Australasian Agribusiness Perspectives
2025, Volume 28, Paper 2
ISSN: 2209-6612

Potential Economic Impacts of Climate Adaptation Research: A Case Study of the Mallee and Gippsland Regions[1]

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Abstract

The potential impact of a recent climate adaptation research project undertaken as a part of the Future Drought Fund program is explored here. The research project examined the cultivation of almonds, citrus and grapes in the Mallee region in North-west Victoria, in conjunction with potatoes and pome fruit (apples and pears), in the Gippsland region. The project was undertaken in close collaboration with key stakeholders and farmer groups in these two regions. This climate adaptation research created a novel Online Decision Support Tool (based on gross margin analysis), allowing the collaborating farmers to test the yield and output outcomes of their crops under varying climate conditions. It is asserted that this Tool can therefore be used in future planning needs to better support crop management in adapting to climate change. The Tool has been developed to be open sourced, ensuring access to the Tool is not inhibited by cost or the need for a subscription, and it has strong public good characteristics which make it suitable for important innovative farm decision-making. It is important to recognise that gross margin-based tools are widely available for farmers to use at present.

It is reasonable to assume that, because of the adoption of the Tool, the projected decline in estimates of almond, citrus, grape, potato and pome fruits yields due to climate change can be reduced subject to the extent of adoption by farmers. The Tool if used could potentially assist farmers to instigate better on-farm production decision-making, including improved resource use efficiency by altering their input mix based on predicted climate change pressures. In this context, we estimate that the gross potential benefits from climate change adaptation research in selected horticultural industries could be in the range of $199 million to $398 million per year in the short to medium term. However, of these potential gross benefits what we can attribute to our Online Decision Support Tool will depend on factors such as the share of farmers already adopting adaptation measures autonomously. Hence, potentially, only that share of the farmers who do not undertake any adaptation measures at present and who would then potentially choose to use our Online Decision Support Tool could achieve some

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[1] This project was undertaken by Deakin University's Centre for Regional and Rural Futures (CeRRF) and the University of Melbourne, in collaboration with the Mallee Regional Innovation Centre and Food and Fibre Gippsland. Funding from the Department of Agriculture, Fisheries and Forestry under the Victoria Agricultural Innovation Hub Project for the climate adaptation research project reported in this paper is greatly appreciated. The authors gratefully acknowledge the comments on this project by Professor Rebecca Lester, David Downie and Dr George Cunningham. Furthermore, the authors have benefited from the valuable comments provided by Professors Bob Farquharson, Bill Malcolm and Garry Griffith of this Journal and Dr James Sillitoe.

of the gross benefits estimated in our analysis. Estimating that share of the farmers who do or don’t undertake any adaptation measures at present, and also who would adopt our Online Tool, has been beyond the scope of this paper. We briefly highlight an approach to estimate adoption rates in future work.

Keywords: Climate adaptation research; Research impact; Gross margin analysis; Almond, Citrus and Grape production; Pome fruit production; Potato production; Online Decision Support Tool.

Introduction

Increasingly, a considerable share of research funding for research organisations and academic institutions comes from external sources. In most cases, these funds are accessed by competitive tender processes, and in this context, developing historical track records of research applications, and the consequent impact of the work, are essential to mount future strong cases for funding. Because systematic funding applications need to be based on previous impactful outcomes of research, one useful way of measuring impact is to assess whether previous research was (i) delivered on time, (ii) within budget and (iii) to the satisfaction of the clients. Further, research impact is generated by publications in scholarly journals and industry reports, and together with visible outreach work (which includes industry and community extension to the research that are strengthened by media appearances), that may give clear indications of the impact of the research.

In addition to the above general impacts, there are at least four other types of impacts specific to the support of university research. First, selected research may be developed to enhance the reputation of a university, showcasing it to be a strong research-oriented institution and having close relationships to the community and industry. This showcasing could potentially help the research ranking and the status of the university. Second, students who are keen to undertake studies in specific fields of research, may be attracted to join a particular university if it has a strong reputation for engagement with their fields of interest. The continued attraction of a large cohort of research students, will bring with it additional revenue and further opportunities for research. Third, staff who are engaging in high quality research may develop strong international competencies in an area, and this will lead to acceptance of resulting publications in high level journals. Finally, positive assessment of the research impacts will help in the reporting to potential funding entities and investors regarding the benefits of the research innovations, both direct and indirect, for (i) individual Institutions, (ii) the industry research sector, (iii) particular region and (iv) the overall economy. It thus provides a convenient indication of potential impacts when developing research and innovation projects, that will help in the description of their research intent and to inform and leverage future investments in the area.

Read and Rudman (2023, p. 970) point out that the attainment of research impact is a goal for many academics, academic institutions and research funders. The ‘impact agenda’ has generated considerable pressure for researchers who now are required to demonstrate evidence of impact for applications to future funding bodies, Institutional research assessments and related career progression.

Given this background, the focus of this paper is a case study exploring the impact of a recent climate adaptation research project undertaken in 2023 as a part of the Australian Government’s Future Drought Fund which was a part of the Agricultural Innovation Hubs Program. The industry focus of this research project has been on the cultivation of almonds, grapes and citrus fruits, particularly in the Mallee region in North-west Victoria, and potatoes and pome fruit (apples and pears) in the Gippsland region. The project was undertaken by the Centre for Regional and Rural Futures (CeRRF) of the Deakin University together with the University of Melbourne, who worked in close collaboration with the key stakeholders and farmers’ groups in the two regions. These included the Mallee Regional Innovation

Centre, Food and Fibre Gippsland, the Commonwealth Department of Agriculture, Fisheries and Forestry , and the Future Drought Fund[2].

It is noteworthy that, with increasing attention on climate change-related adverse effects, funding entities often fund research projects to help agricultural areas better adapt to climate change. It is anticipated that these investigations might reduce the amount of climate-driven damage and contribute to potential cost savings which are attributable to the adoption of these specific research innovations. In the context of a domestic and export-oriented farm sector in Australia, the impacts of climate adaptation research may focus on better use of farm inputs and reducing yield and output losses.

It is important to recognise that impact of using climate adaptation measures in agriculture will largely depend on the rate of adoption of such measures by farmers. This again is influenced by whether individual farmers can or are adopting the measures, given that many changes including climate adaptation measures are already being made autonomously by some growers.

Pannell and Claassen (2020, p. 31) point out that 'farm-level adoption rate is a continuous variable in terms of the number of farmers who adopt a practice to any extent, from zero to 100 per cent. Farmers are heterogeneous in various relevant respects that influence adoption: in whether a practice is actually beneficial in their context, in whether they have the skills necessary to implement the practice successfully, and in whether they are fully aware of the practice and its benefits and costs'. Given these factors, the attribution of a particular climate adaptation measure to potential benefits of its use requires a range of information, and in particular the rate of adoption, and the share of farmers who would actually use that specific adaptation measure. Estimating that share of the farmers who do or don't undertake any climate adaptation measures at present in the context of our study has been beyond the scope of this project. Nevertheless, we briefly highlight an approach to estimate adoption rates in future work.

The format of this paper is as follows. In the next section, a brief discussion of the conceptual landscape that underpins the rationale for undertaking research impact evaluation and assessment is provided. In the following section, the key aspects of the climate adaptation research project undertaken in 2023 is described. The Online Decision Support Tool is then described. The use in the current paper of the research outputs and analysis of the climate adaptation research project is presented in the next section, with a particular emphasis on the economic impacts of that research. This is followed by a discussion section. The final section provides some concluding remarks.

