Resource Futures Program

Global Change Impacts on Australian Wheat Cropping

Howden, S.M.[1], Reyenga P.J.[2] and Meinke, H.[3]

Working Paper Series 99/04

Report to the Australian Greenhouse Office
1999

CSIRO

Disclaimer

1 CSIRO Wildlife and Ecology, GPO. Box 284, Canberra, ACT, 2601
2 Bureau of Rural Sciences, PO Box E11, Kingston, ACT, 2604
3 Agricultural Production Systems Research Unit, PO Box 102, Toowoomba, QLD, 4350

Executive Summary

- Historical increases in atmospheric carbon dioxide (CO_2) concentrations have been well documented with mid-range projections suggesting an approximate doubling of current concentrations to 700 ppm by the year 2100 (e.g. Houghton *et al.* 1996). Increasing atmospheric CO_2 can affect agricultural production both directly through the stimulation of photosynthesis, through improved water use efficiency and indirectly as the increased concentration of CO_2 and other greenhouse gases in the atmosphere may induce climate change. Global change is used here to refer to the combined effect of changes in CO_2 and climate.

- The impacts of global change on crop productivity are difficult to predict, yet the assessment of these impacts is needed for both farm management and policy making purposes. There was previously no comprehensive study of the effects of global change on Australian wheat cropping systems.

- We use an existing validated wheat model APSIM I_WHEAT modified to simulate varying CO_2 to investigate the impacts of doubling CO_2 interactively with a wide range of feasible climate change scenarios on the yields, grain protein levels, gross margins and heat shock hazard for Australian wheat cropping systems.

- We include practical management adaptations to global change, as impacts studies without such adaptation are unlikely to provide a balanced analysis. Key adaptation options investigated in this report are choice of cultivars and sowing windows. Adaptations such as fertilisation rate and crop rotation will be dealt with in subsequent reports.

- Studies are conducted for 10 sites distributed across the existing Australian wheat belt. We have also included a site in the Mitchell grasslands of southern Queensland for while this and similar sites are currently too marginal for cropping they may become viable under feasible changes of CO_2 and climate.

Site Yields

- Doubling of CO_2 concentration to 700ppm alone (ie *without* climate change) was simulated to increase yield within the current wheat belt by 5 to 43% compared with the simulated 100-year historical mean. Yields were increased from 0.85 t/ha to 1.3 t/ha (50% increase) at the Burenda site in south-western Queensland outside the current wheat belt. The relative increase was least at sites where evaporative demand and hence soil moisture stress was least and tended to be greater at drier and warmer sites as found in controlled experiments. The site results were consistent with previous assessments where they have been made.

- Thus there is a possibility that cropping can continue to expand into drier margins where soils are suitable as it has over the past decades. The geographical extent of this expansion could be considerable with sites such as Burenda perhaps forming the new margins to cropping provided that climate changes are not substantially negative. However, in most regions the predominance of unsuitable soils beyond the current cropping margins will limit the increase in area cropped. Such changes in landuse from grazing to cropping could also occur on the wetter margins due to alterations in the relative productivity of the two industries with global change. Changes in landuse of these types will have impacts on many factors including regional viability, degradation issues, rural infrastructure requirements and biodiversity. They are also likely to be associated with major emissions of greenhouse gases arising from land-clearing, loss of perennial grass biomass and soil carbon loss.

Adaptation

- Under the 'most likely' climate change combined with doubling of CO_2, yields increased by 9-37% when planting practices were maintained as at present. However temperature increases are likely to result in a reduction in the duration of the annual frost period, thus allowing earlier planting in some sites. Modifying the planting window to take advantage of this opportunity resulted in yield increases of 13-46% when compared with simulated 100-year historical baseline yields.

- Key varietal adaptations in response to changing conditions are a switch from fast-maturing to slower maturing varieties particularly with increased temperature and rainfall and under the modified planting windows.

National Yields

- When yields were scaled up across the continent based on currently cropped areas doubling CO_2 increased national yields by 24% (3.4Mt) with the greatest increase in Queensland (39%) and least in NSW and Victoria (18%). If climate change was included in the assessment the yield changes were 20% using the current planting window or 26% if planting windows were modified (increases ranged from 14% in South Australia to 33% in Queensland and WA).

- This analysis suggests that the adaptation strategy of changing planting windows alone is worth at least 1M tonnes wheat per year nationally; other adaptations such as choice of variety are already built into the analysis. This scaling up of yields is an underestimate of the possible change as it does not include the possible expansion of cropping areas as noted above. However, there are likely to be opposing influences arising from potential increases in pest and disease incidence with global change (eg Sutherst 1995) and the substantial losses in productivity expected through continuing land degradation processes such as dryland salinity, soil structural decline and acidification.

- It is important to note that this is an analysis of one point in time (approximately year 2100 when CO_2 is anticipated to rise to 700ppm) and that the impacts on yields may differ considerably after this point due to continuing climate change. We develop a general response function which suggests that yields are likely to decline after the year 2100, eventually to below their historical levels

- There are a number of limitations to this study in addition to those above. Chief among these is the representation of climate change used. We do not incorporate explicitly changes in the frequency or intensity of El Niño events - a growing concern. Nor do we include such factors as changes in rain days or rainfall intensity which are likely to impact on cropping in various ways.

Grain quality

- Grain protein contents are likely to fall by 4-14% with climate and CO_2 changes combined and this will significantly downgrade prices received unless fertiliser application or pasture rotations are incorporated to offset this. To maintain protein contents at current levels, there will be a need to increase fertiliser application rates by 40 to 220 kg/ha depending on the scenario. These adaptations will have their own impacts on soil acidification processes and water quality in some regions and on farm economics. Furthermore, such adaptation could be a significant source of greenhouse gas emissions as production, packaging and distribution of nitrogenous fertiliser generates about 5.5 kg CO_2 per kg N and as both fertilisation and legume rotations increase emissions of nitrous oxide.

- Increases in heat shock also may reduce grain quality by affecting dough-making qualities. For sites in southern Australia there was no significant increase in heat shock hazard as anthesis tended to be earlier due to more rapid crop development and particularly where planting windows were brought forward. However, for sites in northern Australia, these ameliorating factors were not sufficient and heat shock risk was increased substantially. Development of heat-tolerant varieties would be needed for the Burenda site (and it surrounding region) to become a viable producer of high quality wheat.

Gross margins

- Doubling CO_2 by itself increased calculated gross margins by 6 to 70% in the existing wheat belt and by 80% at the Burenda site outside the existing wheat belt. Whilst this increase was largely driven by increases in mean yields, it was also due to a reduction in the coefficient of variation of yields by about 15 to 20% due to the buffering effect of high levels of CO_2 during dry years.

- In the combined CO_2/climate change scenarios, modifying planting windows had substantial benefits, with gross margin increases ranging from 28 to 95% in the current wheat belt whereas using the current planting window this range was 5 to 60%. In Burenda, outside the current wheat belt, gross margins changed from -$61/ha to $4/ha. Given these low returns, it is apparent that the relative costs of inputs and the prices received will be critical in determining the viability of future cropping in this region.

- All the above gross margin calculations assume that wheat prices, the grain protein/price relationship and input prices will be the same in the year 2100 as they currently are whereas it is obvious that these will vary. We briefly review existing studies on global change and global food security and on the basis of these it appears that our wheat prices for the year 2100 are likely to be conservative.

Table of Contents

Executive Summary 3
Acknowledgements 7
1 Introduction 8
2 Methods 11
3 Geraldton – Western Australia 17
4 Wongan Hills – Western Australia 21
5 Katanning – Western Australia 28
6 Minnipa – South Australia 35
7 Horsham – Victoria 39
8 Wagga Wagga – New South Wales 46
9 Dubbo – New South Wales 53
10 Moree – New South Wales 60
11 Dalby – Queensland 67
12 Burenda – Queensland 74
13 Emerald – Queensland 81
14 Aggregated Results 88
15 Discussion 93
16 References 97
Appendix 101

Acknowledgements

The authors would like to acknowledge the contributions of Dr Greg McKeon (QDNR), Brett Robinson (APSRU), Dr Peter Johnston (QDPI), Dr Wayne Hall (QDNR), Dr Gary O'Leary, Dr Roger Gifford (CSIRO) and Dr Bruce Kimball (US Department of Agricultural Research Service). Thanks also to Dr Roger Jones (CSIRO Atmospheric Research) for providing code for the probability distribution analysis.

1 Introduction

Historical increases in atmospheric carbon dioxide (CO_2) concentrations have been well documented with mid-range projections suggesting an approximate doubling of current concentrations to 700 ppm by the year 2100 (e.g. Houghton *et al.* 1996). Increasing atmospheric CO_2 can affect agricultural production both directly through the stimulation of photosynthesis, particularly in C_3 plants (Cure and Acock 1986), through improved water use efficiency (Morison and Gifford 1984), and indirectly as the increased concentration of CO_2 and other greenhouse gases in the atmosphere may induce climate change (e.g. Houghton *et al.* 1996). Global change is used here to refer to the combined effect of changes in CO_2 and climate. The impacts of global change on crop productivity are difficult to predict, yet the assessment of these impacts is needed for both farm management and policy making purposes (Kenny *et al.* 1995). Given the uncertainties surrounding the magnitude and direction of regional climate changes, scenario analysis using simulation models combined with experimental research is likely to be the most effective approach for assessment.

Our approach therefore was to use an existing well validated wheat model I_WHEAT (Meinke *et al.* 1998) linked in with the APSIM cropping systems modelling framework (McCown *et al.* 1996). I_WHEAT replaces groups of processes with conservative, biologically meaningful, parameters which enables the model to be used across a range of environments (Meinke *et al.* 1998). It has a daily timestep, requires limited data inputs and is readily parameterised. We have modified I_WHEAT to simulate different CO_2 levels and validated these modifications using results from field-based and glasshouse experiments (Reyenga *et al.* 1999b). This model was run under a wide range of feasible climate change scenarios (described in detail later) for both the current and doubled CO_2 concentrations.

The major concern of most studies of global change impacts to date has been on wheat yields. Changes in yields will have obvious implications in terms of farm economic viability in nations such as Australia and on risks of starvation in subsistence economies. However, grain protein content (ie grain quality) is also a key determinant of the value of wheat in both situations and this tends to have been overlooked in most studies to date, even though grain nitrogen may decline with doubling of CO_2 (Rogers *et al*. 1996, Wolf 1996). The combination of yield and protein levels are key factors affecting farm gross margins which are a basic indicator of economic viability. Thus we focus on these three main factors in this study. There are also concerns whether climate change will increase the incidence of ‘heat shock’ in wheat (Blumenthal *et al*. 1991, Stone *et al*. 1996a), a process which downgrades the uses to which the grain can be put (e.g. heat shocked grain is less desirable for doughmaking). We make a risk assessment of the likely incidence of heat shock under the different scenarios.

In this study we wanted to include possible management adaptations to global change, as impacts studies without such adaptation are unlikely to provide a balanced analysis. Key management decisions which are amenable to adaptation include choice of cultivar, window for sowing, fertiliser application rate, soil surface and fallow management and crop/pasture rotation strategies. A cropping systems approach such as that in APSIM is ideally suited to addressing these adaptations. In this report we will use APSIM I_WHEAT to focus on choice of cultivars and sowing windows. Adaptations such as fertilisation rate and crop rotation will be dealt with in subsequent reports.

Previous studies have been made of some climate change and CO_2 change on Australian wheat systems. McKeon *et al.* (1988) assessed climate changes only (i.e. no CO_2 change) on wheat yields in Queensland and assessed that scenarios of temperature increases (+2^{o}C) would decrease yields by 6% or rainfall change plus temperature increase (winter rain -20%, summer rain +30%) would increase yields by 23%. There was a tripling of soil loss under the full climate change scenario. Hammer *et al.* (1987) assessed likely distribution of wheat growing regions in eastern Australia under climate change and concluded that some further expansion of cropping areas was likely. Wang *et al.* (1992) assessed the interactive impacts of changes in CO_2 and climate on wheat yields in Victoria, and suggested that doubling of CO_2 concentration to 700ppm would increase yields by 28% to 43% but that simultaneous increases in temperature of 3^{o}C would decrease yields by 25 to 60% using current cultivars or a substantial increase in yield if a late-developing variety from Queensland was used. Response to rainfall change were cultivar dependent. However, this study was of one location, did not modify planting windows to allow for changes in frost risk, nor did it enable impacts of nitrogen dynamics to be investigated. The model also does not have a continuous soil water balance and so cannot simulate fallows which are of critical importance in some Australian cropping systems.

Wheat in Australia is grown in a large variety of environments ranging from tropical to mediterranean climates and soils ranging from light, shallow sands to deep, heavy clays. These differences result in regional differences in management. There are also regional economics that distinguish locations. We have chosen sites distributed across the existing wheat belt to sample these differences (Figure 1). We have also included a site in the Mitchell grasslands of southern Queensland. This site is currently too marginal for cropping (Hammer *et al.* 1987) but may become less marginal under feasible changes of CO_2 and climate. The heavy clay soils which underlie these grasslands are widespread and generally suitable for cropping and so increasing viability may have huge implications for the future of both the cropping industry and regional landuse.

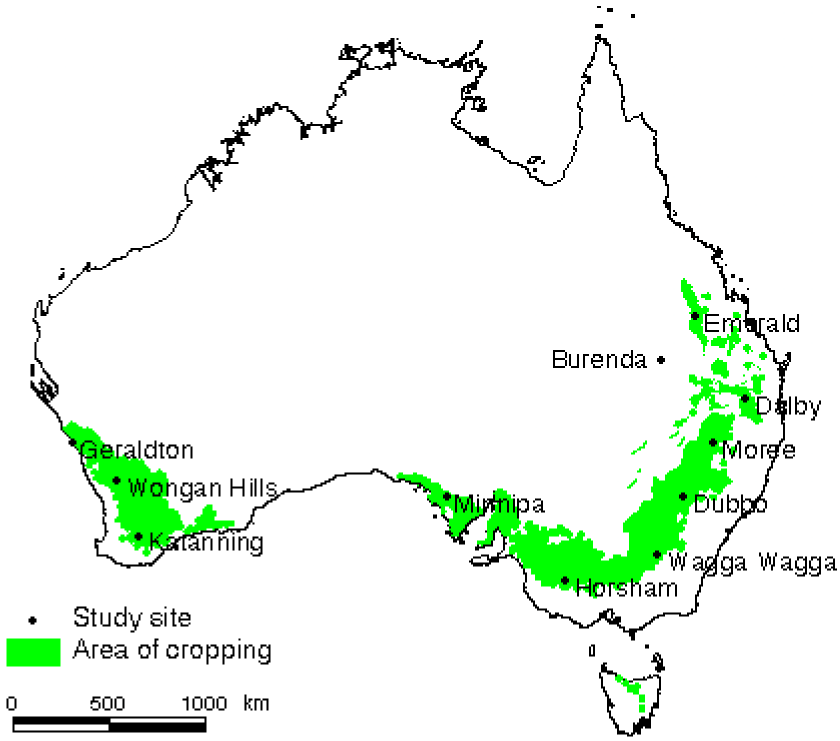


Figure 1: Area of cropping in Australia and location of study sites.

