Critical temperature thresholds
Case study

Lettuce

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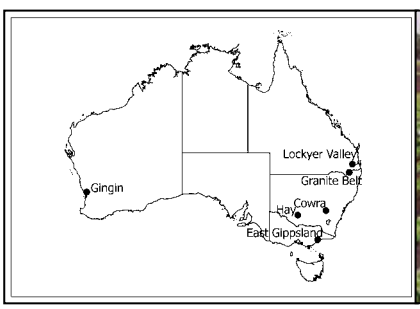

Introduction

Lettuce (*Lactuca sativa* L.) is an annual vegetable from the Asteraceae family. It is grown in all states of Australia and continents throughout the world, and is consumed mainly as a salad vegetable.

The main lettuce production regions in Australia are the Lockyer Valley and Eastern Darling Downs (SE Qld); Hay and Central West (NSW); Lindenow and Robinvale (Vic); Manjimup and Gingin (WA); Virginia (SA) and Cambridge, Richmond and Devonport (Tas).

Commodity production data

- The value of lettuce production in Australia rose by 11.3% to $183 million in 2008/09; production totalled 161,646 tonnes from 7,358 hectares with an average yield of 22.2 tonnes/ha.
- Lettuce was Australia's 6th largest vegetable crop in 2008/09, accounting for 6.2% of total vegetable production by value.
- Production is concentrated in the eastern states – Queensland, NSW and Victoria produce over two-thirds of the national lettuce crop, with WA a significant producer in the west.
- The total number of growers was 533 in 2009.
- The lettuce market consists of the fresh market segment and the processed segment (which is mainly pre-packaged salads).
- There is a wide range of lettuce varieties available in Australia, with the most popular being in the crisphead (iceberg), romaine (cos), butterhead and loose-leaf groups.
- Lettuce is in season all year round (Ausveg, 2011).

***Table 1** : Lettuce Production – Australia 2005 to 2009*

Lettuce (Iceberg & Cos)	**2005-06**	**2006-07**	**2007-08**	**2008-09**
Number of growers	322	343	293	329
Area planted (ha)	5,397	6,323	4,866	5,352
Production (t)	126,664	206,051	128,594	135,263
Yield (t/ha)	23.5	32.6	26.4	25.3
Gross value ($m)	118.7	213.4	117.7	**151.1**
Gross unit value ($/t)	937	1036	915	1117
Farm gate value ($m)	91.1	170.3	88.6	121.8
Lettuce (Looseleaf)	**2005-06**	**2006-07**	**2007-08**	**2008-09**
Number of growers	212	222	229	204
Area planted (ha)	2,490	3,435	2,316	2,006
Production (t)	305,16	57,686	34,223	26,383
Yield (t/ha)	12.3	16.8	14.8	13.2
Gross value ($m)	34.2	60.9	43.9	**32.7**
Gross unit value ($/t)	1,120	1,055	1,283	1,238
Farm gate value ($m)	27.9	48.2	35.4	26.5

Source : - AusVeg, 2011 *- http://ausveg.businesscatalyst.com/resources/statistics/domestic-industry/detailed-data.htm*

Iceberg lettuce is the main lettuce type grown commercially. It has a firm, compact, spherical heart, the leaves are crisp and firmly packed in the head. Cos (Romaine) lettuce is the second most commonly grown lettuce type and is distinguished by an elongated head (similar to Chinese cabbage) dark green, long, narrow, crisp leaves. All coral, babyleaf and salad mix lettuces belong to the loose leaf lettuce group. This group of lettuce has a great variety of sizes, shapes and colours.

Table 2 *: Proportion of Lettuce produced from each state*

Proportion of vegetables produced from each state, 2007-08

percentage

	NSW	Vic	Qld	SA	WA	Tas	NT	Australia
Potatoes	6	26	11	26	10	22	0	100
Pumpkins	33	1	38	10	11	3	5	100
Green peas	8	24	12	0	0	56	0	100
Beans	2	23	49	0	0	25	0	100
Tomatoes	15	38	43	0	4	0	0	100
Onions	4	6	26	23	14	27	0	100
Carrots	2	36	3	19	11	29	0	100
Cauliflowers	17	16	20	3	22	22	0	100
Lettuce	27	7	42	9	15	0	0	100
Broccoli	3	56	15	1	18	7	0	100
Cabbage	27	46	15	6	6	1	0	100
Other vegetables	20	16	48	6	6	2	3	100
All vegetables	11	25	21	17	10	16	0	100

Source :- Crooks, S. (2009). Australian vegetable growing farms: an economic survey, 2006-07, ABARE Report to Horticulture Australia Ltd, Canberra.

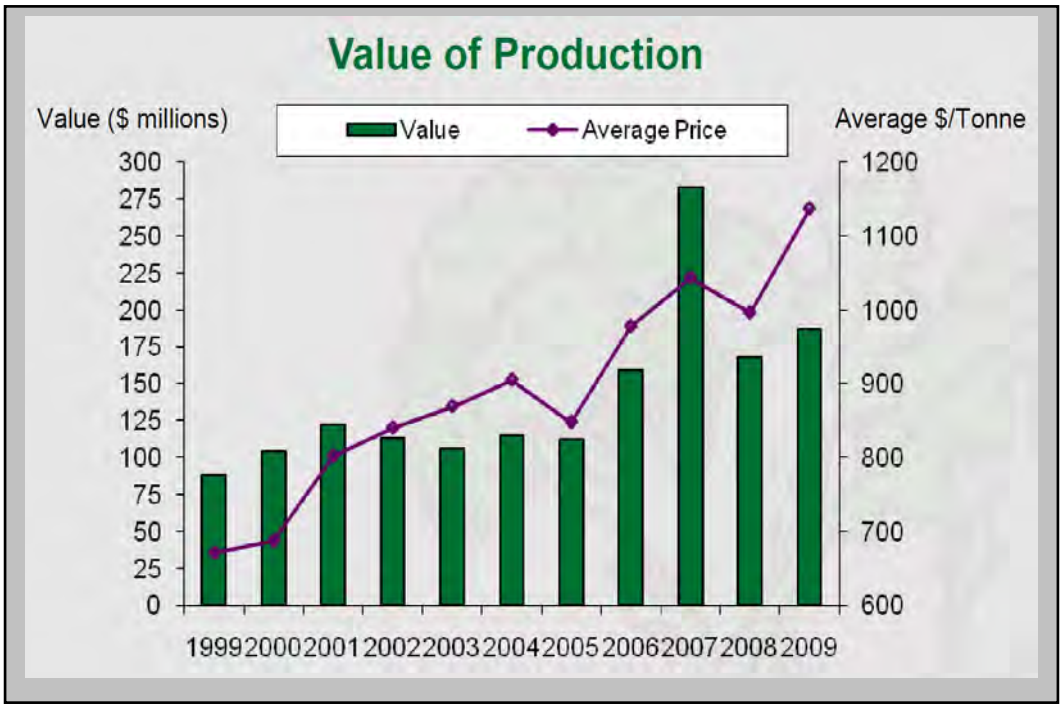

Fig. 1 *– Lettuce – Value of Production – Australia 1999 to 2009*

Production regions

Table 3 (i-iv) *: Major Locations and Seasonal Production of Lettuce by State & Region*

Queensland

Region	Production Season
Lockyer Valley	Autumn/winter/spring
Granite Belt	Summer
Eastern Darling Downs	Summer/autumn

Winter production in the Lockyer Valley commences with the first plantings in mid-summer, followed by consecutive weekly plantings until mid winter. First harvest occurs in late April/early May with final harvest in October, harvest peaking from June to August. Lower yields and quality are often produced in October, especially in warmer years.

