Garnaut Climate Change Review

Defining the impacts of climate change on horticulture in Australia

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Contents

1 Summary

Horticulture in Australia consists of a large number of diverse industries (fruit, vegetables, floriculture, turf and ornamentals), which are grown in a wide range of production regions because of the diverse micro-climates and soils which are available in those regions. Horticulture contributes ≈ $7 billion (gross value at the farm gate) to the economy every year. On this basis, horticulture is the second largest agricultural industry in Australia after the beef industry.

Horticulture is a sub-set of ‘Agriculture’, and vegetables and fruit are sub-sets of ‘Horticulture’.

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of optimum yield and quality.

Climate change will <u>impact</u> horticultural commodities and regions through all of the following:

- changes in the suitability and adaptability of current cultivars as temperatures change, together with changes in the optimum growing periods and locations for horticultural crops
- changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions
- increased incidence of physiological disorders such as tip burn and blossom end rot
- greater potential for downgrading product quality e.g. because of increased incidence of sunburn
- increases in pollination failures if heat stress days occur during flowering
- increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures)
- increased irrigation demand especially during dry periods
- changing reliability of irrigation schemes, through impacts on recharge of surface and groundwater storages
- increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown
- increased risk of soil erosion and off-farm effects of nutrients and pesticides, from extreme rainfall events
- increased input costs—especially fuel, fertilisers and pesticides
- additional input cost impacts when agriculture is included in an Emissions Trading Scheme (ETS).

With increasing temperatures, and changes to rainfall patterns which are currently uncertain, the simplest <u>adaptation</u> strategies will be employed and are currently being employed by growers. These will be the use of more adaptable cultivars and a range of cultural practices which enable growers to maintain current production in current locations—i.e. adapt to the ‘new’ climate in the current location. This will be driven in the first instance to maintain profitability through market timing, market access and market share.

If climate change impacts exceed growers adaptation capacity at a specific location, then a southward shift of production following the southward shift of agroclimatic zones is more likely to occur if growers are to maintain profitability through appropriate market timing, market access and market share.

2 Introduction

Horticulture in Australia consists of a large number of diverse industries (fruit, vegetables, floriculture, turf and ornamentals), which are grown in a wide range of production regions because of the diverse micro-climates and soils which are available in those regions. Horticulture can be considered as a sub-set of ‘Agriculture’, and vegetables and fruit are sub-sets of ‘Horticulture’.

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of optimum yield and quality.

Decisions on the location of production, and crop and cultivar selection is influenced by temperature, access to and timing of markets, suitable soils and availability and reliability of irrigation water.

The majority of horticultural industries have a dependence on irrigation, and very little rain grown production occurs.

Horticultural industries in Australia (not including the wine industry) contribute ≈ $7 billion (gross value at the farm gate) to the economy every year. On this basis, horticulture is the second largest agricultural industry in Australia after the beef industry.

The impacts described in this paper refer in the main to the vegetable and fruit industries (excluding the wine industry), with some references being made to ‘lifestyle horticulture’ (turf, floriculture and ornamentals).

Impact assessments for broad-acre agriculture, especially for the wheat industry have been published widely. This is not the case for horticulture, except for viticulture (the subject of a separate impact review). Climate indices and thresholds of significance for the large range of horticultural crops are also not well known, especially for the vegetable sector. To this end, a clear and defined understanding of how climate change will impact cropping systems and businesses in specific regions is not readily available. Arriving at an understanding is made even more complex by the large number of commodities classified as horticultural crops (over 100 in Australia), and the wide range of regional climates which exist.

Defining specific impacts on this large range of commodities across all production regions of Australia is currently not possible. Also determining the sensitivity of these industries and regions to climate change, what their adaptive capacity is, and finally how vulnerable they are, becomes speculative due to the lack of data on thresholds and tipping points for most commodities.

This review will provide a clear indication of impacts where data is available, and rely on extrapolations of this to other horticultural commodities and production regions.

Temperature affects horticultural crops in many ways, including influencing timing and reliability of plant growth, flowering, fruit growth, ripening and product quality. There are strong trends of increased mean annual temperature in all production regions.

The current trend towards lower frost risk is likely to continue in all frost-affected sites. Frost risks may not change, with drier conditions and less cloud cover potentially cancelling out this effect. With increasing temperatures, vegetable crops in some locations will be planted earlier and are likely to be more at risk to late frost damage. Fruit crops which develop more quickly in a warmer spring are also more vulnerable. Australia’s variable climate adds to the risks of crop damage from late frosts, as seen from the damage to crops in southern Australia in the spring of 2007.

However, whilst there is an expectation of a 10 to 50% increase in days over 35°C by 2030, the occurrence of hot spells is more likely to increase in frequency in inland growing areas and to a lesser extent on the coast.

All of the following issues will affect the Australian horticultural industry in some way:

- changes in time to harvest for some crops and locations
- changes in the suitability and availability of cultivars for current and future production locations
- reduced availability and increased cost of irrigation water in most locations and in some seasons
- greater seasonal variability
- increased pest and disease incidence and 'new' pests, diseases and weeds
- damage from extreme events (rain, hail, wind and heat stress)
- negative impacts on soils and crops due to extreme temperature and rainfall events and flooding.
- changes in frost frequency.

3 Sector definition—economic contribution and location

The Australian **vegetable** and **fruit industries** with a gross value of $2.3 billion, and $2.4 billion respectively in 2003-04, produced by around 2800 commercial enterprises, are important suppliers of food to the Australian domestic market, producing the majority of fresh as well as a large proportion of the processed products consumed in Australia.

The horticultural industry (which includes viticulture and lifestyle horticulture), is almost as large as the beef sector, twice the size as the wool sector, and six times that of the sugar cane growing sector.

Australian horticultural growing enterprises are geographically dispersed across all Australian states.

Constraints to current and future production are the increasing costs of production; availability of labour (horticulture is a significant employer of labour in the agricultural sector); markets, especially the domestic market; climate variability and climate change; availability of water for irrigation and access to profitable export markets.