The aim of this report is to assess the implications of scenarios of feasible climate change under doubled CO_2 concentrations on the yield, grain protein content and gross margin of wheat enterprises across these sites. We include management adaptation to the global changes so as to minimise negative impacts and maximise positive responses. We also investigate changes in the incidence of heat shock for wheat.

2 Methods

Climate Files

I_WHEAT is a daily timestep model which uses daily climate as input data. There are a range of methods of constructing daily climate records for climate change scenarios. These include 1) stochastic weather generator approaches such as LARS-GEN (Semenov and Barrow 1997) which use the variability, means and other characteristics of the historical climate record to randomly generate climate change records, 2) sophisticated hidden-Markov models to downscale GCM data (e.g. Bates *et al*. 1996), 3) statistical interpolations of GCM or LAM (Local Area Model) data (e.g. McKeon *et al.* 1999) and, 4) simple adjustments to daily rainfall and temperature records (e.g. Howden *et al.* 1999). We assessed the utility of option 1 and 2 by running I_WHEAT with records intended to be representative of the current climate and comparing yields and yield variability with simulations using the historical record. We found that yields were seriously underpredicted by the synthetic records due to a lack of representativeness in rainfall regimes, particularly during the sowing window. Option 3 was unavailable as there were no suitable LAM data surfaces available at the time and the GCM results were at too coarse a resolution to be useful for the site-based assessments we needed to undertake. We thus restricted ourselves to option 4 and modified the long-term historical records described in Table 1. Modifications were restricted to changes in daily temperature and rainfall according to the scenarios outlined in the next section. The change in temperature was added to both maximum and minimum temperatures. No changes were made to the frequency of rain days, so rainfall was modified by the proportion defined by the scenarios.

Table 1 Location of meteorological stations and climate records used for long-term wheat simulation

Location	State	Latitude	Longitude	Start Date	End Date
Emerald	Qld	-23.57	148.18	1890	1994
Burenda	Qld	-25.78	146.75	1890	1997*
Dalby	Qld	-27.17	151.27	1887	1994
Moree	NSW	-29.47	149.85	1879	1994
Dubbo	NSW	-32.22	148.57	1874	1994
Wagga Wagga	NSW	-35.19	147.47	1879	1996
Horsham	VIC	-36.65	142.10	1873	1994
Minnipa	SA	-32.83	135.15	1915	1994
Katanning	WA	-33.65	117.90	1910	1993
Wongan Hills	WA	-30.90	116.72	1907	1996
Geraldton	WA	-28.80	114.70	1906	1994

* The climate record for this site was generated by using interpolated daily climate surfaces (Carter *et al.* 1996) due to there being no nearby long-term climate station.

This approach is a pragmatic solution to the problem of generating climate records rather than an ideal solution. The approach implicitly assumes that there is no change in either the frequency or intensity of El Niño/La Niña events with climate change whereas there is growing concern that El Niño frequencies will increase (eg Wilson and Hunt 1997). This will change the proportion of good and bad years in the record and the net impact on wheat may be different from the average change in rainfall. The temperature changes are equally weighted between maximum (daytime) and minimum (nightime) temperatures whereas to date the majority of warming experienced is via increase in minimum temperatures. Our approach is supported by simulation results from recent GCM/LAM simulations (Hennessy *et al.* 1999) but there remains uncertainty as to how the changes will be expressed. Lastly, particularly with greater changes to the daily values, the autocorrelation between factors such as radiation, precipitation, maximum temperature and minimum temperature will change and the climate record will become less representative. Nevertheless, the approach we have adopted is likely to maintain the gross linkages between these factors within the climate scenario envelopes described below.

Simulation Scenarios

There is growing convergence in projections of future global temperature change derived from Global Climate Models. However, there remains some uncertainty as to how these temperature changes translate to smaller scales or even regional level. There is even greater uncertainty regarding precipitation changes due to the complex nature of the processes involved notwithstanding the use of nested, more-detailed local area models within the GCMs (eg Hennessy *et al.* 1999). Our approach is thus not to restrict ourselves to analysing a small subset of the possible GCM results but to develop for each location a surface of all possible combinations of temperature and rainfall change within a certain envelope of change. Based on the CSIRO 1996 Climate Change scenarios for the Year 2100 and considerations described above we decided to limit the surface to an increase of 4^{o}C above current temperatures and $\pm$ 20% changes in rainfall. In presenting the results we have generally compared the factor of interest (ie yield, grain nitrogen or gross margin) under a global change scenario (ie 700ppm CO_2 plus a climate change) as a relative change (%) in the mean compared with that of the historical record using 350ppm CO_2.

The key benefit of using this approach is that as climate scenarios change, new estimates of the likely impact can be made through locating the scenario on the surface without the need to re-run the analyses. A subsidiary benefit is that it is possible to assess rapidly, climatic sensitivities and thresholds. However, many climate change scenarios are currently given as a large range of possibilities (eg the CSIRO 1996 climate change scenarios) and when combined with the global change surfaces we have constructed, provides little directional information to policy-makers. We have used a Monte Carlo sampling approach in conjunction with the CSIRO scenarios to provide some probabilistic estimates of likely climate changes (Jones 1998). This information is provided as an overlay on the surfaces and consists of cumulative probabilities of occurrence (ie the darkest, most probable area indicates that there is a 20% chance of change occurring within that climatic envelope, the next darkest area a 40% chance of occurrence within that envelope etc).

Model Settings

To conduct these simulations we required information on regional management practices, varieties, growing conditions and soil types. Management profiles (see appendix) for the different study regions were compiled by Meinke et al. (unpublished) from expert knowledge of practices in each region and from information available from the literature.

The model was run with a continuous wheat monoculture. The soil water balance was maintained between crops, however, soil N and organic matter were reset at sowing. This is necessary so that starting conditions reflect the 'average' district conditions. Resetting soil N and organic matter also avoids problems such as fertility run-down in a continuous wheat monoculture, which would make interpretation difficult. A latter study will address these 'transient' changes.

In these simulations, sowing can occur within a given planting window after certain planting rules have been met (these are described in the appendix). If there has been no sowing opportunity at the end of the planting window then a crop is automatically sown and is arbitrarily given 25mm of water to ensure crop establishment. The seeds are sown at a density of 100 plants m^{-2} at a depth of 50 mm with 80 kg N ha^{-1} of fertiliser (NO_3-N). This level of nitrogen fertiliser is likely to be more than is current practice in many regions but was adopted so that the results represent good management in the varying environments. The impacts of important factors such as frost damage, pests, weeds and diseases are not modelled. Hence, the yields presented here may be higher than those actually achieved in these regions. Nevertheless, we find very strong correspondence between modelled yields and actual ABS yield records (eg Reyenga *et al.* 1999b) giving some confidence in the representativeness of these simulations. The implications of this for scaling up these results will be covered in a later report.

Crop varieties

All simulations are of a 'smart farmer' who is tactically adapting cultivar management within seasons to allow for seasonal climate variability. We do this by systematically modifying crop phenology (thermal time from emergence to the end of the juvenile phase and the phyllochron interval) based on the sowing date so that early sowings used slower 'varieties' than late sowings (see appendix). In addition, we impose three varietal strategies (standard, slow and quick) to investigate potential strategic cultivar adaptation options to broadscale climate change. An additional adaptation is to change the planting window to adjust this to the new climate (see below). Other adaptations such as changes in fertiliser application alteration of crop rotations and more broadly changes in industries are assessed in later reports.

Information on management practices and varieties are not available for Burenda (Queensland) as no cropping currently occurs in this area. As this site had similar frost frequencies to Dalby, it was assumed that Burenda's planting rules and crop varieties would be similar to those of Dalby.

Modifications to Planting Windows

At most of the study sites, the planting window is currently determined by two factors: the risk of frosts during and after anthesis (flowering) and drought stress during grain filling. Under the higher temperatures of the climate change scenarios the chance of frost can be significantly reduced thereby allowing farmers to plant earlier in the season.

A generally accepted frost risk is 10%; this risk can be determined by a comparison of the 9th decile last day of frost and the 1st decile anthesis date. In order to assess potential changes in the planting window under climate change, we evaluated the change in last day of frost and anthesis day under all temperature scenarios with no change in rainfall. A regression of the change in anthesis date and last day of frost were used to modify the planting window such that there would continue to be a 10% risk of frost. Thus in locations where frost persisted, planting windows were brought forward in a systematic way.

For those site where climate change *removed* the risk of frost (i.e. Emerald, Wagga Wagga Horsham, Katanning and Wongan Hills) a different method was used to evaluate window modifications. Water availability would become then next limiting factor in terms of planting window once frost was remove. To determine an appropriate window in these circumstances the start of the planting window was arbitrarily moved two months earlier for all 0^{o}C temperature change scenarios. The resulting yields were plotted against sowing day and a preliminary visual assessment was conducted. Where the earlier widow resulted in a significant reduction in yields the modification of the planting window was based on dates which appeared to maximise yields. Where there were no obvious problems, the modified planting window was based on the 9th decile sowing day so as to remove high risk years at the start of the test window.

For those sites where frost does not currently restrict planting (i.e. Minnipa and Geraldton), the current planting window is already optimised for water availability. For these sites no modification to the planting window was found to consistently improve yields. Hence, the results from these simulations are not presented.

Gross Margins

A general assessment of the gross margins under the different global change scenarios was made based on rough estimates of on-farm costs (Table 2) and the price received for the grain (Table 3). For this assessment it was assumed that there was a long fallow (no crop sown) in years when there had been a ‘forced sowing’ (ie. planting rules not satisfied). On-farm costs were not varied between regions although undoubtedly variation does occur. The only difference between regions is in the price received for grain due to difference in the State levies.

It is certain that these levels of prices and costs will vary enormously by the year 2100 due to highly uncertain changes in both global supply (from CO_2, climate, technological and land use change) and demand (population growth, consumption per head and new uses eg. biofuels) (eg Rosenzweig and Parry 1994). Few global assessments of these factors have been made, hence we have used these indicative gross margin analyses for comparative purposes only, within the framework of this study. The yield and grain quality response from this study could, however, be incorporated into global wheat market studies (e.g Rosenzweig and Parry 1994) where gross margin values will vary depend upon the scenario being investigated.

Table 2: On-farm costs used to calculate gross margins

On-farm Costs	($/ha)
Fixed costs	100
Variable costs – crop	50
Variable costs – fallow	25
Fertiliser costs (80kg @ $0.8/kg + application $10)	74

Wheat price

The price of wheat used in the gross margin analysis is based on a regression of the estimated price for each State and grain nitrogen (Table 3). This was calculated by subtracting estimates of wheat charges and levies (Table 4) from the average national pool price (1992-1998) for a range of wheat grades (e.g. Australia soft white, Australian Prime Hard) to get an estimate of price based on average nitrogen content of the grain.

Table 3: Method for estimating wheat price based on the nitrogen content of the grain.

State	Price Regression	Price if N>2.6%
Queensland	$y = -66.395x^3+435.6x^2-851.36x+656.81$	$219.19
New South Wales	$y = -66.395x^3+435.6x^2-851.36x+656.81$	$219.19
Victoria	$y = -66.395x^3+435.6x^2-851.36x+656.81$	$219.19
South Australia	$y = -66.395x^3+435.6x^2-851.36x+656.67$	$219.05
Western Australia	$y = -66.498x^3+436.17x^2-852.4x+657.31$	$219.04

Table 4: Charges and levies used to estimate wheat price

Charges	(per tonne)	Levies	
AWB and CBH	$24	National WIF	3.015%
Freight to port	$10	SA levies	$0.14
Freight to silo +CBH	$10	WA levies	$0.15

AWB - Australian Wheat Board CHB - Co-operative Bulk Handling WIF - Wheat Industry Fund

Heat Shock

Wheat plants exposed to very high air temperatures (>32°C) during grain filling produce grain with reduced bread-making qualities (Blumenthal *et al*. 1991, Stone *et al*. 1996a). The proportion of days with temperatures over 32°C during the grain filling period (between date of anthesis and maturity) was compared for the different climate change scenarios.

Presentation of Results

The responses described in the following sections are based on a comparison of the maximum yielding variety in the current climate and CO_2 scenario with the maximum yielding variety in each global change scenario. The data for these ‘optimum’ varieties are then used in the grain nitrogen and gross margin analyses.

The gross margins for Burenda are not presented in the relative response format as the gross margin are largely negative. This makes the use of % change unsuitable so we use raw values instead.

3 Geraldton – Western Australia

Background

Geraldton was chosen to represent the Central region of Western Australia. Wheat is the dominant crop in the region with smaller areas of barley and oats. In 1996 the area of cereal cropping was 884,294 ha with about 89% of this sown to wheat. Regional wheat yield were 1.62 t/ha. Over the last 21 years wheat yields for the region have averaged 1.16 t/ha.

Annual rainfall in Geraldton is about 465 mm and is winter dominant with 87 % falling in the 6 months April-September. The February mean maximum temperature is 32.6 °C and the August mean minimum monthly temperature 8.9 °C. Temperatures range from 0.5 °C to 47.7°C. Mean daily evaporation is 6.8 mm.

Soils are predominantly deep sandy soils with less than 1% organic carbon in the top 10cm.

Modified Planting Window

Frost does not restrict planting in Geraldton under current climate. No modification was made to the planting window for Geraldton as the current window has already been optimised for water availability and preliminary simulations found no modification to the planting window that provided consistent yield improvements.

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 27% increase in potential yields (Figure 3.1). Yield response increased with increased rainfall and declined with increased temperature (Figure 3.1). The maximum yield response (34%) was achieved at the +20% rainfall and 0°C temperature scenario while the lowest (-9%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 0-21% with the most likely response 8-19% (Figure 3.1).

The ‘slow’ variety had higher mean yields in most climate change scenarios (Figure 3.2).