In the Granite Belt, production is summer only. Cold and frosty winters prevent all year round production. First transplantings occur in August, with harvests commencing in November; and final transplanting occurring in March, with harvest completed by May, after which frosts will affect head quality (Harper, et al.,1997).

Victoria

Region	Production Season
Werribee	All year
East Gippsland	All year

Lettuce can be grown all year around in southern Victoria, but the main growing season is from September to May, while in northern Victoria the season runs from May to October.

NSW

Region	Production Season
Riverina	Autumn/winter/spring
Sydney Basin	All year
Central West	Spring and Autumn

Lettuce production is centred in the three main growing areas of Sydney Basin, Riverina and Central West. In the Sydney Basin lettuce is sown and harvested all year round, but declines through summer due to the warm conditions. In the Riverina, lettuce is sown from early February through to late July for harvesting from April to the end of October. Production through summer is not possible due to high temperatures. In the Central West, lettuce is only scheduled for harvesting during spring and autumn. Production outside these times is difficult due to harsh climatic conditions (Napier T, 2004).

Western Australia

Region	Production Season
Perth	All year

Lettuce production is centred in the main growing areas north of Perth. Although lettuce is sown and harvested all year round, production declines through summer due to the warm to hot conditions.

Current level of knowledge on temperature thresholds

***Table 4** : Critical Temperature Threshold - Lettuce*

Crop	Development Phase	Critical Temperature Threshold
Lettuce	Hearting	28^{o}C – mean monthly maximum

For lettuce, the 'hearting' development phase is the most sensitive to temperatures above optimum.

The maximum temperature threshold for the 'hearting' development phase for lettuce, as identified from the literature, is 28^{o}C mean monthly maximum (Lovatt, et al.,1997; Wurr, et al.,1992; Wheeler, et al., 1993). This has been confirmed through engaging with scientists and other supply chain participants, and by comparing mean monthly maximum temperature data with planting times and the commencement and the end of the lettuce harvesting season for a number of locations where lettuce is a major crop in Australia.

For iceberg lettuce, this 'hearting' development phase commences approximately 2 weeks prior to harvest. Therefore it is to be expected that if a 'critical temperature threshold' is reached in the 2 week period prior to the commencement of peak harvest, then this will negatively impact lettuce quality at harvest.

The engagement process with growers, consultants, resellers and supply chain participants was designed to confirm or otherwise the following assumption – "If maximum temperatures have a significant effect on harvest quality, then it is to be expected that first and final lettuce harvest will closely follow the maximum temperature threshold of 28^{o}C, identified from the literature, for each of the production locations in Australia".

The maximum temperature threshold of 28^{o}C for lettuce at the 'hearting' development phase, identified from the literature, has been confirmed by comparing mean monthly maximum temperature data with the commencement and the end of the lettuce harvesting season for a number of the major locations where lettuce is grown in Australia :-

i) Queensland - Lockyer Valley (winter); Granite Belt (summer)

ii) NSW – Hay (winter); and Central West (summer)

iii) Vic – East Gippsland (all year round)

iv) WA - Gingin (all year round)

i) Queensland

Lockyer Valley (SE Queensland)

Lettuce harvest is substantially completed in the Lockyer Valley by the end of October each year, and the majority of the harvest is completed by the end of September, because rising temperatures in late spring and early summer negatively impact on head quality (the 'hearting' development phase in iceberg lettuce is the most sensitive to high temperatures).

The winter-based production season in the Lockyer Valley commences with the first plantings in February, followed by consecutive weekly plantings until the end of June. First harvest occurs in late April/early May, 2 weeks after the "critical threshold" period ends. Final harvests occur in October, with harvest peaking from June to August. Lower yields and poor head quality are often produced in October, especially in warmer years.

In determining the critical temperature threshold for lettuce, the assumption, "If maximum temperatures have a significant effect on harvest quality, then it is to be expected that first and final lettuce harvest will closely follow the maximum temperature threshold of 28^{o}C, identified from the literature, for each of the production locations in Australia", has been tested for the production

system in the Lockyer Valley, SE Queensland, and found to be true as demonstrated by Fig. 2. below.

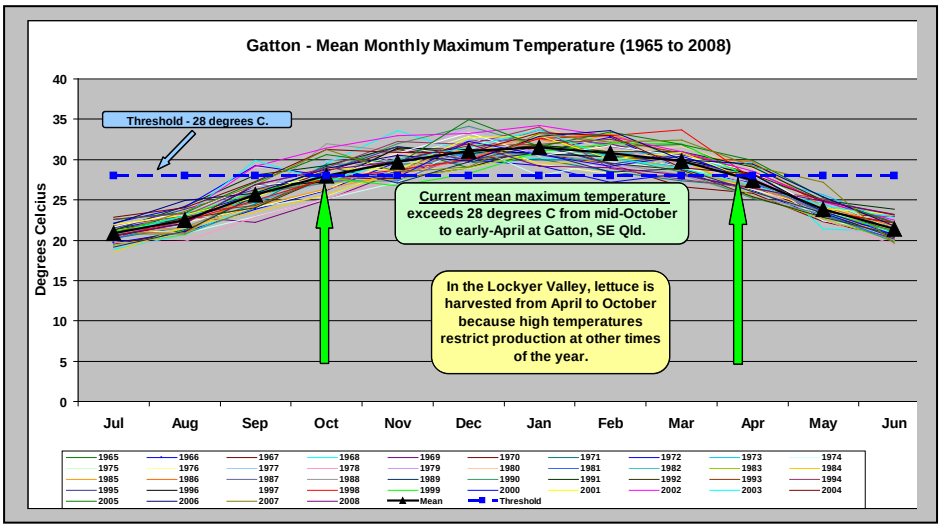

Fig. 2 – Gatton, Qld - Mean Monthly Maximum Temperatures

Granite Belt (SE Queensland)

Using 28°C as the mean maximum temperature threshold for lettuce in the 'hearting' development phase, and the temperature data from **Applethorpe, Qld** (Fig 3.), it would be expected that lettuce harvesting in the Granite Belt would be possible all summer. Frosts and cold temperatures during winter, autumn and spring, restrict plantings during those seasons, otherwise all year round production would be possible. This closely describes the production system in this district, where first plantings occur in August (and harvests commence in November); and final plantings occur in March (and are harvested in May). Due to a variable climate, the individual mean monthly maximum temperatures have exceeded 28°C on a few occasions since 1967 (Fig 3).