3.1 Range of commodities and regional location

Horticulture in Australia consists of a large number of diverse industries (commodities), which are grown in a wide range of production regions because of the diverse micro-climates and soils which are available in those regions. Appendix 1 shows the diversity of production across the many horticultural regions in Australia.

The major fruit and vegetable commodities (in approximate order of GVP) grown in Australia are pome fruit (apples and pears), potatoes, citrus (oranges, mandarins and lemons), bananas, tomatoes and capsicums, stone fruit (apricots, peaches, nectarines and plums), brassicas (broccoli, cabbage and cauliflower), tropical fruit (mango, avocado and pineapple and a large number of other tropical commodities), nut crops (macadamia and almond), berry fruit (strawberries), onion, leafy vegetables (lettuce and celery), carrots, cucurbits (watermelon and rockmelon, pumpkin, cucumber and zucchini), green beans and sweet corn.

4 Impacts of climate change

Climate Change will impact, and is already impacting horticultural industries and businesses as a consequence of the effects of a change in a number of climatic factors:

4.1 Increasing temperatures

All horticultural crops are sensitive to temperature, and most have specific temperature requirements for the development of high yields and quality.

Decisions on the location of production and crop and cultivar selection, are influenced by temperature, access to and timing of markets, suitable soils and availability and reliability of irrigation water.

4.2 Changes in rainfall amounts, distribution and intensity

The majority of horticultural industries have a dependence on irrigation, and very little rain grown production occurs. Rainfall has positive and negative effects on horticultural production.

When 'normal in-season' rainfall events occur, irrigation storages (dams and aquifers) are replenished, and the amount of irrigation required to grow crops is reduced. 'Out of season' rainfall events, especially if high in intensity, often have devastating consequences for product quality and production.

All horticultural regions will continue normal production for extended periods of time as droughts develop. This situation has occurred in many horticultural regions for a number of years without significant rainfall which produces storage replenishing runoff. This is in direct contrast with much of the broad-acre and grazing industries which depend on pre-planting and in-crop rainfall to produce economic yields.

The current drought has demonstrated the limits to which individual production regions can endure—e.g. Production of fruit and vegetable crops in the Murray Darling Basin of NSW and Victoria, in particular, has been severely impacted, but only after more than 5 years of significantly reduced flows in the river system. Similarly, vegetable production in the Lockyer Valley in SE Queensland has continued at normal production levels until 2003, with no significant recharge into the aquifers since 1996. Many other horticultural regions in Australia have approached the limit of irrigation water availability after 2 to 10 years of significantly reduced runoff from rainfall. Over the past few years, most of these regions have received some runoff, and many have had storages completely replenished.

Where future changing climates deliver less rainfall, and consequently less runoff, changes will need to be made to the capture and storage of irrigation water together with more water-use efficient irrigation systems, for growers to be able to continue production.

4.3 Specific impacts—associated with a 1°C rise in Australian temperatures

Many horticultural regions have already experienced a rise in both maximum and minimum temperatures (Appendix 2) compared with the 1961 to 1990 base period. Appendix 2 provides evidence for three important horticultural production regions. As a result of these changes, growers have already experienced up to 1°C rise in temperatures, and have successfully adapted to these changes.

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Defining specific impacts on this large range of commodities across all production regions of Australia is currently not possible. Also determining how sensitive these industries and regions are to climate change, what their adaptive capacity is, and finally how vulnerable they are, becomes speculative due to the lack of data on thresholds and tipping points for most commodities.

The following impacts, including some examples, have already occurred and are likely to continue to occur, with a further increase in temperature.

Production timing

Crops will develop more rapidly and mature earlier (taking less time from planting or fruit set to harvest). Vegetable growers producing summer crops in temperate regions will have the additional option of planting earlier, and later, therefore extending the production season. In tropical and sub-tropical regions, vegetable growers producing winter crops will be negatively impacted as the winter production season will be shortened.

- The winter lettuce and brassica season (mid-April to October) in south-east Queensland will be shortened by several weeks to a month by 2030 without the availability of more adaptable cultivars.
- For citrus, grapes, sweet corn and rockmelons in the Riverina, crops will mature earlier by about 10-14 days.
- For some perennial crops the annual irrigation requirement is increasing, not just because of higher evaporation, but also because the tree can develop more quickly (put on more growth) during a 12 month period. It has been estimated that for citrus in the Central Burnett (Queensland), heat accumulation has increased from 2800 Heat Units to over 3100 Heat Units. This is about equivalent to adding an additional month to the yearly water requirement for citrus in this region. The fact that winter temperatures are increasing more rapidly than summer temperatures is particularly important as the winter was once a period when very little heat accumulation occurred.
- Temperatures will be increasing, but photoperiods will not change. Onions are very photoperiod sensitive, so the effect will be on reducing time to harvest, which will have implications for bulb size and quality (smaller bulbs produced as the crop develops more rapidly); the fruiting season of strawberries will be reduced under increasing temperatures as runner production commences and flower (and fruit) production is reduced as day temperatures reach 28-30ºC.
- Soil temperatures will increase earlier in spring in temperate regions, providing opportunities for sweet corn to be planted earlier than is currently possible. Similarly, cucurbit crops which are currently established in the field using greenhouse grown transplants, will be able to be planted more cost effectively using direct seeding techniques, as long as the risks of late frosts are accounted for.

Product quality and yield

Increased heat stress will affect fruit size, quality and pollination of some crops.

- For avocados, increased heat stress will adversely affect fruit size and the capacity to ‘store’ a mature crop on the tree.
- Many vegetable crop cultivars are currently not as adaptable to higher (or more variable) temperatures as they were a decade ago.
- Poor pollination, especially under low humidity and high temperatures will occur in many crops (e.g. sweet corn, cucurbits, tomato and avocado), together with a reduction in the number of pollinator insect species present.
- Floral abortion will occur in capsicum when temperatures exceed 30ºC.

