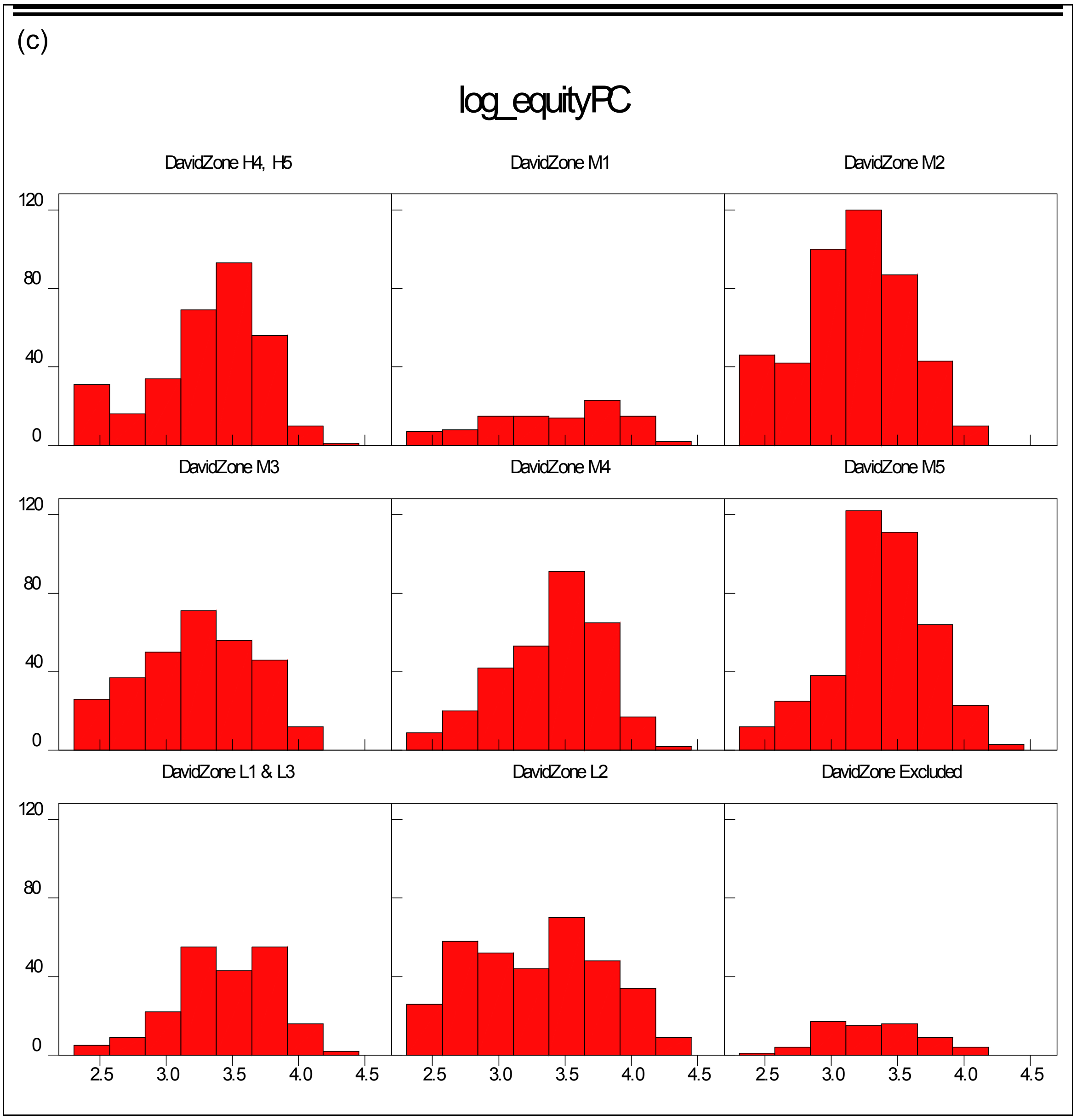

Figure A4.3: Histogram (c) log_equityPC

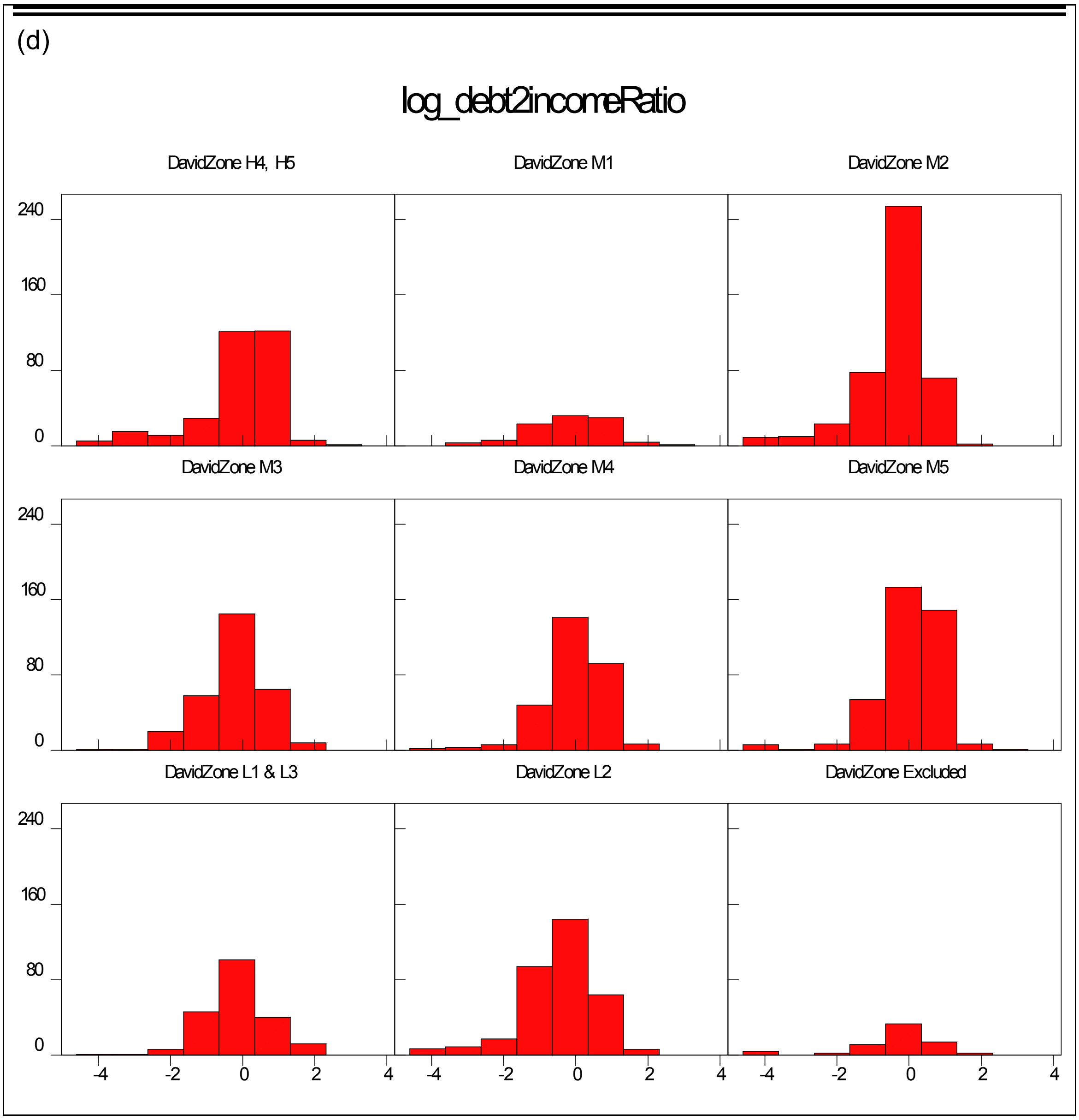

Figure A4.4: Histogram (d) log_debt2incomeRatio

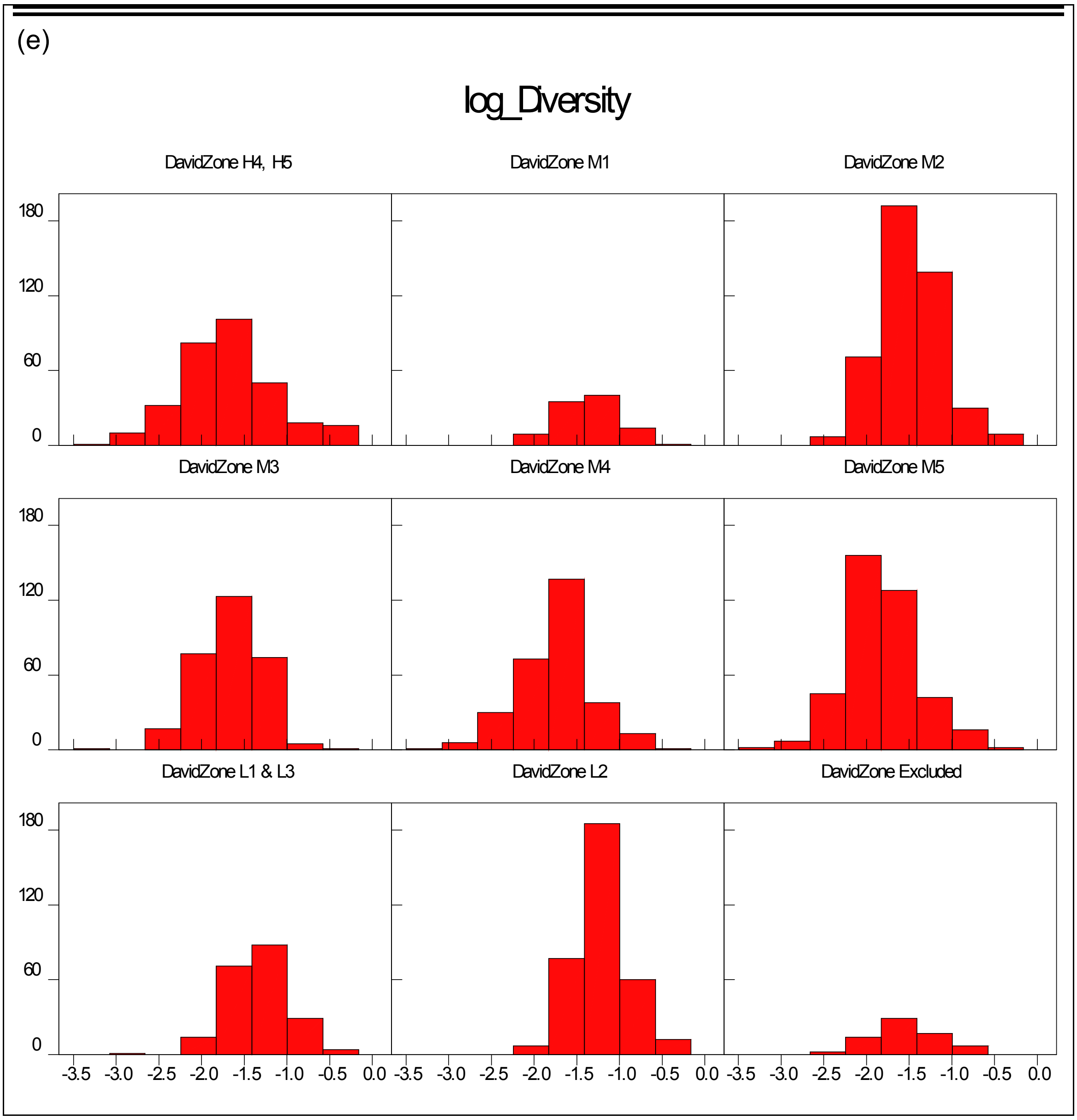

Figure A4.5: Histogram (e) log_Diversity

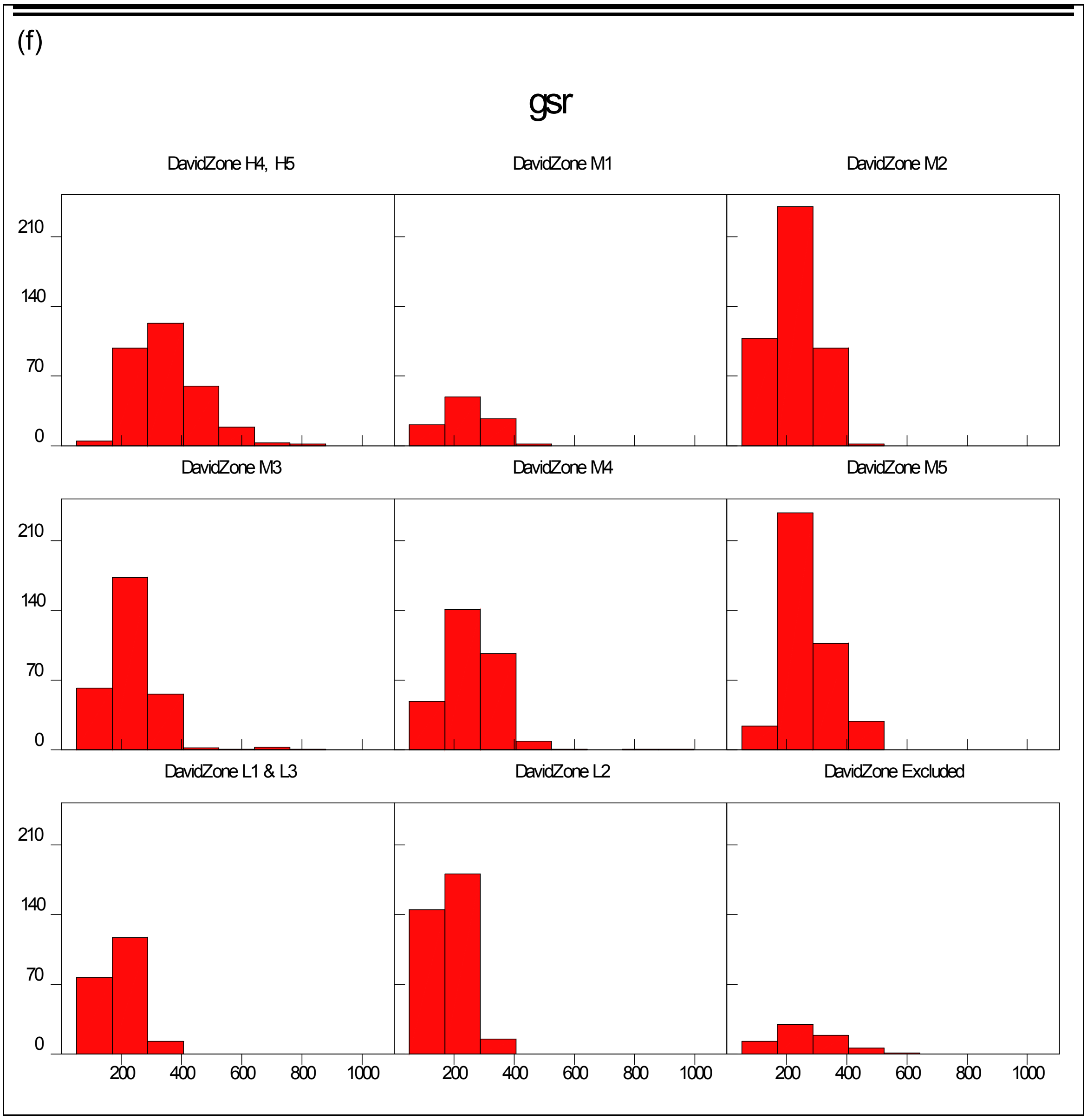

Figure A4.6: Histogram (f) gsr

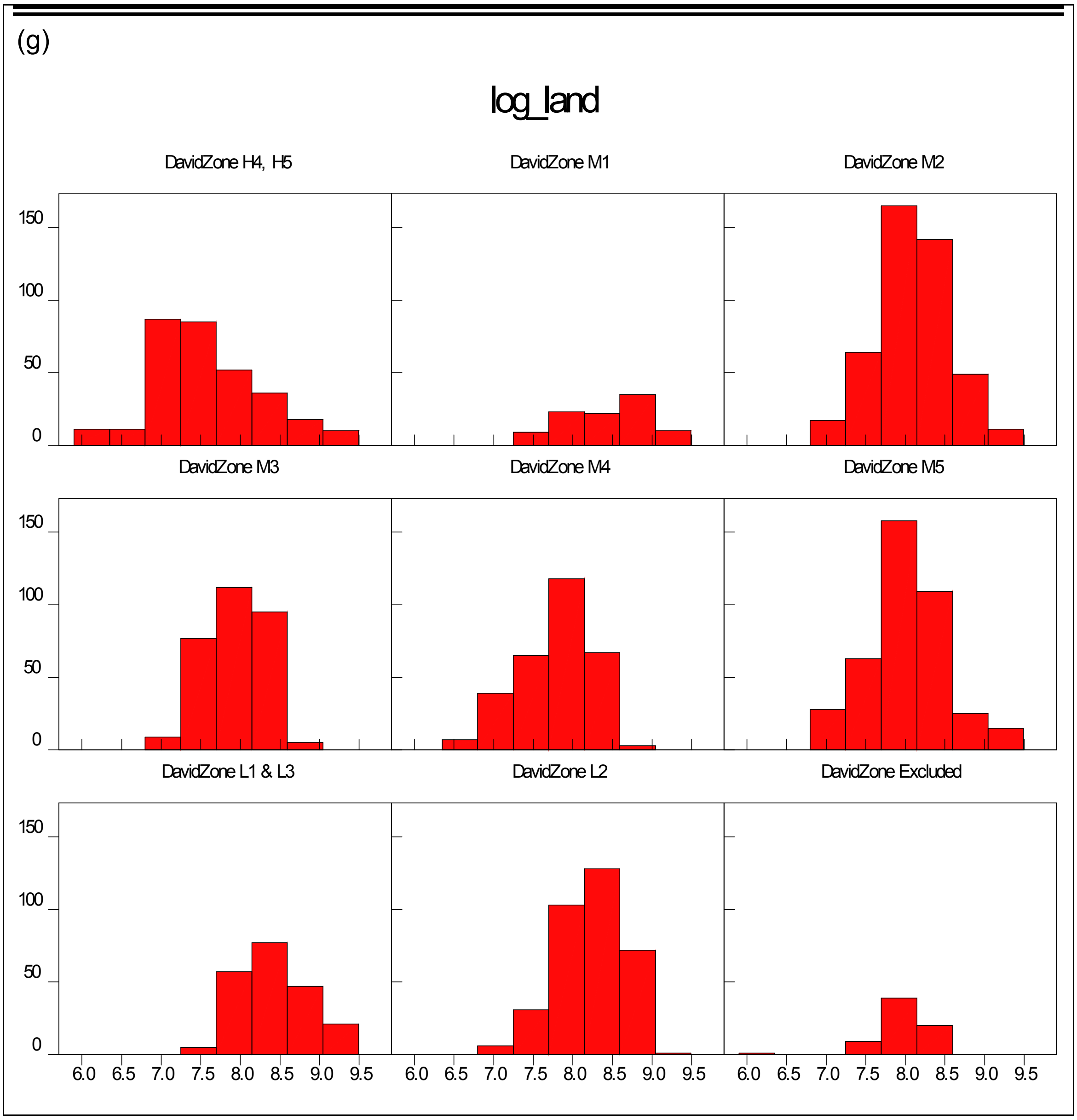

Figure A4.7: Histogram (g) log_land

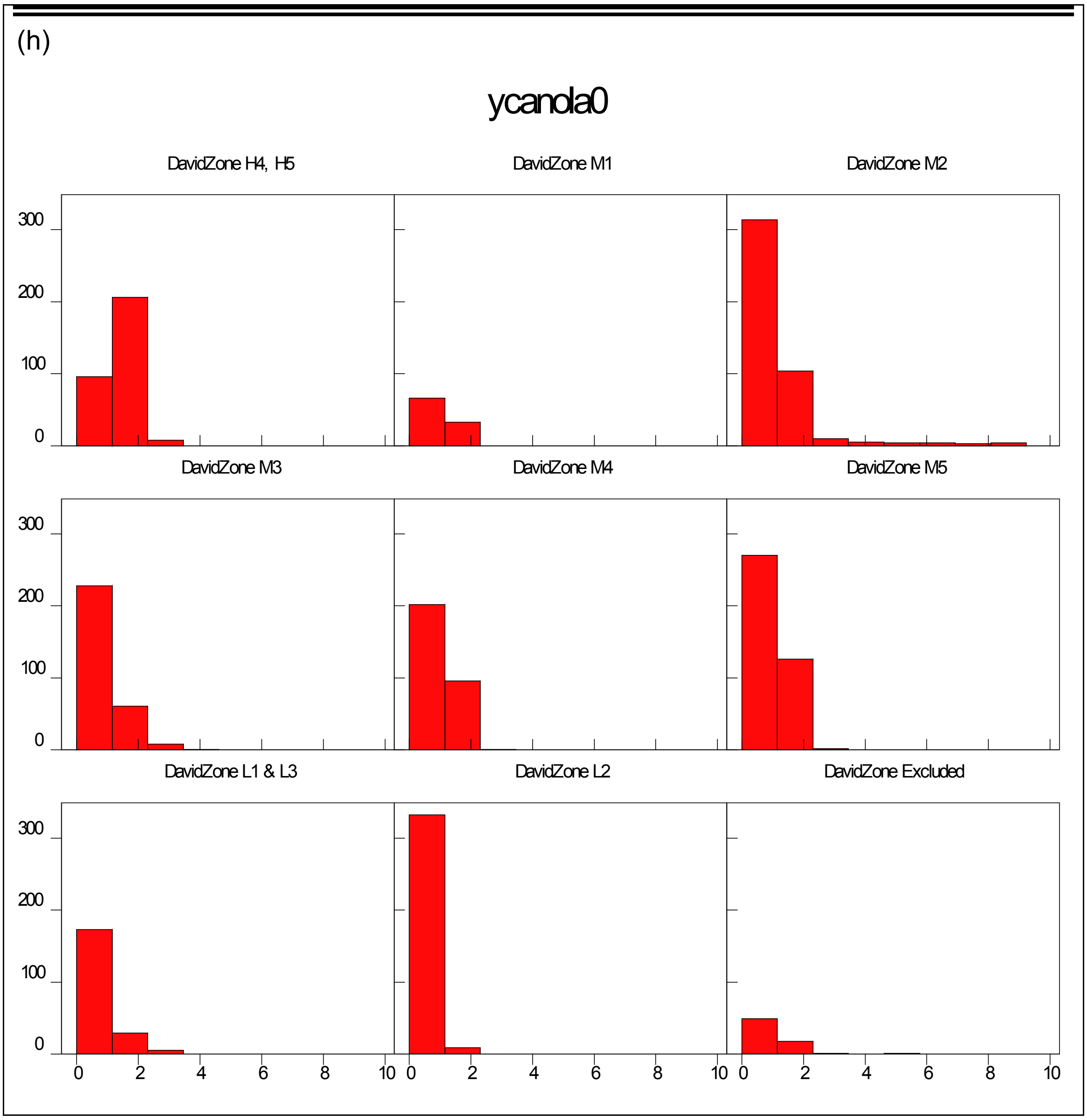

Figure A4.8: Histogram (h) log_ycanola0

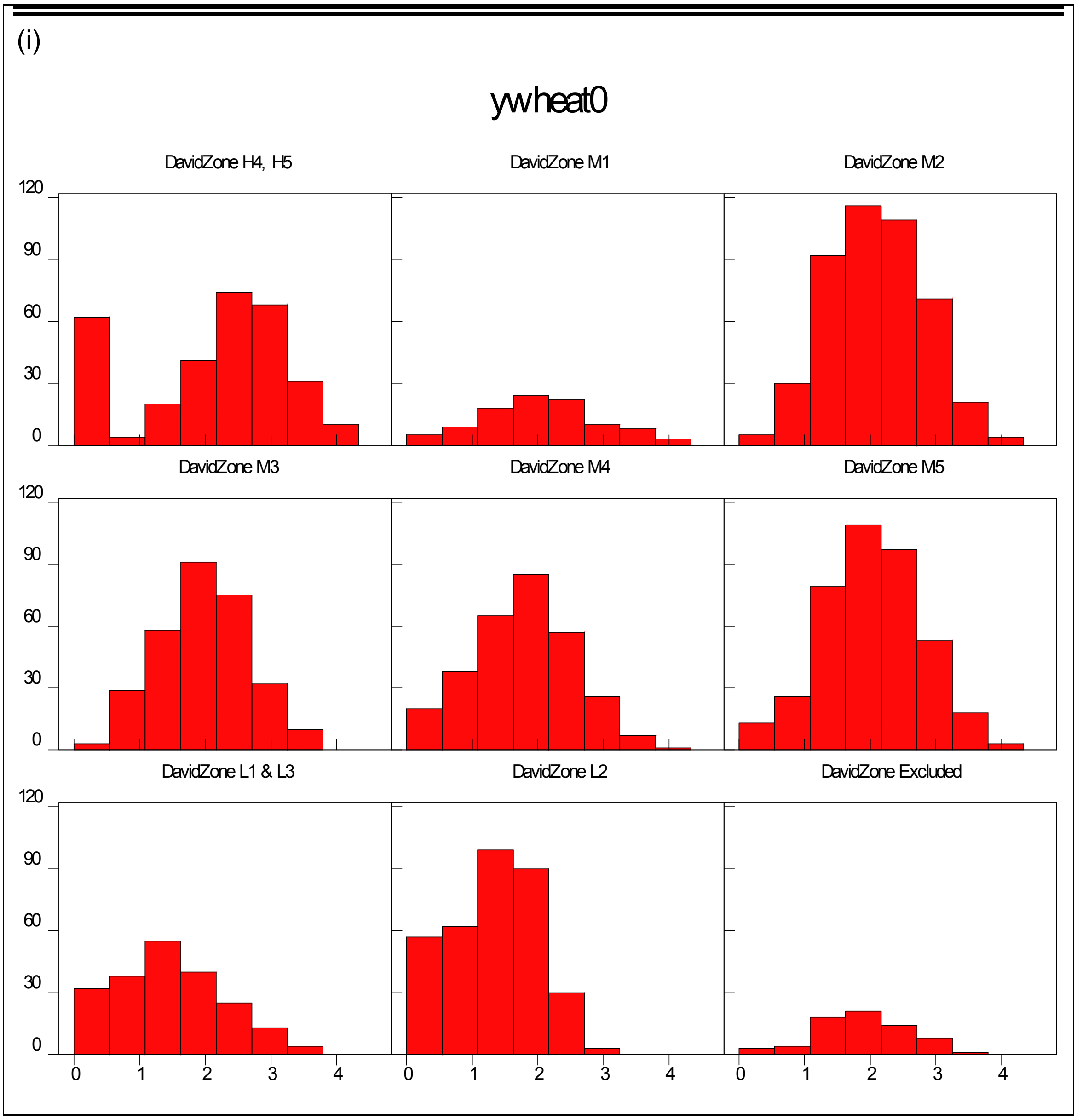