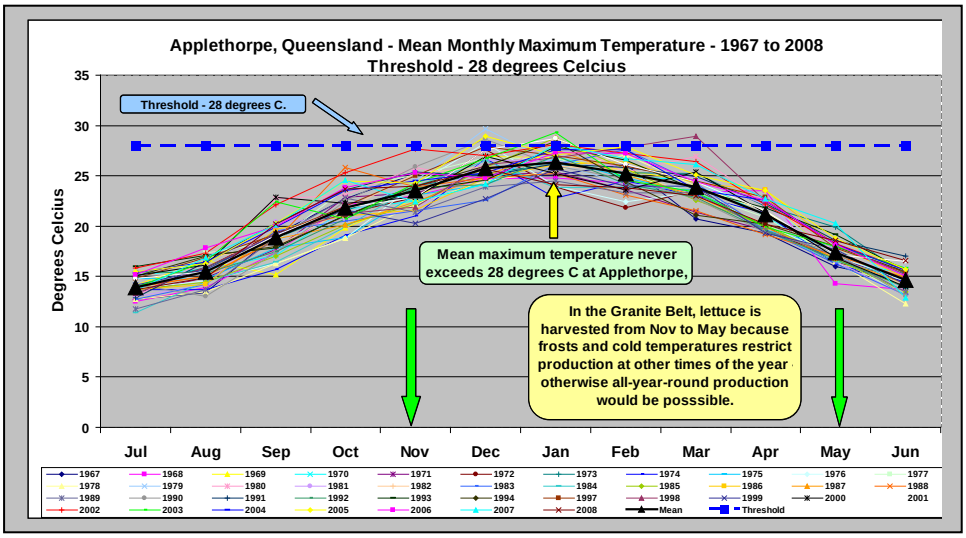

Fig. 3 – Applethorpe, Qld - Mean Monthly Maximum Temperatures

ii) New South Wales

Hay (southern NSW)

The maximum temperature trend for September in Gatton is more than 2°C above that in October for **Hay, NSW** for the past decade, with significant variability from year to year at both locations. That is, the maximum temperature threshold of 28°C, which occurs at Gatton in mid September (Fig. 2), does not occur at Hay until after the end of October (approximately 6 weeks later – Fig. 4), coinciding with the end of the harvest season at each location.

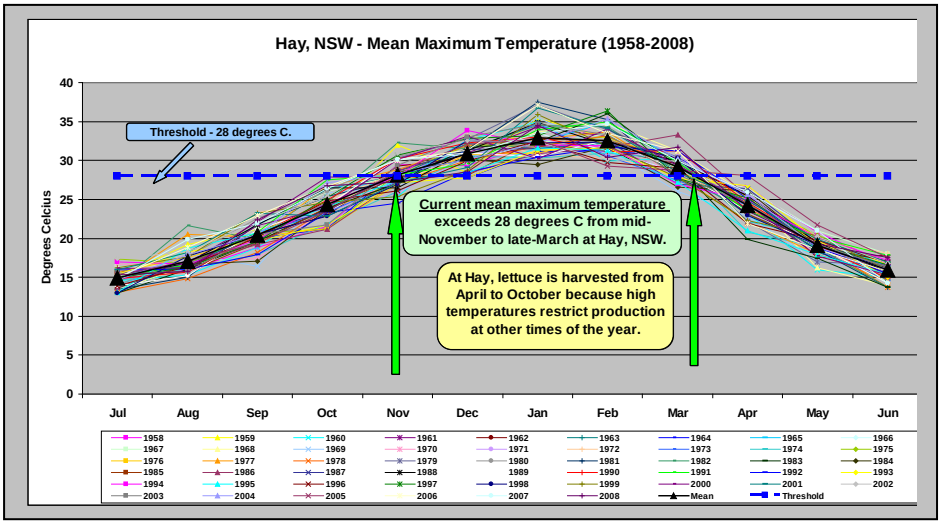

Fig. 4 – Hay, NSW - Mean Monthly Maximum Temperatures

Cowra (southern NSW)

Using 28°C as the mean maximum temperature threshold for lettuce in the 'hearting' development phase, and the temperature data from **Cowra, NSW** (Fig 5.), it would be expected that lettuce harvesting at Cowra would cease in mid-December and commence again in mid-March. This closely describes the production system in this district - "In the Cowra district, the early lettuce crops are planted from July to September and harvested from September to December. The late crops are planted from January to March and harvested from March to June" (Wade, 2005).

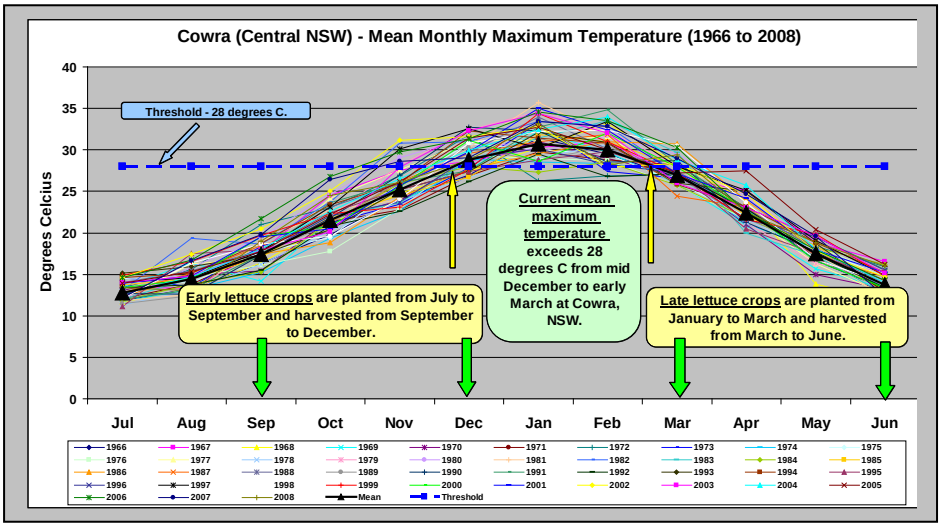

Fig. 5 – Cowra, NSW - Mean Monthly Maximum Temperatures

iii) Victoria

East Gippsland (Vic)

Using 28°C as the mean maximum temperature threshold for lettuce in the 'hearting' development phase, identified from the literature, and the temperature data from **Bairnsdale, Vic** (Fig 6.), it would be expected that lettuce harvests could occur in all months of the year – i.e. based on the long term mean monthly maximum temperatures, there would not be many years when the maximum temperature threshold for lettuce at the 'hearting' development phase, would be reached.