- Tomatoes have a threshold of 35°C—above this they are likely to experience a reduction in quality—the number of times that this occurs is likely to increase in the future.
- Higher temperatures will reduce tuber initiation in potatoes.
- Increasing carbon dioxide could increase the incidence of brown fleck disorder in potato.
- Poor pollination will occur in many crops grown for seed (lettuce, sweet corn, cucurbits and carrots).
- Lettuce tipburn, a disorder occurring under low humidity and temperatures greater than 30ºC, will become more prevalent in the absence of more adaptable cultivars.
- Out of season high temperatures cause bolting (premature seed head production) of lettuce and celery, resulting in poor quality heads, and reduced yields. Increasing temperatures will force growers to narrow the production window for these crops to maintain quality and yields.
- Pollen germination in tomato is affected at temperatures above 27ºC leading to fewer fruit numbers (or smaller fruit) and lower yields.
- Colour development in apples occurs through the production of anthocyanin. Anthocyanin production is reduced by high temperatures. Similarly, in capsicum red colour development during ripening is inhibited above 27ºC.
- Pome and stone fruits require a specific amount of winter chilling to develop fruitful buds and satisfactorily break dormancy in the spring. Increasing minimum temperatures under climate change may induce insufficient chilling accumulation resulting in uneven or delayed bud break. For the pome fruit growing regions of Manjimup (WA) and the Granite Belt (Qld), which are currently marginal for chilling (i.e. there are some years when climate variability is such that 1200 chilling hours are not reached), a 1°C warming will significantly decrease the number of years when sufficient chilling will be achieved. A 2°C warming may make apple production at these sites, using traditional high chill cultivars such as Red Delicious, uneconomical. Plantings would need to concentrate on varieties such as Gala and Pink Lady, with chilling requirements below 1000 hours.
- Using long term averages, some interesting chill accumulation trends begin to emerge for some of the major stonefruit production regions, when a 1°C and a 2°C rises in temperature are applied. In the coolest regions, the variety mix will most likely remain the same. However, in some of the Victorian and South Australian stonefruit growing regions where high chill varieties are currently grown, a change in the mix of varieties from high chill to medium chill may be required. At the other end of the scale, some of the warmer regions may need to consider varieties adapted to even lower chill requirements, and some regions may not be able to grow stonefruit at all. Other factors including water availability and summer temperatures will also affect the viability of these industries.
- A number of fruit commodities (e.g. pome fruit, stone fruit and avocadoes) require cross-pollinating cultivars for effective fruit set. Increasing temperatures may adversely affect the synchronisation of flowering of these cultivars, resulting in inefficient pollination and reduced yield and quality.

Inputs (availability and costs)

- More irrigation (water) will be required because of higher evaporative demand. This will increase the costs of purchasing water, if it is available, and pumping water under hotter conditions. This, together with increasing fuel costs because of greenhouse gas emissions issues, will increase the cost of producing all irrigated crops. In some regions irrigation systems will not be able to cope with the increased demand.

- There will be increased irrigation requirements for preventing tip-burn (lettuce) and other induced disorders such as blossom-end rot (tomatoes).
- Overhead irrigation may be more of a necessity for cooling in lettuce and other leafy vegetables—contrasting with potentially reduced availability and quality of water for irrigation.
- Perennial fruit crops are very vulnerable to short-term shortages of irrigation water availability. To some extent where this has occurred in the recent drought, the high value of horticultural crops has enabled some growers to purchase irrigation water and divert it from other lower returning agricultural uses.
- Competition for irrigation water has already occurred, and the cost of water has increased. Water for irrigation in horticultural crops will be diverted from other uses as long as the economic returns are sufficient. Secure supplies of water will need to be considered at a cost which relates to the return for the product grown with a secure water supply.
- If drought conditions do become more frequent, or their severity increases due to climate change, then the lifestyle (or amenity horticulture) sector will be affected. More drought tolerant plants and more efficient irrigation techniques will be required for industry and consumers to be able to adapt.
- Climate change will increase the cost of labour for harvesting, especially in northern regions, as fewer people (predominantly backpackers) will find the regional climate favourable in which to work. Increasing travel costs, will exacerbate this.
- The cost of freight, packaging, pesticides and fertiliser will increase as a result of greenhouse gas mitigation activities, and the increasing costs of fossil fuels (see mitigation opportunities—latter section of this report).

Effects on cultural practices

- An increasing incidence of out of season and extreme rainfall events, including consequent flooding, will affect the timing of cultural practices as well as the negative effects on yield and product quality. The damage caused to the vegetable industry (crop damage, erosion, soil and infrastructure losses) in the Lockyer Valley in May 1996 from out of season flooding was estimated to be $20M.
- Increasing temperatures will impact greenhouse crop production, especially production in sub-tropical regions, where current summer temperatures restrict production to the cooler months of the year, because temperature thresholds are often exceeded. Additional technologies for cooling greenhouses will be required for these production systems to continue. Greenhouse production in temperate (or highland) regions will be impacted less, and for summer production the impacts may not be felt for many years, especially where temperature thresholds are much higher than current maximum temperatures. Positive impacts on reduced costs of heating for winter production will occur as temperatures rise.
- Most vegetable crops will develop more rapidly, changing current crop schedules and marketing arrangements. More frequent consecutive plantings for crops such as lettuce and brassicas will be required to regain regular production patterns. Therefore there is a need for a better understanding of the indices (e.g. the number of days over a specific temperature threshold, say 35°C) which will be a part of future climates, and the effects these will have on yield and quality, as well as other factors such as time to harvest, pollination, etc.

Pest and disease effects

In general, higher temperatures will increase pest and disease activity, alter their development rate, including that of host crops, and increase survivability of some organisms, especially in warmer winters. Changing rainfall amounts and patterns will modify this temperature effect for each organism.