Conceptual Landscape

Meaning of research impact: some definitional issues

In explaining the meaning of research impact, Reed et al. (2021, p. 2) firstly noted that it is 'the tendency of the researchers to discuss the actual impacts of the work rather than specifically defining what impact means, and this observation indicates the somewhat complex and elusive nature of this issue. In this regard, the most widely used definitions rarely explicitly recognise the subjectivity associated with determining several key factors which determine the outcomes of a research program'. In addition, the following issues, also presented by Reed et al. (2021, p. 2), are useful for this discussion, since they recognise that 'to avoid any suggestion of bias, it should be clearly understood who the main beneficiary of the research is. In addition, it should be expressed to what extent the research has

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[2] Research in the climate adaptation project was undertaken by Monique Marais, Dr Kaitlyn Height, Andre Vikas, Dr Madeleine Johnson, Alex Russell, Professor Ruth Nettle and A/Professor Robert Faggian.

made a necessary and sufficient contribution towards the benefit. It should be noted that the extent and importance of the impact of the research is in the eye of the beholder. In this respect, a benefit perceived by one group at one time and place may be perceived as harmful or damaging by another group at the same or another time or place. These are value judgements and assumptions which are implicit in most definitions of research impact, and which are rarely unpacked in any detail. Notwithstanding these judgements, the word 'impact' could clearly refer to either positive or negative outcomes of the investigation, but it is usually understood that the implicit focus is on the benefits'.

Secondly, Reed et al. (2021, p. 3) found that 'definitions of research impact rarely consider the nature or level of attribution between research and impact, which can vary considerably. Hence, the task of any impact evaluation is to establish whether there is a causal relationship between the outcomes of the research and its impact, providing evidence that the research was necessary (at least) or sufficient (at best)'. Building on these considerations and their extensive review, these authors define research impact as a 'demonstrable and/or perceptible benefit to individuals, groups, organisations and society (including human and non-human entities in the present and future), that are causally linked (necessarily or sufficiently) to the research' (Reed et al., 2001, p.3).

Rationale for defining research impact

When developing an overview of the research contributions of an entity, it is essential to clearly distinguish between research and speculation. Each research contribution can be recognised as having a contribution to the understanding of an area, but only evidenced-based work can be fully relied upon as a basis for action. By clarifying the basis of impactful research, there is a fair and defensible opportunity to identify ways to reward researchers who generate 'high impact' research. In addition, the development of a research manifesto which leads to a program of impactful research contributes significantly to the addressing of sustainable research funding.

Nature of research impact evaluation and assessment

According to Cvitanovic et al. (2021, p. 4), 'research *impacts* can manifest across a range of scales, for example, impacts on individuals, impacts on research, impacts on organisations, impacts on ecosystems, and impacts on society at large'. In addition, Reed et al. (2021, p.3) 'define the process of assessing the '*significance*' and '*reach'* of both positive and negative effects of research'. In this respect, research impact may be evaluated either (i) over different time horizons, (ii) at different social scales (from individuals to society), (ii) over different spatial scales (from local to international) and (iv) across multiple domains (including social, economic, environmental, health and well-being, and cultural). Indeed, there are a range of intermediary domains where impacts can occur. These include general understanding and awareness of an issue, facilitating attitudinal and behavioural change, influencing decision-making and policy development, and stimulating capacity building. It is noted that evaluation of research impact must go beyond the immediate measurement of outcomes, to assessments of implicit effects of research that may need to be accessed indirectly and evaluated in qualitative terms. Research impact evaluation is not only concerned with identifying ultimate, *end-of-pipe* impacts, such as economic benefits, but also the range of intermediate impacts that occur on the pathway to impact. These can include understanding and awareness of a critical issue, instituting behaviour change and assisting in policy formulation.

It has been claimed that '*significance*' and '*reach*' of research are the two most used criteria to assess the impact made by specific research programs (Reed et al., 2021, p.3). Consequently, they suggest that 'the *significance* of an impact can be defined as the magnitude, or intensity of the effect of research on individuals, groups, or organisations, whilst the *reach* of an impact can be defined as the number, extent or diversity of individuals, groups or organisations that benefit from research'. Using this definition, *reach* can be further understood in two ways. First, there is the notion of 'scaling-out' which refers to the way an impact can spread socially, being (i) in terms of from one individual to another, (ii) transmission throughout a community or organisation, or (iii) from one specific interest group to another. In this latter case, it can also move spatially, such as from the individual farm to the catchment level, or from one state or country to another. The second way that *reach* can be observed is in the scaling up and scaling down of an understanding or practice (Reed et al., 2021, p.3).

Research adoption and research impacts

It is noteworthy that the impacts of research will be considerably influenced by the adoption of specific research outcomes by the intended and potential users of that research. In this context, it is useful to refer to the literature on adoption of agricultural technologies and innovations. For example, Pathak et al. (2019, pp. 1293-1294), reported that 'Tey and Brindal (2012) have examined the factors influencing the adoption rates of precision agricultural technologies which consist of socio-economic factors, agro-ecological factors, institution factors, informational factors, farmers' perceptions, behavioural factors and technological factors'. In this respect, operator age, years of farming experience and formal education are examples of *socio-economic factors* whereas tenure, farm specialization, farm size, farm sales, variable fertilizer rates, livestock sales, debt-to-asset ratio, production value, owned land minus rented land, yield, part-owner farmers, full-owner farmers, farm income/profitability, soil quality, percentage of main crop in total farmland, percentage of farm land as county land area, percentage of cropped land to total farmland, percentage of farmland as large farms and off-farm employment, were classified as *agro-ecological factors* (Tey and Brindal, 2012). Likewise, distance from a fertilizer dealer, region, use of forward contract and development were categorized as *institution factors*, and use of consultant services and perceived usefulness of extension services in implementing precision farming practices were placed under *information factors*. Perceived profitability of using precision agriculture is classified into *farmers' perceptions*, willingness to adopt variable-rate technology was kept under *behavioural factors* and yield mapping, use of computer, farms with irrigation facility, and generated map-based input prescription were classified into *technological factors* (Tey and Brindal, 2012).'

Adoption rates can be different for different agricultural research innovations and technologies. Therefore, it is useful to identify what factors contribute to the adoption or rejection of different research actions. In this context, Kuehne et al. (2011, p.1) have developed a tool called the Adoption and Diffusion Outcome Prediction Tool (ADOPT). This tool has been designed to (i) predict an innovation's likely peak extent of adoption and likely time for reaching that peak, (ii) encourage users to consider the influence of a structured set of factors affecting adoption, and (iii) engage R&D managers and practitioners by making adoptability knowledge and considerations more transparent and understandable. The tool has been specifically structured around four aspects of adoption: characteristics of the innovation, characteristics of the population, actual advantage of using the innovation, and learning of the actual advantage of the innovation.

Climate Adaptation Research

In this section the climate adaptation research undertaken on the cultivation of almonds, citrus and grapes in the Mallee region in North-west Victoria, and potatoes and pome fruit (apples and pears), in the Gippsland region, is described.

Background to the case study industries

Almonds

Victoria is one of the largest almond growing areas in Australia, accounting for almost 64 per cent of all almonds produced in Australia (RMCG, 2021). The area of land under almond cultivation is approximately 22,390 ha in Victoria[3], and in 2020, Victorian almond production amounted to around 70,162 tonnes (Almond Board of Australia, 2020), of which about 75 per cent of the output is exported annually (Mallee Regional Innovation Centre, 2021).

The average yield of almonds is estimated to be around 3.2 tonnes of almond kernels per ha, and almonds require between 12 to 14 megalitres of water per ha to produce the average yield (Australian Almonds, 2023). The retail price of Australian almonds in 2023 ranged between $28.58 and $51.15 per kilogram (Selina Wamucii, 2023a), which indicates the significant economic contribution of almonds to the economic strength of the agricultural industry.

Of relevance to this research impact analysis is that a study conducted in 2022 by the Mallee Catchment Management Authority and Agriculture Victoria (2022a) estimated that almond yields in Victoria on average could decline by 5 per cent, 11 per cent and 14 per cent by 2030, 2050 and 2070 respectively, due to climate change. This assumes that there will be no change or adaptation to current management practices or alteration in varietal mix under the climate scenarios, which are anticipated to be between the Representative Concentration Pathways (RCP) 4.5 and RCP 8.5.