Lettuce harvesting occurs in all months in **East Gippsland**, but quality drops off significantly in the middle of winter (due to low temperature effects on quality). In East Gippsland heart size is smaller and quality is lower in winter than at locations such as Hay where the average winter temperatures are slightly higher.

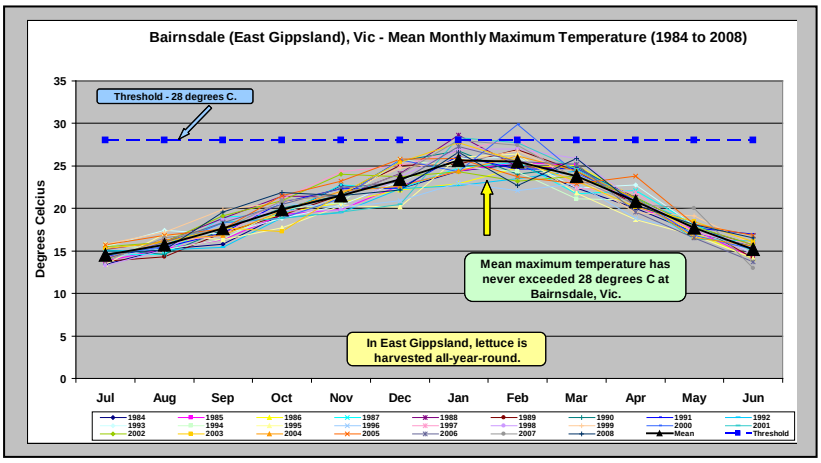

Fig. 6 – Bairnsdale, Vic - Mean Monthly Maximum Temperatures

iv) Western Australia

Gingin (WA)

Using 28°C as the mean maximum temperature threshold for lettuce in the 'hearting' development phase, it would be expected that lettuce harvesting at **Gingin, WA** would cease by early December and commence again in April (Fig 7).

This does correspond with the production of high quality lettuce from this region. Production does however continue over the December to March period, with reduced quality and yields. This quality continues to be marketable in WA during this period. More southerly production districts (e.g. Manjimup), do produce higher quality lettuce over this period.

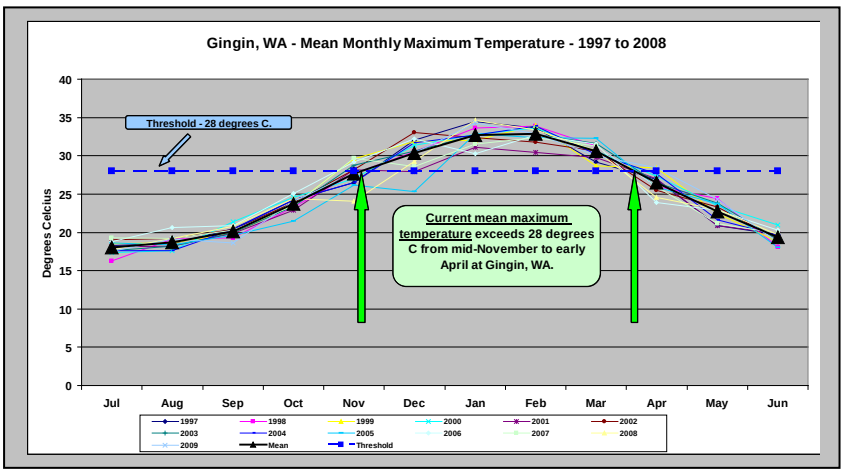

Fig. 7 – Gingin, WA - Mean Monthly Maximum Temperatures

Projected regional temperature changes

The projections of future maximum temperature change for the major lettuce production regions have been produced using the OZCLIM scenario generator developed by CSIRO Atmospheric Research and the International Global Change Institute (http://www.cmar.csiro.au/ozclim).

OZCLIM generates future climate change scenarios based on twelve different Global climate models (GCMs) and eighteen different greenhouse gas emission projections (IPCC, 2001). In this way it represents a comprehensive range of future climate uncertainties for use in climate change impact and adaptation research.

The CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, was chosen to represent a change in temperature. It is a scenario based on the world community taking less action on climate change and remaining fossil fuel dependant.

Lockyer Valley, SE Queensland

Table 5 *: Gatton, SE Queensland – Temperature ^{o}C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean Max ^{o}C	20.8	22.5	25.7	**28.0**	29.7	31.0	31.5	30.8	29.8	**27.4**	23.9	21.4
Threshold	28	28	28	**28**	28	28	28	28	28	**28**	28	28
2030 Mean Max – A1FI Scenario	20.8	22.6	26.0	**28.6**	30.3	32.0	32.0	31.1	30.1	**27.6**	24.2	21.4

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at **Gatton (SE Queensland)** exceeds 28^{o}C from early-October through to mid-April - a potential reduction in season length of approximately 3 weeks (Fig. 8).

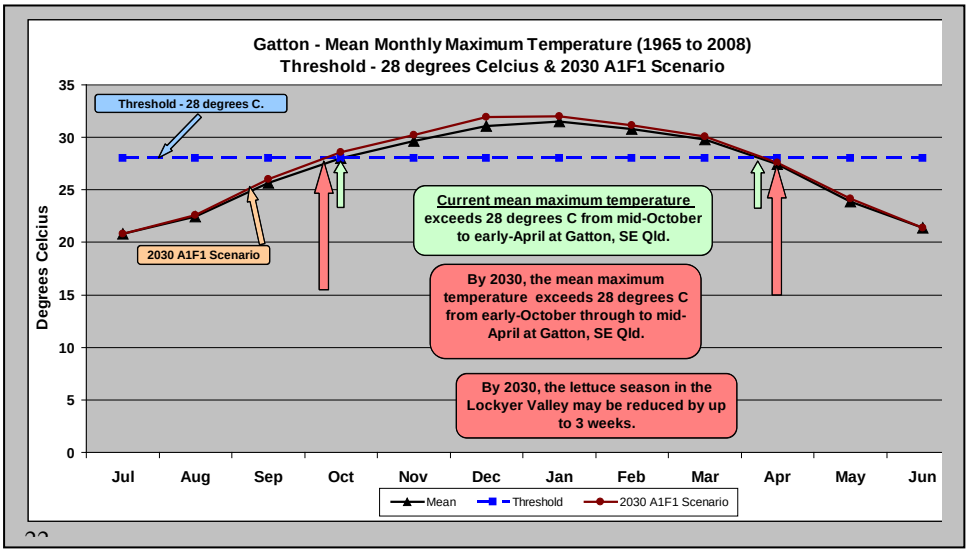

Fig. 8 *– Gatton, Qld - Mean Monthly Maximum Temperatures & Projected Increases*

Granite Belt, SE Queensland

***Table 6** : Applethorpe, SE Queensland – Temperature ^{o}C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean	13.9	15.5	18.8	21.8	23.5	25.8	26.4	25.2	23.9	21.1	17.4	14.6
Threshold	28	28	28	28	28	28	**28**	28	28	28	28	28
2030 Mean Max – A1FI Scenario	15.4	17.1	20.6	23.5	25.5	27.6	**27.9**	26.9	25.6	22.7	19.1	15.9

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean monthly maximum temperature at **Applethorpe (SE Queensland)** does not yet exceed 28^{o}C (although for practical purposes it does equal the threshold), enabling a continuation of planting and harvests over the summer as is currently occurring.

