Research Team – **David Carey,** Senior Horticulturist, Horticulture and Forestry Science, DAF Qld & **Peter Deuter**, Horticultural Consultant, PLD Horticulture.

Drought and Climate Adaptation Program

Critical Temperature Thresholds (CTT).

Local weather conditions influence all stages of plant establishment, development and growth, ultimately determining crop productivity and marketability. Every crop has a unique range of optimum, and tolerable environmental conditions that favour its growth. Identifying and understanding the relationships between crop growth stages and 'expected' weather is very important in maximizing crop productivity. For a crop to be successfully grown and marketed in a region, the sequences of its growth phases must align with the climate, in order to maximise the potential of good growth, quality and marketable (harvestable) yield.

Grotjahn, R. (2021) demonstrates the effect of short durations of temperatures, above or below the optimum, which can have devastating consequences on horticultural crops and their produce. For high temperatures it may be measured in hours to days. Two days in a row, above the optimum, are more severe than one day. This makes the task of identifying Critical Temperature Thresholds difficult, and exacerbated by the fact that, "the thresholds have ranges due to the variation among cultivars and the conditions each plant experiences over time" (Grotjahn, R., 2021, p.40).

Introduction

Cabbage (*Brassica oleracea* L. var*. italica* Plenck) is a popular vegetable grown at a wide range of locations in Queensland and throughout Australia. Cabbage is closely related to cauliflower and broccoli, and the optimal growing requirements for all are similar, though cabbage is a little more heat tolerant. The quality of the cabbage head is strongly influenced by temperature and climatic conditions (Hara,T., 1982). According to Warland et.al.,(2006) cabbage yield and quality decline as the number of days above 30°C in the growing season increase. Numerous authors including Daniel et.al.,(2023) back up this up, Daniel and his Kenyan co-authors determined that temperatures above 24°C delay cabbage maturity, vegetative growth and lead to, "fluffy" loose heads, or failure of head formation. Research in the USA by Kahn et.el.,(2009) determined that mature cabbage plants can tolerate short durations of temperatures as low as -3°C

Cabbage is mostly eaten fresh, steamed, boiled, stir-fried or even pickled and is also used extensively in the Food Service and Fast-Food sector in Coleslaw. According to the latest industry data 83% of Australian cabbage was marketed as fresh product with the remainder going to the food sector for further processing. In Australia, the majority of Australia's fresh market cabbage production occurs in Queensland 32% and Victoria 30%, with New South Wales growing 26%, Western Australia, 9%, South Australia ,3% and Tasmania <1%.

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In Queensland, the Lockyer Valley and Stanthorpe districts are the major production regions. In New South Wales, the Bathurst and Windsor regions are major production locations, while in Victoria, the Werribee and Gippsland regions are central to production. The Adelaide plains growing region is important in S.A, while in W.A., Manjimup and Gingin are important. This geographic spread of growing locations allows fresh cabbage to be available year-round within Australia[1].

Summary

Cabbage is one of the most important leafy vegetables worldwide and the importance of head cabbage in tropical and subtropical regions has increased considerably in recent decades according to Teshome (2019). Cabbage is an annual crop, usually transplanted in the field in most Australian growing areas, though some direct seeding does occur. To ensure continual supply throughout the local growing season, producers' plant regularly, usually every week or ten days with individual plantings ready for harvest around 12 – 16 weeks later. Temperature drives plant growth and maturity, so growers select the most appropriate variety for their location and season.

Most vegetable crops including cabbage are adapted to a modest range of temperatures with the optimum varying considerably for warm and cool season varieties. Several researchers including Fang, (2004) have outlined how plant breeders have identified natural variation in varietal performance under different temperature conditions. Teshome & Bobo (2019) detailed how their research evaluated a number of exotic Drumhead cabbage varieties to select the most adaptable and high yielding for their local growing conditions. Adeniji et al., in their 2010 paper assessed 32 cabbage varieties (open pollinated & hybrids) and demonstrate that proper cultivar (variety) choice is critical to obtaining high yields and desirable cabbage head quality.

Cabbage head quality is ultimately judged by consumers who "buy with their eyes", looking for firm, cabbage heads of uniform colour and shape with no leaf yellowing or blemishes.

[1] https://www.horticulture.com.au/globalassets/hort-innovation/australian-horticulture-statistics-handbook/ahsh-2021-22-vegetables-r.pdf

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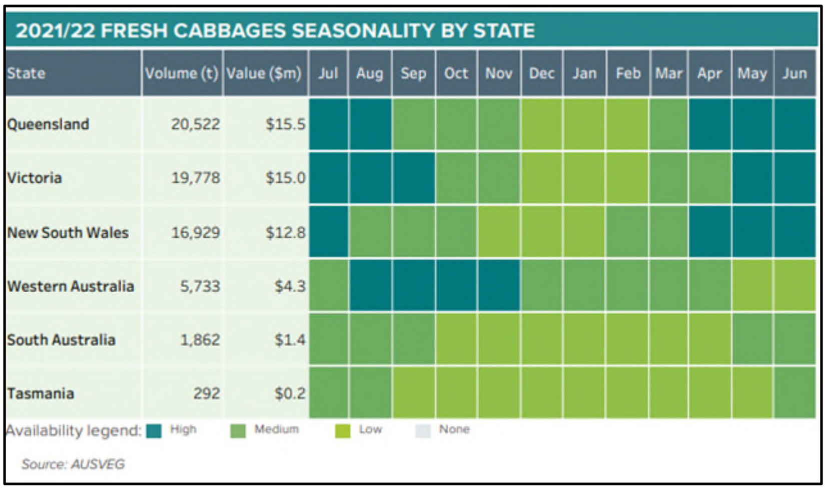
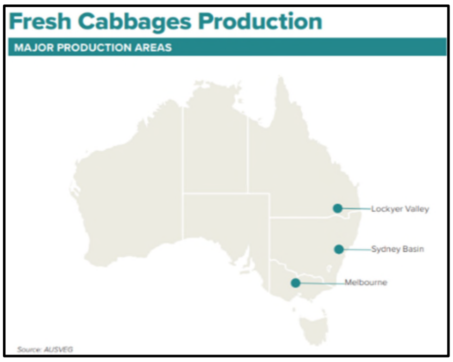
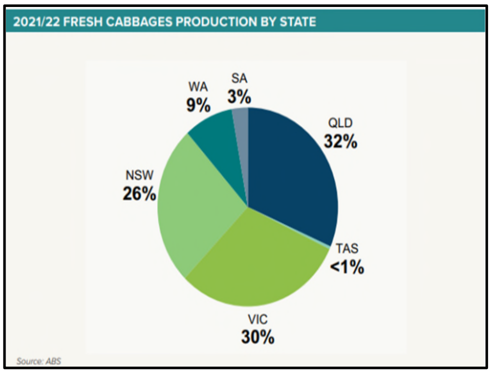


Figure 1. Australian cabbage availability by month and production volume in each state (2021-22)





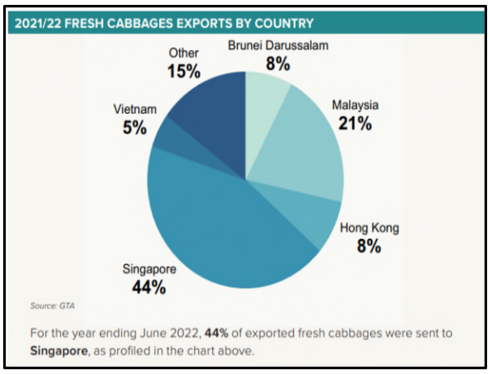


Figure 2. Cabbage growing locations in eastern Australia & each States, contribution to the national crop, major export destination data, a Drumhead cabbage and a Sugarloaf (pointed) cabbage.

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 Note graphs are best view at >140 magnification

Critical Temperatures and Development Phases.

The development of the cabbage plant from transplanting to harvest can be divided into three phases: a juvenile phase, the rosette phase and a head formation and growth (filling) phase (Fang, 2004). In the juvenile phase the young plant produces leaves at a temperature dependent rate. and cannot be induced to initiate a head. The juvenile phase ends when the plant achieves a critical number of leaves and begins to form a head (Hand and Atherton, 1987). Theunissen & Sins (1984) state that at the beginning of head formation, the youngest leaves first stand upright around the vertical central axis of the plant and later are compressed together instead of spreading out. There is limited growth in height, but the plant assumes its characteristic cabbage shape and at this stage, heads consisting of a number of loosely compacted leaves have been formed. Next the young head begins to develop, size and weight as the new inner leaves grow and begin to pack tightly inside the filling head which grows and expands until the maximum size has been reached.

Cool sunny days with temperatures between 15ºC and 25ºC and night temperatures between 10ºC and 15ºC are considered optimal growing conditions (Heisswolf et al.,2004)

The importance of temperature to successful cabbage production is revealed by Hara & Sonoda(1982) who quote earlier research by Yokominzo (1975 in Japanese). This work outlines how cabbage plants were adapted to northern parts of Japan in the initial stage of their introduction from Europe, as these early European varieties were susceptible to high temperatures. As the cabbage varieties were improved, tolerance to high temperatures was increased and cabbage production became feasible even in the warmer southern parts of Japan. The advances in modern breeding to facilitate growth of commercial cabbage crops at higher temperatures is further highlighted and investigated by Teshome and Bobo (2019). These researchers explain that the importance of head cabbage in tropical and subtropical regions has increased considerably in recent decades, with recent estimates indicating Africa has around 100,000 ha planted to Drumhead cabbage.

Published field trial results from work by Teshome and Bobo (2019) identified a number of modern varieties that produced marketable cabbages in the Adola Rede district of Ethiopia, which is characterised by mean annual temperatures around 12ºC to 34ºC.

Cabbage growth phases.

Theunissen & Sins (1984) describe that the growth phases of the cabbage plant from planting / transplanting to harvest can be divided into three phases, seed germination, a juvenile phase, a head development phase and finally the head growth (filling) phase. These researchers state that the cabbages, round (Drumhead), Sugarloaf and Savoy, all have very similar development stages.

Germination phase.

Hegarty (1975) has shown that diurnally alternating temperatures increased the germination of cabbage seeds. Maynard, & Hochmuth, (2006) recommend germination tests for cabbage seed should be conducted at 20 to 30°C.

Wagenvoort & Bierhuilzen (1977) investigated vegetable seed germination and determined that soil temperatures from 5 to 25°C resulted in acceptable germination of cabbage seed. Rodreguez et.al., (2015) determined that with the, high temperature tolerant cabbage variety they evaluated, seed was unable to germinate at air temperatures below 12°C. The same researchers determined that at temperatures above 32 °C, both germination and leaf expansion was dramatically compromised.

Fang et al., (2004), state that the optimal temperature for seed cabbage is 18 to 25°C, at which, germination will occur in 2 – 3 days.

The optimal temperature for seed germination is > 18°C & < 25°C
The Critical Temperature Threshold for seed germination is > 12°C & < 32°C

Juvenile phase – critical temperatures.

Once germinated young cabbage seedlings enter the vegetative (juvenile) phase. Vegetative development is considered to begin at seed germination and continues through seedling growth (25-30 days – depending on planting date), and into the rosette stage. The rosette stage starts with the appearance of the second leaf whorl and lasts until head formation begins (25-40 days later, depending on temperature), according to a Fang et al., (2004).