Grain Nitrogen

The nitrogen content of the grain was reduced by about 15% with the doubling of CO_2. Grain N was further reduced with increased rainfall but increased with increased temperature (Figure 13.3). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –5 to –13% with the most likely response –9 to –12 (Figure 3.3).

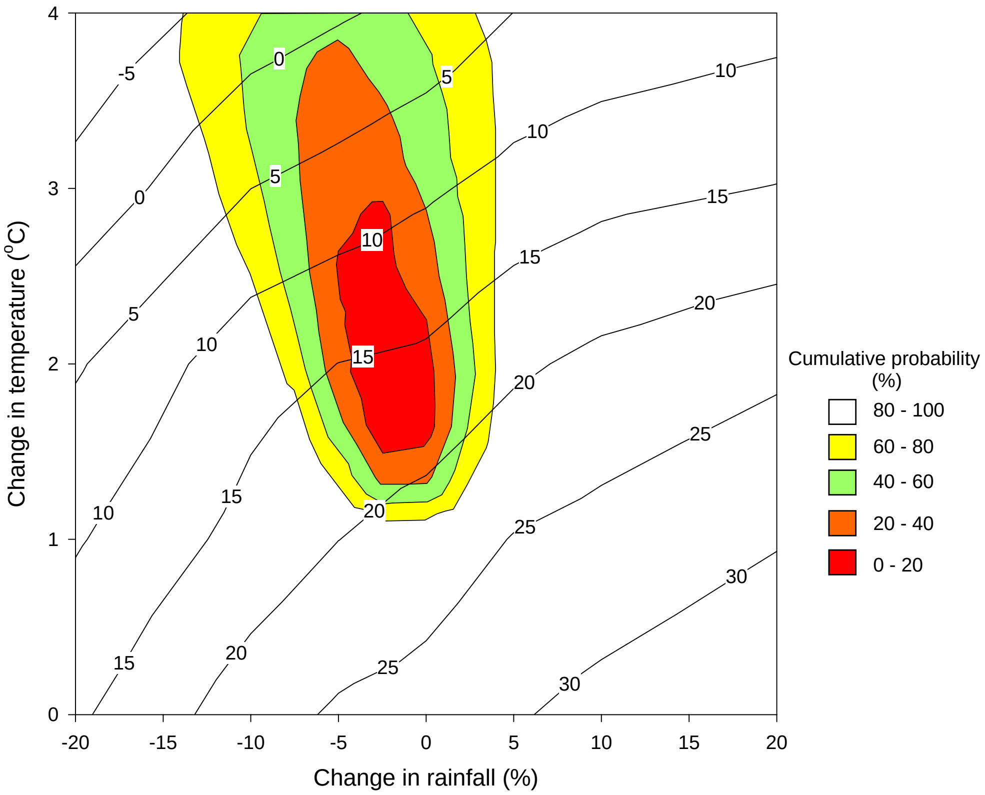


Figure 3.1: Geraldton – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios. The cumulative probability of climate change is shown in the shaded areas.

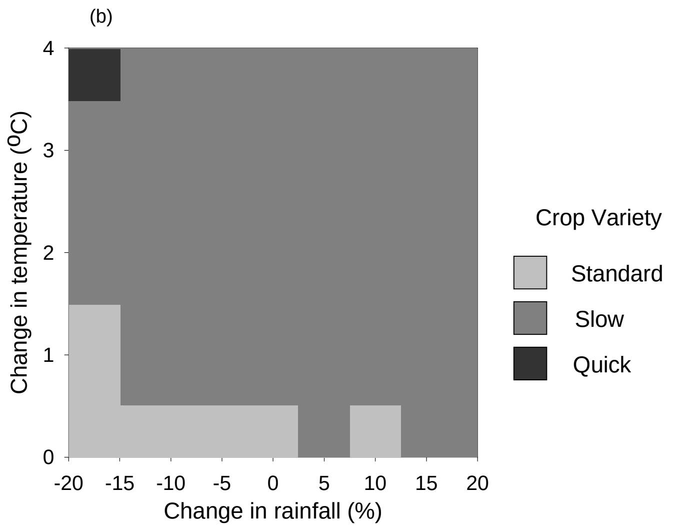


Figure 3.2: Maximum yielding crop 'variety' simulated under global change scenarios

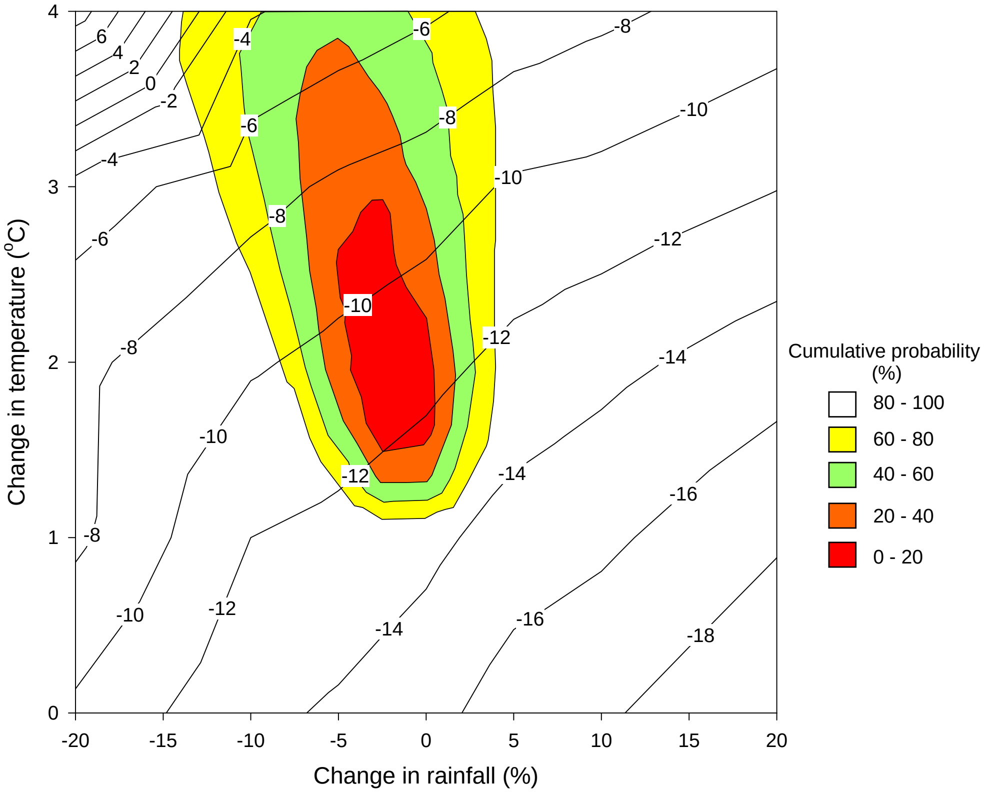


Figure 3.3: Geraldton - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios . The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be \$232/ha. Doubling of CO_2 alone resulted in a 19% increase in gross margins (Figure 3.4). Gross margins increased with increased rainfall and decline with increased temperature. The maximum change in GM (26%) achieved at the +20% rainfall and 0°C temperature scenario and the lowest (-19%) occurring with the –20% rainfall and 3°C temperature scenario (Figure 3.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about –10 to 11% with the most likely response –4 to 8% (Figure 3.4).

Heat Shock

The risk of heat shock in Geraldton is very low. The earlier anthesis and maturity with increased temperatures meant that there was little increase in heat shock under the current planting window (Table 3.2).

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 7% to 10% under the lowest rainfall scenario but was reduced to 5% under the highest (Table 3.2).

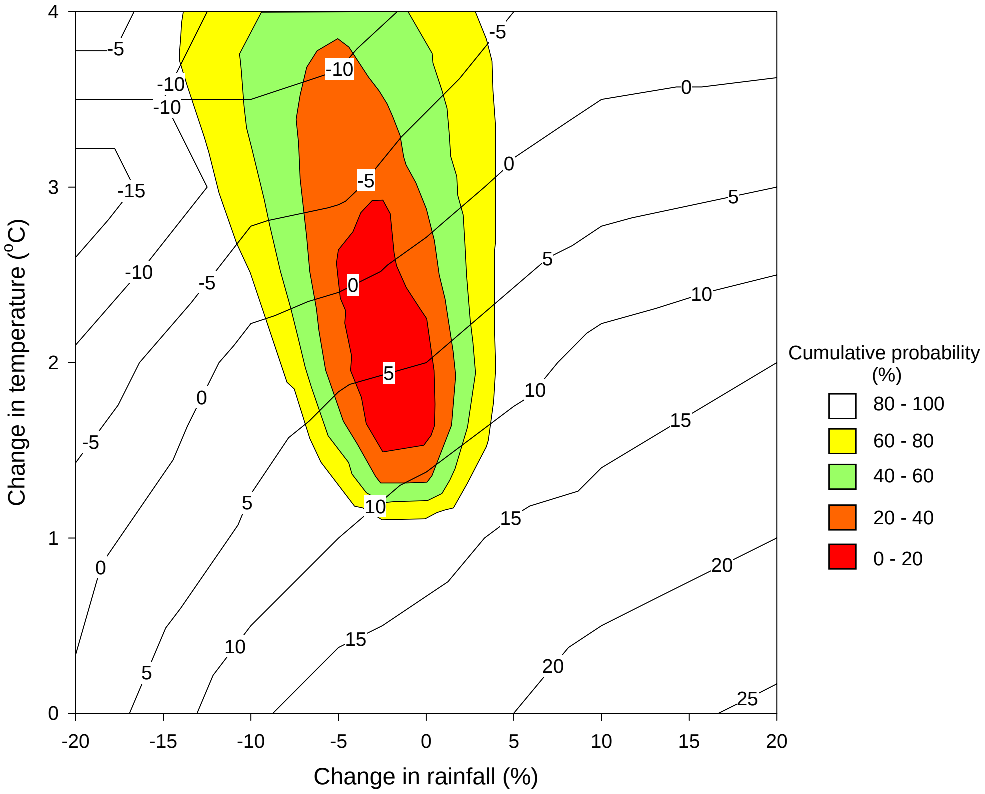


Figure 3.4: Geraldton – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios. The cumulative probability of climate change is shown in the shaded areas.

Table 3.1: Proportion of days in Geraldton with temperatures greater than 32°C during grain filling

Rainfall Scenario (%)	Temperature Change (°C) 0	1	2	3	4
-20	0.01	0.01	0.02	0.02	0.01
-10	0.01	0.02	0.02	0.02	0.02
-5	0.01	0.02	0.01	0.02	0.02
0	0.01	0.02	0.01	0.02	0.02
5	0.01	0.01	0.01	0.02	0.02
10	0.01	0.01	0.01	0.02	0.02
20	0.01	0.01	0.01	0.02	0.02

Table 3.2: Frequency of 'forced sowings'(%) at Geraldton under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window
-20	10
-10	8
-5	8
0	7
5	7
10	6
20	5

4 Wongan Hills – Western Australia

Background

Wongan Hills was chosen to represent the Midlands region of Western Australia. Wheat is the dominant crop in the region with smaller areas of barley and oats. In 1996 the area of cereal cropping was 2,264,542 ha with about 86% of this sown to wheat. Regional wheat yield were 1.69 t/ha. Over the last 21 years wheat yields for the region have averaged 1.23 t/ha.

Annual rainfall in Wogan Hills is about 390 mm and is winter dominant with 77 % falling in the 6 months April-September. The January mean maximum temperature is 34.4 °C and the August mean minimum monthly temperature 6.6 °C. Temperatures range from –0.9°C to 34.4 °C. Mean daily evaporation is 6.2 mm.

Soils in the region include deep sandy soils and yellow, earthy sands.

Modified Planting Window

The risk of frost damage was only present in Wongan Hills under the 0-1°C climate scenarios. As there is no frost risk with higher temperatures the change in planting window was based rainfall (Table 4.1). The ‘quick’ variety was excluded from the 0°C scenarios as the 10% risk of frost was exceeded.

Table 4.1: Modified planting window under different climate change scenarios for Wongan Hills

Crop ‘Variety’			Rainfall Scenario (%)	2-4°C
0°C			-20	30 Mar - 10 Jul
	Standard	20 Apr - 10 Jul	-10	27 Mar - 10 Jul
	Slow	20 Apr - 10 Jul	-5	26 Mar - 10 Jul
1°C			0	25 Mar - 10 Jul
	Standard	7 Apr - 10 Jul	5	23 Mar - 10 Jul
	Slow	30 Mar - 10 Jul	10	22 Mar - 10 Jul
	Quick	20 Apr - 10 Jul	20	20 Mar - 10 Jul

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 30% increase in potential yields (Figure 4.1). Using the current planting window, the yield response increased with increased rainfall and temperature up to the 1°C scenario (Figure 4.1). Temperature changes above 1°C had a negative effect on yields. The maximum yield response (45%) was achieved at the +20% rainfall and 1°C temperature scenario while the lowest (-10%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the