Due to a variable climate, the individual monthly mean maximum temperatures have exceeded 28^{o}C on several occasions since 1967. It is expected that by 2030, this situation will occur more frequently, as the mean maximum temperature approaches and then exceeds the 2030 Scenario.

For January (the hottest month of the year in the Granite Belt), the mean maximum temperature is expected to almost reach the threshold by 2030 (Fig. 9), so actual temperatures for individual years at or about 2030 will exceed the threshold of 28^{o}C, at times.

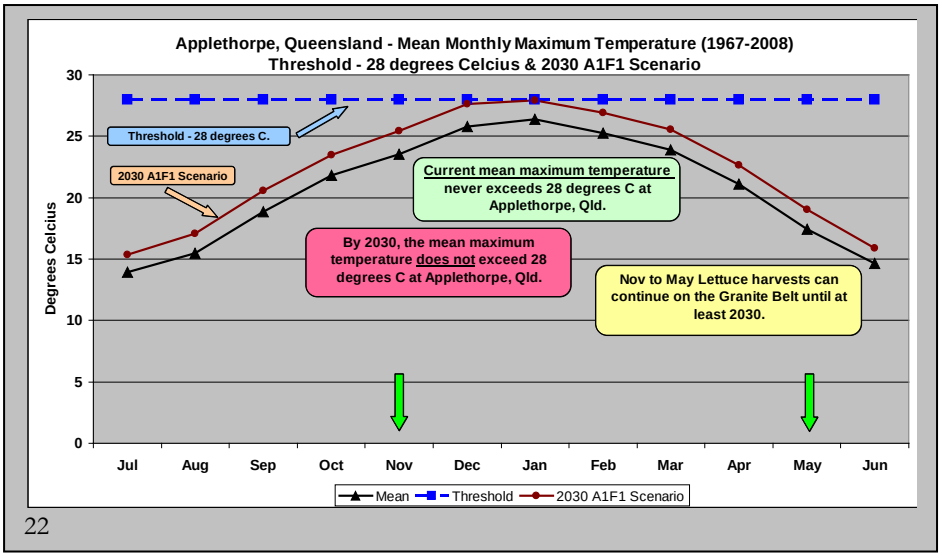

***Fig. 9** – Applethorpe, Qld - Mean Monthly Maximum Temperatures & Projected Increases*

Hay, NSW

***Table 7** : Hay, NSW – Temperature ^{o}C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean	14.9	17.0	20.4	**24.3**	28.2	30.8	32.9	32.6	29.1	**24.2**	19.1	15.9
Threshold	28	28	28	**28**	28	28	28	28	28	**28**	28	28
2030 Mean Max – A1FI Scenario	16.0	18.3	21.7	**25.3**	29.5	32.3	33.8	33.6	30.5	**25.6**	20.5	16.8

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at **Hay (NSW)** exceeds 28°C from early-November through to the end of March – a potential reduction in season length of approximately 3 weeks (Fig. 10).

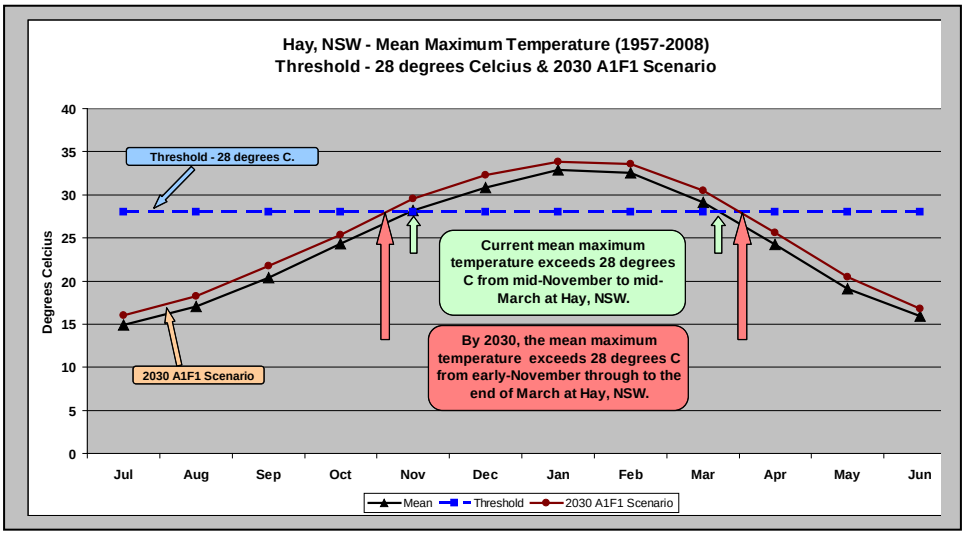

Fig. 10 *– Hay, NSW - Mean Monthly Maximum Temperatures & Projected Increases*

Central West (Cowra), NSW

Table 8 *: Cowra, NSW – Temperature °C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean	12.7	14.4	17.4	21.5	**25.2**	28.8	30.7	30.0	**26.9**	22.4	17.5	13.8
Threshold	28	28	28	28	**28**	28	28	28	**28**	28	28	28
2030 Mean Max – A1FI Scenario	14.7	16.7	19.9	23.7	**27.6**	31.4	33.0	32.1	**29.2**	24.8	19.9	15.7

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at **Cowra (NSW)** exceeds 28°C from mid-November to late-March – a potential reduction in season length of approximately 7 weeks (Fig. 11).