Cimo et al., (2020) investigated the effect of low temperatures on cabbage growth and found that plant growth is evident when average daily temperatures are above 9.5°C with no growth occurring when average daily temperatures are below 6.5° C. This work gives some insight into plant growth rates and the cold tolerance of the cabbage plant.

Kahn et al., (2009) state that cabbage is more heat tolerant than both broccoli and cauliflower, but prolonged high temperatures cause puffy heads, long internal stem cores and tipburn. These authors identify the upper limit for growth as about 30° C.

The optimum temperature range for cabbage production is 15 to 25°C, but optimal temperature varies with growth stage, being 7-25°C during outer leaves growth, according to Fang etal.,(2015). Rodriguez et al., in their 2015 research into cabbage production under Spanish conditions determined that at temperatures above 32°C leaf expansion was dramatically compromised.

Optimal temperature for vegetative growth is > 7°C & < 25°C
The Critical Temperature Threshold for vegetative growth is > 6.5°C & < 32°C

Head growth – critical temperatures.

Cabbage is one of the most important vegetables worldwide according to Talekar (2000) and Daniel (2023). Its production varies around the world with China being the leading producer (32,800,000 tonnes) followed by India (8,500,000 tonnes), and Russia (3,309,315 tonnes) according to Jaiswal (2020).

Fang et al., (2015) state that the optimum temperature range for cabbage production varies with growth stage but is 15-20°C during head formation. Adeniji et al., (2010) who researched cabbage production in sub-Saharan Africa determined that a minimum temperature of 4°C and a maximum of 24°C was required for quality head development. The quality of the cabbage head is strongly influenced by temperature and climatic conditions (Hara, T., 1982). According to Warland et.al.,(2006) cabbage yield and quality decline as the number of days above 30°C in the growing season increase. Numerous authors including Daniel et.al.,(2023) back up this up, Daniel and his Kenyan co-authors determined that temperatures above 24°C delay cabbage maturity, vegetative growth and lead to lose heads, or failure of head formation.

Rodriguez et al., in their 2015 research into cabbage production under Spanish growing conditions determined that at temperatures above 32°C leaf expansion was dramatically compromised. In this work the authors go on to state that under high temperatures there was a reduction of fresh weight due to decreased photosynthetic activity.

Figure 3. Chinese cabbage head with internal seed stalk (left) and non – heading, due to high temperature on right .

Low minimum temperatures are well tolerated by mature cabbage, plant growth rate is severely slowed but eating quality is unaffected (Adeniji et al.,2010). Cabbage is usually consumed when the head (leaf whorl) is firm and head expansion (growth) has stopped.

Cabbage is a biennial plant and exposing mature heads to low temperatures <4°C for 5 weeks will initiate seed stalk production, flowering and seed production according to a number of authors, including Nieuwhof (1969).

The optimal temperatures for head growth are > 15°C & <24°C.

The Critical Temperature Threshold for head growth is > 4°C & < 32°C

Future climate implications – crop performance and yield.

A range of commercial cabbage varieties are available to Australian growers. These varieties are grouped according to their suitability to a geographic production location and season.

The Australian climate is warming (reference below), meaning that some current cabbage varieties, production locations and production timeslots will change or may even become commercially non-viable due to a decline in marketable yield and or shortened production season. In cooler growing areas, warming minimum temperatures could allow earlier planting in spring and an extension of the current growing season later into autumn. In Queensland and Australia, the fresh, and food service industry is supplied year-round. Growers in different areas produce in their "traditional" vegetable production season and locations. These geographically diverse production locations allow vegetable farmers to maximise crop quality and yield, throughout the year, by aligning the crops critical temperature thresholds with suitable local production time slots (windows). Producers choose the correct variety, or varieties for their production location, season, and local climate.

Increasing production costs (seed, fertilizer, fuel, packaging, labour, transport and electricity) mean that in today's horticultural farming businesses, marketable yield must be maximised from every planting, if a farm is to remain viable.

The warming trend could see the Lockyer Valley's current year-round cabbage production window, shorten, as hotter summer maximum temperatures further impact cabbage head quality increase water requirements, ramp up growing difficulty and reduce marketable yield.

Producers will need to continue to adapt to these changes, revising their production location, varieties, management practices and crop timing in response to their knowledge and their own on-going seasonal experiences.

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Plant breeders may be able to develop and introduce new more heat resistant varieties, although this option appears limited (non-existent) given Australia's reliance on overseas breeding and the fact that, currently, in some hotter growing locations, even with the best varieties, both head quality and yield suffer.

Consumer demand drives product supply and modern consumers have no tolerance for blemished product. Cabbage supply contracts and product quality will determine consumer demand, and locations that run the risk of producing lower quality product will inevitably be avoided as the chain stores source and buy vegetables from more favourable (safer) production locations, to ensure year-round supply.

Locations or months previously deemed non-viable due to maximum or minimum temperature constraints may become commercially viable. For example, the cabbage production season in the Granite Belt, could extend further into the autumn and begin earlier in the spring, extending the edges of the current production window, as minimum temperatures rise. Conversely as both minimum and maximum temperatures rise in the Lockyer Valley, the current, "traditional" production season is likely to shorten. Increasing maximum temperatures and heatwaves associated with extreme summer temperatures will impact production viability, yield and quality in the hotter, stormier summers.

Queensland is already experiencing the impacts of climate change:

The Climate Change in Australia website {CSIRO and Bureau of Meteorology, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/), cited [January 2023] contains the following statements[2].

All of Queensland has warmed since 1910.

Average annual temperature has increased by 1.5°C since 1910. Under a high emissions scenario (RCP8.5), by mid-century, Queensland can expect an average annual temperature increase of around 1.3 - 2.5°C (central **estimate of 1.9°C**).

These statements about Queenslands changing climate refer to annual average temperature increases (1.3 – 2.5°C), so they smooth out the usual fluctuations in daily, weekly and monthly temperature at any location. The State of the Climate 2022 Report [3], Future Climate section states, "new research in Australia and around the world, together with the IPCC's Sixth Assessment Report, enhance understanding of the state of Australia's future climate. In coming decades, Australia is projected to experience, continued warming, with more extremely hot days and fewer extremely cool days."

[2] https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/
[3] https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate

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This has serious implications for horticultural production in Queensland, higher temperatures will impact, existing crops, production timing, and locations. While some production may be able, or forced to move to a new location, land suitability, water availability, workforce and supporting infrastructure (e.g., road networks & power availability) pose significant constraints.

Cabbage-Critical Temperatures Thresholds (from published research).

	Critical Temperature ^{0}C	
Growth Stage	**Lower**	**Upper**
Germination	> 12	< 32
Juvenile (vegetative)	> 6.5	< 32
Head growth	>5.0	< 32

It is important to realise that to achieve a mean monthly maximum of 30°C (for example), there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in a row above a critical temperature, tends to tip the system into decline. To simulate the effects of high temperatures on consecutive days, we have used the critical temperature + 2°C for 3 days and applied this to each crops' threshold. So, for cabbage in the head growth stage, the literature indicates the Critical Temperature Threshold is 32°C mean maximum temperature. To simulate the effects of high temperatures, we have chosen **34°C for 3 consecutive days as the Critical Temperature Threshold** for the **head growth** stage.

Commodity production data.

Australia produced around $49.3 million dollars' worth of cabbage for the fresh market in 2021-22. Around 85% of this production was sold as fresh produce, with the rest (15 %) going to processing. The majority of fresh market cabbage is grown in Queensland (32%) and Victoria (30%), with New South Wales producing 26% of the national crop. Western Australia grows 9% while South Australia and Tasmania produce 3% and 1 % of the national crop respectively. Cabbage production occurs in all states, with product transported inter-state to fill any supply shortages. Cabbage export opportunities do arise from time to time, but this market is ad-hoc, price sensitive and very price competitive. The modern Australian supply chain relies largely on state based, grower businesses contracted to fulfill pre-arranged supply orders to the Supermarkets on a daily or weekly basis.

A number of Queensland businesses grow high quality cabbage at carefully chosen locations, both, throughout the state and inter-state, so as to maximise their supply period. These Queensland based businesses move production throughout the year, so maximising crop quality and yield. Production sites are selected based on climatic suitability, to maximise product quality and supply continuity [4].

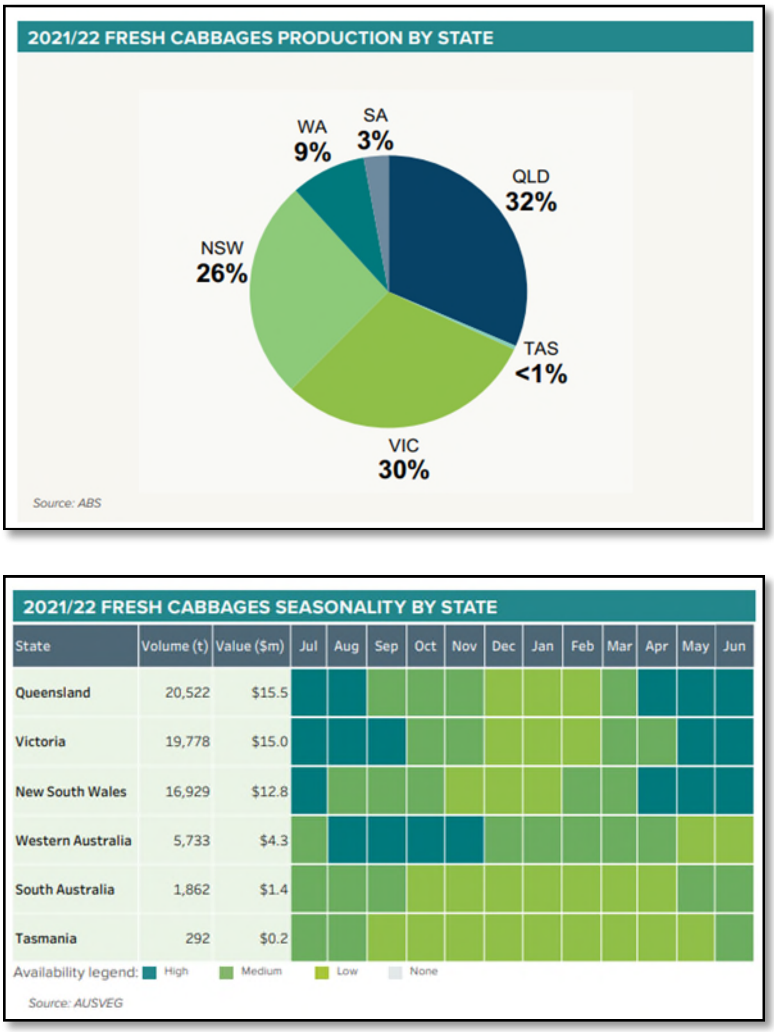

Figure 4. Cabbage production in each state and corresponding seasonal availability (Source: web reference above).

[4] https://www.horticulture.com.au/globalassets/hort-innovation/australian-horticulture-statistics-handbook/ahsh-2021-22-vegetables-r.pdf

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Production regions, seasons and critical temperature thresholds

Critical Temperature Thresholds - Climate Monitor analysis/verification of annual historical temperatures at selected production areas.**

I. Queensland

a) Lockyer Valley, Southeast Queensland (autumn, winter, spring and early summer crops).