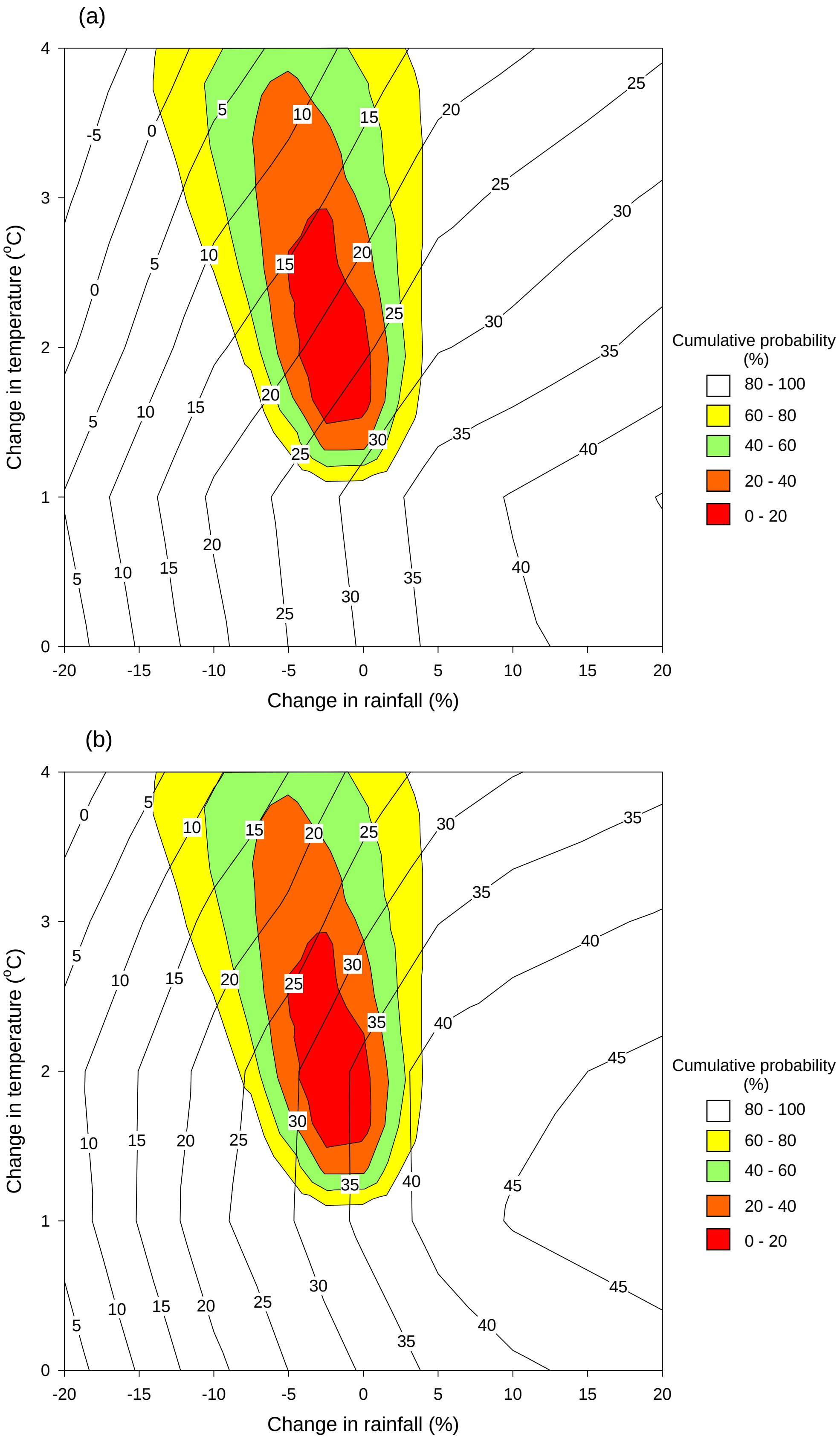


Figure 4.1: Wongan Hills – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 5 to 30% with the most likely response 15 - 27% (Figure 4.1).

Modifying the planting window resulted in higher yields under all global change scenarios with the maximum yield response (49%) achieved at the +20% rainfall and 1°C temperature scenario (Figure 4.1). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 13-39% with the most likely response about 25-36% (Figure 4.1).

Under the current planting window, the highest mean yielding 'variety' switched from the faster to slower maturing 'varieties' as temperature increased. When the planting window was brought forward the slower maturing 'variety' began producing higher mean yields (Figure 4.2).

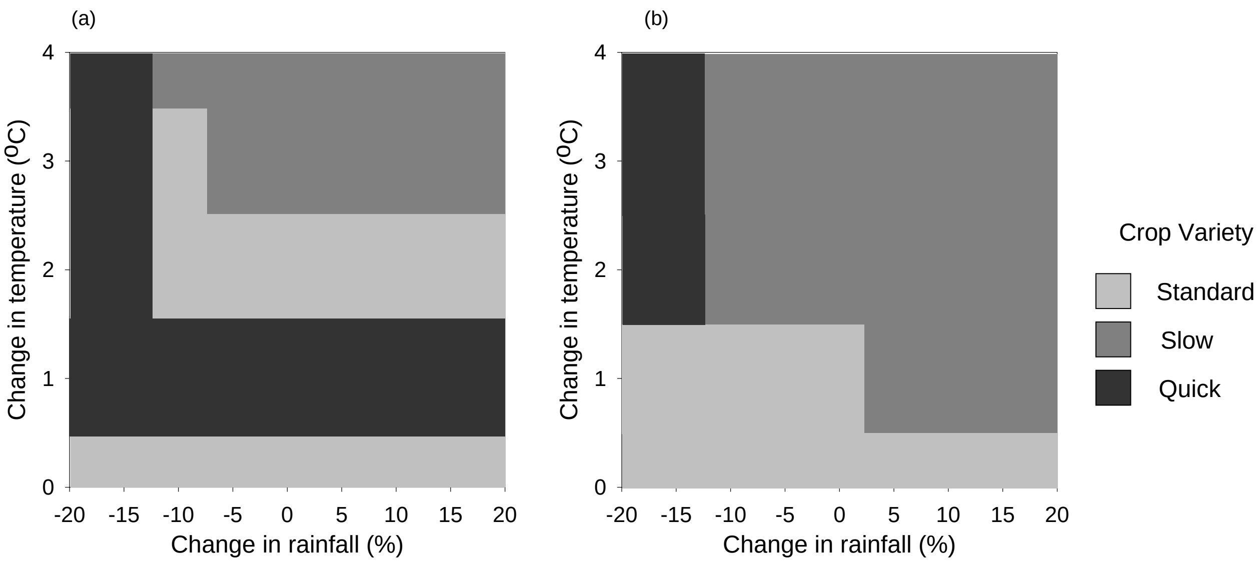


Figure 4.2: Maximum yielding crop 'variety' simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 14% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 4.3). The quality of the grain was actually increased (+9%) under the –20% rainfall and +4°C scenario but declined to –17% under the +20% rainfall and 0°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –5 to –11% with the most likely response –9 to –11% (Figure 4.3).

Modifying the planting window resulted in greater reductions in grain nitrogen than those under the current planting window (Figure 4.3). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -8 to -15% with the most likely response about –12 to –15% (Figure 4.3).

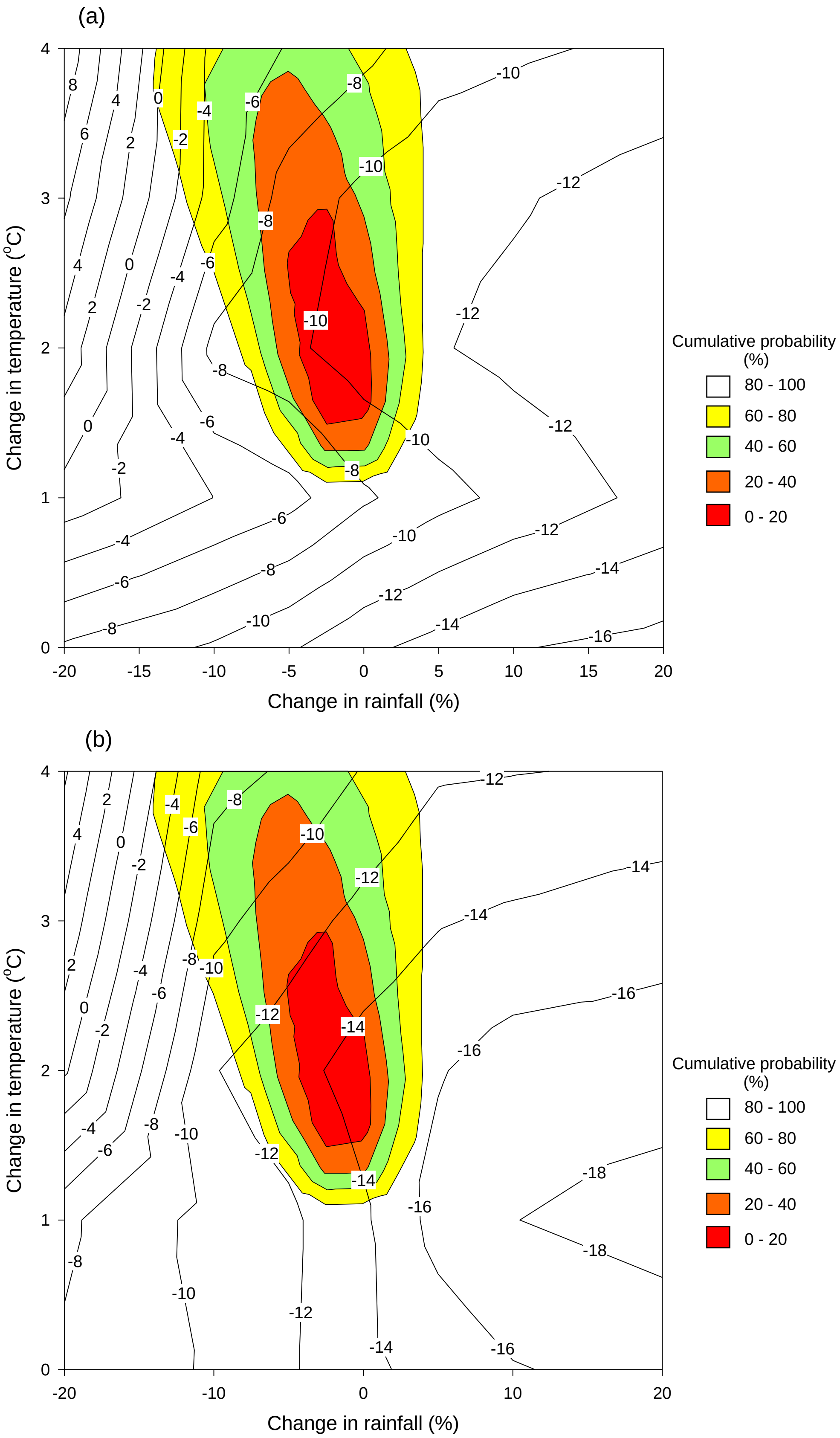


Figure 4.3: Wongan Hills - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $165/ha. Doubling of CO_2 alone resulted in a 32% increase in gross margins (Figure 4.4). Gross margins increased with increased rainfall. Temperature also had a positive effect but only up to the 1°C temperature change. The maximum change in GM (77%) achieved with the +20% rainfall and 1°C scenario and the lowest (-27%) occurring with the –20% rainfall and 0°C scenario (Figure 4.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about –5 to 40% with the most likely response 9-35% (Figure 4.4).

Modifying the planting window resulted in higher GM than those under the current planting window (Figure 4.4). The maximum response (79%) occurring in the +20% rainfall and 1°C scenario (Figure 4.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 12-59% with the most likely response about 30-51% (Figure 4.4).

Heat Shock

The risk of heat shock in Wongan Hills is very low. The earlier anthesis and maturity with increased temperatures meant that there was little change in heat shock under the current planting window (Table 4.2). Modifying the planting window enabled earlier sowings, largely removing the risk of heat shock (Table 4.3).

Table 4.2: Proportion of days in Wongan Hills with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.03	0.01	0.01	0.01	0.01
-10	0.02	0.01	0.02	0.02	0.03
-5	0.02	0.01	0.02	0.03	0.03
0	0.02	0.01	0.02	0.03	0.02
5	0.02	0.01	0.02	0.02	0.02
10	0.01	0.01	0.01	0.02	0.02
20	0.01	0.01	0.01	0.02	0.02

Table 4.3: Proportion of days in Wongan Hills with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.03	0.02	0.01	0	0
-10	0.02	0.02	0.02	0.02	0.01
-5	0.02	0.01	0.02	0.01	0.01
0	0.02	0.01	0.01	0.01	0.01
5	0.02	0.01	0.01	0.01	0.01
10	0.01	0.01	0.01	0.01	0.01
20	0.01	0.01	0.01	0	0

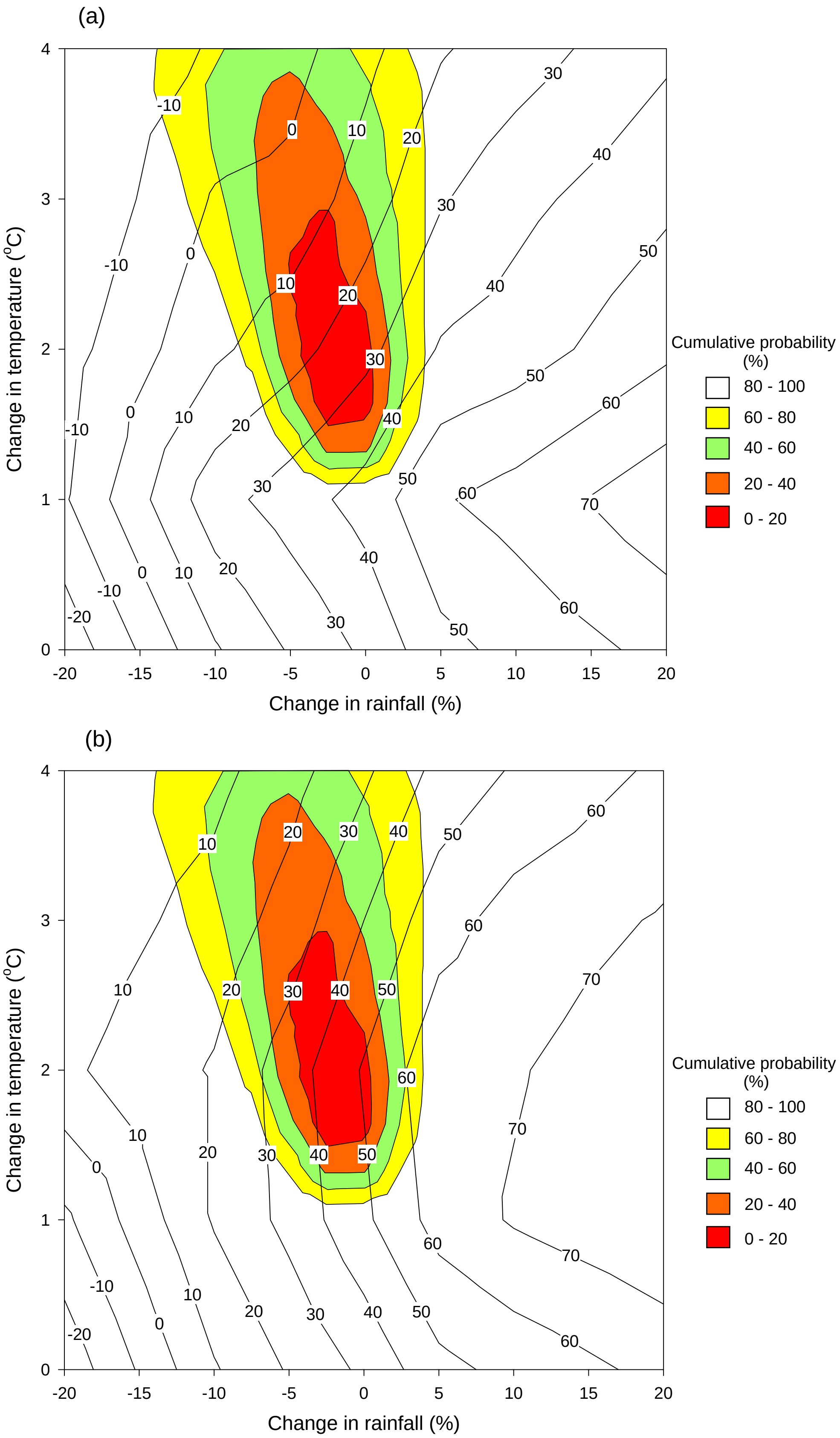


Figure 4.4: Wongan Hills – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 19% to 28% under the lowest rainfall scenario but was reduced to 11% under the highest (Table 4.4). The modified planting window reduced the number of 'forced sowings'.