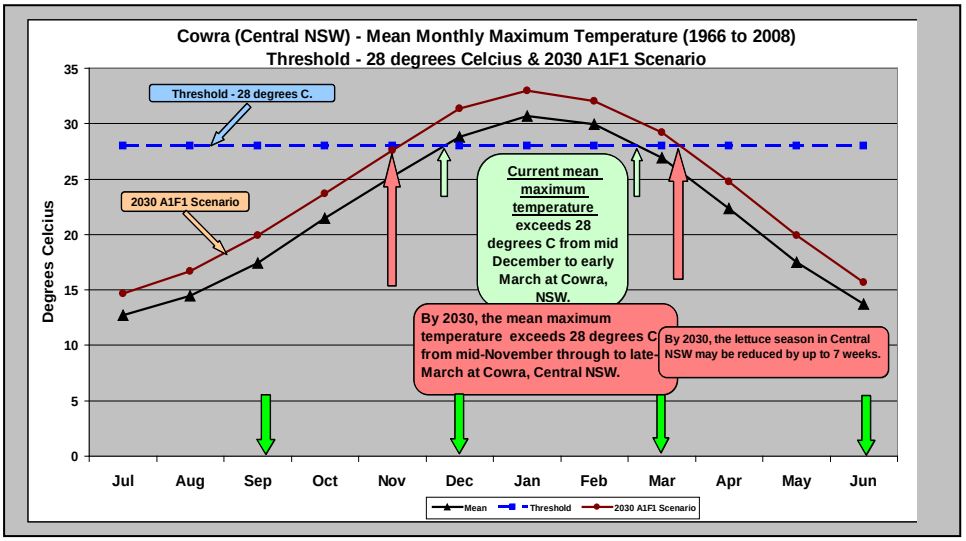

Fig. 11 *– Cowra, NSW - Mean Monthly Maximum Temperatures & Projected Increases*

East Gippsland, Victoria

Table 9 *: Bairnsdale, Vic – Temperature °C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean	14.5	15.7	17.6	19.9	21.5	23.4	**25.7**	**25.5**	23.8	20.8	17.7	15.2
Threshold	28	28	28	28	28	28	28	**28**	28	28	28	28
2030 Mean Max – A1FI Scenario	15.6	17.0	19.0	21.4	23.4	25.5	27.3	**27.6**	25.3	22.2	18.9	16.0

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at **East Gippsland (Vic)** does not yet exceed 28°C (although for practical purposes it does get close to the threshold), enabling a continuation of planting and harvests over the whole year as is currently occurring.

Due to a variable climate, the individual monthly mean maximum temperatures have exceeded 28°C on a few occasions since 1984.

For January and February (the hottest months of the year in East Gippsland – Table 13), the mean maximum temperature is expected to almost reach the threshold by 2030, so actual temperatures for individual years at or about 2030 will exceed the threshold of 28°C, at times (Fig. 12).

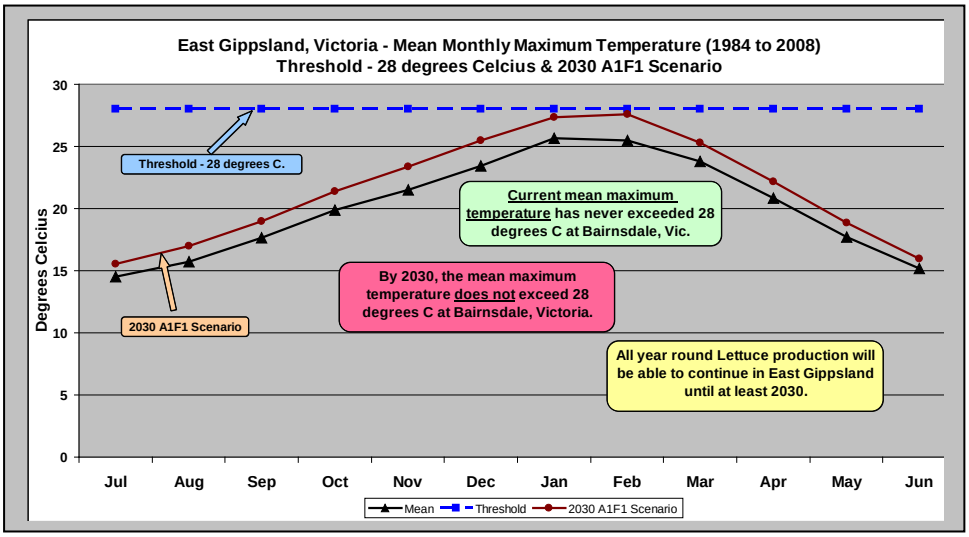

Fig. 12 *– East Gippsland, Vic - Mean Monthly Maximum Temperatures & Projected Increases*

Gingin, WA

Table 10 *: Gingin, WA – Temperature °C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean	18.1	18.7	20.2	23.7	**27.6**	30.4	32.7	32.9	30.6	**26.5**	22.8	19.4
Threshold	28	28	28	28	**28**	28	28	28	28	**28**	28	28
2030 Mean Max – A1FI Scenario	18.2	18.9	20.8	24.0	**27.7**	30.8	33.7	33.8	31.8	**27.5**	22.9	19.3

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at **Gingin (WA)** exceeds 28°C from mid-November through to mid-April – a potential reduction in season length of approximately 2 weeks (Fig. 13).

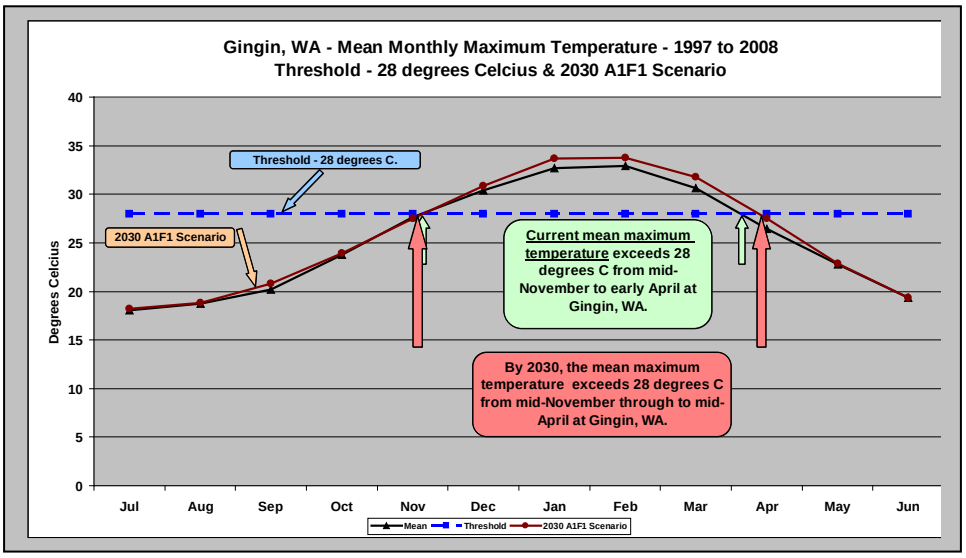

Fig. 13 *– Gingin, WA - Mean Monthly Maximum Temperatures & Projected Increases*

Impact of projected temperature increases

Lockyer Valley (SE Queensland)

Climate is changing, and for the Lockyer Valley mean maximum temperatures have increased over the past five decades by 1.1°C. Climate is expected to continue to change, so that the effects of further increasing temperatures, especially during the spring in the Lockyer Valley, is expected to influence the timing of the first and final lettuce planting and subsequent harvest dates. Growers are likely to respond by delaying the first planting dates in the summer and bringing the last planting dates forward into the winter.

Currently, the winter-based harvest season in the Lockyer Valley commences with the first plantings in February, followed by consecutive weekly plantings until the end of June. First harvest occurs in late April/early May, 2 weeks after the "critical threshold" period ends. Final harvests occur in October, with harvest peaking from June to August.