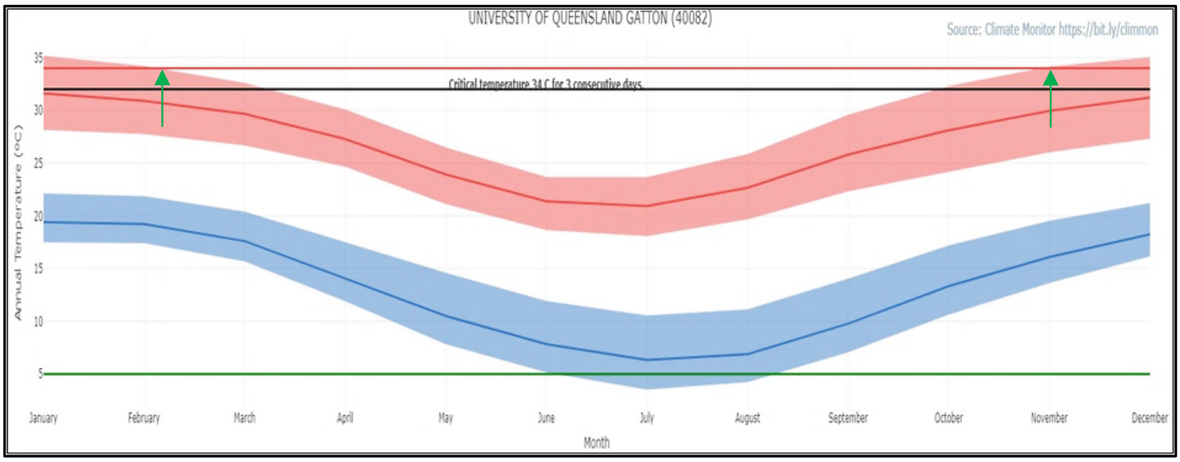

Figure 5. Monthly historical maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), at Gatton, with cabbage critical temperatures – overlaid. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

** Climate Monitor is a Web based Tool which allows the user to analyse and graph minimum and maximum temperature and rainfall for all available years, calculate thermal time (chill and heat units) and be able to retrieve, analyse and graph temperature thresholds (for a chosen location).

Cabbage is traditionally gown through autumn, winter, and spring in the Lockyer Valley, production region. Planting often starts from mid-February, with regular (often weekly) plantings occurring throughout the growing season, with an early November final harvest being the norm. Several growers who are contracted to 12-month supply "push the envelope" and do grow through the summer in order to supply, contracted, food processing orders. Cabbage head size, taste, and quality decline in these "out of season plantings". These speculative over-summer plantings also incur extra, irrigation (electricity) costs, and suffer much greater pest and disease pressure. In some years and seasons a hot end to spring will cause head quality issues and crop loss. Figure 5 above, illustrates temperatures that determine the traditional growing season Note that in some years the cabbage plants upper CTT of 34°C is reached from November through until February. The traditional

cabbage production season in the Lockyer Valley aligns well with the 32°C upper limit for quality cabbage head growth.
The cooler months from April to October produce large, dense, high-quality cabbages, both red and green, ideal for both the fresh and processing market. Both production volume and head quality peak during this traditional cool growing period in the Lockyer Valley.

To satisfy fresh market consumer demand throughout the hot summer months, high quality cabbage are grown in cooler locations ,mostly in southern states, with some also grown on the Granite Belt.

Using the unique weather data analysis capability of Climate Monitor, producers can easily review historical temperatures at any location in Australia. It is important to realise that to achieve a mean monthly maximum above 32°C there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in a row above a critical temperature tends to tip the system into decline. An analysis of the number of times a maximum temperature of 34°C has occurred for 3 consecutive days in November to February at Gatton is displayed below. The November to February summer period is unsuitable for cabbage production. In the hot summer of 2019, an El Nino year, the Lockyer Valley recorded 10 occasions when the maximum daily temperature exceeded 34°C for at least 3 days in a row - a total of <u>at least 30 days</u> (Figure 6).

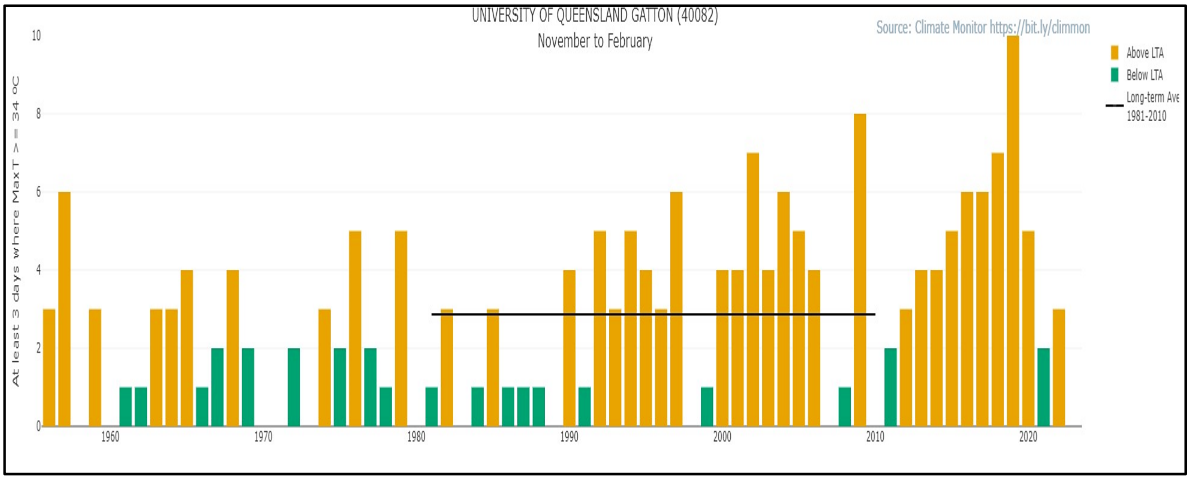

Figure 6. Climate Monitor analysis showing the <u>number of times each year</u> and season (November – February) that Gatton has experienced at <u>least 3 consecutive days</u> that were 34°C or above.

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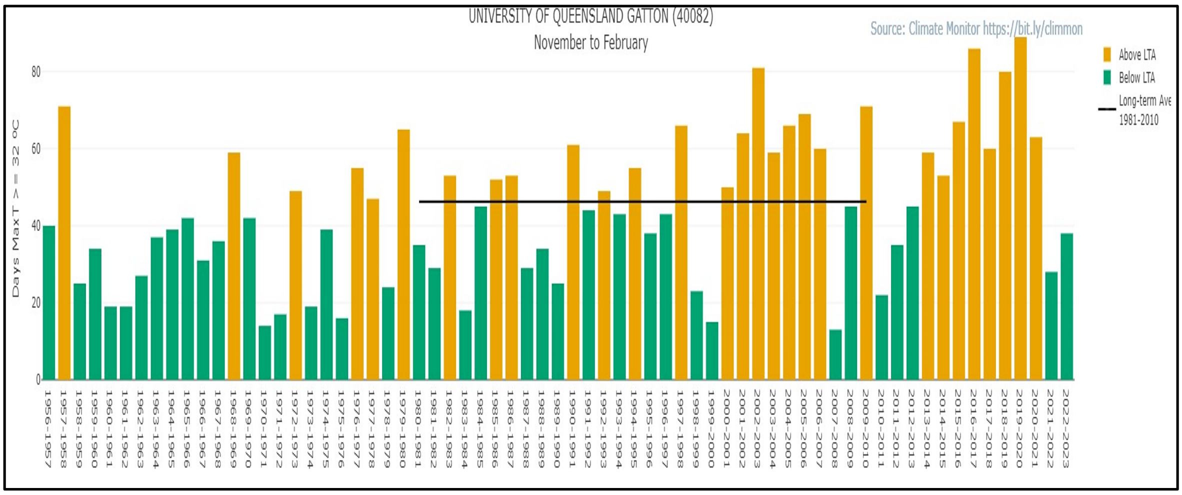

Figure 7. Climate Monitor analysis showing the number of times in each year that Gatton has experienced days that were 32°C or above over the Lockyer Valley summer season November to February. These temperatures are above the upper CTT for growing marketable cabbage heads.

The critical temperature range for cabbage head growth, is days with minimums above 5°C and maximum temperature equal to or less than 32°C, as detailed in the literature review above. The analysis below based on these temperature parameters over the Lockyer Valley's traditional peak cabbage production season April – October shows these optimum temperatures are common, occurring on average for 178 days during the "production season".

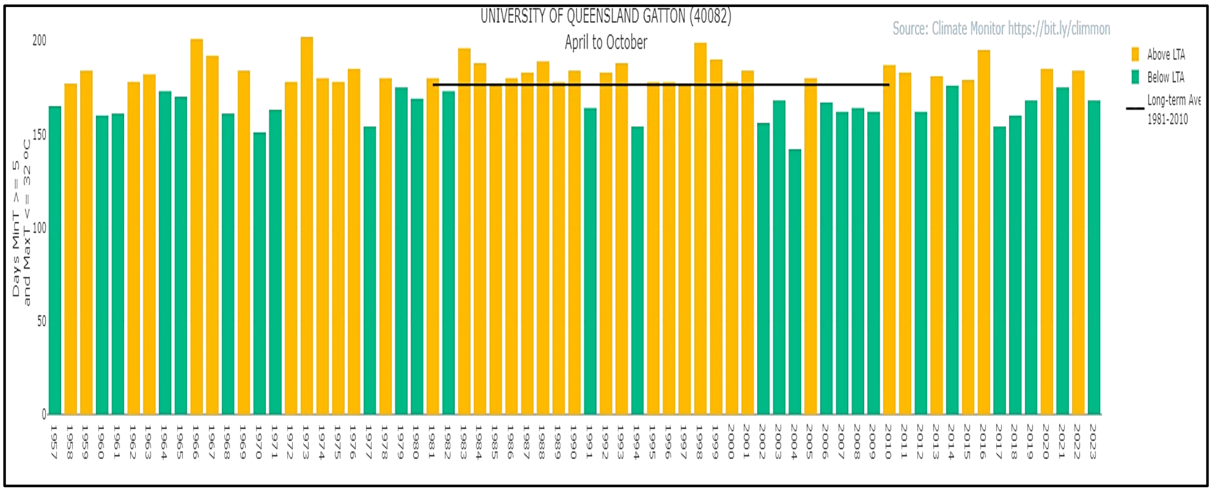

Figure 8. Climate Monitor analysis showing the number of days in each year that Gatton has experienced days with minimums ≥5 and maximum temperatures ≤32°C between April and October, the cabbage plants optimum temperature range for quality head production.

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 Note graphs are best view at >140 magnification

b) Granite Belt, Southern Queensland (Late spring, summer and early autumn production).