Table 4.4: Frequency of 'forced sowings'(%) in Wongan Hills under different rainfall and temperature scenarios

Rainfall Scenario (%)	**Current Window**	**Modified Planting Window**				
		0°C	**1°C**	**2°C**	**3°C**	**4°C**
-20	28	28	24	21	21	21
-10	22	22	22	19	19	19
-5	21	21	21	18	18	18
0	19	19	18	14	14	14
5	16	16	10	10	10	10
10	14	14	9	9	9	9
20	11	11	7	6	6	6

5 Katanning – Western Australia

Background

Katanning was chosen to represent the Lower Great Southern region of Western Australia. The main crops in this region are wheat and barley. In 1996 the area of cereal cropping was 565,730 ha with about 42% of this sown to wheat. Regional wheat yield were 2.3 t/ha. Over the last 21 years wheat yields for the region have averaged 1.49 t/ha.

Annual rainfall in Katanning is about 482 mm and is winter dominant with 74 % falling in the 6 months April-September. The January mean maximum temperature is 30.3°C and the July mean minimum monthly temperature 5.5°C. Temperatures range from –2.0 °C to 43.7°C. Mean daily evaporation is 4.8 mm.

Soils are predominantly deep sandy soils with some brown bleached duplex.

Modified Planting Window

The risk of frost damage was only present in Katanning under current climate. As there is no frost risk with climate change the change in planting window was based rainfall (Table 5.1). The 'quick' variety was excluded from the 0°C scenarios as the 10% risk of frost was exceeded.

Table 5.1: Modified planting window under different climate change scenarios for Katanning

Rainfall Scenario (%)	0°C	1-4°C
-20	20 Apr - 10 Jul	12 Apr - 10 Jul
-10	20 Apr - 10 Jul	6 Apr - 10 Jul
-5	20 Apr - 10 Jul	3 Apr - 10 Jul
0	20 Apr - 10 Jul	31 Mar - 10 Jul
5	20 Apr - 10 Jul	28 Mar - 10 Jul
10	20 Apr - 10 Jul	25 Mar - 10 Jul
20	20 Apr - 10 Jul	19 Mar - 10 Jul

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 26% increase in potential yields (Figure 5.1). Using the current planting window, the yield response increased with increased rainfall and temperature up to the 1°C scenario (Figure 5.1). Temperature changes above 1°C had a negative effect on yields. The maximum yield response (63%) was achieved at the +20% rainfall and 1°C temperature scenario while the lowest (3.5%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the

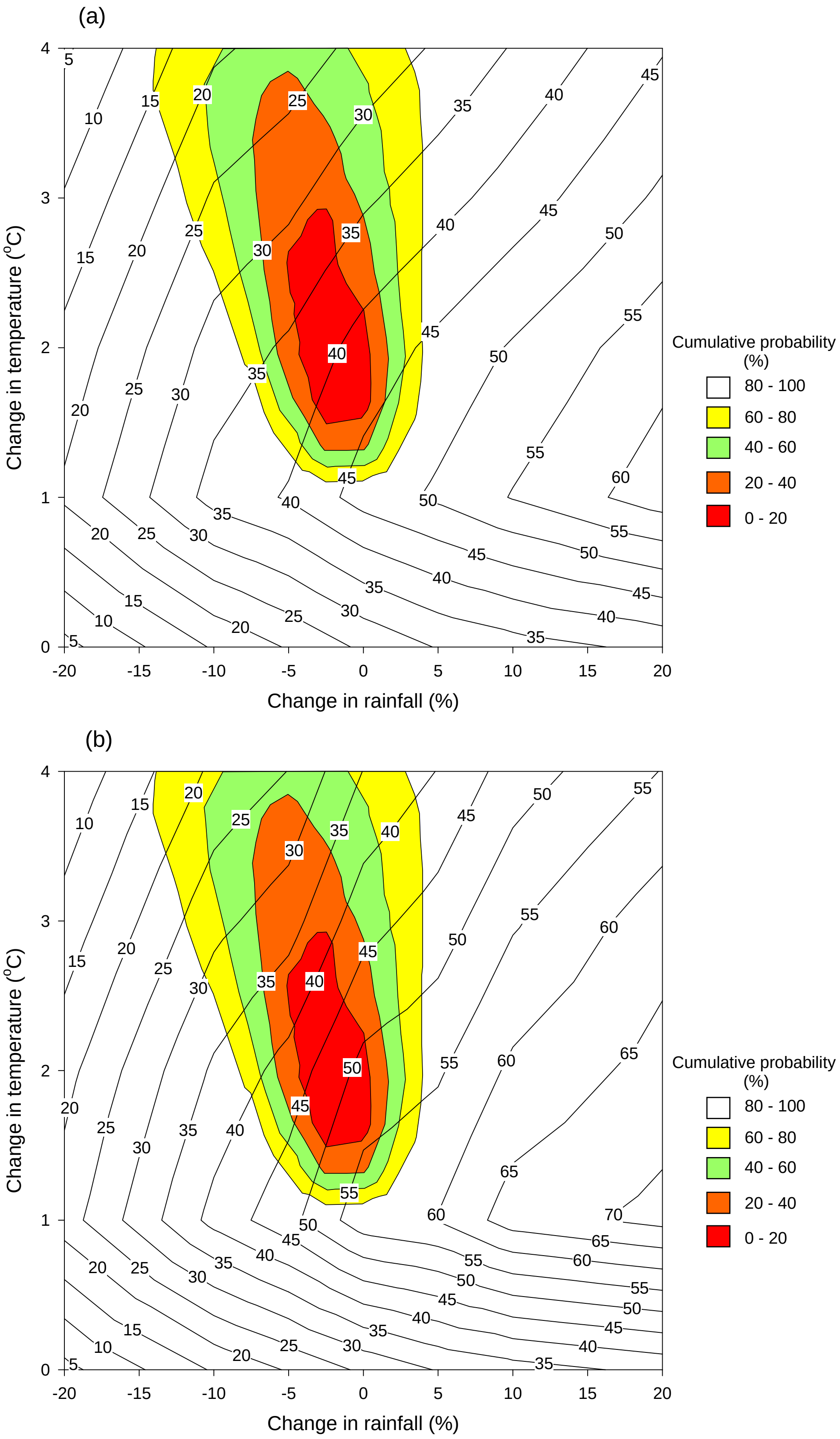


Figure 5.1: Katanning – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 22-46% with the most likely response 31-44% (Figure 5.1).

Modifying the planting window resulted in higher yields under all global change scenarios with the maximum yield response (71%) achieved at the +20% rainfall and 1°C temperature scenario (Figure 5.1). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 25-56% with the most likely response about 36-54% (Figure 5.1).

Under the current planting window, the quick ‘variety’ had higher mean yields in most climate change scenarios. When the planting window was brought forward the ‘optimum’ variety switched from the faster to slower maturing ‘varieties’ as temperature increased (Figure 5.2)..

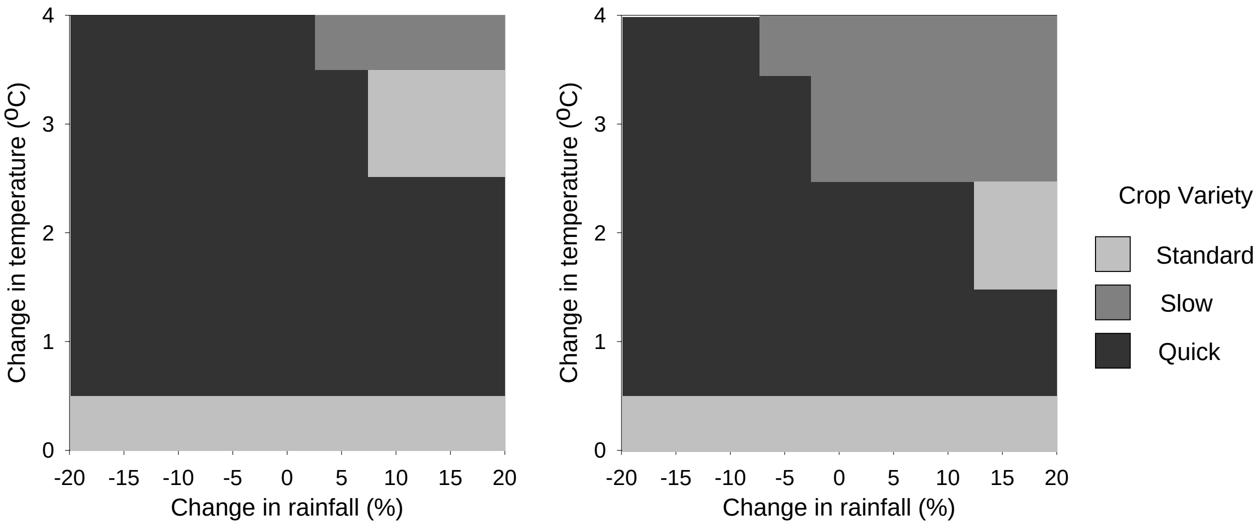


Figure 5.2: Maximum yielding crop ‘variety’ simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 14% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 5.3). The quality of the grain was actually increased (+8%) under the –20% rainfall and +4°C scenario but declined to –19% under the +20% rainfall and 1°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about 3 to –12% with the most likely response –3 to –11% (Figure 5.3).

Modifying the planting window resulted in greater reductions in grain nitrogen than those under the current planting window (Figure 5.3). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of 0 to -16% with the most likely response about –6 to –13% (Figure 5.3).

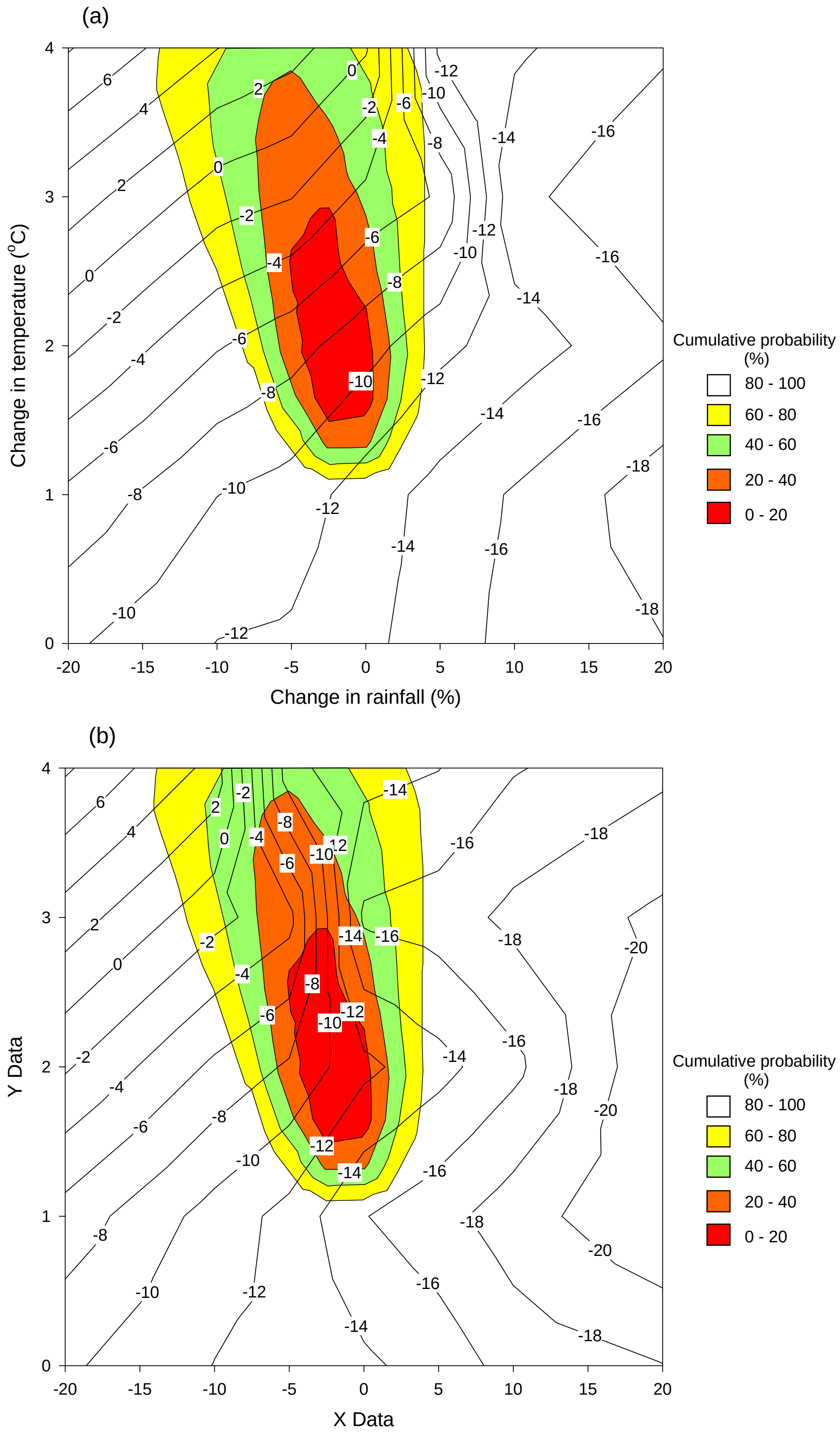


Figure 5.3: Katanning - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $145/ha. Doubling of CO_2 alone resulted in a 23% increase in gross margins (Figure 5.4). Gross margins increased with increased rainfall. Temperature also had a positive effect but only up to the 1°C temperature change. The maximum change in GM (107%) achieved with the +20% rainfall and 1°C scenario and the lowest (-44%) occurring with the –20% rainfall and 0°C scenario (Figure 5.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about –30 to 69% with the most likely response 39-62% (Figure 5.4).