- Higher temperatures will generally result in increased insect pest activity—e.g. an extra generation of insect pests such as heliothis will be possible in most locations.
- Higher temperatures will result in a longer period of pest activity, especially where production is extended—e.g. Diamondback Moth (DBM) is a pest of worldwide significance wherever brassica vegetable crops are grown. This pest is most destructive when an extended season occurs or where temperatures during the production season are high. With a warming climate DBM will have an increased impact in all brassica growing regions, particularly sub-tropical regions, and increasingly so in temperate regions.
- Under warmer (and perhaps drier) conditions in the future, thrips will reproduce and survive more easily. This situation has already been experienced during the drought conditions of the past 5 or more years.
- Higher temperatures will have negative effects on survivability and reproduction of some important parasites and predators—e.g. scale parasites in citrus and trichogramma in vegetables.
- Higher temperatures will provide opportunities for new pests which are currently not able to survive cold/cool winters—e.g. #1. Silverleaf Whitefly will extend into southern regions, where it either currently doesn't exist, only occurs sporadically, or occurs only in modified environments such as greenhouses—e.g. #2. The Murrumbidgee Irrigation Area (MIA) is Queensland Fruit Fly (QFF) free, and this freedom status is maintained by monitoring and trapping. Greater incursion pressure can be expected in the MIA from QFF, as the climate becomes more favourable for QFF development and survival.
- Increasing temperatures, especially during the winter, will provide a survival mechanism for pests such as Silverleaf Whitefly, and its weed and crop hosts. This will allow an extension of the current SLW habitat from subtropical to more temperate regions as climate continues to change.
- For scale and mites pests in a range of horticultural crops especially citrus, dryer and dustier conditions will increase the occurrence and appearance of these pests earlier in the season.
- Higher temperatures, combined with lower humidity will compromise the effectiveness of some biological pesticides—e.g. Nuclear Polyhedrosis Virus (NPV) used extensively in sweet corn and tomatoes for managing heliothis, is most effective under cool, moist conditions.
- Pathogens which require free moisture or high humidity to reproduce and establish (e.g. Black Spot in Apple, Brown Rot in Stone Fruit and a range of leaf and soil-borne pathogens of fruit and vegetables), will be less prevalent in those regions where spring and summer rainfall is likely to reduce and dry conditions prevail for longer periods between rainfall events, and vice versa for those regions where rainfall increases.
- As the number of extreme rainfall events increases, soil conditions will favour the establishment and reproduction of soil borne pathogens such as *Phytophthora cinnamomi* in avocado and *Sclerotinia scleroteorum* in lettuce as well as many plant parasitic nematodes.
- As for insects and diseases, weeds will have opportunities to spread to regions where they are currently unable to establish because of temperature constraints. This will provide opportunities for vectors of virus diseases—e.g. Silverleaf Whitefly (a vector of Tomato Yellow Leaf Curl Virus which is hosted on a range of weed species in the Solanum genus) will be able to over-winter in more southerly regions as temperatures, especially winter temperatures, rise.

Marketing arrangements

Higher temperatures will change production and marketing arrangements between regions. Crops will develop more rapidly and mature earlier, taking less time from planting or fruit set to harvest.

- In tropical and sub-tropical regions, vegetable growers producing winter crops will be negatively impacted as the winter production season will be shortened e.g.—the season for lettuce, sweet corn and brassica vegetable crops in SE Qld, will be shorter by approximately 2 weeks on either end of the winter season. This will provide opportunities for other more southerly regions which are currently too cold to produce crops in late autumn and early spring, to grow crops and market products in this time slot.

- Citrus and grapes in the Riverina will mature earlier by about 10-14 days. This may have a positive impact, by providing growers with options to market crops earlier with potentially higher returns.

Post-harvest costs

- Under higher temperatures, poor rind colour development occurs in citrus, especially with higher night temperatures in the Riverina and the Burnett. Regreening in Valencia's during summer, will require longer periods of degreening.
- De-greening may become a future management practice, especially for Navel oranges produced in southern regions, to satisfy the needs of consumers.
- Increased costs of grading and marketing for susceptible fruit and vegetables will occur for removing increased amounts of blemished product. Reduced marketable yields associated with damage from sunburn and poor pollination will also occur.
- Post-harvest cooling costs for most vegetable crops will increase as additional field heat will need to be removed prior to transport to market.

Production location

Production of some crops in some regions will benefit from an extended production season, whilst others will contract. It is expected that this will be a gradual induced relocation of production, in the absence of adaptation actions which include introduction of more adaptable cultivars in those areas where higher temperatures become a limitation to production. The establishment of the citrus industry in Emerald in Central Queensland in the 1980s and 1990s following a significant increase in winter temperatures as compared with the 1960s, is an example of a change to location as a consequence of a changing climate.

- It will be possible for some production districts to extend their production season into the winter—e.g. The Central West of NSW currently produces lettuce only in the spring and autumn. Warmer winters will allow lettuce production to expand into and eventually through the winter as well, whereas current winter lettuce production in the Lockyer Valley will contract as winter temperatures rise. Similarly avocado production will become viable in those districts (e.g. highland areas of southern Qld and northern NSW), which are currently too cold for current cultivars to consistently set fruit.
- If rainfall increases do occur, especially in the tropics, then the disease management advantages offered by dry winter seasons for the production of crops such as rockmelons and mangoes will be significantly reduced.
- Increasing temperatures will impact greenhouse production, especially production in sub-tropical regions, where current summer temperatures restrict production to the cooler months of the year, because temperature thresholds are often exceeded. Additional technologies for cooling greenhouses will be required for these production systems to continue, or this production will be induced to move to more temperate or to highland regions where maximum temperatures are mitigated by altitude. Positive impacts on reduced costs of heating for winter production will occur as temperatures rise.

Increased productivity

Increases in temperature and CO_2 may increase yields of some crops, providing positive productivity outcomes.

- Large variations in response to increased CO_2 levels have been found across a range of horticultural commodities. Where positive responses have been found (e.g. potato, lettuce, avocado and citrus), increasing temperatures may offset any increased productivity.

Environmental impacts

- An increase in the intensity of rainfall will increase the potential for erosion events and the export of nutrients and sediments from fields, affecting water quality and impacting other ecosystems such as the Great Barrier Reef. This will require practices aimed at intercepting raindrops and runoff, e.g. residue and stubble retention.
- An increasing awareness of climate change will increase the need for growers to use carbon-neutral practices and reduce practices that are deemed detrimental to the environment.
- Rising sea-levels will impact aquifers used for irrigation in coastal regions.
- With minimum temperatures increasing, the incidence of frosts is projected to decrease. Frost risks may not change, with drier conditions and less cloud cover potentially cancelling out this effect. With increasing temperatures, vegetable crops in some locations will be planted earlier and with the above scenario are likely to be more at risk to late frost damage. Fruit crops which develop more quickly in a warmer spring are also more vulnerable. Australia's variable climate adds to the risks of crop damage from late frosts, as seen from the damage to crops in southern Australia in the spring of 2007.