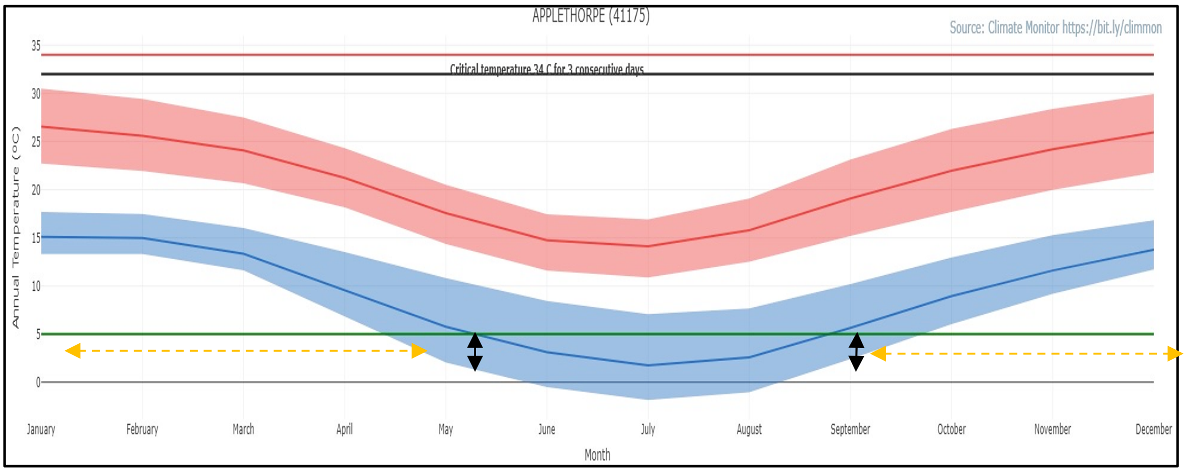


Figure 9. Climate Monitor analysis showing the annual historic monthly maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with cabbage critical temperatures – overlaid, at Applethorpe. Note, the graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years. The dotted arrows show the cropping period.

Using 5–32^{0} C as the mean minimum and maximum temperature threshold for marketable cabbage production in the "head growth phase", and the annual temperature data from Applethorpe, Qld, it would be expected that cabbage harvesting in the Granite Belt would be possible all summer. Frosts and cold temperatures during winter, late autumn and early spring, restrict plantings during those seasons. This closely describes the actual production system in this district, where first plantings occur in late August (and harvests commence in mid-December), and final plantings occur in February, which are then harvested in May (on the higher altitude, less frost prone farms).

The Granite Belt is a warm season cabbage production area, and using the analysis power of Climate Monitor, growers can easily review historical temperatures at their production location. Maximum Critical Temperature Thresholds are not exceeded at present, even in the peak of summer, underlining the potential and importance of this high-altitude Queensland production location. Current minimum temperatures prevent economically viable production through late autumn and winter. This is when the warmer temperatures in the Lockyer Valley allow growers to produce high quality cabbage in their milder winter climate.

Future temperature insight.

As underlying temperatures continue to rise, and extreme heat days become more frequent [5] it is likely that the Granite Belt production window will lengthen, due to rising minimum spring temperatures, and autumn temperatures remain high for longer. In the Lockyer Valley the season will shorten as late spring and early summer maximums continue to rise further, impacting yield and quality.

The Representative Concentration Pathways scenario RCP8.5 (Schwalm, et al., 2020), has been chosen in this study to represent a future climate (2016-45), in an effort to understand the impacts on each of the current production locations.

[5] http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml),

a) Lockyer Valley (Gatton)

Projected future (2016-45) and current climate data for Gatton.

Data source: Climate Services for Agriculture output, My Climate View

Past and projected future average maximum temperature

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario ℹ What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
26.6 °C	27.3 °C	28.2 °C

This chart shows the past and future range in average annual maximum temperature at your location. Annual is defined as between 1 January and 31 December.

Past and projected future average minimum temperature

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario ℹ What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
12.9 °C	13.2 °C	14.2 °C

This chart shows the past and future range in average annual minimum temperature at your location. Annual is defined as between 1 January and 31 December

Past and projected future annual hot days

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario ℹ What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
21 days	30 days	42 days

This chart shows the past and future range in total annual hot days at your location. Hot days are defined as days with a maximum temperature greater than or equal to 34 °C between 1 January and 31 December.

Past and projected future annual cold days

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario ℹ What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
8 days	7 days	4 days

Figure 8. Projected future temperature, annual hot and frost days for Gatton under the high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1963 – 1992 for comparison of the 2016 to 2045 average temperature shift.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Projected annual crop specific upper CTT hot days risk shift (1963 – 92 baseline period).

Data source: Climate Services for Agriculture output, [My Climate View]

** This chart shows the average number of days in past and projected future years and year periods that* ***the crop specific upper CTT*** *has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

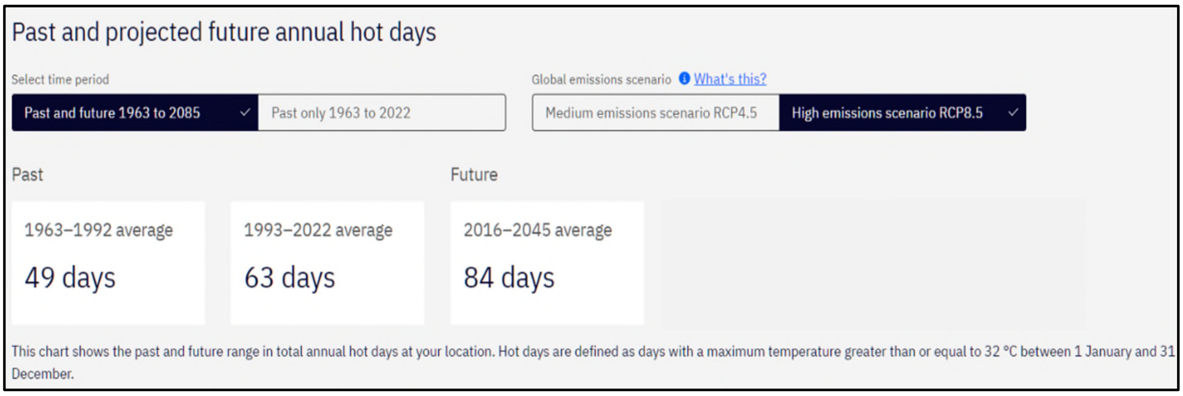


Figure 9. Cabbage specific, upper CTT heat risk shift comparison table for Gatton.

The high emissions pathway model indicates a temperature shift, showing a 1.6°C annual increase in maximum temperatures and a 1.3°C annual increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Gatton equals or exceeds 32°C increases from 63 to 84 (Figure 9).

The future annual hot days shift as displayed above (Figure 9) indicates that by 2045, on average Gatton in the Lockyer Valley will experience at least 84 days where the maximum temperature is ≥ 32°C an increase of 21 days per year in the lead up to 2045, compared to the what actually occurred in the 1993-2022 period. Note also the projected 71% increase in the number of days of 32°C or above compared to what actually occurred in the 1963-1992 period.

Future temperatures at Gatton and the impact on the timing and occurrence of cabbage critical temperature thresholds (CCT).

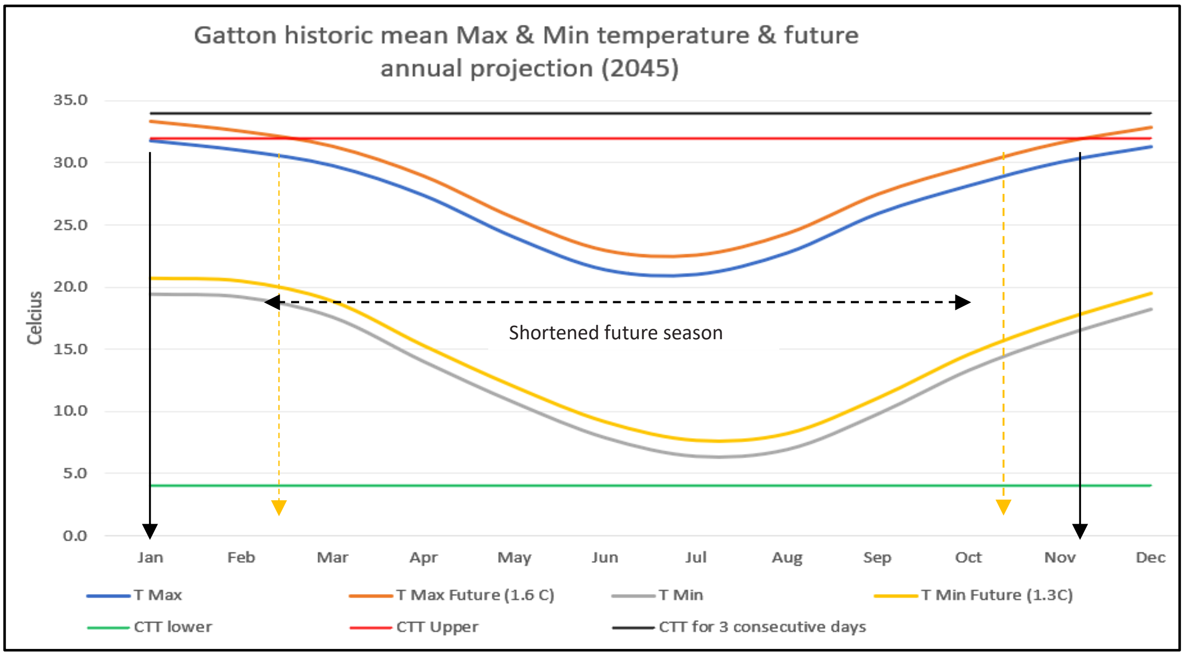


Figure 10. Current mean monthly temperatures at Gatton, cabbages upper CTT (32° C) & the impact of projected future mean annual temperature shifts (2016-2045) on the optimum growing season.

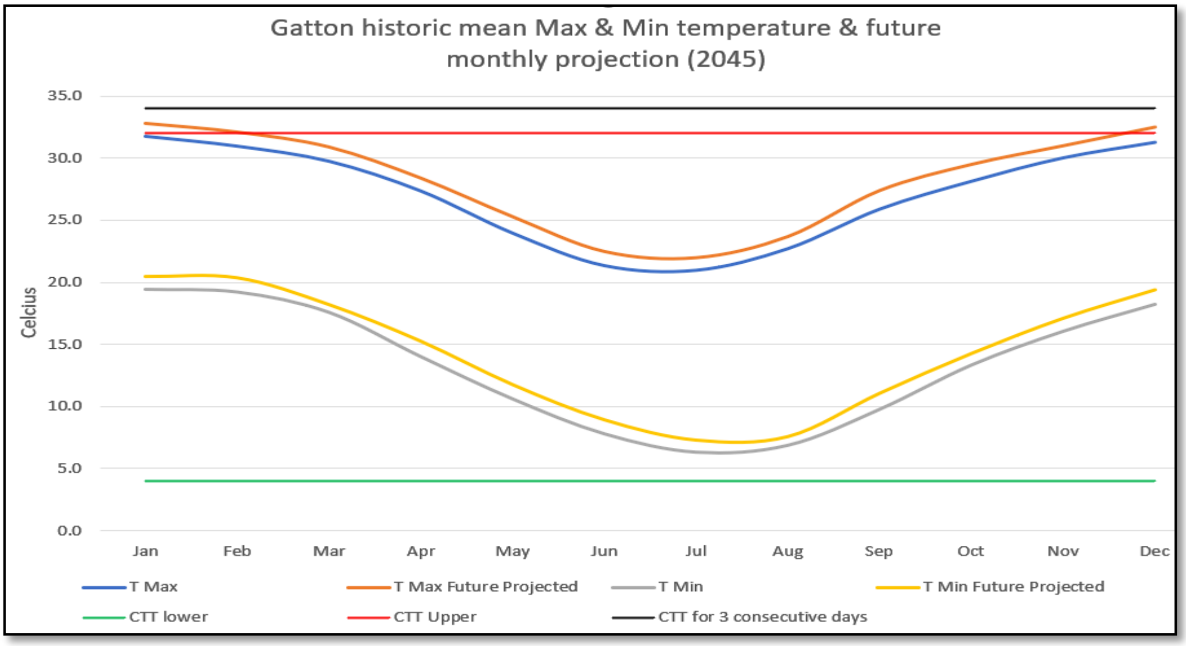


Figure 11. Current mean monthly temperatures at Gatton, cabbages' upper CTT (32° C) & the impact of projected future mean monthly temperature shifts (2016-2045) on the optimum growing season. (Note, the monthly future climate data displayed here is not publicly available but reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures).