Modifying the planting window resulted in high GM than those under the current planting window (Figure 5.4). The maximum response (128%) occurring in the +20% rainfall and 1°C scenario (Figure 5.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 35-100% with the most likely response about 63-95% (Figure 5.4).

Heat Shock

The risk of heat shock in Katanning is very low. The earlier anthesis and maturity with increased temperatures meant that there was no increase in heat shock under the current planting window (Table 5.2). Modifying the planting window enabled earlier sowings, largely removing the risk of heat shock (Table 5.3).

Table 5.2: Proportion of days in Katanning with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.01	0.01	0.01	0	0
-10	0.01	0.01	0	0	0
-5	0.01	0.01	0	0	0
0	0.01	0	0	0	0
5	0.01	0	0	0	0.01
10	0.01	0	0	0.01	0.01
20	0.01	0	0	0	0.01

Table 5.3: Proportion of days in Katanning with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.01	0.01	0	0	0
-10	0.01	0	0	0	0
-5	0.01	0	0	0	0.01
0	0.01	0	0	0	0
5	0.01	0	0	0	0
10	0.01	0	0	0	0
20	0.01	0	0	0	0

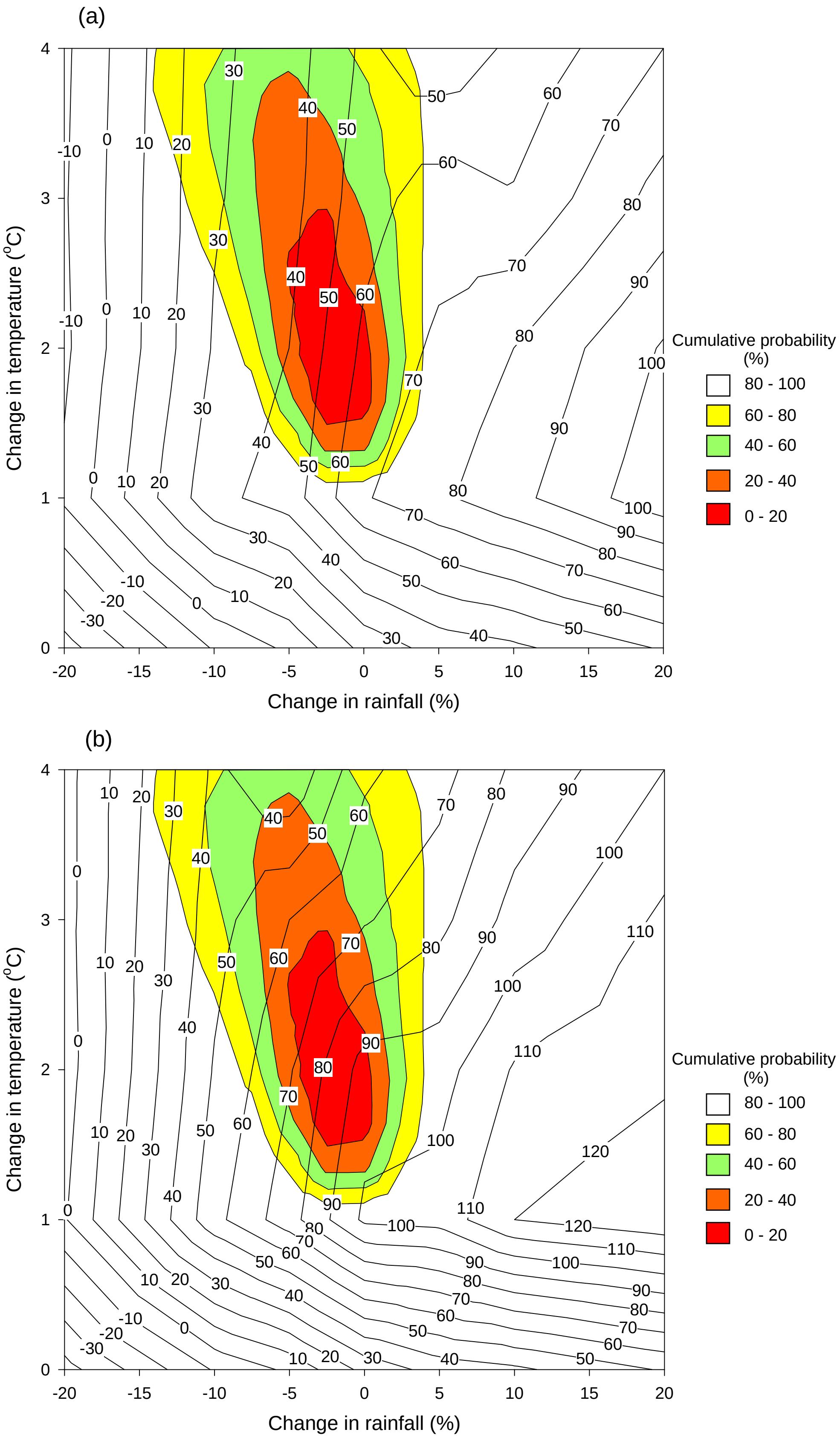


Figure 5.4: Katanning – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 20% to 38% under the lowest rainfall scenario but was reduced to 12% under the highest (Table 5.4). The modified planting window reduced the number of 'forced sowings'.

Table 5.4: Frequency of 'forced sowings'(%) in Katanning under different rainfall and temperature scenarios

Rainfall Scenario (%)	**Current Window**	**Modified Planting Window**				
		0°C	**1°C**	**2°C**	**3°C**	**4°C**
-20	38	36	36	36	36	36
-10	27	23	23	23	23	23
-5	26	19	19	19	19	19
0	20	13	13	13	13	13
5	18	13	13	13	13	13
10	17	11	11	11	11	11
20	12	8	8	8	8	8

6 Minnipa – South Australia

Background

Minnipa was chosen to represent the Eyre Peninsular region of South Australia. Wheat is the dominant crop in this region with smaller areas of barely and oats. In 1996 the area of cereal cropping was 1,056,885 ha with about 67 % of this sown to wheat. Regional wheat yield were 1.36 t/ha. Over the last 18 years wheat yields for the region have averaged 1.14 t/ha.

Annual rainfall in Minnipa is about 327 mm and is winter dominant with 68 % falling in the 6 months May-October. The February mean maximum temperature is 31.6 °C and the July mean minimum monthly temperature 6.5°C. Temperatures range from –1.2°C to 46.4°C. Mean daily evaporation is 6.3 mm.

Soils are predominantly shallow red sandy soils or sandy yellow leached duplex soils.

Modified Planting Window

Frost does not restrict planting in Minnipa under current climate. No modification was made to the planting window for Minnipa as the current window has already been optimised for water availability and preliminary simulations found no modification to the planting window that provided consistent yield improvements.

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 24% increase in potential yields (Figure 6.1). Yield response increased with increased rainfall and declined with increased temperature (Figure 6.1). The maximum yield response (37%) was achieved at the +20% rainfall and 0°C temperature scenario while the lowest (-18%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about –5 to 19% with the most likely response 7-18% (Figure 6.1).

The ‘quick’ variety had higher mean yields in all climate change scenarios (Figure 6.2).

Grain Nitrogen

The nitrogen content of the grain was reduced by about 13% with the doubling of CO_2. Grain N was further reduced with increased rainfall but improved with increased temperature (Figure 6.3). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about 3 to –9% with the most likely response –2 to –8 (Figure 6.3).

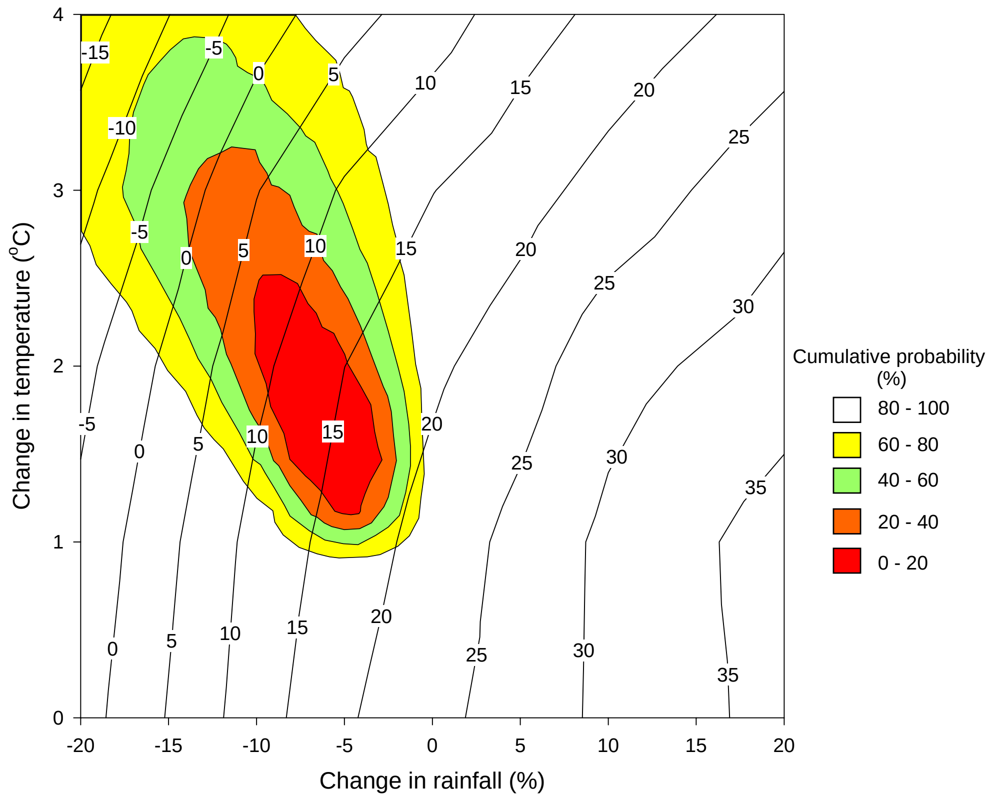


Figure 6.1: Minnipa – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios. The cumulative probability of climate change is shown in the shaded areas.

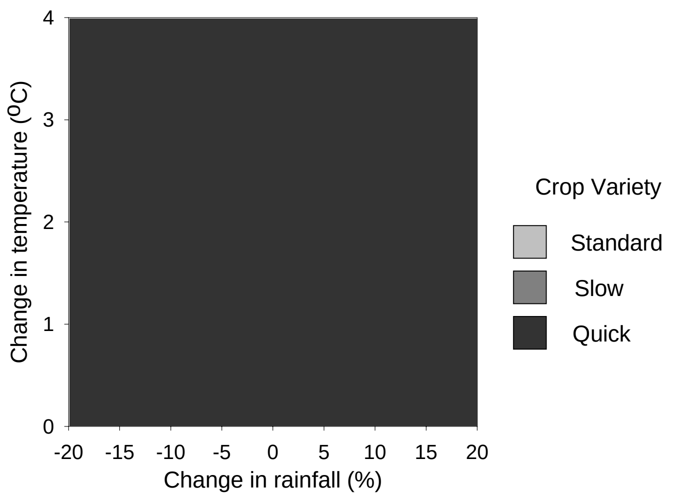


Figure 6.2: Maximum yielding crop 'variety' simulated under global change scenarios

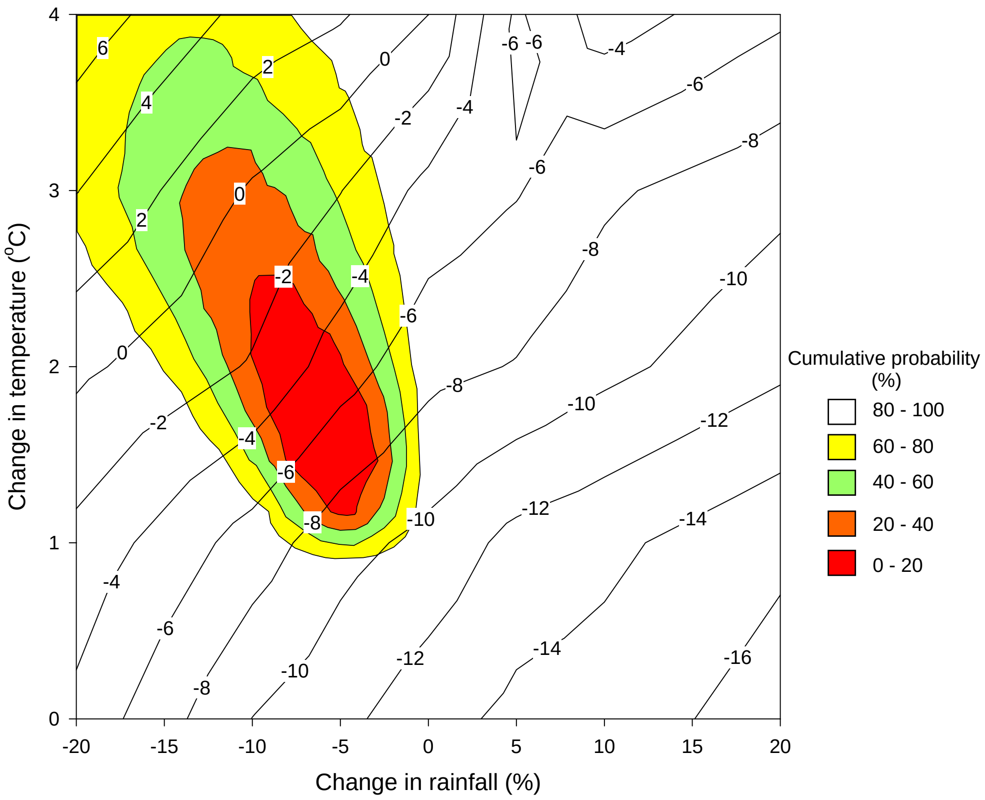


Figure 6.3: Minnipa - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios . The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $143/ha. Doubling of CO_2 alone resulted in a 33% increase in gross margins (Figure 6.4). Gross margins increased with increased rainfall, with the maximum change in GM (82%) achieved with a 20% increase in rainfall and the lowest (-38%) occurring with the –20% rainfall scenario (Figure 6.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about –15 to 30% with the most likely response 5-28% (Figure 6.4).

Heat Shock

The risk of heat shock in Minnipa is very low. The earlier anthesis and maturity with increased temperatures meant that there was little increase in heat shock under the current planting window (Table 6.1).