Figure A4.9: Histogram (i) ywheat0

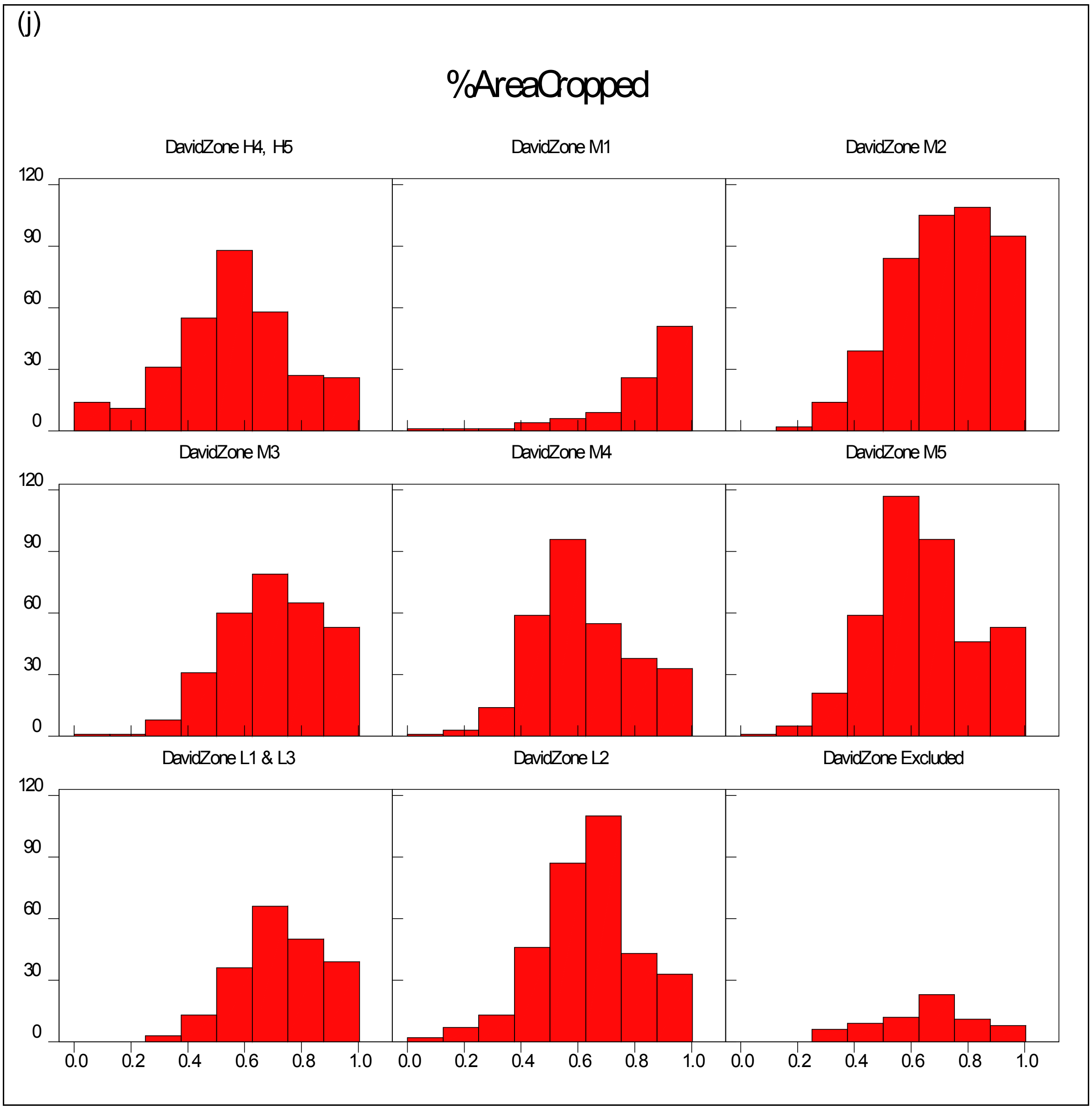

Figure A4.10: Histogram (j) %AreaCropped

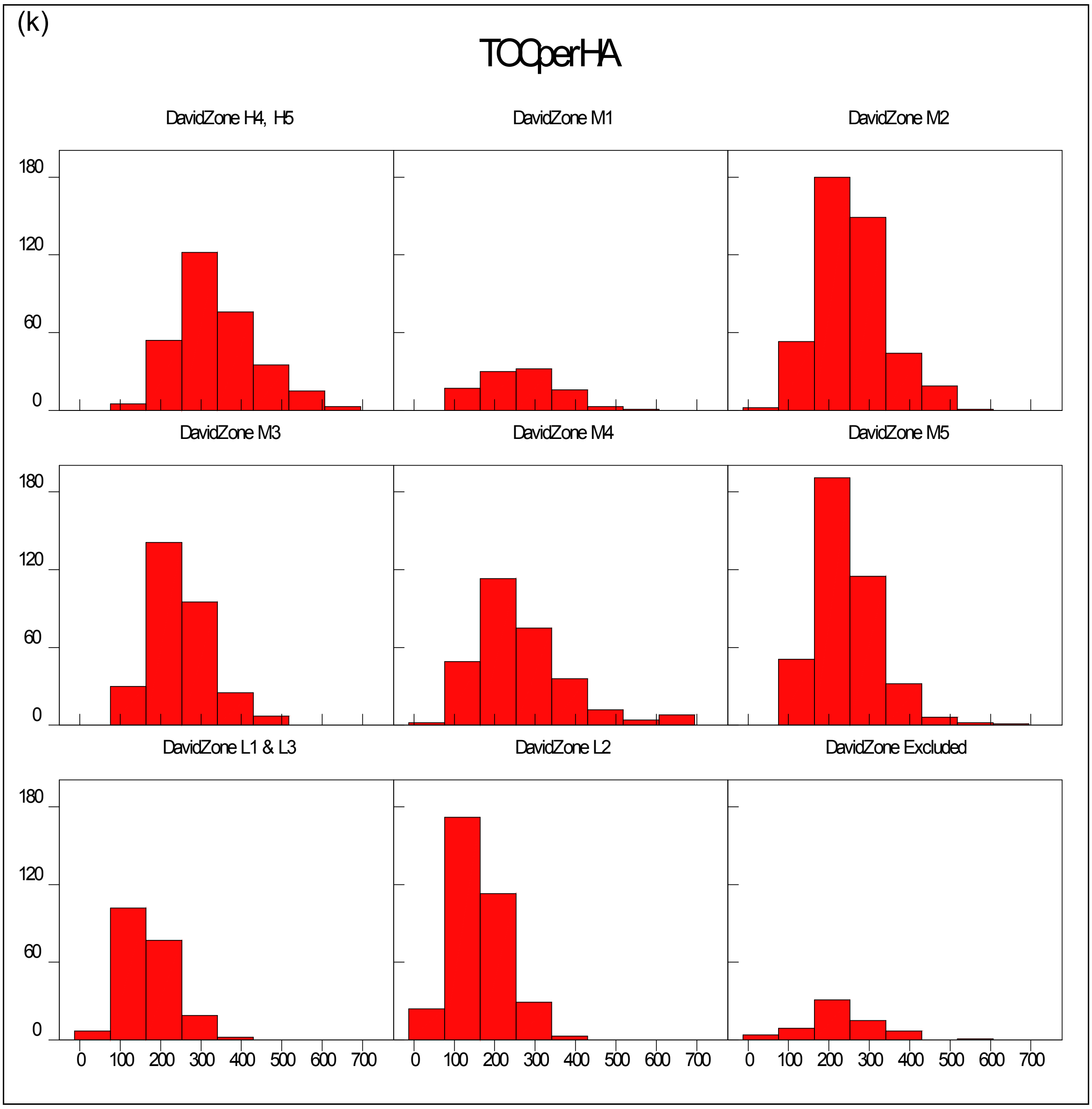

Figure A4.11: Histogram (k) TOOperHA

Appendix 5: Statistical tests of socio-managerial differences between farms grouped by farm performance category

The following tables examine the statistical tests of difference for a range of socio-managerial traits or actions undertaken by farms classed by their performance. So, for example, growing farms are compared to less secure farms to see if