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Maximum temperatures currently prevent high quality fresh market cabbage production in the Lockyer Valley during the late spring, and summer period. The projected increase in future daily maximum temperatures in the Lockyer Valley will result in a further & significant shortening of the high-quality fresh market cabbage production window. Currently average monthly maximum temperatures allow transplanting to begin in early February, with final harvest occurring in early November.

Figure 10 & Figure 11 above show how and why this shift will shorten the Lockyer Valley growing season. Cabbage plants will experience maximum temperatures that exceed their upper CCT, both earlier and later in the calendar year. Transplanting of the first crops could be delayed by around 3 weeks until March, with last harvests brought forward by almost a month, from the beginning of December back to the beginning of November. This would be a 7-week reduction in the Lockyer Valley's (historical) cabbage growing season. Higher daily temperatures would require extra irrigation and associated labour and electricity costs. Remember the graphics above, depict mean monthly temperatures and do not convey daily and weekly temperature variations and extremes.

Error! Reference source not found., 10 & Figure 11 above, however, mean minimum temperatures currently have little impact on cabbage production timing or head quality in the Lockyer Valley. The projected warmer minimums would increase plant growth rates and shorten the time between planting and harvest, especially in winter and early spring.

Maximum temperature is the critical weather factor that dictates the cabbage production window in the Lockyer Valley. Projected increases in future maximum temperatures throughout the Lockyer Valley summer season will further reduce the current cabbage production window (Figure 11).

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

a) Granite Belt, Stanthorpe (Applethorpe)

Projected future (2016-45) and current climate data for Applethorpe.

Data source: Climate Services for Agriculture output, My Climate View

Past and projected future average maximum temperature

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
20.4 °C	21.1 °C	22.1 °C

This chart shows the past and future range in average annual maximum temperature at your location. Annual is defined as between 1 January and 31 December.

Past and projected future average minimum temperature

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
8.8 °C	9.1 °C	10.1 °C

This chart shows the past and future range in average annual minimum temperature at your location. Annual is defined as between 1 January and 31 December

Past and projected future annual hot days

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
1 day	1 day	2 days

This chart shows the past and future range in total annual hot days at your location. Hot days are defined as days with a maximum temperature greater than or equal to 35 °C between 1 January and 31 December.

Past and projected future annual cold days

Select time period: Past and future 1963 to 2085 | Past only 1963 to 2022

Global emissions scenario What's this?: Medium emissions scenario RCP4.5 | High emissions scenario RCP8.5

Past		Future
1963–1992 average	1993–2022 average	2016–2045 average
56 days	53 days	40 days

This chart shows the past and future range in total annual cold days at your location. Cold days are defined as days with a minimum temperature less than or equal to 2 °C between 1 January and 31 December.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Figure 12. Projected future temperature outlook for Applethorpe under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1963 – 1992 for comparison of the 2016 to 2045 average temperature shift.

The high emissions pathway model indicates a temperature shift, showing a 1.7ºC increase in average annual maximum temperatures and a 1.3ºC increase in average annual minimum temperatures by 2045. The annual number of hot days at Applethorpe increases from 1 day to 2 days ≥ 35º C and this is accompanied by a projected decrease in annual frost risk from 56 to 40 days (Figure 12).

Projected annual crop specific upper CTT hot days shift (1963 – 92 baseline period).

** This chart shows the average number of days in past and projected years that the crop specific upper CTT has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

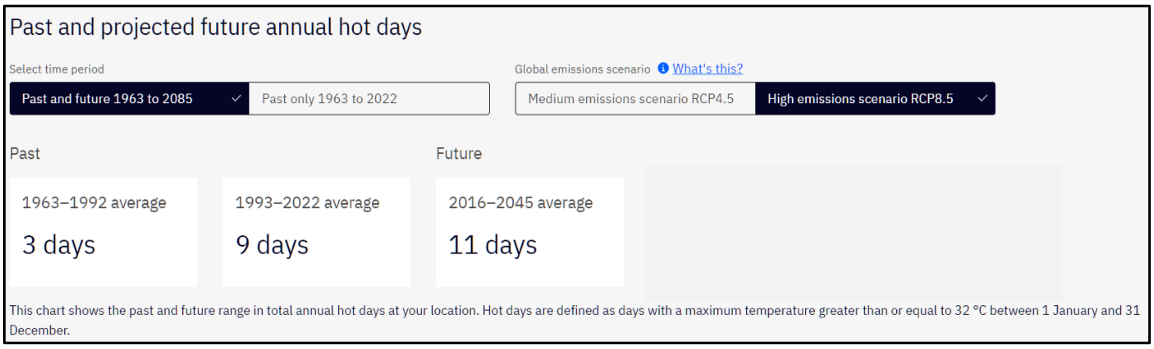


Figure 13. The cabbage plants specific, upper CTT hot days shift comparison table for Applethorpe.

Data source: Climate Services for Agriculture output, My Climate View

Figure 13 above shows that by 2045, Applethorpe will have on average have at least an extra 2 days each year when the maximum temperature equals or exceeds cabbages' upper CTT. It is worth noting that this projection represents, close to a fourfold increase when compared to the 1963-1992 period.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

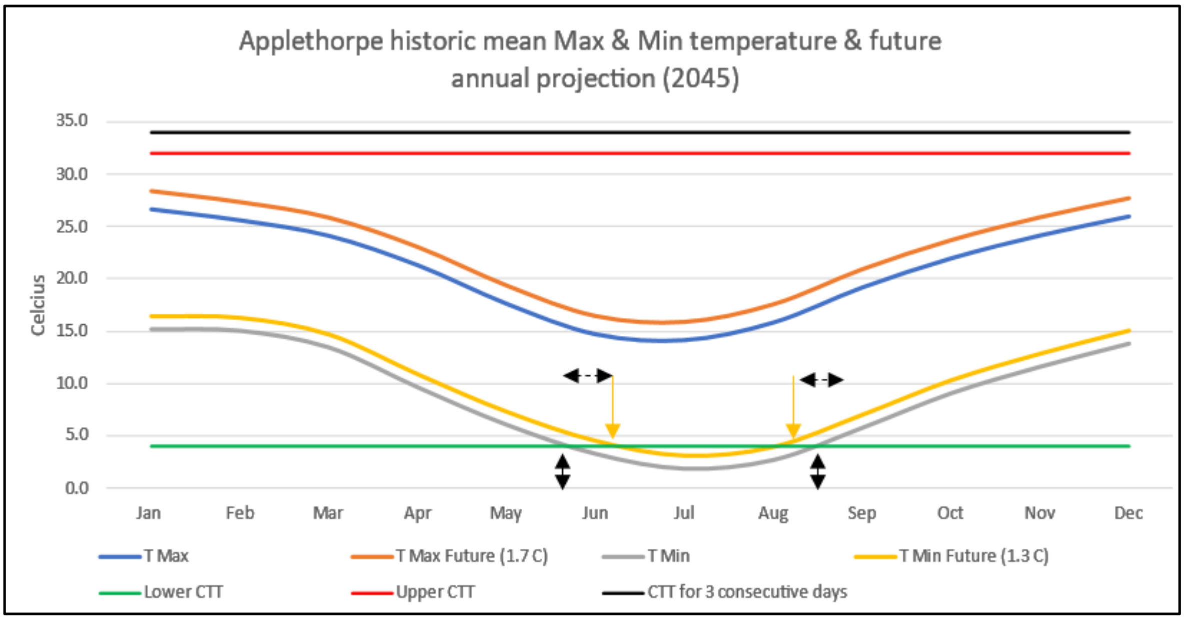


Figure 14. Current mean monthly temperatures at Applethorpe, cabbages upper CTT (32° C) & the impact of projected future ***mean annual*** *temperature shifts (2016-2045) on the optimum growing season.*

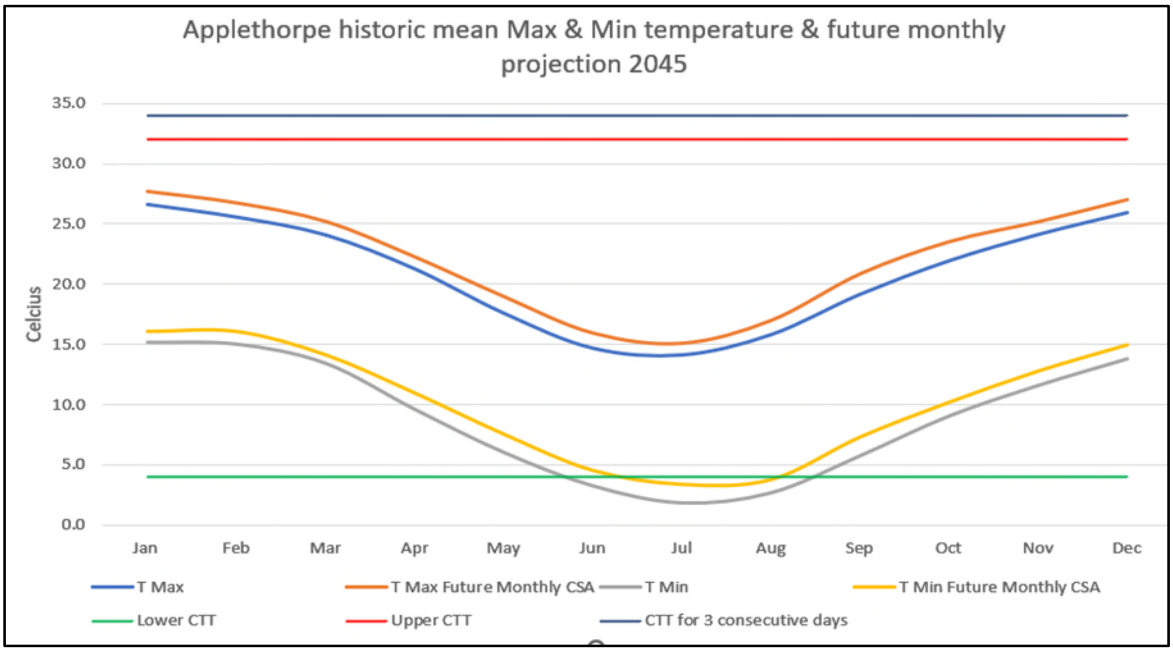


Figure 15. Current mean monthly temperatures at Applethorpe, cabbages' upper CTT (32° C) & the impact of projected future mean monthly temperature shifts (2016-2045) on the optimum growing season. (Note, the monthly future climate data displayed here is not publicly available but reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures).

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Minimum temperatures currently prevent cabbage production in the Granite Belt during the late autumn and colder winter period. The forecast increase in average monthly minimum temperatures in the Granite Belt as detailed above (2016-45) will allow an extension of the existing cabbage production window. Currently average monthly minimum temperatures fall below cabbages' lower CTT in May and stay below the lower CTT until September.

Figure 15 above shows how the projected mean minimum monthly temperature shift, will lengthen the Granite Belt growing season. Cabbage plants will not experience minimum temperatures that are below their lower CCT until later in the autumn. The cold winter period that currently prevents quality cabbage production will also be shortened further by a warmer spring. Transplanting of the first crops could be brought forward by several weeks, with last harvests also extended later into the autumn.