Forced Sowings

The frequency of years where the planting rules were not satisfied and ‘forced sowings’ occurred increased from 16% to 34% under the lowest rainfall scenario but was reduced to 10% under the highest (Table 6.2).

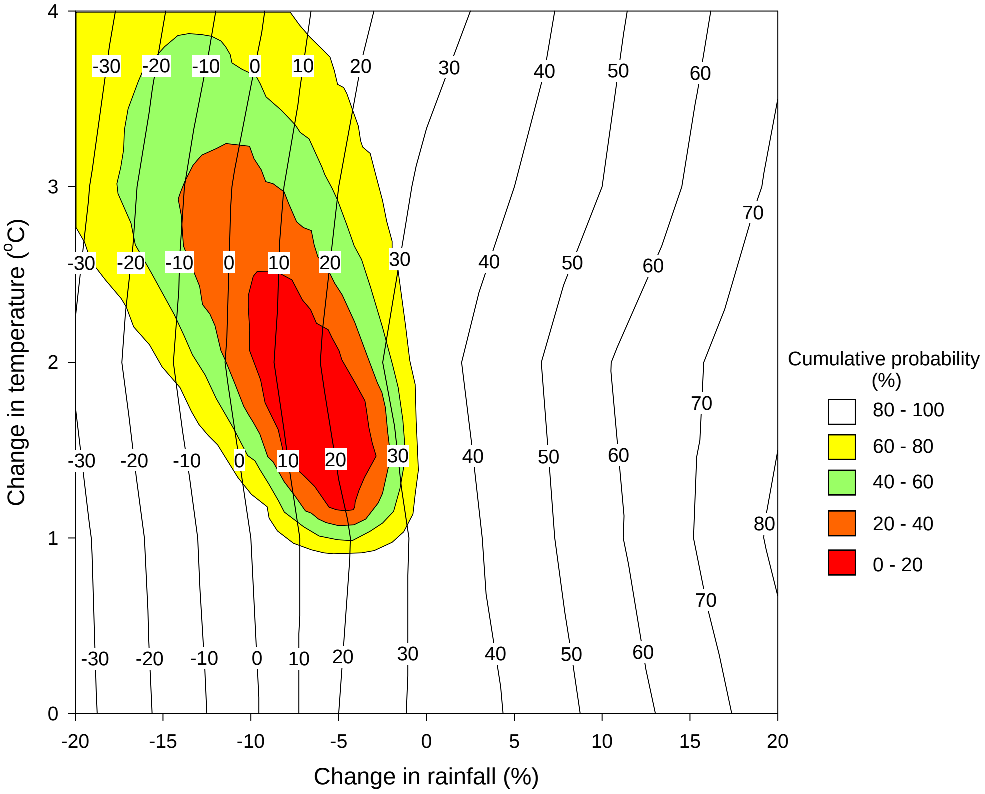


Figure 6.4: Minnipa – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios. The cumulative probability of climate change is shown in the shaded areas.

Table 6.1: Proportion of days in Minnipa with temperatures greater than 32°C during grain filling

Rainfall Scenario (%)	**Temperature Change** (°C) 0	1	2	3	4
-20	0.02	0.02	0.02	0.02	0.03
-10	0.01	0.01	0.02	0.01	0.03
-5	0.01	0.01	0.02	0.01	0.01
0	0.01	0.01	0.02	0.01	0.01
5	0.01	0.01	0.01	0.01	0.02
10	0.01	0.01	0.01	0.01	0.01
20	0.01	0.01	0.01	0.01	0.01

Table 6.2: Frequency of 'forced sowings'(%) at Minnipa under different rainfall and temperature scenarios

Rainfall Scenario (%)	**Current Window**
-20	34
-10	24
-5	19
0	16
5	15
10	14
20	10

7 Horsham – Victoria

Background

Horsham was chosen to represent the Wimmera region of Victoria. The main crops in this region are wheat and barley. In 1996 the area of cereal cropping was 599,926 ha with about 50% of this sown to wheat. Regional wheat yields were 2.62 t/ha. Over the last 23 years wheat yields for the region have averaged 2.03 t/ha.

Annual rainfall in Horsham is about 452 mm and is winter dominant with 60% falling in the 6 months April-September. The January mean maximum temperature is 29.7°C and the July mean minimum temperature is 3.7°C. Temperatures range from –5.6°C to 45.7°C. Mean daily evaporation is 4.9 mm.

Soils are predominantly grey, self mulching clays or red clays which can have sealing and hard setting problems.

Modified Planting Window

The risk of frost damage was present in Horsham in the 0-3°C climate change scenarios, However, the warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 7.1) with water availability restricting sowing in the 3-4°C scenarios. The 'quick' variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 7.1: Modified planting window for 'standard' and 'slow' varieties under different temperature scenarios for Wagga Wagga.

Temperature Change (°C)	Standard	Slow
0	1 May - 31 Jul	1 May - 31 Jul
1	4 Apr - 31 Jul	27 Mar - 31 Jul
2	11 Mar - 31 Jul	4 Mar - 31 Jul
3	4 Mar - 31 Jul	4 Mar - 31 Jul
4	4 Mar - 31 Jul	4 Mar - 31 Jul

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in an 18% increase in potential yields (Figure 7.1). Using the current planting window, the yield response increased with increased rainfall and temperature up to the 2°C scenario (Figure 7.1). Temperatures changes greater than 2°C had a negative effect on yields. The maximum yield response (30%) was achieved at the +20% rainfall and 2°C temperature scenario while the lowest (-19.5%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 2-22% with the most likely response 12-21% (Figure 7.1).

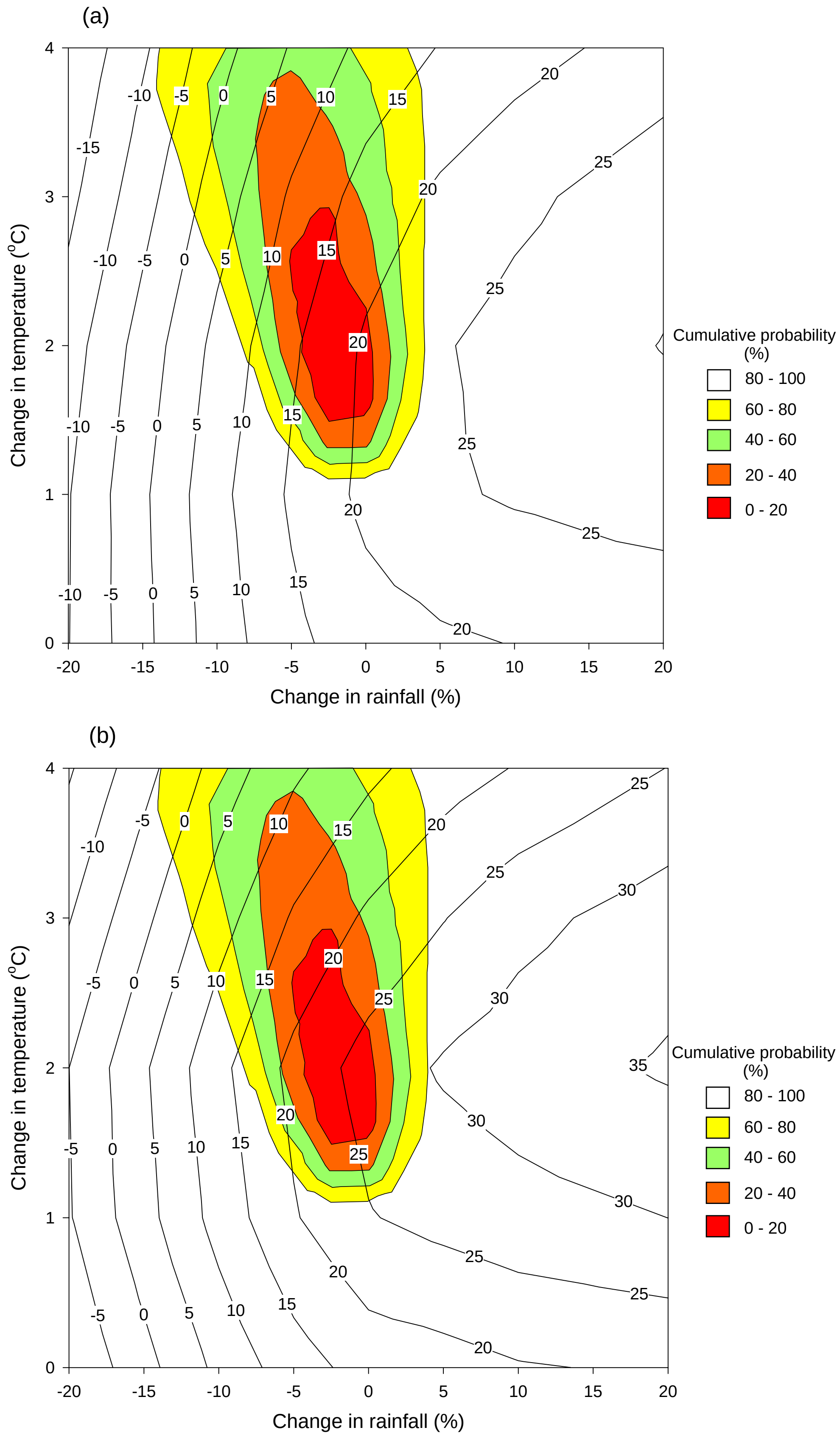


Figure 7.1: Horsham – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Modifying the planting window resulted in higher yields under all global change scenarios with the maximum yield response (36%) achieved at the +20% rainfall and 2°C temperature scenario (Figure 7.1). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 5-28% with the most likely response about 17-26% (Figure 7.1).

Under the current planting window, the highest mean yielding ‘variety’ switched from the ‘standard’ to ‘slow’ with a 2°C increase in temperature. When the planting window was brought forward the slower maturing ‘variety’ began producing higher mean yields with only a 1°C increase (Figure 7.2).

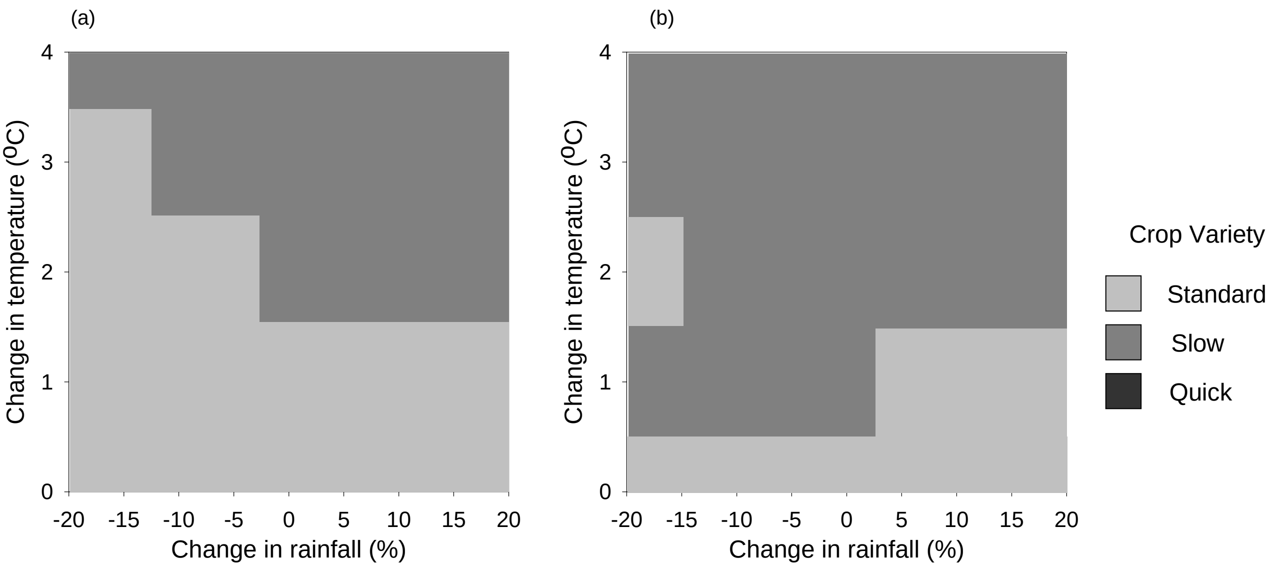


Figure 7.2: Maximum yielding crop ‘variety’ simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 14% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 7.3). The quality of the grain was actually increased (+6%) under the –20% rainfall and +4°C scenario but declined to –19% under the +20% rainfall and 0°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about 0 to –11% with the most likely response –4 to –10% (Figure 7.3).

Modifying the planting window resulted in greater reductions in grain nitrogen than those under the current planting window (Figure 7.3). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -4 to -15% with the most likely response about –8 to –14% (Figure 7.3).