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean maximum temperature at Gatton (SE Queensland) exceeds 28°C from early-October through to mid-April.

As a consequence, the first consecutive lettuce plantings in the Lockyer Valley will gradually be delayed as we approach 2030. Initially this will be by a few days, and eventually by up to 2 weeks. Similarly, at the end of the winter season, the last harvests will occur approximately one week earlier in the spring, because of increasing temperatures in September and October.

The impact of these changes is that **the winter lettuce season in the Lockyer Valley will be shortened by approximately three (3) weeks**. Initially this will have a small impact on lettuce growing businesses, but if over time the winter season continues to be reduced in length, market access and profitability will be negatively impacted.

The **"Buffer Level"** between the current mean maximum temperature and the threshold temperature in autumn and early summer (the two times when the mean temperatures cross the threshold) in the Lockyer Valley, is **0.6°C (April)** and 2.3°C (September) – Table 5. **This will be reduced to 0.4°C and 2°C in 2030 respectively**.

Consequently, a delay in the commencement of plantings is more likely under a future climate, than is the delay of final harvests, because the current and the 2030 mean maximum temperatures are closer to the threshold in the autumn, than they are at the close of the season in the early summer, in the Lockyer Valley.

If more adaptable lettuce cultivars are available to growers up to and after 2030, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded. At this point, market access and the profitability of a reduced winter season in the Lockyer Valley will be a major determining factor in the vulnerability of the winter lettuce industry in south-east Queensland.

Granite Belt (SE Queensland)

Mean Maximum Temperatures never exceed the 28°C threshold for lettuce at Applethorpe, so **currently**, lettuce harvesting in the Granite Belt is not constrained by summer temperatures. This closely describes the production system in this summer lettuce production district. The Granite Belt is a highland region of SE Queensland, and as such summer temperatures are influenced by altitude.

Because lettuce is a cold sensitive crop, production in the Granite Belt is constrained by low temperatures in the winter, rather than high temperatures in the summer.

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean monthly maximum temperature at **Applethorpe (SE Queensland)** does not yet exceed 28°C, enabling a continuation of planting and harvests over the summer, as is currently occurring.

Due to a variable climate, the mean monthly maximum temperatures have exceeded 28°C on a few occasions since 1967. It is expected that by 2030, this situation will occur more often as the mean maximum temperature approaches the 2030 Scenario.

As maximum temperatures continue to rise, due to further climate change, the temperature threshold of 28°C will eventually be reached in the Granite Belt. The impact will be in reduced quality, in the absence of more adaptable cultivars. This may be compensated for by higher returns, as other summer producing districts in Australia are more adversely affected. Eventually, this has the potential to induce a break in summer production, in the first instance in the hottest month which is January (Table 6).

At beginning and end of the summer season, growers may be able to take advantage of earlier planting in the spring, and later planting in the autumn. These future early and late plantings are currently constrained by low minimum temperatures. The availability of a profitable market at these times of the year will also have a significant influence over the capacity of growers to take advantage of these earlier plantings, which will extend future planting and harvest times in this lettuce growing district.

The **"Buffer Level"** between the current mean temperature and the threshold temperature in January, the hottest month in the Granite Belt, is **1.6°C**. **This will be reduced to 0.1°C in 2030** (Table 10).

Consequently, by 2030 individual January mean monthly maximum temperatures will exceed 28°C on more occasions than currently occur.

Hay (NSW)

Climate is expected to continue to change, so that the effects of further increasing temperatures will influence the timing of lettuce planting and harvest dates in this region. Growers are likely to respond by bringing these planting dates forward.

Currently, the winter-based production season in southern NSW commences with first harvests in late April, 2 weeks after the "critical threshold" period ends, and final harvests occur in October.

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean monthly maximum temperature at **Hay (NSW)** exceeds 28°C from early-November through to the end of March.

The **"Buffer Level"** between the current mean temperature and the threshold temperature in autumn and early summer (the two times when the mean temperatures cross the threshold) in southern NSW, is **3.7°C (Oct)** and 3.8°C (April). **This will be reduced to 2.7°C and 2.4°C in 2030 respectively** (Table 7).

The consequence is that the winter lettuce season in southern NSW will be shortened by approximately three (3) weeks.

Initially this will have a small impact on lettuce growing businesses, but if over time the winter season continues to be reduced in length, then market access and profitability will be negatively impacted.

If more adaptable lettuce cultivars are available to growers up to and after 2030, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded.

At this point, market access and the profitability of a reduced winter season in southern NSW will be a major determining factor in the vulnerability of the winter lettuce industry in this region.

Cowra (NSW)

Currently, the lettuce production season in the Cowra district is based on early crops being planted from July to September and harvested from September to December, and late crops are planted from January to March and harvested from March to June.

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean monthly maximum temperature at **Cowra (NSW)** exceeds 28°C from late-November to mid-March.

The **"Buffer Level"** between the current mean temperature and the threshold temperature in early autumn and the summer (the two times when the mean temperatures cross the threshold) in the Central West, is **1.1°C (March)** and 2.8°C (November). **By 2030 this will be reduced to 0.4°C (November) and in March the threshold is exceeded by 1.2°C** (Table 8).

Consequently, a delay in the commencement of plantings is more likely under a future climate, than is the delay of final harvests. This is because the current mean maximum temperatures are closer to the threshold in the early autumn, than they are at the close of the season in the early summer. i.e. the threshold is likely to be met in the early Autumn by 2030 .

The consequence is that the lettuce season in Central West NSW will be shortened by approximately three (3) weeks.

Initially this will have a small impact on lettuce growing businesses, but if over time the season continues to be reduced in length, then market access and profitability will be negatively impacted.

If more adaptable lettuce cultivars are available to growers up to and after 2030, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars are exceeded. At this point, market access and the profitability of a reduced season in central west NSW will be a major determining factor in the vulnerability of the lettuce industry in this region.

East Gippsland (Victoria)

Currently, mean monthly maximum temperatures never exceed the 28°C threshold for lettuce in East Gippsland, so lettuce harvesting in this region is not constrained by temperatures in excess of 28°C, and therefore lettuce harvests can occur in all months of the year. Lettuce harvesting occurs in all months in East Gippsland, but quality drops off significantly (heart size is smaller and quality is lower) in the middle of winter, due to low temperature effects on quality.

East Gippsland's weather is influenced by its proximity to the ocean, and as such summer and winter temperatures are ameliorated.

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean monthly maximum temperature at **East Gippsland (Victoria)** does not yet exceed 28°C, enabling a continuation of planting and harvests over the summer as is currently occurring.

As maximum temperatures continue to rise, due to further climate change, the temperature threshold of 28°C will eventually be reached in East Gippsland. The impact will be in reduced quality, in the absence of more adaptable cultivars. This may be compensated for by higher returns, as other summer producing districts are more adversely affected. Eventually, this has the potential to induce a break in summer production, in the first instance in the hottest month which is January.