Citrus

This climate adaptation research also focussed on oranges and mandarins, which are here combined into a ‘citrus’ category. In this regard, according to Citrus Australia[4] the Murray Valley region, located in northwest Victoria and southwest NSW, is the second largest citrus growing area in Australia with 5,714 ha of planted citrus making up 21 per cent of Australia's citrus crop, based on 2020 data. The Murray Valley predominately grows Navel oranges and Afourer mandarins. According to Hort Innovation and Fresh Logic (2022), Victorian citrus production in 2021-22 amounted to around 123,620 tonnes (oranges 30,922 tonnes and mandarins 92,698 tonnes) with around 80 per cent of the output of oranges and 40 per cent of the output of mandarins being exported in 2022 (Hort Innovation and Fresh Logic, 2022).

The average yield of citrus in Australia was estimated to be around 20 tonnes per ha in 2021[5]. According to Falivene (2018), without the annual hand pruning, yields would be 15 tonnes per ha to 20 tonnes per ha, based on evidence from the Sunraysia region. According to Citrus Australia[6], citrus crops are sensitive to temperature and humidity, thus diurnal temperature variation is an important factor in colour development, and many physiological changes in the tree and fruit are also dictated by temperature in some way. Colour development affects the traditional harvest period, causing delays for domestic and export markets. Increased temperature has been shown to negatively impact fruit set, reducing the potential crop yield and affecting individual fruit size. It is noted that the retail price of Australian citrus in 2023 ranged between $1.50 and $4.51 per kilogram (Selina Wamucii, 2023b).

Of relevance to this research impact analysis is that a study conducted in 2022 by the Mallee Catchment Management Authority and Agriculture Victoria (2022b) estimated that citrus yields in Victoria (Washington Navel orange and Afourer mandarin), on average could decline by 5 per cent, 11 per cent and 14 per cent by 2030, 2050 and 2070 respectively. This assumes that there will be no

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[3] https://www.horticulture.com.au/globalassets/hort-innovation/resource-assets/am15007-guide-to-Australian-almonds-brochure.pdf

[4] https://citrusaustralia.com.au/growers-industry/regions/murray-valley/

[5] https://ourworldindata.org/grapher/orange-yields?tab=table

[6] https://citrusaustralia.com.au/about/advocacy/climate/

change or adaptation to current management practices or alteration in varietal mix under the climate scenarios, which are anticipated to be between RCP 4.5 and RCP 8.5.

Grapes

The Victorian wine industry spans 22 diverse regions. Around 80 per cent of the fruit originates from the Victorian side of the Murray Darling-Swan Hill wine region, producing warm-climate varieties, mostly for the bulk wine trade. Rutherglen, Heathcote, the Mornington Peninsula and the Yarra Valley regions produce premium wines. In 2019–20, there were 800 commercial grape growers in Victoria, operating on around 17,000 hectares of vineyards. Victoria produced 182,000 tonnes of wine grapes in 2019–20, and, as such, Victoria is Australia's third largest wine grape-producing state behind South Australia and New South Wales (Agriculture Victoria, 2021).

The estimated average yield of grapes in 2019-20 was approximately 12 tonnes per hectare which is slightly lower than the 10-year average of 12.55 tonnes per hectare[7]. According to Australian Bureau of Agricultural and Resources Economics and Science (ABARES) analysis, average wine grape prices fell by 14 per cent to $547 per tonne in 2022−23 (ABARES, 2023). The fall in the weighted average grape price is forecast to be driven by further reductions in the red grape price which is expected to fall 20 per cent to $566 per tonne. This is a return to the price levels received by growers after the signing of the China−Australia Free Trade Agreement in December 2015 and the subsequent rise in Chinese demand for Australian red wine varieties[8]. According to Agriculture Victoria (2021), it is estimated that around 1,200 persons worked on farms that grew wine grapes in the year to May, during 2021.

Grape growers in the Murray–Darling Basin usually rely on irrigation water to supplement rainfall. The average volume of water used by grape growers in an irrigation season depends on water allocations, price of water on the temporary market and seasonal conditions (that is, evapotranspiration and rainfall). Prevailing seasonal conditions and market prices over summer can significantly influence grape growers' total water use, because the November to January period is critical for grape production in the Basin. Rainfall was extremely low from 2006–07 to 2009–10 and resulted in low inflows to water storages and, consequently, lower water allocations. As the drought worsened, many grape growers purchased temporary allocation of water to maintain production or keep grapevines alive[9].

In relation to the climate change impacts on the growth of grapes, a study conducted in 2022 by the Mallee Catchment Management Authority and Agriculture Victoria (2022c) estimated that table grape yields in Victoria on average could decline by 7 per cent, 18 per cent and 23 per cent by 2030, 2050 and 2070 respectively. This assumes that there will be no change or adaptation to current management practices or alteration in varietal mix under the climate scenarios, which are anticipated to be between RCP 4.5 and RCP 8.5. It is important to note that Robinvale, where the above study was conducted, is part of the Mallee region which produces over 90 per cent of Victoria's wine and table grapes[10]. In the absence of any comparable specific estimates for wine grapes, we assume the above estimates to hold for all grapes produced in Victoria.

Potatoes

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[7] https://winetitles.com.au/statistics-2/viticulture/

[8] https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/wine-and-winegrapes#prices-continue-to-reflect-a-twospeed-market

[9] https://www.agriculture.gov.au/abares/research-topics/surveys/irrigation/grapes#water-use-and-irrigation-technology

[10] https://agriculture.vic.gov.au/crops-and-horticulture/wine-and-grapes

The land area under potato cultivation in Victoria is around 6,430 hectares which is around 23 per cent of the total land used for potato production in Australia[11], with Ballarat and Gippsland being some of the major potatoes growing regions in Victoria. According to Hort Innovation and Fresh Logic (2022) Victoria produced around 263,406 tonnes of potatoes in 2021-22, with the estimated average yield of potatoes being approximately 40 tonnes per hectare[12]. Overall, the retail price of Australian potatoes in 2023 ranged between $ 1.50 and $ 6.02 per kilogram (Selina Wamucii, 2023c).

According to Luck et al. (2011), without adaptation measures, it is predicted that potato yield will decrease by 18–32 per cent with climate change. Borus (2017), quoting Hijmans (2003), points out that in the absence of adaptation, global potato yields are projected to decrease by up to a third by 2050 depending on the region, compared to 9 to 18 per cent with adaptation in 2040-2069. Potato growers have four broad options for adapting to changed growing conditions and seasons; (i) change the planting dates to suit the prevailing conditions, (ii) move to new areas such as higher altitudes, (iii) if the first two options are not possible, farmers can apply sustainable agricultural practices, technologies and innovations such as heat and water stress tolerant cultivars, and irrigation, or (iv) in a worst case scenario, abandon cultivation of potatoes (Borus (2017), quoting Ebi et al. (2011)).

According to CSIRO (2008), while Miglietta et al. (2000) found a positive effect of CO_2 on potato crop growth, this may be counteracted by the effect of a temperature rise, depending on the initial temperature regime. In this respect, Rosenzweig et al. (1996) found a minimal compensating effect of CO_2 on potato yields. For potatoes, planting later in the season to avoid the very hot temperatures may be compromised by the shorter day lengths later in the year. These may have a negative impact on yield (Rosenzweig et al., 1996), hence, any change in sowing needs to be accompanied by changes in day length requirements (CSIRO, 2008).

Given the wide range of climate change impact estimates on potato growing, we assume here a plausible 5 per cent reduction in potato yields in the short to medium term in Victoria, particularly in the context of possible severe weather effects.

Pome fruit (apples and pears)

According to Finger (2020), the total planted area of pome fruits in Australia in 2020 was estimated to be 12,640 hectares (9,625 apples, 3,015 pears), whilst the estimated total planted area in Victoria in 2020 was 7,100 hectares.