Maximum temperatures will also increase as shown in, Figure 12, 14 & 15 above, however, annual maximum monthly temperatures will remain well below 32ºC, the cabbage plants upper CTT. Changes in mean monthly maximum temperature will not limit cabbage quality or alter the production window in the Granite Belt (2016-45). When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Minimum temperature is the critical weather factor that will continue to dictate the cabbage production window in the Granite Belt. Forecast increases in minimum temperatures will allow growers to transplant earlier in the spring, and harvest later into the autumn. This should result in a significant extension of the Granite Belts' (historical) cabbage growing season, enhancing product availability and quality.

Interstate production – future insights.

Future climate data analysis for all locations (2016-2045) is based on current projections sourced from Australias, Climate Services for Agriculture website, My Climate View.

ii) New South Wales (Forbes)

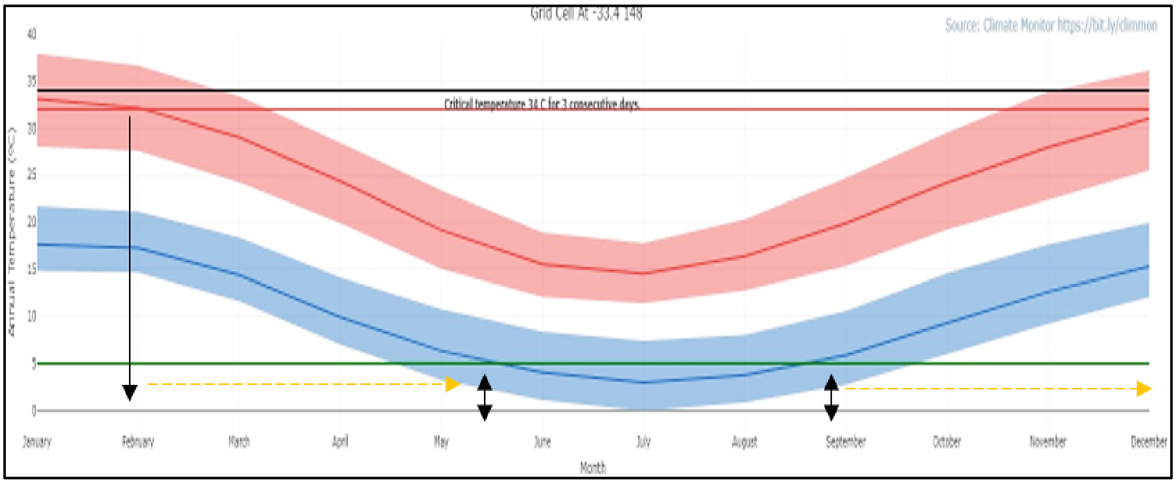


Figure 16. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with cabbage critical temperatures – overlaid, at Forbes. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Commercial Australian seed catalogues (e.g., Seminis Australian product guide)[6], indicate that by using modern varieties in the Forbes district, cabbage can be transplanted from September onward with last harvest occurring in May. The Critical Temperature Threshold analysis above indicates that the peak of summer is too hot for quality cabbage production, while it is too cold during June, July and August in most years. February to May and September through until the end of November sit within the upper and lower CTT for quality cabbage production in most years. Hotter drier years (El Nino influence) will see reduced quality, due to higher maximum temperatures.

[6] Seminis Australia vegetable product guide

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Projected future (2016-45) and current climate data for Forbes.

Table 1. Projected future temperature comparison for Forbes under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Hot Days T Max ≥ 35^{0}C	Annual Cold Days ≤ 2^{0}C
1963-1992 Past Average	23.7	9.9	25	37
1993 -2022 Recent Average	24.5	10.0	34	49
2016-45 High Emissions Future Average	25.5	11.1	44	30

The high emissions pathway model indicates a temperature shift, showing a 1.8^{o}C increase in maximum temperatures and a 1.2^{o}C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Forbes equals or exceeds 35^{o}C increases from 25 to 44 (Table 1). The projected temperature shift will alter the existing production pattern, with hotter summers further delaying late summer planting and bringing forward the current November cut-off. Warmer minimum temperatures will allow earlier spring planting and slightly extend the harvest, later into the autumn. When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Projected annual crop specific upper CTT hot days shift (1963 – 92 baseline period).

***** *This chart shows the average number of days in past and projected years that the crop specific upper CTT has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.***

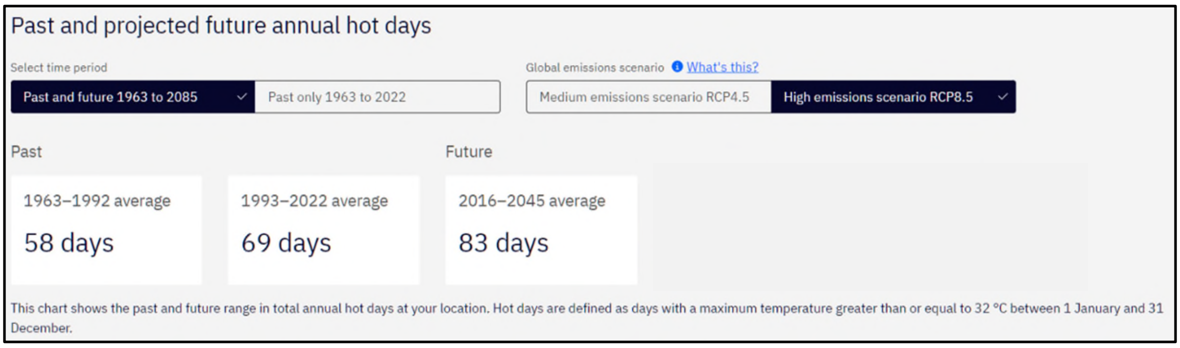


Figure 17. Cabbage specific, upper CTT heat risk shift comparison table for Forbes.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Figure 17 above shows that by 2045, Forbes will have at least 83 days when the maximum temperature equals or exceeds cabbages upper CTT. This is 14 more days (2 weeks) more than experienced in the recent past (1993-2022).

iii) Victoria (Bairnsdale)

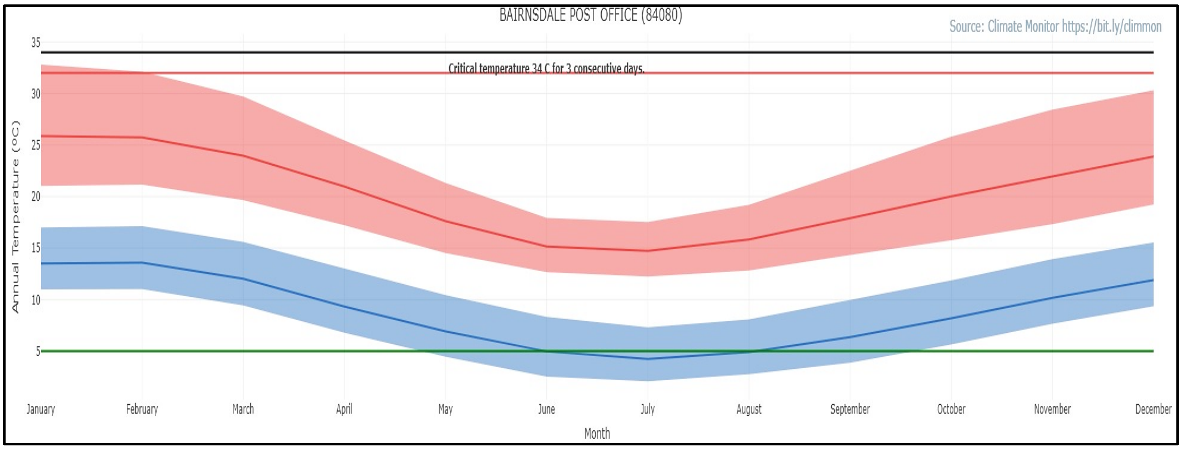


Figure 18. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with the cabbage plants critical temperatures – overlaid, at Bairnsdale. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Minimum temperatures limit cabbage production at this location from June until early September in some years. Low temperatures at Bairnsdale, slow growth rates, limiting crop growth and development. Currently maximum temperatures in some years in January exceed the upper CTT and may in the warmer years impact cabbage quality.

Projected future (2016-45) and current climate data for ***Bairnsdale***

Table 2. Projected future temperature comparison for Bairnsdale under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020)

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Hot Days T Max ≥ 35^{0}C	Annual Cold Days ≤ 2^{0}C
1963-1992 Past Average	20.3	8.8	5	20
1993 -2022 Recent Average	20.7	9.6	7	6
2016-45 High Emissions Future Average	21.4	10.2	8	6

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

The high emissions pathway model indicates a temperature shift, showing a 1.1°C increase in maximum temperatures and a 1.4°C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Bairnsdale exceeds 35°C increases from 5 to 8 (Table 2). The projected temperature shift will alter the existing production pattern, with the projected hotter summers likely to reduce January harvest quality in some years. Warmer minimum temperatures will allow earlier spring plantings and slightly extend the harvest, later into the autumn. When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Projected annual crop specific upper CTT hot days shift (1963 – 92 baseline period).

***** This chart shows the average number of days in past and projected years that the crop specific upper CTT has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

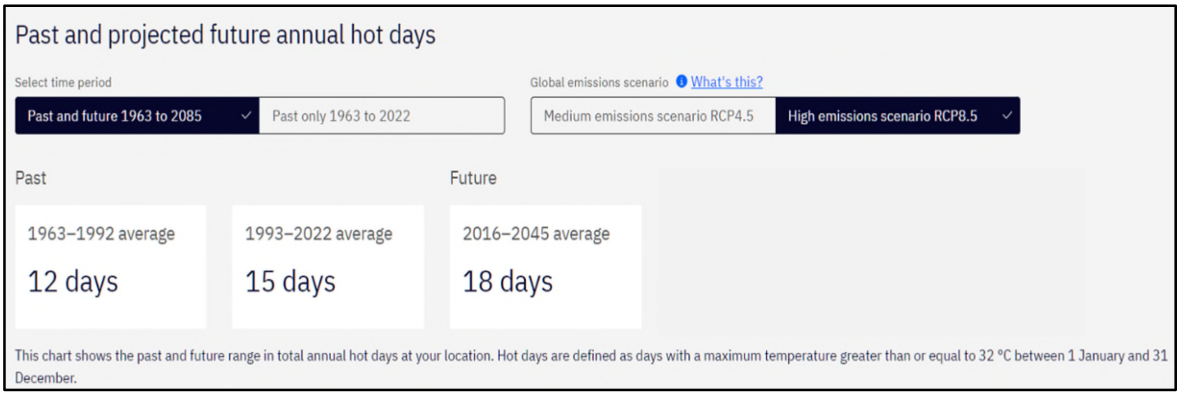


Figure 19 Cabbage specific, upper CTT hot days shift comparison table for Bairnsdale.