The **"Buffer Level"** between the current mean temperature and the threshold temperature in January, the hottest month in East Gippsland, is **2.3°C**. **This will be reduced to 0.7°C in 2030** (Table 9).

Consequently, by 2030 individual January mean monthly maximum temperatures will exceed 28°C on occasions.

Because lettuce production is carried out all year round in East Gippsland, and quality drops off significantly (heart size is smaller and quality is lower) in the middle of winter due to low temperature effects on quality, in the future, growers may be able to take advantage of earlier plantings in the spring and later plantings in the autumn. These planting times are currently constrained by low minimum temperatures.

The availability of a profitable market at these times of the year will also have a significant influence over the capacity of growers to take advantage of these earlier plantings, which will potentially extend future planting and harvest times in this lettuce growing district.

Gingin (WA)

Using 28°C as the man maximum temperature threshold for lettuce in the 'hearting' development phase, it would be expected that lettuce harvesting at Gingin, WA would cease by early December and commence again in April. This corresponds with the production of high quality lettuce from this region.

Currently, production does continue over the December to March period, with reduced quality and yields. This quality continues to be marketable in WA during this period.

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean maximum temperature at **Gingin, WA** exceeds 28°C from late-November through to mid-April.

Because lettuce production is carried out all year round in Gingin, and quality drops off significantly over the summer, in the future, quality will be more severely affected by increasing summer temperatures.

The **"Buffer Level"** between the current mean temperature and the threshold temperature in autumn and early summer (the two times when the mean temperatures cross the threshold) at Gingin, is **1.5°C (April) & 0.4°C (November)**. **By 2030, this will be reduced to 0.5°C in April & 0.3°C in November -** Table 10.

As a consequence, summer production at Gingin will eventually be discontinued, as the effects on quality are amplified by higher temperatures, especially in February, the hottest month.

If more adaptable lettuce cultivars are available to growers up to and after 2030, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded. At this point, market access and the profitability of a production season at Gingin will be a major determining factor in the vulnerability of the lettuce industry in this region of WA.

Adaptation through management practices

Lockyer Valley (SE Queensland)

Climate is expected to continue to change, so that the effects of further increasing temperatures, especially during the spring in the Lockyer Valley, is expected to influence the timing of the final lettuce planting and harvest dates. Growers are likely to respond by bringing these planting dates forward.

The consequence is that the winter lettuce season in the Lockyer Valley will be shortened by approximately three weeks. Initially this will have a small impact on lettuce growing businesses, but if over time the winter season continues to be reduced in length, then market access and profitability will be negatively impacted.

It is expected that it will not be until after 2030 that market access and the profitability of a reduced winter season in the Lockyer Valley will be major determining factors in the vulnerability of the winter lettuce industry in south-east Queensland.

If **more adaptable lettuce cultivars** are available to growers, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded.

Granite Belt (SE Queensland)

As maximum temperatures continue to rise due to further climate change, the temperature threshold of 28^{o}C will eventually be reached in the Granite Belt. Using the A1FI Scenario, by 2030 the mean maximum temperature at Applethorpe (SE Queensland) does not yet exceed 28^{o}C, enabling a continuation of planting and harvests over the summer.

Due to a variable climate, the monthly mean maximum temperatures have exceeded 28^{o}C on a few occasions since 1967. It is expected that by 2030, this situation will occur more often as the mean maximum temperature approaches the 2030 Scenario.

At some period of time after 2030, when the threshold is reached, the impact will be in reduced quality, in the absence of more adaptable cultivars. **This may be compensated for by higher returns**, as other summer producing districts are more adversely affected. Eventually, this has the potential to induce a break in summer production, in the first instance in the hottest month which is February.

At beginning and end of the summer season, **growers may be able to take advantage of earlier planting in the spring, and later planting in the autumn.** These future early and late plantings are currently constrained by low minimum temperatures.

The availability of a profitable market at these times of the year will also have a significant influence over the capacity of growers to take advantage of these earlier plantings which will extend future planting and harvest times in this lettuce growing district.

Hay (NSW)

Climate is expected to continue to change, so that the effects of further increasing temperatures during the spring in southern NSW are expected to influence the timing of final lettuce planting and harvest dates in this region. **Growers are likely to respond by bringing these planting dates forward.**

The consequence is that the winter lettuce season in southern NSW will be shortened by approximately three weeks. Initially this will have a small impact on lettuce growing businesses, but if over time the winter season continues to be reduced in length, then market access and profitability will be negatively impacted.

If **more adaptable lettuce cultivars are available** to growers, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded. At this point, market access and the profitability of a reduced winter season in southern NSW will be a major determining factor in the vulnerability of the winter lettuce industry in this region.

It is expected that it will not be until after 2030 that market access and the profitability of a reduced winter season in Hay will be major determining factors in the vulnerability of the winter lettuce industry in southern NSW.

Cowra (NSW)

Climate is expected to continue to change, so that the effects of further increasing temperatures is expected to influence the timing of lettuce planting and harvest dates in this region. **Growers are likely to respond by bringing these planting dates forward.**

The consequence is that the winter lettuce season in southern NSW will be shortened by approximately three weeks. Initially this will have a small impact on lettuce growing businesses, but if over time the winter season continues to be reduced in length, then market access and profitability will be negatively impacted.

If **more adaptable lettuce cultivars are available** to growers, this impact will be ameliorated until such time as the genetic capability of more adaptable lettuce cultivars is exceeded. At this point, market access and the profitability of a reduced winter season in central west NSW will be a major determining factor in the vulnerability of the winter lettuce industry in this region.

It is expected that it will not be until after 2030 that market access and the profitability of a reduced winter season in Cowra, will be major determining factors in the vulnerability of the winter lettuce industry in central NSW.

East Gippsland (Victoria)

As maximum temperatures continue to rise, due to further climate change, the temperature threshold of 28^{o}C will eventually be reached in East Gippsland. The impact will be in reduced quality, in the absence of more adaptable cultivars. **This may be compensated for by higher returns**, as other summer producing districts are more adversely affected. Eventually, this has the potential to induce a break in summer production.

If **more adaptable lettuce cultivars are available** to growers, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded. At this point, market access and the profitability of a reduced winter season in south-eastern Victoria will be the major determining factors in the vulnerability of the lettuce industry in this region.

Gingin (WA)

Because lettuce production is carried out all year round in Gingin, and quality drops off significantly over the summer, in the future, quality will be more severely affected by increasing summer temperatures.

As a consequence, summer production at Gingin will eventually be discontinued, as the effects on quality are amplified by higher temperatures, especially in February, the hottest month.

If **more adaptable lettuce cultivars are available** to growers up to and after 2030, this impact will be ameliorated, until such time as the genetic capability of more adaptable lettuce cultivars is exceeded. At this point, market access and the profitability of a production season at Gingin will be major determining factors in the vulnerability of the lettuce industry in this region of WA.

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