the differences in the farmers' actions are significant or not. Usually both one and two-tailed tests of significance are included. If the one tail test result is not significant then usually the two-tailed test result is not presented as it would similalrly be insignificant. To strengthen the validity of the tests unequal sample variances is assumed.

Table A5.1 No. of cropping innovations continuing to be used if adopted during the last 10 years

t-Tests: Two-Sample Assuming Unequal Variances		
No. of cropping innovations continuing to be used if adopted during the last 10 years		
	Growing	*Less secure*
Mean	8.1882353	7.40909091
Variance	3.4641457	5.73572939
Observations	85	44
Hypothesized Mean Difference	0	
df	71	
t Stat	1.8835516	
P(T<=t) one-tail	0.0318606	
t Critical one-tail	1.6665997	
P(T<=t) two-tail	0.0637213	
t Critical two-tail	1.9939433	
	Growing	*Secure*
Mean	8.1882353	7.5
Variance	3.4641457	4.25471698
Observations	85	54
Hypothesized Mean Difference	0	
df	104	

t Stat	1.9905356	
P(T<=t) one-tail	0.0245779	
t Critical one-tail	1.6596374	
P(T<=t) two-tail	0.0491557	
t Critical two-tail	1.9830375	
	Growing	*Strong*
Mean	8.1882353	7.70588235
Variance	3.4641457	2.51693405
Observations	85	34
Hypothesized Mean Difference	0	
df	71	
t Stat	1.4237305	
P(T<=t) one-tail	0.0794522	
t Critical one-tail	1.6665997	
P(T<=t) two-tail	0.1589044	
t Critical two-tail	1.9939433	

Table A5.2 Use of leasing, contractors, super funds, succession planning, FMDs, off-farm assets

t-Test: Two-Sample Assuming Unequal Variances		
Use of leasing, contractors, super funds, succession planning, FMDs, off-farm assets		
	Growing	*Less secure*
Mean	3.964706	2.977272727
Variance	1.986835	2.673890063
Observations	85	44
Hypothesized Mean Difference	0	
df	77	
t Stat	3.404036	
P(T<=t) one-tail	0.000528	
t Critical one-tail	1.664885	
P(T<=t) two-tail	0.001057	
t Critical two-tail	1.991254	
	Growing	*Secure*
Mean	3.964706	3.388888889
Variance	1.986835	2.619496855
Observations	85	54
Hypothesized Mean Difference	0	
df	102	
t Stat	2.147678	
P(T<=t) one-tail	0.017054	
t Critical one-tail	1.65993	
P(T<=t) two-tail	0.034108	
t Critical two-tail	1.983495	
	Growing	*Strong*