Financial viability

- An increase in the intensity of cyclones will have effects on production systems, the community and consumers. The effects of Cyclone Larry (March 2006—$A350 million crop, property and infrastructure losses) on the banana industry and communities of North Queensland, and the Australian consumer, could easily be repeated in the future in other industries and communities in northern Australia.
- Increasing fuel costs will increase the cost of producing all crops.
- Increasing competition will come from regions that progressively become more suitable for production of similar commodities.
- If quality is valued by the consumer, then growing crops in their 'ideal' environment, where the appropriate cultivars perform best, will become an advantage to those growers and locations where this coincides.
- Perennial horticulture in particular has a long-term investment horizon. There will be a need for more information on how to decide on the long-term investments required for these commodities (especially those where cultivars are not rapidly changing—avocados vs. low-chill stonefruit vs. vegetables).

Source of current (and future) cultivars

- The majority of vegetable cultivars used in horticulture are sourced from overseas (this is especially the case for most of the seed propagated cultivars—potatoes are a notable exception). Australian production of all commodities is very small in relation to the major fruit and vegetable producing countries of USA and Europe, from where most cultivars are sourced.
- Breeding specifically for Australian conditions for many commodities will not be a viable option for most vegetable seed companies. Growers of these horticultural commodities will remain

dependant on cultivars being available and adaptable to Australian environments as climates continue to change.

- The commercial reality of the vegetable seed industry, is that cultivars available to Australian growers are those produced for other countries where production is significantly larger. The specific ‘needs’ of Australian growers will be difficult to satisfy separately from the needs of growers in the much larger growing regions of the world.

- For perennial crops, the capacity of growers to change to better adapted cultivars, if better adapted cultivars are available, is limited by the costs and the time from planting to first harvests in fruit crops. This is a long investment horizon. The other limitation is knowing what cultivars would be adapted to the changed environment—this would need to be extrapolated from other production regions. The costs of getting it wrong are very high.

5 Mitigation

It is not known if horticulture is a net emitter or sequester of greenhouse gases (GHG). Many factors will need to be understood to be able to determine this for the large range of commodities, regions and farming systems utilised by growers in these regions.

There is a high probability that most horticultural cropping systems will be net emitters of GHGs, although it is expected that this will be relatively low when compared with other agricultural commodities. The lowest emitters will be those commodities and farming systems which minimise tillage operations and better manage nitrogen fertiliser applications. Both of these practices are increasingly being incorporated into Best Management Practices (BMPs) for horticultural farming systems. These farming systems may also be able to sequester carbon, and potentially provide another income opportunity for horticultural businesses in a changing climate.

There are potential negative impacts on horticulture with the introduction of an emissions trading scheme (ETS) into agriculture. The large number of horticultural commodities utilising the wide range of farming systems in the diversity of production regions, will be a significant challenge to compliance with an ETS, as well as potentially imposing costs in excess of the benefits which might come from an involvement in an ETS.

6 Adaptation

Flexibility has been the key to adaptation in horticulture to date, and is likely to continue to be an important component of adaptation strategies as climates continue to change. Growers have been able to manage climate variability reasonably well, although major improvements could be made if tools to assist with the management of climate variability, both temperature and rainfall, were designed specifically with the needs of horticultural growers and industries in mind.

The current drought has provided opportunities for some growers who have been able to shift production to where water for irrigation is available. Those who have done this successfully will be in a much better position to also manage climate change successfully.

The following are desirable climate change adaptation outcomes for horticulture:

- resilient and adaptive horticultural production systems which are less vulnerable to climate change and climate variability
- improved resilience to changes in pest and disease incidence
- increased ability to capitalise on new market opportunities
- regionally specific climate change scenarios, which are very relevant to managers of horticultural enterprises
- practical tools available to horticultural growers and their advisors to better manage climate change and climate variability.

6.1 Site selection

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).

A pilot study linking climate change scenario modelling and land suitability modelling was conducted in the East Gippsland region in 2004 to model the potential implications of climate change on the future production of selected agricultural commodities (cool climate grapes, plantation blue gum, spring wheat). Similar studies in major horticultural regions would determine vulnerability of current commodities, and develop adaptation strategies to better cope with the impacts.

6.2 Crop management

Chemical treatments such as hydrogen cyanamide to induce budbreak in fruit crops, cultural treatments including evaporative cooling through overhead irrigation, strategic applications of nitrogen and irrigation, and sunburn protection using kaolin based products are currently being used in subtropical and tropical cropping systems. Their use will increase, especially if alternative more adaptable cultivars are not available.

Planting dates of some crops such as sweet corn are based on soil temperature conditions which automatically allow the adaptation to climate variability to occur. The changes in production times which result from increasing temperatures, will need to be taken into account with changes to production and marketing plans.

6.3 Cultivar selection

Selection of available cultivars which are more adaptable to a changing and variable climate will be the main tool for adaptation in the vegetable industry.

In the perennial fruit industry, the need for a much longer term investment horizon may reduce the wider application of this adaptation strategy.

Breeding for lower chill requirements in stonefruit is already occurring. These cultivars will be more adaptable in existing production areas as temperatures increase. Similarly, the current mandarin breeding strategy in Queensland is anticipating warmer production conditions in the future.

6.4 Water management

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.

6.5 Pests and diseases

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.

6.6 Use of seasonal forecasts

Fruit and vegetable growth and quality are very sensitive to environmental extremes. Current seasonal rainfall and temperature forecasts have limited application to horticulture because of the lead time and season length requirements of horticulture. Tools used in managing climate variability have mainly been designed and constructed for a specific purpose and for a specific agricultural or pastoral industry. The combination of long season (3 months) and short lead-time (zero), which are incorporated in current tools for managing climate variability, are appropriate for other agricultural industries, but are a significant constraint to the use of these forecasting tools in horticulture, where a much shorter season length (several weeks to one month) and a much longer lead-time (3 to 4 months), would be much more useful.