Data on planted area per variety varies considerably across the nation and continues to be a significant challenge for crop estimation, variety mix calculation and, as such, limits the potential for analysis of future growth or decline of pome fruit production (Finger, 2020, p. 9).

In 2021-22, Victoria's production of fresh apples and pears and their values were 140,426 tonnes ($259.6 million) and 110,351 tonnes ($119.1 million) respectively, with a total of 250,777 tonnes ($379 million) (Hort Innovation and Fresh Logic, 2022). According to Apple and Pear Australia Limited (APAL)

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[11] http://www.rmcg.com.au/app/uploads/2019/08/PT18003-Potato-strategy_Final-report.pdf

[12] https://ourworldindata.org/grapher/potato-yields?tab=table and https://www.horticulture.com.au/globalassets/hort-innovation/levy-fund-financial-and-management-documents/sip-pdfs-new/hortinnovation-sip-potato-grower-2017-2021.pdf

Orchard Business Analysis Update[13], which was reported in May 2021, the average gross yield of the Australian model orchard in 2019 was high, at 50.3 t/ha, while the subsequent year of 2020 was lower, at 42.9 t/ha. This is attributed to the lower fruit numbers following a large crop in the 2019 season and the drought and fires affecting two orchards that contributed data. The average Class 1 yield in 2019 was outstanding at 35.2 t/ha. Average yields are increasing. Over the period from 2008 to 2012 the average yield was reported at 36 t/ha while over the four years (2016–20) average yields were 10 t/ha higher at 46 t/ha.

The retail price of Australian apples in 2023 ranged between $ 6.02 and $ 13.54 per kilogram (Selina Wamucii, 2023d). The retail price of Australian pears in 2023 ranged between $4.21 and $5.27 per kilogram (Selina Wamucii, 2023e). Based on the above figures, we assume here an average price range for pome fruits of $ 5.00 per kilogram to $ 9.00 per kilogram as an approximation.

Thomson et al. (2014, p. 21) point out that many pome fruit-growing regions in Australia are likely to become too hot in the future for viable production from existing tree varieties, and there are few cooler regions available to establish new orchards. Yet, it is anticipated that economically sustainable production in existing locations could be maintained, at least in the short term, by deploying adaptive strategies such as on-farm practices that help cool and protect fruit crops. Under predicted climate change scenarios, the need for adaptation is clear if the Australian pome fruit industry is to survive.

In the main production state of Victoria, average annual temperatures are expected to increase 0.9 °C by 2030 relative to a base year of 1990 and 2.8 °C by 2070 under a high emission scenario (Watterson et al., 2007, as reported in Thomson et al., 2014, p. 21). As the climate warms, reduced winter chill is likely to affect the timing and quality of bud dormancy release and flowering, which will in turn influence fruit set and yield. Responses will vary between growing regions and cultivars, with cultivar response depending on specific requirements for conditions of chill and heat. Extreme heat in the orchard during summer and autumn can affect fruit quality through sunburn damage, poor blush development, watercore, rapid fruit ripening and reduced fruit growth. Of particular interest in this research was the effect of heat on sunburn browning. The level of sunburn browning risk varied with geographical location. Shepparton (Victoria), Mount Barker (South Australia) and Manjimup (Western Australia) were the most adversely affected by projected increases in the percentage of days with potential sunburn browning risk. The percentage of risk days in Shepparton was predicted to increase from 18 per cent at present to 28 to 36 per cent in 2050 without netting[14].

Summary of climate adaptation research

This climate adaptation research is particularly designed to enable an understanding of how farmers and agricultural managers in the industries of interest can respond to projected changes to the climate, and how they might capitalise on the output of this research.

The researchers were subsequently involved the development of economic models to simulate on-farm operations using gross margin analysis, to gain greater insight into the relationship between gross income and variable cost involved in the growing of commodities of interest. It is noted that because of this relationship, it was possible to estimate break-even yields of commodities under different climate scenarios.

The Online Decision Support Tool

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[13] https://apal.org.au/orchard-business-analysis-update/

[14] https://apal.org.au/effects-climate-change-apple-pear-production/

In this regard, this research has created a novel Online Decision Support Tool which is described in detail on the Mallee Regional Innovation Centre (MRIC) website[15]. The Tool (see Box 1 for a very short summary of the Tool), allows the user to test the outcome of varying climates. It is equally important to note that the Tool can be used in future planning needs to better support adaptation to climate change scenarios.

It is noteworthy that gross margin analysis tools have been used across various crops and across various jurisdictions in Australia to help farmers with making decisions about what to grow based on an analysis of potential income and likely operating costs. Examples include AUSVEG Gross Margin Tool for vegetable crops[16], cash crops and livestock enterprises in Meander Vally and Midlands in Tasmania[17] and in South Australia[18], and the use of the Agricultural Productions Systems Simulator (APSIM) to model crop yields for which gross margins were estimated[19].

It is important to recognise that gross margins are best used to compare enterprises that make use of the same resources on a property. They cannot be used where varying capital input is needed for an enterprise. Estimates of inputs and production can vary from what actually occurs. Although a crop might have the highest gross margin, it might be the most sensitive to variation. Commodity prices, seasonal conditions, pests and disease can significantly affect the eventual gross margin. Risk can be assessed by comparing gross margins calculated with varying values for an input[20].

Box 1. The online decision support tool

The climate adaptation research undertaken by the Centre for Regional and Rural Futures (CeRRF) of Deakin University in conjunction with the University of Melbourne produced a novel online decision support tool as an output from detailed models that captured insights and information about commodity specific performance in the face of projected climate change and identified economic constraints and value-chain productivity and profitability.

This online tool serves as a decision-making and knowledge sharing mechanism to support on-farm and regional adaptation into the future. Through the integration of farmer and agricultural expert workshops, the models were ground-truthed to ensure the resultant data and information was underpinned by the practical realities of farming and to optimise the tool usability.

The tool uses gross margin analysis, validated with inputs from workshops and meeting with specific groups, where the effects arising from changes in commodity price, fertiliser cost and water price on the economic margins of farmers were evaluated. The Figure below depicts the basic methodology used in developing the gross margins for each agricultural commodity with the relevant assumptions.

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[15] https://eng.unimelb.edu.au/mric/drought-hub/horticultural-economic-modelling-tool/_nocache

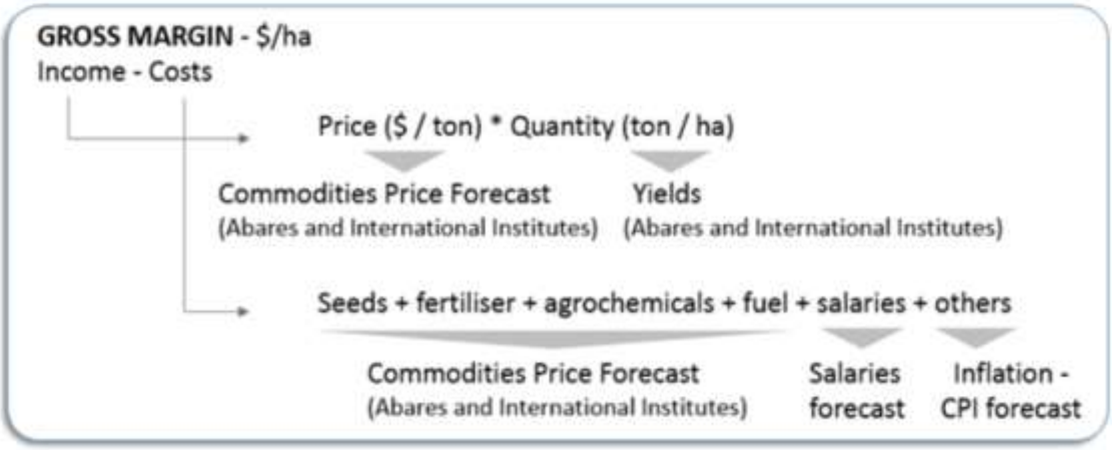
[16] https://ausveg.com.au/resources/economics-statistics/gross-margin-tool/