Mean	3.964706	3.617647059
Variance	1.986835	1.758467023
Observations	85	34
Hypothesized Mean Difference	0	
df	64	
t Stat	1.266485	
P(T<=t) one-tail	0.104965	
t Critical one-tail	1.669013	
	Strong	*Less secure*
Mean	3.617647	2.977272727
Variance	1.758467	2.673890063
Observations	34	44
Hypothesized Mean Difference	0	
df	76	
t Stat	1.909314	
P(T<=t) one-tail	0.029998	
t Critical one-tail	1.665151	
P(T<=t) two-tail	0.059996	
t Critical two-tail	1.991673	

Table A5.3 Use of farm business software, marketing strategies, decision support tools, precision ag technology, electronic paddock recording, GPS technology

t-Test: Two-Sample Assuming Unequal Variances		
Use of farm business software, marketing strategies, decision support tools, precision ag technology, electronic paddock recording, GPS technology		
	Growing	*Less secure*
Mean	3.670588235	3.272727273
Variance	1.271148459	1.458773784
Observations	85	44
Hypothesized Mean Difference	0	
df	82	
t Stat	1.813926981	
P(T<=t) one-tail	0.036673433	
t Critical one-tail	1.663649185	
P(T<=t) two-tail	0.073346865	
t Critical two-tail	1.989318521	
	Growing	*Secure*
Mean	3.670588235	3.518518519
Variance	1.271148459	1.461914745
Observations	85	54
Hypothesized Mean Difference	0	
df	107	
t Stat	0.74178423	
P(T<=t) one-tail	0.229921591	
t Critical one-tail	1.659219312	
	Growing	*Strong*
Mean	3.670588235	3.529411765

Variance	1.271148459	1.10516934
Observations	85	34
Hypothesized Mean Difference	0	
df	65	
t Stat	0.648037251	
P(T<=t) one-tail	0.25962175	
t Critical one-tail	1.668635976	
	Strong	*Less secure*
Mean	3.529411765	3.272727273
Variance	1.10516934	1.458773784
Observations	34	44
Hypothesized Mean Difference	0	
df	75	
t Stat	1.001734727	
P(T<=t) one-tail	0.159846395	
t Critical one-tail	1.665425374	
P(T<=t) two-tail	0.319692789	
t Critical two-tail	1.992102124	

Table A5.4 Age of primary male

t-Test: Two-Sample Assuming Equal Variances		
Age of primary male		
	Growing	*Less secure*
Mean	50.5	50.54545455
Variance	89.70988	108.2071882
Observations	82	44
Pooled Variance	96.12427	
df	124	
t Stat	-0.02481	
P(T<=t) one-tail	0.490124	
t Critical one-tail	1.657235	
	Growing	*Secure*
Mean	50.5	44.98148148
Variance	89.70988	98.28266946
Observations	82	54
Pooled Variance	93.10061	
df	134	
t Stat	3.263477	
P(T<=t) one-tail	0.000698	
t Critical one-tail	1.656305	
P(T<=t) two-tail	0.001397	
t Critical two-tail	1.977826	
	Growing	*Strong*
Mean	50.5	50.78787879
Variance	89.70988	74.10984848
Observations	82	33

Pooled Variance	85.29217	
df	113	
t Stat	-0.15121	
P(T<=t) one-tail	0.440041	
t Critical one-tail	1.65845	
	Strong	*Secure*
Mean	50.78788	44.98148148
Variance	74.10985	98.28266946
Observations	33	54
Pooled Variance	89.18231	
df	85	
t Stat	2.782669	
P(T<=t) one-tail	0.003321	
t Critical one-tail	1.662979	
P(T<=t) two-tail	0.006641	
t Critical two-tail	1.988268	

Table A5.5 Quality of care for cropping gear

t-Test: Two-Sample Assuming Unequal Variances		
Quality of care for cropping gear		
	Growing	*Less secure*
Mean	22.35294	19.295455
Variance	20.73109	28.44556
Observations	85	44
Hypothesized Mean Difference	0	
df	76	
t Stat	3.240228	
P(T<=t) one-tail	0.000887	
t Critical one-tail	1.665151	
P(T<=t) two-tail	0.001773	
t Critical two-tail	1.991673	
	Growing	*Secure*
Mean	22.35294	20.666667
Variance	20.73109	16.075472
Observations	85	54
Hypothesized Mean Difference	0	
df	123	
t Stat	2.29136	
P(T<=t) one-tail	0.011822	
t Critical one-tail	1.657336	
P(T<=t) two-tail	0.023644	
t Critical two-tail	1.979439	
	Growing	*Strong*
Mean	22.35294	20.558824

Variance	20.73109	19.890374
Observations	85	34
Hypothesized Mean Difference	0	
df	62	
t Stat	1.970599	
P(T<=t) one-tail	0.026619	
t Critical one-tail	1.669804	
P(T<=t) two-tail	0.053239	
t Critical two-tail	1.998971	

	Strong	*Less secure*
Mean	20.55882	19.295455
Variance	19.89037	28.44556
Observations	34	44
Hypothesized Mean Difference	0	
df	75	
t Stat	1.138447	
P(T<=t) one-tail	0.129279	
t Critical one-tail	1.665425	
P(T<=t) two-tail	0.258557	
t Critical two-tail	1.992102	

Table A5.6 Community involvement and personal care

t-Test: Two-Sample Assuming Unequal Variances		
Community involvement and personal care		
	Growing	*Less secure*
Mean	20.72941176	18.15909091
Variance	21.19971989	24.27642706
Observations	85	44
Hypothesized Mean Difference	0	
df	82	
t Stat	2.871650985	
P(T<=t) one-tail	0.002597601	
t Critical one-tail	1.663649185	
P(T<=t) two-tail	0.005195203	
t Critical two-tail	1.989318521	
	Growing	*Secure*
Mean	20.72941176	18.98148148
Variance	21.19971989	26.32040531
Observations	85	54
Hypothesized Mean Difference	0	
df	104	
t Stat	2.036303028	
P(T<=t) one-tail	0.022130668	
t Critical one-tail	1.659637437	
P(T<=t) two-tail	0.044261337	
t Critical two-tail	1.983037471	
	Growing	*Strong*
Mean	20.72941176	20.11764706

Variance	21.19971989	18.71301248
Observations	85	34
Hypothesized Mean Difference	0	
df	64	
t Stat	0.684063015	
P(T<=t) one-tail	0.248202457	
t Critical one-tail	1.669013026	
	Strong	*Less secure*
Mean	20.11764706	18.15909091
Variance	18.71301248	24.27642706
Observations	34	44
Hypothesized Mean Difference	0	
df	75	
t Stat	1.865613366	
P(T<=t) one-tail	0.033003057	
t Critical one-tail	1.665425374	
P(T<=t) two-tail	0.066006114	
t Critical two-tail	1.992102124	

Appendix 6: Statistical methods used in analysis of socio-managerial data

The socio-managerial data was integrated with the index scores for economic viability, training, innovation use, business acumen and enterprise management. In addition, variables providing indexes for economic and enterprise success, socio-demographic descriptions of family and labour structure provided further variables to characterise farm businesses. Analysis was conducted using standard descriptive statistics (Excel) as well as numerical classification; comprising cluster analysis, multi-dimensional scaling ordination and network analysis (Wardell-Johnson 2005).