Temperature is the major factor in determining where horticulture crops can be grown successfully, and then how well these crops perform under varying seasonal conditions. Horticultural industries' requirements for seasonal temperature (and rainfall) forecasting information, is wide and varied because of the large number of commodities and cropping systems, spread over a very wide range of climatic regions.

7 Conclusions

Because horticulture in Australia consists of a large number of diverse industries, which are grown in a wide range of production regions, climate change impacts will be as diverse. Many horticultural regions have already experienced a rise in both maximum and minimum temperatures compared with the 1961 to 1990 base period. As a result of these changes, growers have already experienced an impact of climate change of up to 1°C rise in temperatures, and in the main, have successfully adapted to these changes.

Rises in temperatures up to 4°C will be a real challenge to horticulture, as climate indices or thresholds of significance for the large range of horticultural crops are not well known, especially for the vegetable sector. To this end, a clear and defined understanding of how climate change will impact cropping systems and businesses in specific regions at temperatures up to 4°C is not readily available.

Arriving at an understanding is made even more complex by the large number of commodities classified as horticultural crops (over 100 in Australia), and the wide range of regional climates which exist.

All of the following will affect Australian horticultural industries in some way, and increasingly so as temperatures rise above the level to which growers have been able to readily adapt:

- changes in time to harvest for some crops and locations
- changes in the suitability and availability of cultivars for current and future production locations
- reduced availability and increased cost of irrigation water in most locations and in some seasons
- greater seasonal variability
- increased pest and disease incidence and ‘new’ pests, diseases and weeds
- damage from extreme events (rain, hail, wind and heat stress)
- negative impacts on soils and crops due to extreme temperature and rainfall events and flooding
- changes in frost frequency.

8 Acknowledgments

I wish to thank my many colleagues working in horticultural research and extension around Australia, who have provided valuable information and examples for inclusion in this review.

Appendix 1 Horticultural commodity by region

The major fruit and vegetable commodities (in approximate order of GVP) grown in Australia are pome fruit (apples and pears), potatoes, citrus (oranges, mandarins and lemons), bananas, tomatoes and capsicums, stone fruit (apricots, peaches, nectarines and plums), brassicas (broccoli, cabbage and cauliflower), tropical fruit (mango, avocado and pineapple and a large number of other tropical commodities), nut crops (macadamia and almond), berry fruit (strawberries), onion, leafy vegetables (lettuce and celery), carrots, cucurbits (watermelon and rockmelon, pumpkin, cucumber and zucchini), green beans and sweet corn.

Main regions in Australia where horticultural crops are grown

State	Region	Major horticultural commodities (excluding viticulture)
WA	Ord	Cucurbits, Melons
	Carnarvon	Bananas, Capsicum
	SW WA	Carrots, Brassicas, Potato, Pome fruit
SA	Lower SE	Potato
	Riverland	Onions, Carrots, Citrus, Stone fruit
	Central Murray	Onions
Vic	Sunraysia	Carrots, Citrus, Stone fruit, Asparagus, Almonds
	Werribee	Brassicas, Leafy vegetables
	Gippsland	Brassicas, Leafy Veg, Sweet corn, Asparagus
	Yarra Ranges	Strawberry
	Goulburn Valley	Tomato, Pome and Stone fruit
	Loddon	Tomato, Pome fruit
	East Central Highlands	Potato, Strawberries
NSW	Riverina	Citrus, Cucurbits, Melons, Onions, Carrots, Sweet corn, Tomato
	Sunraysia	Citrus,
	Central West	Sweet corn, Pome and Stone fruit, Asparagus
	North Coast	Bananas, Macadamia, Tropical fruit
	Central Macquarie	Sweet corn
Tas	Northern Region	Potato, Beans, Onions, Sweet corn
	Southern Region	Pome fruit
Qld	Wet Tropics	Bananas, Tropical fruit
	Dry Tropics	Tropical fruit, Beans, Cucurbits, Tomato, Capsicum, Melons, Sweet corn
	Burnett and Sunshine Coasts	Strawberry, Cucurbits, Melons, Tomatoes, Macadamia, Tropical fruit, Stone fruit
	Burnett	Citrus, melons
	SE Qld	Brassicas, Lettuce, Onions, Potato, Capsicum, Cucurbits, Carrots, Sweet corn, Tomato
	Granite Belt	Pome and Stone fruit, Brassicas, Lettuce, Tomato

Appendix 2 Three regional examples of historical climate change

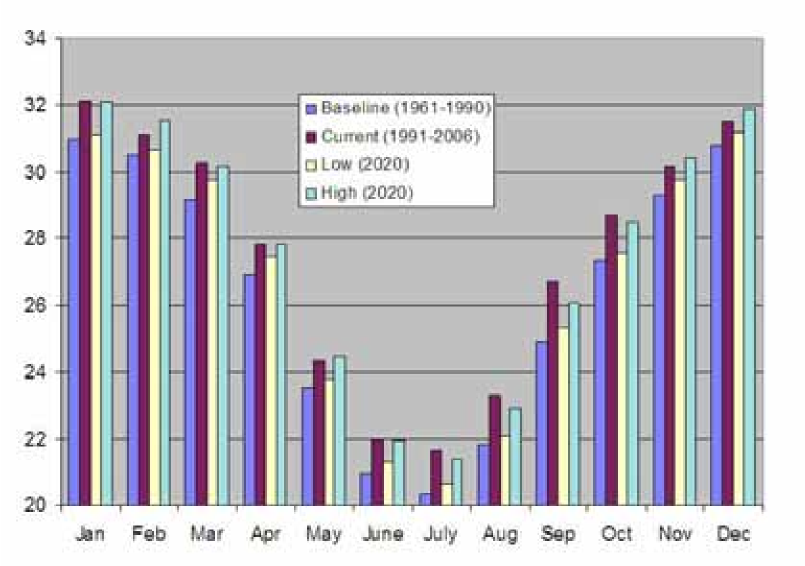
Many horticultural regions have already experienced a rise in both maximum and minimum temperatures compared with the 1961 to 1990 base period. Three regions of horticultural significance (Burdekin, Lockyer Valley and Riverina) are examples of an already changing climate, to which growers have successfully adapted.