[17] https://nre.tas.gov.au/Documents/Users%20guide%20to%20gross%20margin%20financial%20analysis%20tools%20(August%202014).pdf

[18] https://sagit.com.au/wp-content/uploads/2022/01/21112.01-Gross-Margins-Guide-2022_WEB.pdf

[19] https://www.sciencedirect.com/science/article/pii/S1161030113000026

[20] https://sagit.com.au/wp-content/uploads/2022/01/21112.01-Gross-Margins-Guide-2022_WEB.pdf



Assumptions

- The gross margin is calculated as the difference between the gross income (price * quantities sold) and the variable costs which vary according to the production requirements. These variable costs include fertilisers and agrochemicals, water, packaging materials, levies, sales commissions, and insurances. Although the owner may be working in a farm, salary costs are also considered, to properly reflect the production costs.
- Fixed costs are not included, nor is cost of land rent, financial interest and taxes due to profits.
- Models were developed with aggregate information for the whole country, and where possible, validated with specific data for Victoria or the region under study.
- The results reflect the average performance of an agribusiness. It is important to note that the margins obtained by farmers can vary significantly, depending on several aspects (price received, impacts of climate, technological advance and managerial practices, among others).

The assumptions made in estimating the margins for the last fiscal year can be adjusted to better reflect the circumstances of each farmer.

- The margins were estimated for the following products: almonds, citrus, grapes, potato and pome fruit. However, it is recommended that the analysis could be complemented by a broader range of commodities to obtain a more comprehensive economic picture.
- Margins were estimated per hectare, to allow comparison of the relative profitability of the various products.
- The margins are estimated for an existing, established and mature business. The economic costs of changing or initiating a new business are not considered.

In summary, this novel Online Decision Support Tool captures insights and information about commodity specific performance in the face of projected climate change and can identify economic constraints and value-chain productivity and profitability. The Online Decision Support Tool serves as a decision-making and knowledge-sharing mechanism to support on-farm and regional adaptations into the future.

It is anticipated that the use of this novel Online Decision Support Tool will allow users to adjust prices of key inputs, yield levels, water costs and fertiliser costs or, alternatively, make percentage changes of the key variables to represent whole-of-system changes to all operations. The Tool can generate outputs related to the ramifications that these changes will have on the break-even yield. The Tool was specifically designed with the intention of empowering growers to make strategic on-farm decisions around their future adaptation strategies, and as such, the Tool has been made to be open sourced, ensuring access to the Tool is not inhibited by cost or the need for a subscription.

Given that much of the current agricultural and agri-environmental policy is concerned with influencing the behaviour of farmers in adopting new practices and making better informed on-farm decisions, the development of this novel Online Decision Support Tool is timely, particularly in the context of adaptations required to meet climate change effects. In this latter respect, innovations such as this novel Online Decision Support Tool are often used in flexible ways and can be changed over time to adapt to varying individual contexts.

It is important to recognise that the degree of adoption of the Online Decision Support Tool will be influenced by the investment by the farmers to use the Tool in terms of time and effort. Mastering new technology is a major source of competitive advantage in all aspects of agriculture - something which the best operators do very well - and if learning to use the Online Decision Support Tool is a means to open further opportunities, then this becomes a private and commercial matter.

Hansen et al. (2022), quoting the National Farmers Federation (NFF, 2020), point out that farmers generally prioritise learning from their peers and in-person events. This therefore will apply to the introduction of the Online Decision Support Tool also. As highlighted by Hansen et al. (2022), given that many agricultural producers prefer to be provided with practical facts in a logical sequence rather than lots of information (see Nicholson et al., 2015), field days, demonstrations and smart farms can play an important role in increasing producer awareness of the Online Decision Support Tool. At the same time, they will help to demonstrate the relevant knowledge and skills needed for this Tool, whilst exposing the economic value propositions through well-evidenced use of innovative systems (see Ayre et al., 2019).

It is also noteworthy that the direct role of government in enhancing adoption of agricultural innovations and technologies is relatively limited, except in situations as a facilitator/enabler of extension in building technical capacity among farmers to help accelerate the adoption of technologies that increase net social benefits. This issue fits in with the chain failure/chain goods literature (see Malcolm et al. (2017) for a discussion of chain failure and chain goods.)

Research Impact Analysis

In this section the potential research impacts of the climate adaptation research described above are presented, with a particular emphasis on the economic impacts of that research.

It is plausible to assume that as a result of the adoption of the Tool, the projected/estimated decline in the industry yield and output due to climate change, can be reduced to some extent by better on-farm production decision making. Consequently, we assume that the Tool will be widely used in the Victorian almond, citrus, grape, potato and pome fruits growing sectors over time.

The climate change impacts on yields of different industries reported earlier have been used in the following analysis. These refer to our assumption of a 5 per cent projected (avoidable) decline in almonds, citrus, potatoes and pome fruit yields and a 7 per cent (avoidable) decline in grapes yield by 2030 due to climate change. These assumptions are based on the empirical estimates referred to in the earlier discussion.

Almond

With a *baseline* land area under almond cultivation currently of around 22,390 ha in Victoria and given an estimated average yield of around 3.2 tonnes of almond kernel per ha, the estimated output is 22,390 x 3.2 = 71,648 tonnes per year. When looking toward the future of the industry, there are several assumptions that need to be made in the *counterfactual* case. These assumptions lead to the following likely possibilities:

i. The potential impact of a 5 per cent projected decline in almond yield by 2040 means a lower yield of 3.2 – (3.2 x 0.05) = 3.04 tonnes per ha. The associated estimated total almond output is 22,390 x 3.04 = 68,065 tonnes per year.
ii. Based on the above figures, the potentially avoidable decline in almond output in Victoria is 71,648 - 68,065 = 3,583 tonnes per year, with the assumed use of the Online Decision Support Tool. This Tool is designed to help almond growers to avoid the impact of the estimated 5 per cent projected decline in almond yield and hence the total associated output.
iii. At a price range of $28.58 to $51.15/kg for almonds, the saving of lost revenue associated with the avoidable decline in almond output in Victoria is 3,583 tonnes x $28.58 x 1,000 = $ 102,402,140 to 3,583 x 51.15 x 1,000 = $183,270,450.

Based on the above estimates, the Victorian almond growing industry could potentially save around $102 million to $183 million per year by adopting the use of the Online Decision Support Tool to help almond growers to avoid the impact of a 5 per cent projected decline in almond yields.

To appreciate the role of the almond industry to the agricultural sector and the broader economy, estimates show that in 2019-20, the almond industry contributed $1.6 billion to the Australian Gross Domestic Product (GDP) and employed 9,560 people. This includes $534.6 million in growing and processing activities, $44.0 million in industry investment, and $1.1 billion because of flow-on economic activity ($510.5 million production induced and $544.3 million consumption induced). This equates to approximately 0.1 per cent of Australia's GDP, or $1 for every $1,000 of GDP (RMCG, 2021). This highlights the fact that even a small reduction in the impact of climate change using the Online Decision Support Tool in the almond industry can have considerable socio-economic benefits in a range of areas.

Citrus

With a *baseline* land area under citrus cultivation around 5,714 ha in Victoria and given an estimated average yield of around 20 tonnes of citrus per ha, the estimated output is 5,714 x 20 = 114,280 tonnes per year. When looking toward the future of the industry, there are several assumptions that need to be made in the *counterfactual* case. These assumptions lead to the following likely possibilities:

i. The potential impact of a 5 per cent projected decline in citrus yield by 2040 means a lower yield of 20 – (20 x 0.05) = 19 tonnes per ha. The associated estimated total citrus output is 5,714 x 19 = 108,566 tonnes per year.
ii. Based on the above figures, the potentially avoidable decline in citrus output in Victoria is 114,280 – 108,566 = 5,714 tonnes per year, with the assumed use of the Online Decision Support Tool. This Tool is designed to help citrus growers to avoid the impact of the estimated 5 per cent projected decline in citrus yield and hence the total associated output.
iii. At a price range of $1.50 to $4.51/kg for citrus, the saving of lost revenue associated with the avoidable decline in citrus output in Victoria is 5,714 tonnes x $1.50 x 1,000 = $ 8,571,000 to 5,714 x 4.51 x 1,000 = $25,770,140.