The relationships between farm businesses' socio-managerial characteristics were investigated through clustering, ordination, network analysis and statistical evaluation. Sets of enterprises were clustered according to the similarities of their characteristics. The multivariate analysis package, PATN, was used to identify these clusters within the farm business population (Belbin 1995). The analysis requires forming separating business actions or farm practices from descriptive characteristics of the farm business (e.g. cropping, livestock or mixed farming businesses). The business actions or farm practices are known as intrinsic variables whilst the others are known as extrinsic variables (or descriptive variables).

This multivariate analysis approach does not depend on a normal distribution of data or a priori decisions about the importance of specific variables (dependent and independent variables) in defining the clusters, ordination or networks. The state of the system is portrayed by the co-ordinates of farm businesses with variables characterising enterprise activities and structure in a matrix within a three dimensional space (see Wardell-Johnson 2005).

Dissimilarity between farm enterprises was based on defining and descriptive characteristics quantified using the Bray Curtis metric which range standardises data to ensure equivalent contributions are assessed (Bray and Curtis 1957). Farm businesses were clustered using unweighted pair group arithmetic averaging (UPGMA) with beta set at -0.1. This clustering strategy was space-dilating and resisted the formation of a single large group (Booth 1978). Groups of characterising variables (attribute clusters) were derived using the two-step metric (Belbin et al. 1984) with beta set at -0.1. The association between cases (forming the clusters) and their defining/ descriptive characteristics (attribute clusters) were compared using the Kruskall-Wallace test. This statistic is a non-parametric equivalent of the F-ratio and is based on the average rank of each attribute (Belbin 1995).

The dissimilarity matrix was visually presented through semi-strong hybrid multidimensional scaling ordination (SSH MDS). SSH MDS seeks to provide in few dimensions, an accurate representation of the resemblance between farm businesses on the basis of their defining and descriptive attributes. The relationship of farm businesses to innovation, training and descriptive variables with the ordination axis was evaluated using principal axis correlation (see the PCC procedure in PATN, Belbin 1995). The significance of correlation of clusters, and each defining and describing variable were assessed using randomization tests (with 100 permutations) and Monte Carlo permutations (see the MCAO procedure of PATN, Belbin 1995).

The results of the numerical classification are portrayed in a range of visual forms. Multi-dimensional scaling ordination exposes diversity in farm businesses and includes 'outliers'. This ordination provides a compact summary of the data showing co-ordinates of farm businesses with variables shown as clustered dots in abstract dimensional space. This cluster analysis demonstrates the affinities between enterprises and characterising variables to define groups into various clusters.

A minimum spanning tree (MST) shows the network of relationships between individual farm businesses (each dot) and the other members within their cluster (defined by colour). A two-way table shows the strength of relationships between individual enterprise and characterising variables. White blocks show no statistical correlation/ relationship while blue shows some relationship and black blocks show strong correlation. Row and column dendrograms portray visually the statistical clustering of farm businesses (rows) and characterising variables (columns). Overlaid statistically significant biplot vectors indicate statistically critical tensions within the enterprise clusters. Each biplot vector shows direction of correlation with ordination axes (positive association with individuals and social assemblages). Positive association is in the direction of the biplot label and emanates from the centre of the ordination space. Negative association of the variable with the individual enterprise and enterprise assemblages is in the opposite direction from the biplot vector label across ordination space. The neutral zone is in the centre of the ordination space. Only statistically significant results are shown. Thus, only ordinations with a stress level below 0.2 are shown. The ordination might be in either three dimensions or two depending on ease of interpretation for significant vectors, and of stress levels achieved.

Appendix 7: Responding to non-normality in data distributions

In the earlier section 'Categories of farm performance' in this report, a linear mixed model (LMM) was fitted to the economic measures of interest in order to investigate temporal trends for each zone and for farms within zones. These models make similar distributional assumptions to other linear models, i.e. residual errors are normally and independently distributed with common variance. In addition the same assumption is made about each set of random effects.

It was recognised that the economic measures of interest may not be normally distributed, and more importantly with respect to estimates and their standard errors, they may not have symmetrical distributions. Hence, it was decided to use the most commonly adopted response to this problem which was transforming variables where appropriate. This method has been shown to give reasonable empirical results (Arellano-Valle et al., 2005). The need to transform the variables and the success of the transformation was assessed by examining histograms of random effects and residual errors.

All economic measures of interest required transformation. Descriptions of distributions of random effects for farms, random effects for year/zone and residual errors for the transformed variables are shown in the Table 13 below.

TableA7.1 Distributional outcomes of transformed variables

Variable	*Residual errors*	*Farm effects*	*Year/zone effects*
LOG_e(opPERha-MIN(opPERha)+0.5)	√[1]	√	√
LOG_e(roc-MIN(roc)+0.1)	√	Slight positive skew	√
LOG_e((110-equityPC)	√	√	√
LOG_e(debt2incomeRatio+0.01)	Bell-shaped distribution for majority of residuals with a few low values.	Slight negative skew	√
LOG_e(0.85-Diversity)	√	√	√

[1] Bell-shaped distribution similar to a normal distribution.

Arellano-Valle et al. (2005) show that the analysis of data from a mildly skewed distribution, using a model which assumes normally distributed random effects and residual errors, leads to unbiased parameter estimates which are slightly less efficient (i.e. lower standard errors) than if a model with a more flexible representation (via the skew-normal distribution) is used. Thus we might expect that the efficiency of estimates from the linear mixed models for LOG_e(debt2incomeRatio+0.01) and, perhaps, LOG_e(roc-MIN(roc)+0.1) are less than would be achieved with a more flexible model. However, in this report the main concern is the sign associated with estimates and the relative size of estimates for different factor levels.

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