As a result of these changes, growers have already experienced up to 1°C rise in temperatures. Temperatures for the Low Scenario for 2020 are close to current temperatures in each of these three regions. Growers have, in the main, successfully adapted to these changes.

1 Burdekin (north Queensland)

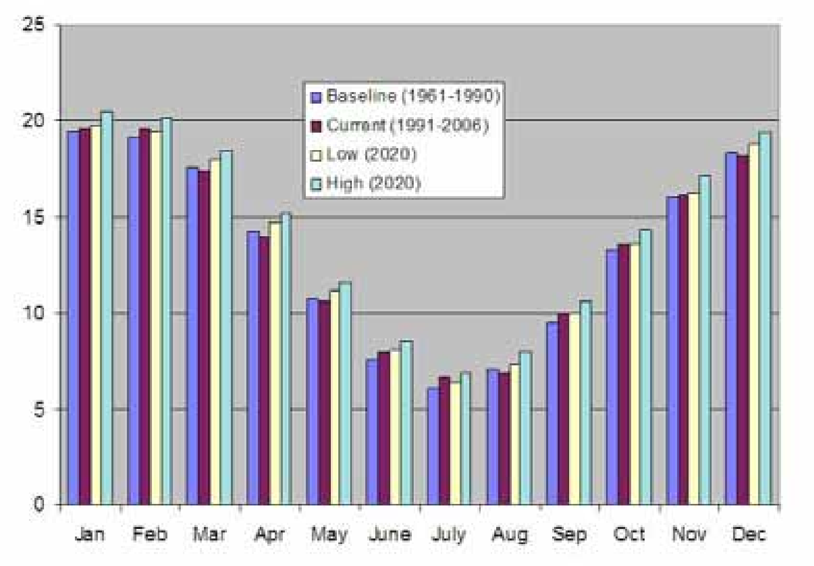
a) Mean monthly <u>maximum</u> temperature: historical (baseline), current and projected 2020 (low and high scenarios)—Ayr, north Queensland (projections by CSIRO Marine and Atmospheric Research)

°C



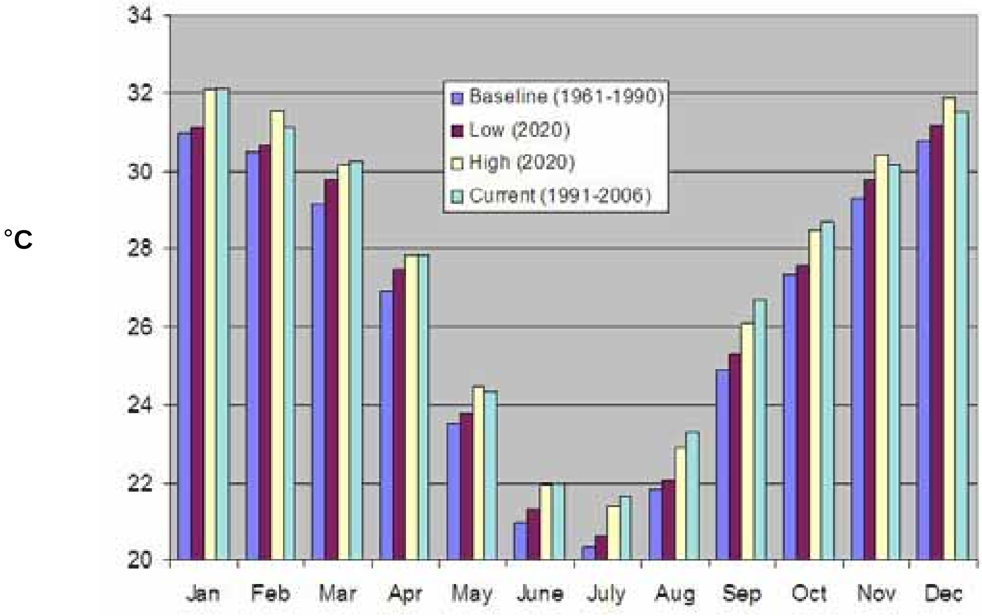
b) Mean monthly <u>minimum</u> temperature: historical (baseline), current and projected 2020 (low and high scenarios)—Ayr, north Queensland (projections by CSIRO Marine and Atmospheric Research)

°C

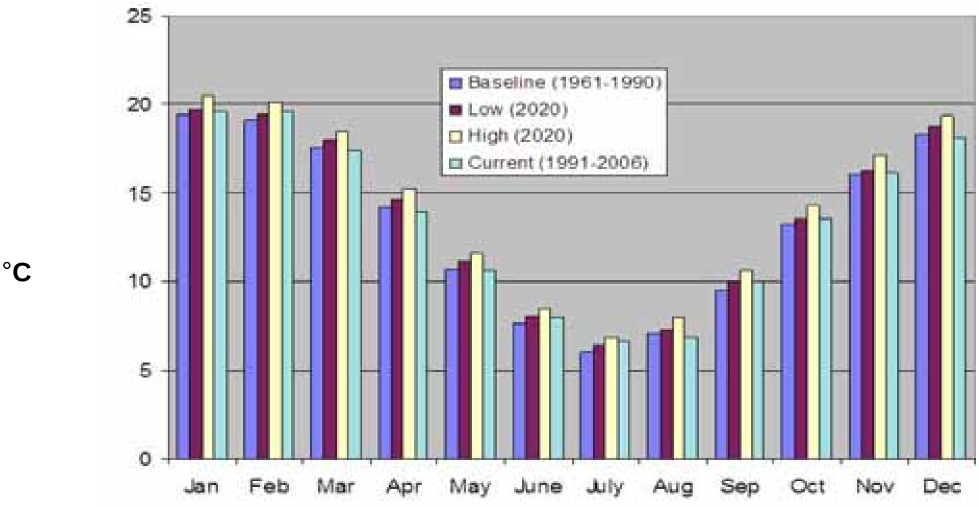


2 Lockyer Valley (south-east Queensland)

a) Mean monthly maximum temperature: historical (baseline), current and projected 2020 (low and high scenarios)—Gatton, south-east Queensland (projections by CSIRO Marine and Atmospheric Research)