Figure 19Figure 19 above shows that by 2045, Bairnsdale will have at least 18 days each year when the maximum temperature equals or exceeds cabbages upper CTT. This is a significant change compared to the 1963-1992 historical weather data.

iv) Tasmania (Devonport)

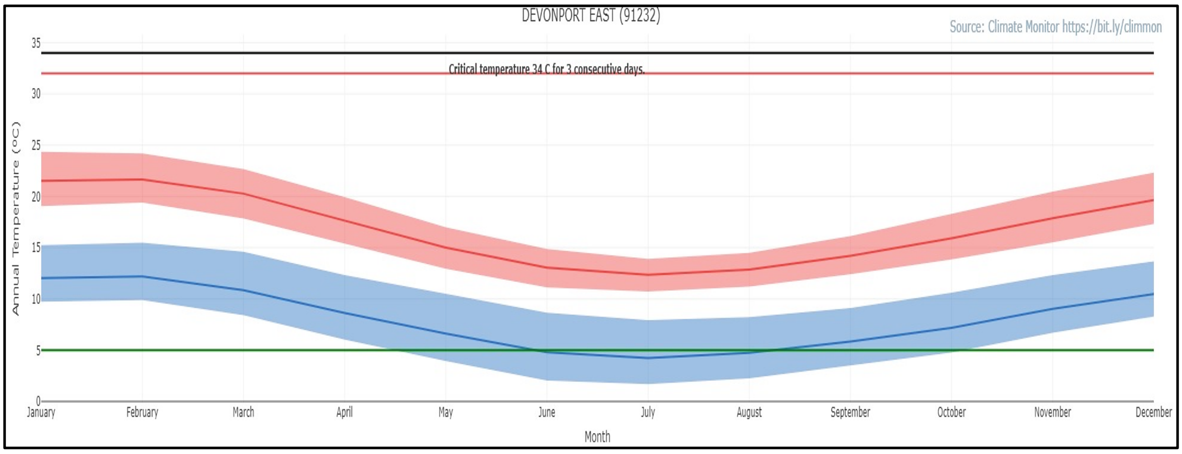


Figure 20. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with cabbage critical temperatures – overlaid, at Devonport. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Maximum and minimum temperatures from early September until late May are adequate for cabbage production with growth rates slowing as winter approaches. Tasmanian growers use robust cool weather varieties with the main harvest season being January to June. Minimum temperatures from June until early September limit crop growth and development. Cabbages upper CTT (32°C) rarely occurs in Tasmanian summers. The projected temperature shift will only slightly alter the existing production pattern, with the projected warmer minimum temperatures allowing earlier spring plantings and slightly extending the harvest, later into the autumn. The projected higher maximums and minimums will improve plant growth rates and at this southerly location are unlikely to alter cabbage quality. When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Projected future (2016-45) and current climate data for Devonport.

Table 3. Projected future temperature comparison for Devonport under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020)

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Hot Days T Max ≥ 35^{0}C	Annual Cold Days ≤ 2^{0}C
1963-1992 Past Average	17	7.8	0	29
1993 -2022 Recent Average	17.4	8.3	0	20
2016-45 High Emissions Future Average	18.1	9.0	0	13

The high emissions pathway model indicates a temperature shift, showing a 1.1°C increase in maximum temperatures and a 1.2°C increase in minimum temperatures by 2045. Importantly the number of cold days at Devonport will decrease from 29 to 13, a significant decrease (**Error! Reference source not found.**). The projected temperature shift may slightly alter the existing production pattern, or enable different varieties being grown. Warmer minimum temperatures will allow earlier spring plantings and slightly extend the harvest, later into the autumn.

Projected annual crop specific upper CTT heat risk shift (1963 – 92 baseline period).

** This chart shows the average number of days in past and projected years that <u>the crop specific upper CTT</u> has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

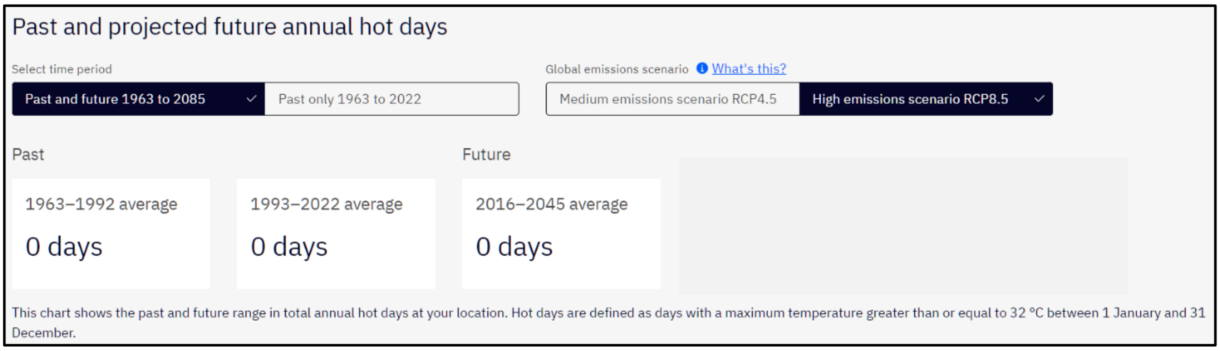


Figure 21. <u>Cabbage specific</u>, upper CTT heat risk shift comparison table for Devonport.

Figure 21 above confirms that hot days equalling or exceeding cabbages upper CTT will not impact crop quality at this location.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from <u>Climate Monitor</u>, a free, publicly available DCAP web-tool.

A further investigating of the projected temperature data for Devonport indicates that on average, by 2045 locals can expect 1 day each year that equals or exceeds 30°C, well below cabbages upper CTT.

Minimum temperatures will continue to determine and limit the cabbage season in Devonport.

v) South Australia (Virginia)

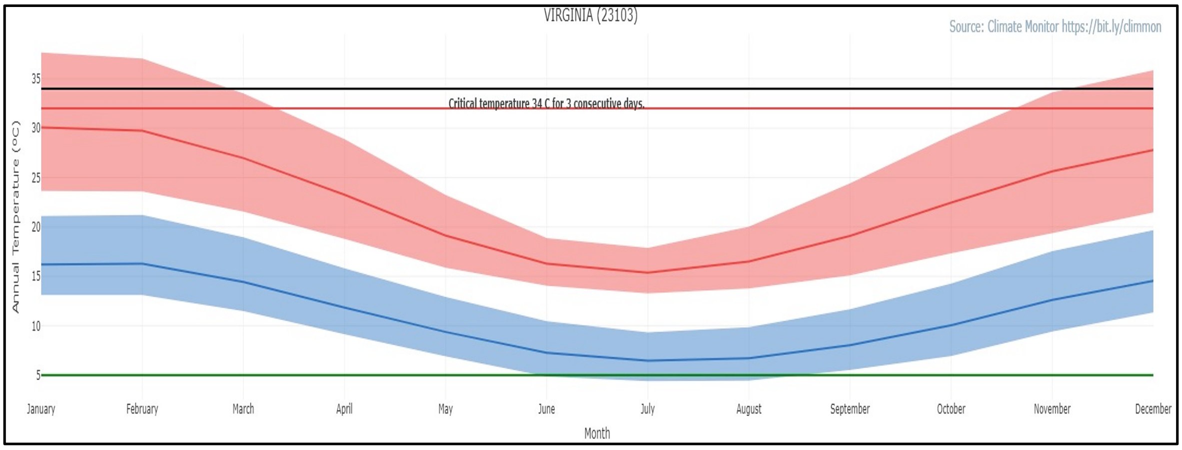


Figure 22. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with cabbages critical temperatures – overlaid, at Virginia. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Minimum temperatures from late August until early June are adequate for cabbage production with growth rates slowing as winter approaches, but maximum temperatures limit production from November until March in many years. South Australian growers use robust cool weather slow growing varieties through the winter. Minimum temperatures from June until early September limit crop growth and development in cooler years. Cabbages upper CTT is exceeded during the summer months in many years. When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Projected future (2016-45) and current climate data for Virginia.

Table 4. Projected future temperature comparison for Virginia under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Hot Days T Max ≥ 35^{0}C	Annual Frost Risk Days ≤ 2^{0}C
1963-1992 Past Average	22.4	11.2	21	2
1993 -2022 Recent Average	23.1	11.5	25	2
2016-45 High Emissions Future Average	23.8	12.3	30	1

The high emissions pathway model indicates a temperature shift, showing a 1.4°C increase in maximum temperatures and a 1.1°C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Virginia exceeds 35°C increases from 21 to 30 (Table 4).

Projected annual crop specific upper CTT heat risk shift (1963 – 92 baseline period).

** This chart shows the average number of days in past and projected years that the crop specific upper CTT has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

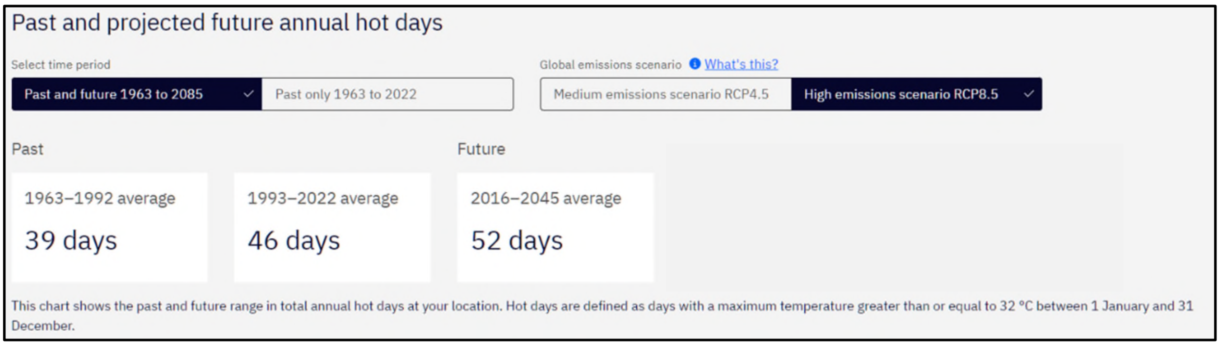


Figure 23. Cabbage specific, upper CTT heat risk shift comparison table for Virginia.

Figure 23 shows that by 2045, Virginia will experience at least 52 days annually when the maximum temperature equals or exceeds cabbages upper CTT. This is a significant change when compared to past temperature observations.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

 Note graphs are best view at >140 magnification

vi) Western Australia (Gingin)

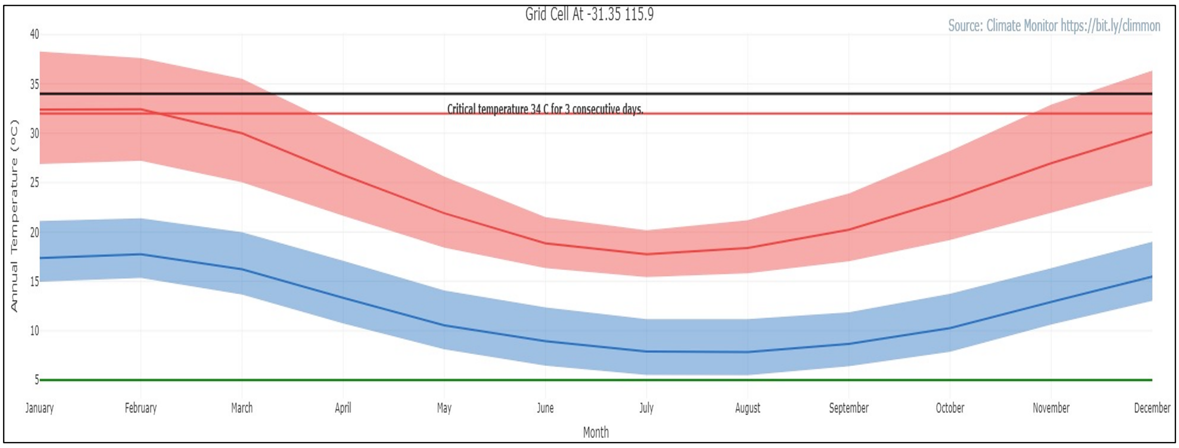


Figure 24. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with cabbage critical temperatures – overlaid, at Gingin. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

The Critical Temperature Threshold analysis for the Gingin production area indicates that currently mean maximum temperatures in January and February greatly exceeds 32°C in most years, and it is not until early March that mean maximum temperatures drop below the maximum CTT of cabbage, in most past years. Maximum temperatures in November and December in many years also exceed cabbages upper CTT.