Based on the above estimates, the Victorian citrus growing industry could potentially save around $8.5 million to $25.7 million per year.

Grapes

With a *baseline* land area under grapes cultivation currently of around 17,000 ha in Victoria and given an estimated average yield of around 12 tonnes of grapes per ha, the estimated output is 17,000 x 12 = 204,000 tonnes per year. When looking toward the future of the industry, there are several assumptions that need to be made in the *counterfactual* case. These assumptions lead to the following likely possibilities:

i. The potential impact of a 7 per cent projected decline in grape yield by 2040 means a lower yield of 12 – (12 x 0.07) = 11.16 tonnes per ha. The associated estimated total grapes output is 17,000 x 11.16 = 189,720 tonnes per year.
ii. Based on the above figures, the potentially avoidable decline in grapes output in Victoria is 204,000 – 189,720 = 14,280 tonnes per year, with the assumed use of the Online Decision Support Tool. This Tool is designed to help grape growers to avoid the impact of the estimated 7 per cent projected decline in grapes yield and hence the total associated output.
iii. At a price of $547 per tonne for grapes, the saving of lost revenue associated with the avoidable decline in grapes output in Victoria is 14,280 tonnes x 547 = $ 7,811,160.

Based on the above estimates, the Victorian grapes growing industry could potentially save around $ 7.8 million per year.

Potatoes

With a *baseline* land area under potato cultivation currently of around 6,430 ha in Victoria and given an estimated average yield of around 40 tonnes of potatoes per ha, the estimated output is 6,430 x 40 = 257,200 tonnes per year. When looking toward the future of the industry, there are several assumptions that need to be made, which lead to the following likely possibilities:

i. The potential impact of a 5 per cent assumed decline in potato yield by 2040 means a lower yield of 40 – (40 x 0.05) = 38 tonnes per ha. The associated estimated total potato output is 6,430 x 38 = 244,340 tonnes per year.
ii. Based on the above figures, the potentially avoidable decline in potato output in Victoria is 257,200 – 244,340 = 12,860 tonnes per year, with the assumed use of the Online Decision Support Tool. This Tool is designed to help potato growers to avoid the impact of the assumed 5 per cent decline in potato yield and hence the total associated output.
iii. At a price range of $1.50 to $6.02 per kilogram for potatoes, the saving of lost revenue associated with the avoidable decline in potato output in Victoria is 12,860 tonnes x $1.50 x 1,000 = $ 19,290,000 to 12,860 tonnes x $6.02 x 1,000 = $ 77,417,200.

Based on the above estimates, the Victorian potato growing industry could potentially save around $ 19 million to $ 77 million per year.

Pome fruits (apples and pears)

Lucas Group[21] reported in April 2023 that pear and apple crop estimates are set to retract to 2020 levels due to extreme weather events. Heading into the 2023 harvest period, the adverse flooding in the eastern states in late 2022 and two significant hail events in the Goulburn Valley are expected to impact the supply of apples and pears in the domestic market in 2023. A major hail event on 22 December 2022 that affected orchards from Tatura to Bunbartha means that Apple and Pear Australia

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[21] https://lucasgroup.com.au/pear-fect-storm-extreme-weather-leads-to-reduced-pome-crop-for-2023-harvest/

Limited (APAL) anticipated almost 12 per cent fewer apples and 35 per cent fewer pears will be available in the national class 1 supply of pome fruit in 2023 (see Lucas Group, 2023). The 2023 Apple and Pear Crop Estimate echoes this outlook, acknowledging that gross apple production is expected to be down 7.9 per cent from 2022 to a total output of just 290,000 tonnes. Similarly, the crop forecast predicts gross pear production will be down 16.1 per cent at 72,000 tonnes.

Given the paucity of quantitative information on the climate change impacts on pome fruits (apples and pears), it is assumed that the *baseline* level of Victoria's gross production of pome fruits as 250,777 tonnes per year. When looking toward the future of the industry, there are several assumptions that need to be made, which lead to the following likely possibilities:

i. The potential impact of a 5 per cent assumed decline in pome fruits output in the short to medium term means a lower output of 250,777 – (250,777 x 0.05) = 238,239 tonnes in Victoria per year.

ii. Based on the above figures, the potentially avoidable decline in pome fruit output in Victoria is 250,777 – 238,239 = 12,538 tonnes per year, with the assumed use of the Online Decision Support Tool. This Tool is designed to help pome fruit growers to avoid the impact of the assumed 5 per cent decline in pome fruit output.

iii. At an approximate average price range for pome fruits of $5.00 per kilogram to $9.00 per kilogram the saving of lost revenue associated with the avoidable decline in pome fruit output in Victoria is 12,538 tonnes x $5.00 x 1,000 = $62,690,000 to 12,538 tonnes x $9.00 x 1,000 = $ 112,842,000.

Based on the above estimates, the Victorian pome fruit growing industry could potentially save around $ 62 million to $ 112 million per year by adopting the use of the Online Decision Support Tool to help pome fruit growers to avoid the impact of a 5 per cent assumed decline in pome fruit output.

As shown in Table 1, the above analysis indicates that the overall estimated potential economic benefit of the use of the Online Decision Support Tool can range from $199 million to $398 million per year in the short to medium term. This refers to a 5 per cent projected (avoidable) decline in almonds, citrus, potatoes and pome fruit yields and a 7 per cent (avoidable) decline in grapes yield by 2030 due to climate change.

Discussion

Whilst reflecting on the nature of the findings reported in Table 1, it is important to recognise the important differences between (a) the *potential (gross) economic benefits* (where climate adaptation measures and the relevant technologies are fully available and implementable with a 100 per cent adoption rate at the farm level), and (b) the *plausible (gross) benefits* (where there is some probability less than 100 per cent regarding the rate of adoption of the adaptation measures such as the relevant technologies being available, of working as intended, and of being adopted at the farm level).

As highlighted earlier, the adoptability of possible climate change adaptation measures and technologies will be affected by farmers' socio-economic factors, their perceptions and behavioural factors, and technological knowhow and understanding, and agro-ecological factors, institutional factors and informational factors.

Further, it is useful to know what type of climate adoption measures farmers might be both able and willing to undertake to minimise yield reductions. That would help them to capture some of the estimated potential (gross) benefits which are available. In this context it is useful to know what the costs will be to achieve in that situation.

Table 1. Potential economic benefits of climate adaptation research

Commodity	**Potential impact assessed due to the adoption of climate adaptation research output (Online Decision Support Tool)**	**Quantitative estimate of the impact in terms of potential savings to growers ($ million/year)**
Almonds	Potentially avoidable decline in almond output due a 5 per cent projected decline in almond yields by 2030 due to climate change	$102 million to $183 million
Citrus	Potentially avoidable decline in citrus output due a 5 per cent projected decline in citrus yields by 2030 due to climate change	$8.5 million to $25.7 million
Grapes	Potentially avoidable decline in grapes output due a 7 per cent projected decline in grape yields by 2030 due to climate change	$7.8 million
Potatoes	Potentially avoidable decline in potato output due an assumed 5 per cent decline in potato yields in the short to medium term due to climate change	$19 million to $77 million
Pome fruits (apples and pears)	Potentially avoidable decline in pome fruits output due an assumed 5 per cent decline in pome fruits output in the short to medium term due to climate change	$62 million to $112 million
Total		$199 million to $398 million

Climate adaptation measures

In this context, Putland (2014) in reviewing climate research, development and extension needs for the Australian horticulture industry, has suggested a range of adaptation measures that farmers might be able to adopt. These include:

- selecting or moving crop-growing sites based on climate suitability for a chosen crop;
- altering crop management activities, such as adjusting planting, fertilising, irrigation and harvest dates;
- Undertaking canopy management to adjust orchard temperatures or to manage increased vegetative growth resulting from enriched carbon dioxide levels;
- breeding and selecting varieties more suited to the new climate regimes;
- maximising the use of available water with increased storage, improved water management and increased irrigation efficiency;
- altering fertiliser application and weed management in response to enriched carbon dioxide levels to maintain yield and nutritional quality; and
- undertaking integrated pest management approaches to suppress existing and new pest infestations.