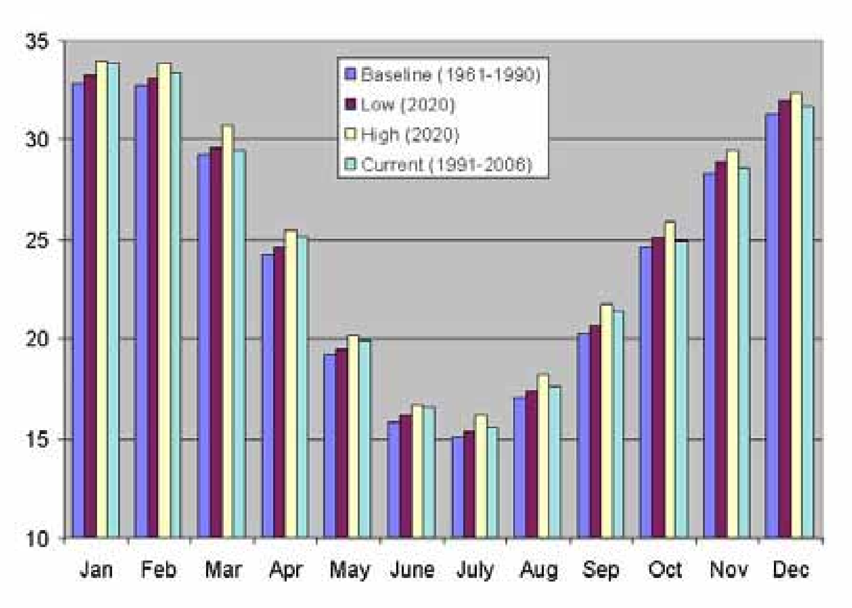
b) Mean monthly minimum temperature: historical (baseline), current and projected 2020 (low and high scenarios)—Gatton, south-east Queensland (projections by CSIRO Marine and Atmospheric Research)



3 Riverina (southern NSW)

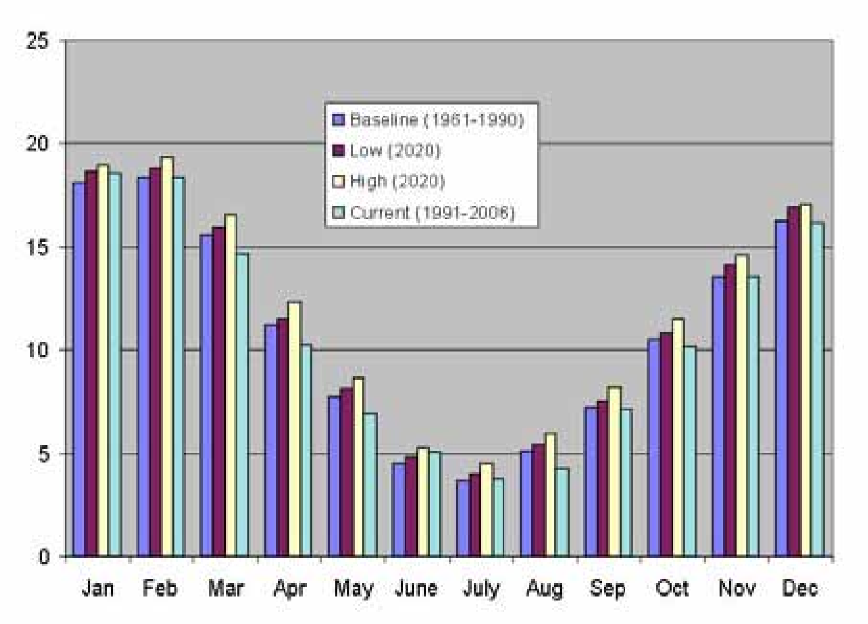
a) Mean monthly maximum temperature: historical (baseline), current and projected 2020 (low and high scenarios)—Griffith, southern NSW (projections by CSIRO Marine and Atmospheric Research

°C



b) Mean monthly minimum temperature: historical (baseline), current and projected 2020 (low and high scenarios)—Griffith, southern NSW (projections by CSIRO Marine and Atmospheric Research

°C



Appendix 3 Glossary

Anthocyanin is a pigment responsible for the red colour of the skin of fruits (and some leaves and stems).

Blossom End Rot is a disorder of tomato, capsicum and some of the cucurbits, caused by a deficiency of calcium at the growing point of the fruit. Sunken, necrotic areas at the blossom end of fruit are the result. Calcium deficiency at this growing point is caused by the combination of a number of factors including rapid growth induced by high levels of nitrogen fertiliser application, and high temperatures combined with water stress. A similar situation will cause Tip Burn in lettuce.

Bolting is the premature flowering in leafy crops such as lettuce and celery, where a flower stalk develops prematurely in the heart of the plant. Marketability of the crop is significantly reduced. High temperatures are usually involved in inducing bolting.

Chilling is a requirement which a number of deciduous crops (apples, pears and stonefruit) need to meet before satisfactory fruit bud development occurs, and proper budbreak can occur in the spring. A chilling requirement is usually described as the number of hours below a threshold temperature, which is accumulated over the cooler months of the year when the plant is in a dormant phase.

Cultural Practices are on-farm agronomic activities which are utilised by farmers to produce high yielding and high quality crops. They include land preparation, planting, fertiliser application, pest, disease and weed management, irrigation, harvesting etc.

Degreening is the breakdown of chlorophyll in response to fruit maturity and ripening under the influence of cooler temperatures in autumn and winter, in citrus. This can be commercially induced through the application of ethylene to mature green fruit.

Photoperiod refers to the length of the day (and night) which change according to the seasons. Some flowering plants sense these seasonal changes in daylength as a signal to commence flowering. These are short-day and long-day plants. Those plants which are not influenced by daylength (photoperiod) are day-neutral.

Re-greening is the opposite process to degreening—i.e. the reformation of chlorophyll in mature degreened citrus fruit due to higher than expected temperatures in autumn and winter.

Tip Burn is a disorder of some leafy vegetable crops (especially lettuce), caused by a deficiency of calcium at the margins of developing leaves—see Blossom End Rot.