The minimum threshold (5°C) for cabbage production is not limiting at this location. Optimum temperatures for quality cabbage growth occur from April until the end of October in most years currently. Projected minimum temperature increases at this location will enhance plant growth rates during future winters.

Future maximum temperature increases will further reduce the growing window for cabbage at Gingin. Increased summer maximum temperatures will further shorten the local production season.

When considering projected maximum and minimum temperature shifts at any location, the reader should keep in mind the daily duration (number of hours each day) the plant is likely to experience these conditions.

Projected future (2016-45) and current climate data for Gingin.

Table 5. Projected future temperature outlook for Gingin under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Hot Days T Max ≥ 35^{0}C	Annual Cold Days ≤ 2^{0}C
1963-1992 Past Average	24.5	12.5	25	1
1993 -2022 Recent Average	25.2	12.7	31	1
2016-45 High Emissions Future Average	25.8	13.4	36	1

The high emissions pathway model indicates a temperature shift, showing a 1.3°C increase in maximum temperatures and a 0.9°C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Gingin exceeds 35°C increases from 25 to 36 (Table 5). These projected maximum temperature changes will see a shortening of the summer growing period, while the slight increase in minimums will enhance plant growth rates through the winter

Projected annual crop specific upper CTT hot days (1963 – 92 baseline period).

** This chart shows the average number of days in past and projected years that the crop specific upper CTT has or is projected to occur using the high emissions greenhouse gas scenario RCP 8.5.*

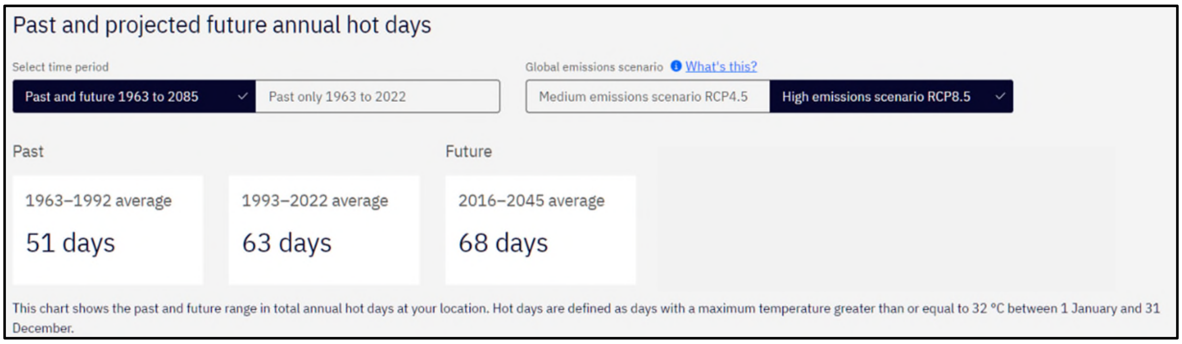


Figure 25. Cabbage specific, upper CTT heat risk shift comparison table for Gingin.

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Figure 25 above shows that by 2045, Gingin will have at least 68 days when the maximum temperature equals or exceeds cabbages upper CTT. This represents an increase of 17 days compared to the average in the 1963-1992 period.

Annual Heat and Frost Risk, by the year 2045, for cabbage production at reviewed locations in Australia.

Growing Location	Current Max Temp °C	Projected Max temp change °C by 2045	Current Min Temp °C	Projected Min temp change °C by 2045	Current number of hot days ≥ 35° C	Projected number of hot days ≥ 35° C by 2045	Current number of cold days ≤ 2° C	Projected number of cold days ≤ 2° C by 2045
Gatton (Qld)	**27.3**	+0.9	**13.2**	+1.0	**20**	27	**7**	4
Applethorpe (Qld	**21.1**	+1	**9.1**	+1.0	**1**	2	**53**	40
Forbes (NSW)	**24.5**	+0.9	**10.0**	+1.1	**34**	44	**49**	30
Bairnsdale (Vic)	**20.7**	+0.7	**9.6**	+0.6	**7**	8	**6**	6
Virginia (SA)	**23.1**	+0.7	**11.5**	+0.8	**25**	30	**2**	1
Gingin (WA)	**25.2**	+0.6	**12.7**	+0.7	**31**	36	**1**	1

The projected future climate data used in this CTT document is sourced from the new re-designed (Sept 2023) My Climate View website version (formerly CSA). The site has undergone several format and projected data period changes in the last 18 months and those that were available and used at the time of writing this CTT document are for the 2045 period.
The historic location specific, high quality climate information use herein, is sourced from Climate Monitor, a free, publicly available DCAP web-tool.

Do your own analysis.

If you are interested in other production locations within Australia, you can evaluate a location yourself.

1. Use Climate Monitor to easily analyse and graph the location of interest.

   Access Climate Monitor at

   https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/

   Click on the **Go Climate Monitor** button under the picture.

2. Use the Climate Services for Agriculture site to explore the projected temperature, rainfall and evaporation changes***.***

   Access Climate Services for Agriculture future climate projections at

   https://myclimateview.com.au/

Appendix I

https://www.climatechangeinaustralia.gov.au/en/changing-climate/future-climate-scenarios/greenhouse-gas-scenarios/

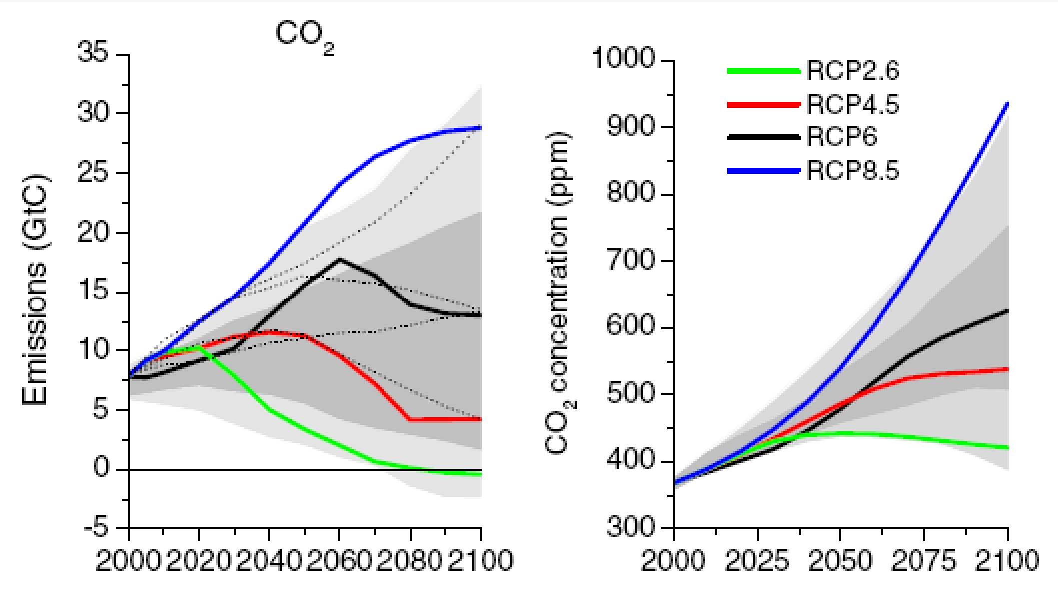
GREENHOUSE GAS SCENARIOS

(REPRESENTATIVE CONCENTRATION PATHWAYS - RCPS)

The future of anthropogenic greenhouse gas and aerosol emissions (and hence their resultant radiative forcing) is highly uncertain, encompassing substantial unknowns in population and economic growth, technological developments and transfer, and political and social changes.

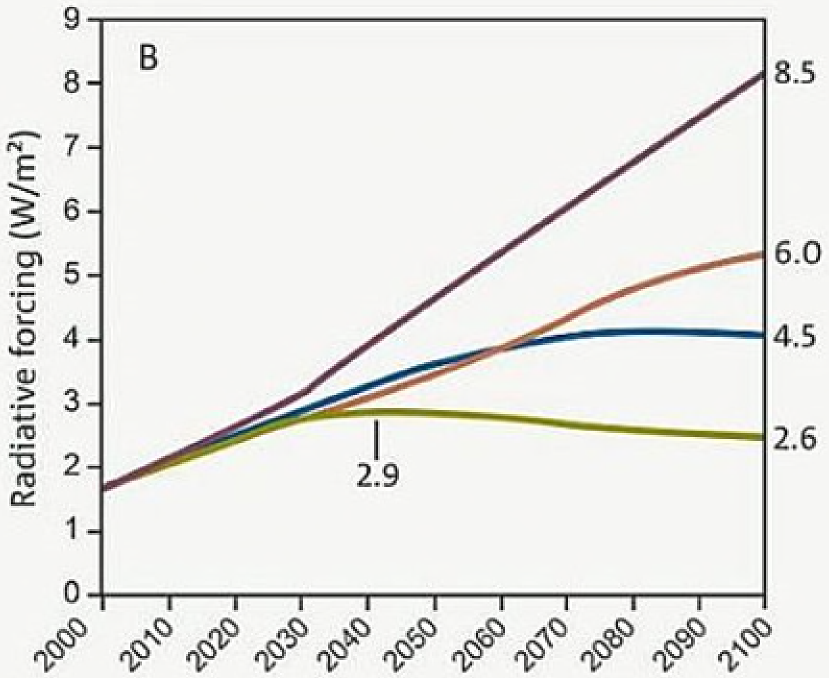
The climate modelling community has developed Representative Concentration Pathways (RCPs) to explore credible future options. The Australian climate change projections found on this site are derived from climate models forced by the RCPs.

These scenarios span the range of plausible global warming scenarios. They provide a range of options for the world's governments and other institutions for decision making.



Emissions of CO_2 across the RCPs (left), and trends in concentrations of carbon dioxide (right). Grey area indicates the 98th and 90th percentiles (light/dark grey) of the values from the literature). The dotted lines indicate four of the SRES marker scenarios.

SOURCE: van Vuuren et. al., (2011)



Radiative forcing for the different RCPs. The numbers on the right show the final radiative forcing at 2100 and give each scenario its name (8.5, 6.0, 4.5 and 2.6 W/m²)

SOURCE: Climate Change in Australia Technical Report

RCPs are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, which are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square metre (W/m²).

The RCPs represent a wider set of futures that the previous emissions scenarios used by climate modelling community (SRES), and now explicitly include the effect of mitigation strategies. As with SRES, no particular scenario is deemed more likely than the others, however, some require major and rapid change to emissions to be achieved.

THERE ARE FOUR RCPS

RCP8.5- a future with little curbing of emissions, with a CO_2 concentration continuing to rapidly rise, reaching 940 ppm by 2100.

RCP6.0– lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100.

RCP4.5- CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration reaches 540 ppm by 2100.

RCP2.6 - the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing carbon dioxide from the atmosphere. The CO_2 concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100).

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