Use of more suitable cultivars, sites/locations and irrigation technologies

Deuter (2009, p. 20), in his review of Australian horticulture's response to climate change and climate variability, has pointed out that 'with increasing temperatures and changes to rainfall patterns which are currently uncertain, the simplest adaptation strategies (*autonomous and assisted adaptation*) will be employed and are currently being employed by growers'. These strategies will presumably involve the use of more adaptable cultivars and a range of cultural practices which will enable growers to maintain current production in current locations, thereby adapting to the 'new' climate in the current location. Furthermore, according to Deuter (2009, p. 20) 'growers are already undertaking adaptation measures such as moving some of their production to more favourable locations and using more 'adaptable' crops or cultivars. Growers in some regions (summer season), may be able to take advantage of extending production into winter. Growers in other regions (winter season) will have their production season shortened. Increasing number of heat stress days will result in a narrowing of production windows, and the potential for production to shift to more suitable (cooler) regions. Current (and future) Integrated Pest and Disease Management (IPDM) Systems will make a significant contribution to overcoming the climate change impacts'.

Furthermore, Deuter (2009) goes on to suggest that 'site selection to avoid unsuitable climate factors is practiced as a matter of course in horticulture. For all horticultural crops, temperature is the main climatic factor which determines where and when crops are grown, and also has a significant influence on crop performance (i.e. time to harvest, product quality, and to a less extent, yield). Many horticultural growers have adopted more efficient irrigation technologies which are providing significant water-use efficiencies. This will continue, together with an increased understanding of crop water requirements and the use of new technologies to monitor and manage irrigation systems. Integrated Pest and Disease Management (IPDM) practices are common in all horticultural regions and commodities, and continuous improvement in these systems, and their adoption, will be an important part of adapting to a changing climate' (Deuter, 2009, pp. 25-26).

Better land management

Anderson et al. (2020), point out that in the face of climate change, land management strategies will need to be undertaken by growers to adapt to changing climate patterns and to consider new levels of prevalent pests and pathogens, with the aim to maximise yield and minimise environmental impact. These challenges to current land management practices will include changes in the growing season's length and timing, alterations in the distribution of suitable production areas, and increased incidences of extreme weather events. In addition, legislative restrictions related to the use of pesticides, fungicides and other chemical treatments may restrict farmers' responses to pathogens as concern about their distribution and infection rates is likely to occur.

The nature of adaptation management practices by growers in the face of climate change includes a wide range of activities including soil nutrient management, tillage intensity, crop choice, rotational water management, and agricultural diversification. Water availability will be a significant concern as rainfall variability increases, and water harvesting, storage and utilisation practices could reduce some of the risks associated with extended periods of little rainfall (see Anderson et al., 2020).

It is also recognised that the adoption of any agricultural innovation normally follows a recognisable pattern of (i) early adopters, (ii) mass adoption and (iii) plateauing effect. Adoption of this pattern could arguably influence the extent of the potential economic benefits of adaptation measures. Furthermore, potential economic benefits will also be influenced by the ongoing barriers to adoption, such as technical literacy of the farmers, a gradual drop-off of the use of the adaptation measures over time, financial constraints restraining the ability of farmers to act on the information being provided. In addition, there will likely be region-specific differences in how the adoption measures are used and/or acted upon which can restrict generalised approaches to this problem.

Cost of adaptation measures

The cost of adaptation measures will have a major influence on the extent to which growers will be able to successfully implement changes to their current management approaches in an already changing climate. In this regard, the 'cost of adaptation' is the total expenditure dedicated to adaptation, and will include the total investment needs, which refers to the level of investment required to implement all the measures described in a given adaptation plan. It has been noted that the 'actual spending' consists of the expenditure mobilised for adaptation of introduced measures and must be tracked and categorised accordingly (see European Environment Agency, 2023).

Fitzsimons (2012, pp. 8-9), in analysing the farm-level adaptive capacity to climate change in Australia, points out that 'horticulturalists will face additional costs in relation to managing climate change/variability with respect to responding to three critical risks. These are (i) an increase in annual variability of cash flow due to extreme events, (ii) the increased costs of managing climate variability and their ability to respond to risk, and (iii) choosing between ways to risk-proof their farms in terms of infrastructure, water allocations, crop sunburn protection, or insurance'.

Currently, there is a paucity of data related to the estimated potential gross cost levels, and what might be the costs required to achieve climate adaptation measures for many farm products. This includes those products covered in this article. Nevertheless, the following estimates may provide a broad indication of the likely magnitude of the cost of climate adaptation to some extent at a State and/or region level.

Kompas et al. (2019, p. 17, p. 23 and Table 4) examined the cost of options needed to address the impacts of climate change, including land management practices and revegetation[22] in Victoria and Queensland. They compared the costs of doing nothing with the cost benefit of avoiding potential damages in the future. They estimated that the associated annual cost of proactive investment will be in the range of \$14 million to \$18 million at a discount rate of 10 per cent and 3 per cent respectively. In an earlier investigation, Wimalasuriya et al. (2012) examined climate change adaptation in the Mallee region in Victoria and estimated that the potential annual economic benefits (i.e. gross cost savings) associated with adaptation will be in the range of \$63 million to \$126 million.

Although the above estimates are not directly comparable with the analysis in this article, they provide a broad indication of the range of magnitudes of the cost of climate adaptation in the Australian farm sector in general. Furthermore, according to Kingwell (2006), Quiggin and Horowicz (2003) have pointed out that agricultural adjustment costs will be increased where climate-dependent long-lived assets, such as water supply, cannot be increased rapidly enough in the face of climate change. Indeed, where climate change is rapid, essential adjustment costs can feature as an important component of the costs of climate change, but, if the rate of climate change is slow enough, then crop varietal development and agronomic and management innovation will be able to cushion adjustment costs and reduce the projected decline in farm profit (Kingwell, 2006, p. 10 and p. 17).

Adoption rates and measuring them

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[22] These can be actions such as (i) restoring natural habitats through re-establishing trees, shrubs and grasslands that absorb carbon and protect biodiversity, (ii) changing methods of cropping and pasture management through no-till farming or changing crop rotations, and (iii) adding carbon to the soil and increasing productivity of agricultural land and planting trees on farmland in order to provide shade and windbreaks, thus reducing stock losses and potentially increasing the productivity of surrounding land.

Publicly available adoption rates of farm innovation/management measures in Australia are quite limited. Kuehne et al. (2017, pp. 121-122) in their analysis of using the Adoption and Diffusion Outcome Prediction Tool (ADOPT), have provided some examples of adoption rates based on a review of literature:

- the use of autosteer (GPS guidance in tractors) which became commercially available in 1998 (Rennie, 2002). By 2012 this was adopted by 77 per cent of Australian grain growers (Llewellyn and Ouzman, 2014; Robertson et al., 2012);
- growing transgenic Bt cotton varieties or genetically modified Bt cotton which was commercially introduced to the Australian cotton industry in 1996. By 2005 approximately 90 per cent of Australia's cotton growers planted the insect resistant varieties (Holtzapffel et al., 2008; Pyke, 2007) increasing to nearly 100 per cent adoption in 2010 once the requirement for refuges of non Bt cotton was relaxed (as quoted by Kuehne et al., 2017, p.122);
- growing high yielding narrow-leaf lupins which was launched in Western Australia cropping regions in 1978. Most districts reached peak narrow-leaf lupin adoption of between 60 and 90 per cent in 9–10 years (Marsh et al., 2000);
- the Mace wheat variety in Western Australia which was a consistently high performing variety across a wide range of environments and soil types, was grown by farmers from 2009. It reached an adoption level of 67 per cent of wheat sown in 2015 (Department of Agriculture and Food, 2016); and
- levels of adoption of using no-till cropping systems which began in 1980s. In the South Australian wheatbelt it started in 1990s and reached 84 per cent among South Australian farmers before plateauing (Llewellyn and D'Emden, 2010) and subsequently, appropriate no-tillage machinery became widely commercially available, and the practice became defined and extended as no-till cropping (Crabtree, 2010).

More recently, Montes de Oca Munguia et al. (2021, p. 3) have undertaken the adoption pathway analysis of four practices in the rural agribusiness sector in New Zealand, particularly sheep and beef cattle farming and dairy farming. In particular, they examined four practices:

> • Use of Body Condition Scoring (BCS). The assessment of BCS is used to estimate body fat reserves in both cows (visual) and ewes (feeling backbone with fingers and thumb). BCS is used as a management tool by pastoral farmers to determine livestock’s feed requirements and improve reproductive performance.
>
> • Use of pasture management software. Use of software and applications in computers, tablets and smartphones to calculate feed demand, feed availability and feed quality for sheep and cattle at different times of the year and for different levels of production. Information can be used for both tactical, operational and strategic decisions.
>
> • Use of Plantain and/or Lucerne for summer grazing. Plantain and Lucerne are used to increase the amount and quality of summer feed in grazing systems. Plantain is more often used as a pasture mix, but it can also be used as a special purpose crop; Lucerne is used on soils with low soil moisture-holding capacity to increase production vis-a-vis grass.
>
> • Use of a formal, audited nutrient management plan. Used to manage nutrients (namely, nitrogen and phosphorous) on the farm in a formal, audited way. Nutrient management plans can be developed in conjunction with a fertiliser or farm consultant or as part of an

environmental plan developed by industry or local government. Nutrient management may include managing the type, placement and timing of fertiliser applications; crop rotations; precision application; and excluding stock from waterways.

A total of 152 responses were collected by Montes de Oca Munguia et al. (2021, p. 4) from 411 invitations sent out originally, yielding a response rate of 37 per cent. Surveys took an average of 15 minutes to complete. Amongst all submitted surveys,138 were complete. These completed responses formed the basis of their adoption rate analysis.

The results of the adoption rate analysis by Montes de Oca Munguia et al. (2021, pp. 4, 9, 10 and 11) indicated that:

- if the adoption of BCS was measured binarily (i.e. the time of first use), the adoption rate would be estimated at 80 per cent;
- if the adoption of pasture management software was measured binarily, the adoption rate would be estimated at 43 per cent;
- the adoption pathway for the use of Plantain and/or Lucerne for summer grazing indicated that the binary adoption for this practice would be estimated at 59 per cent; and
- the adoption pathway for the use of formal, audited nutrient management plans if measured binarily, would be estimated at 38 per cent.

The above estimates indicate the variability of adoption rates for various farm management practices. Given this background and acknowledging that we do not know at this stage what the adoption rate of the use of the Online Decision Support Tool will be, here an outline of an adoption study approach that could generate some of the required data for future research is briefly outlined.

The following approach is based on the method used by Montes de Oca Munguia et al. (2021) in their recent adoption research study. It involves user surveys. The adoption survey could be a standalone one or could be added to an appropriate internet-based farm survey conducted by industry organisations.

According to Montes de Oca Munguia et al. (2021, p.4) a series of questions to define measures of adoption for agricultural innovations can be used in the adoption survey. These questions could include for example:

Trial and current use

1. To what extent has the INNOVATION been used in your business to this day?
2. Did you use the INNOVATION on a limited basis in order to decide to use it further?
3. Have there been any changes in the level of implementation since you adopted the INNOVATION?

Timelines

4. Approximately when did you first become aware of the INNOVATION being used in your industry?
5. When did you start trialling or using the INNOVATION as part of your operation?

Future intentions

6. Do you intend to make any changes to the current level of use of the INNOVATION in

the near future?
7. Would you consider using the INNOVATION in the near future?

The survey responses could potentially generate some of the required data and form the basis of analysis of adoption rates.

Concluding Remarks

The climate adaptation research described in this paper involved the development of an economic model to simulate on-farm operations, and this has allowed greater insight into the relationship between gross income and variable cost involved in growing commodities such as almonds, citrus, grapes, potato and pome fruit. Consequently, using this model, it is asserted that it will be possible to estimate break-even yields of commodities under different climate scenarios. The research has also created a novel Online Decision Support Tool, allowing the user to test the outcome of varying climates, which can be used in future planning to better support farm management in the face of climate change effects.

It is plausible to assume that because of the adoption of the Tool, the projected decline in almond, citrus, grape, potato and pome fruits yields due to climate change can be reduced to some extent by better on-farm production decision making. These actions will include improved resource use efficiency by altering the input mix as enabled by using the Tool. Consequently, we assume that this approach will be widely used in the Victorian almond, citrus, grape, potato and pome fruits production sectors over time.

Even under low or medium level of adoption of the Tool across the production sectors of interest which face a reduction in potential output due to climate change, the use of this Online Decision Support Tool will likely have considerable economic benefits. Indeed, our initial analysis indicates that the overall estimated potential economic benefit of the use of the climate adaptation research output reported here can range from $199 million to $398 million per year in the short to medium term. This refers to a 5 per cent (avoidable) projected decline in almonds, citrus, potatoes and pome fruit yields and a 7 per cent (avoidable) decline in grapes yield by 2030 due to climate change.

The actual extent of the estimated potential economic benefits (i.e. $199 to $398m) will be influenced by the ongoing barriers to adoption of the Tool such as technical literacy of the farmers, drop-off of the use of the Tool over time in its usage, financial constraints in the ability of farmers to act on the information being provided by the tool, to name a few. Furthermore, there will likely be region-specific differences in how the Tool is used and/or acted upon.

The adoption of any innovation normally follows a recognisable pattern (early adopters, mass adoption, plateauing effect, etc). These patterns could also influence the extent of the estimated potential economic benefits reported in this article.

As highlighted earlier, the direct role of government in enhancing adoption of agricultural innovations and technologies is relatively limited, except in situations as a facilitator/enabler of extension in building technical capacity among farmers to help accelerate the adoption of technologies relating to minimising market failures. In that context, there may be a potential role of government (as a part of the advocacy role to encourage climate adaptation measures) to help disseminate the use of the Online Decision Support Tool described in this article at agricultural field days, demonstrations and smart farms in order to increase producer awareness of the Tool.

The above analysis has been aimed at providing a broad indication of the overall and plausible economic benefits of the use of the Online Decision Support Tool based on using the currently available data from the industries of interest. In this regard, it is important to recognise that yields and production of these commodities will be affected by many factors including weather conditions (rainfall and temperature), irrigation supplies, use of new varieties, implementation of better practices, and several other agronomic, economic, trade and supply chain and logistics related factors.

An important caveat to our analysis is that in this project we have not been able to estimate the adoption rate of our Online Tool given resource and time constraints. That means we are unable at this stage to quantitatively apportion or attribute to our Online Decision Support Tool the potential gross benefits estimated in our study.

It is noteworthy that what we can attribute to our Online Decision Support Tool will depend on factors such as the share of farmers already adopting adaptation measures autonomously. Hence, only that share of the farmers who do not undertake any adaptation measures at present and who would then potentially choose to use our Online Decision Support Tool could achieve some of the gross benefits estimated in our analysis. Estimating that share of the farmers who do or do not undertake any adaptation measures at present, and also who would adopt our Online Tool has been beyond the scope of this paper. Nevertheless, we have briefly highlighted an approach to estimate adoption rates in future work.

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