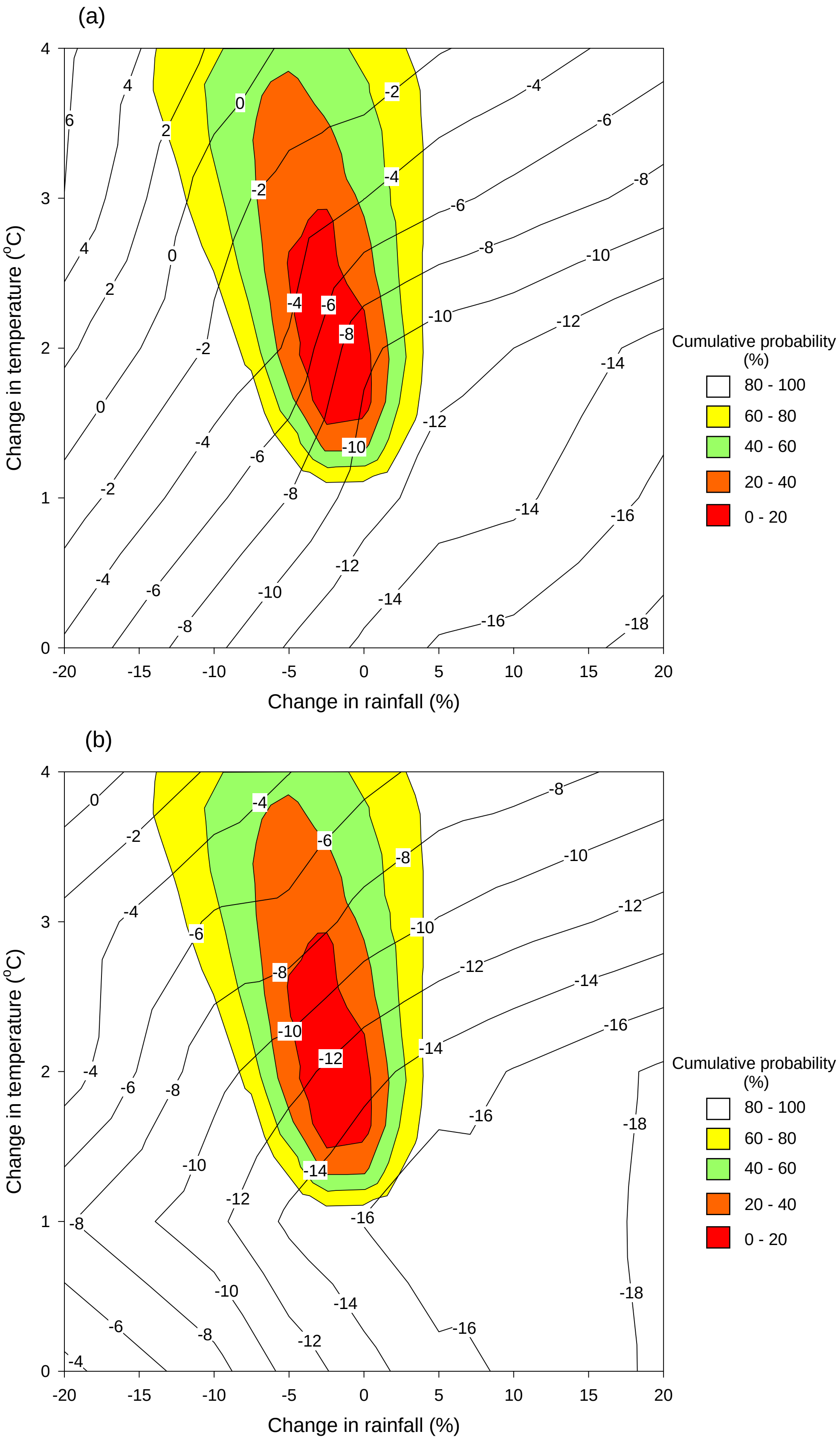


Figure 7.3: Horsham - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be \$529/ha. Doubling of CO_2 alone resulted in an 8% reduction in gross margins (Figure 7.4). Gross margins increased with increased rainfall. Temperature also had a positive effect but only with higher rainfall and only up to a 3°C temperature change. The maximum change in GM (31%) achieved with the +20% rainfall and 3°C scenario and the lowest (-32%) occurring with the –20% rainfall and 0°C scenario (Figure 7.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about 0 to 21% with the most likely response 12-18% (Figure 7.4).

Modifying the planting window resulted in high GM than those under the current planting window (Figure 7.4). Temperature increases up to 2°C had a positive effect on gross margins. The maximum response (36%) occurring in the +20% rainfall and 2°C scenario (Figure 7.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 15-32% with the most likely response about 24-31% (Figure 7.4).

Heat Shock

The risk of heat shock in Horsham is very low. The earlier anthesis and maturity with increased temperatures meant that there was no increase in heat shock under the current planting window (Table 7.2). Modifying the planting window enabled earlier sowings, further reducing the risk of heat shock (Table 7.3). Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock will not increase and may in fact decline if the planting window is modified (Table 7.2 and Table 7.3).

Table 7.2: Proportion of days in Horsham with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.02	0.02	0.02	0.02	0.02
-10	0.02	0.02	0.02	0.02	0.02
-5	0.02	0.02	0.02	0.02	0.02
0	0.02	0.02	0.02	0.02	0.02
5	0.02	0.02	0.02	0.02	0.02
10	0.02	0.02	0.02	0.02	0.02
20	0.02	0.02	0.02	0.02	0.02

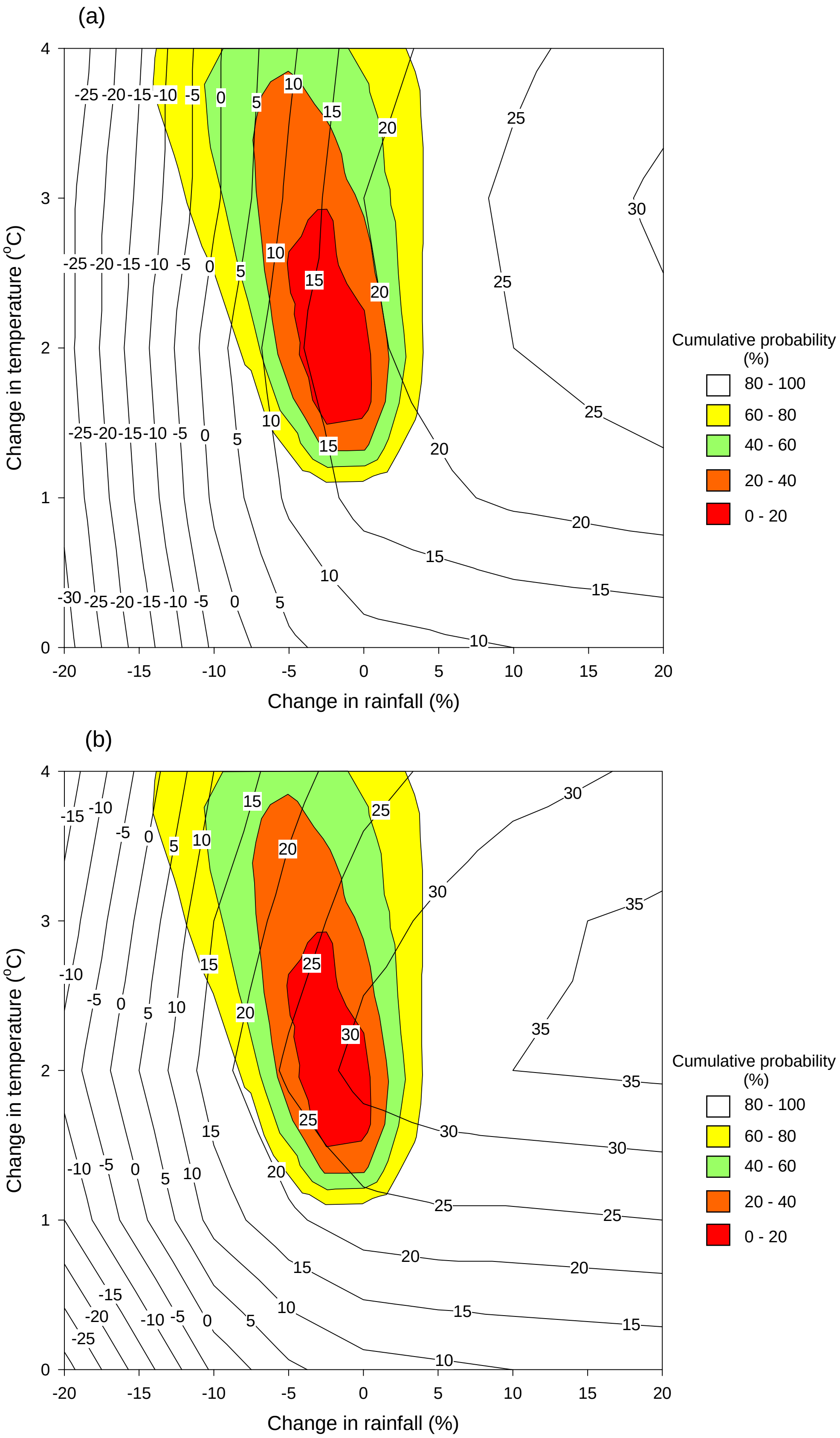


Figure 7.4: Horsham – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Table 7.3: Proportion of days in Horsham with temperatures greater than 32°C during grain filling with modified planting window

Rainfall Scenario (%)	Temperature Change (°C) 0	1	2	3	4
-20	0.02	0.02	0	0.01	0
-10	0.02	0.02	0.01	0	0
-5	0.02	0.01	0	0	0
0	0.02	0.01	0	0	0
5	0.02	0.01	0	0	0
10	0.02	0.01	0	0	0
20	0.02	0.01	0	0	0

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 10% to 25% under the lowest rainfall scenario but was reduced to 7% under the highest (Table 7.4). The modified planting window reduced the number of 'forced sowings'.

Table 7.4: Frequency of 'forced sowings'(%) in Horsham under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window 0°C	1°C	2°C	3°C	4°C
-20	20	20	8	7	7	7
-10	12	12	5	4	4	4
-5	11	11	5	4	4	4
0	10	10	5	4	4	4
5	10	10	7	4	4	4
10	9	9	7	4	4	4
20	7	7	7	4	4	4

8 Wagga Wagga – New South Wales

Background

Wagga Wagga was chosen to represent the Murrumbidgee region of New South Wales. This region is a winter cropping area with wheat, barley and oats the main crops. In 1996 the area of cereal cropping was 654,937 ha with about 51% of this sown to wheat. Regional wheat yields were 2.7 t/ha. Over the last 17 years wheat yields for the region have averaged 1.99 t/ha.

Annual rainfall in Wagga Wagga is about 585 mm and occurs uniformly throughout the year. The January mean maximum temperature is 31.2°C and the July mean minimum temperature is 2.7°C. Temperatures range from –6.3°C to 44.6°C. Mean daily evaporation is 5.0 mm.

Soils are predominantly deep red-brown or red earths.

Modified Planting Window

The risk of frost damage was present in Wagga Wagga in all climate change scenarios, However, the warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 8.1) with water availability restricting sowing in the 3-4°C scenarios. The 'quick' variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 8.1: Modified planting window for 'standard' and 'slow' varieties under different temperature scenarios for Wagga Wagga.

Temperature Change (°C)	Standard	Slow
0	15 Apr - 1 Aug	15 Apr - 1 Aug
1	6 Apr - 1 Aug	28 Mar - 1 Aug
2	22 Mar - 1 Aug	13 Mar - 1 Aug
3	8 Mar - 1 Aug	1 Mar - 1 Aug
4	1 Mar - 1 Aug	1 Mar - 1 Aug

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 5% increase in potential yields (Figure 8.1). Using the current planting window, the yield response increased with increased temperature but changed little with increased rainfall (Figure 8.1). The maximum yield response (19%) was achieved at the +10% rainfall and 4°C temperature scenario while the lowest (4%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 8-14% with the most likely response 8-12% (Figure 8.1).

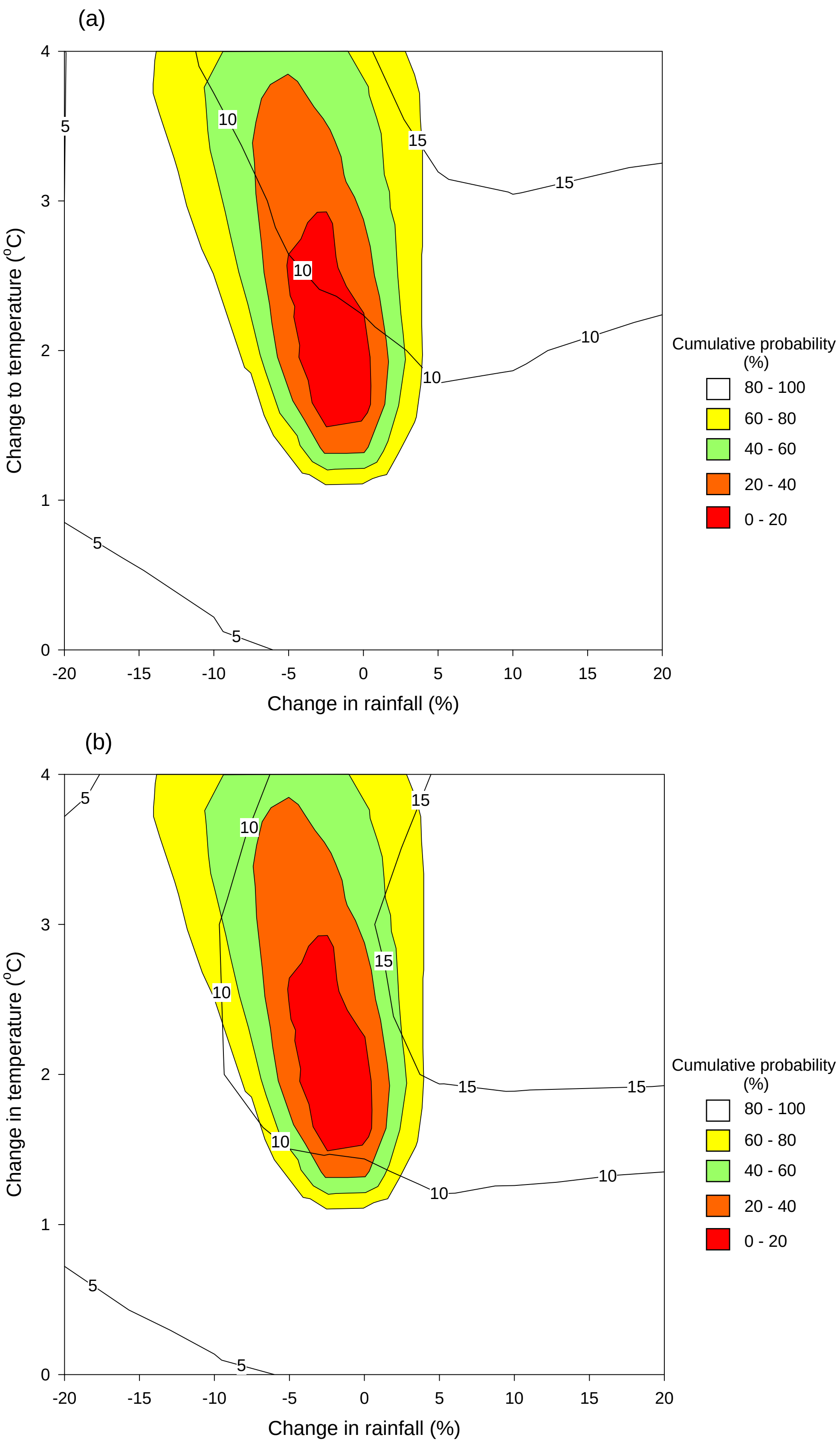


Figure 8.1: Wagga Wagga – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Using the modified planting window, yield response increased with increased temperature but changed little with increased rainfall for the 0-2°C scenarios (Table 8.1) after which rainfall had a positive effect on yields. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 9-15% with the most likely response about 10-13% (Figure 8.1).

Under both planting windows, the ‘standard’ variety had higher mean yields in most climate change scenarios (Figure 8.2).

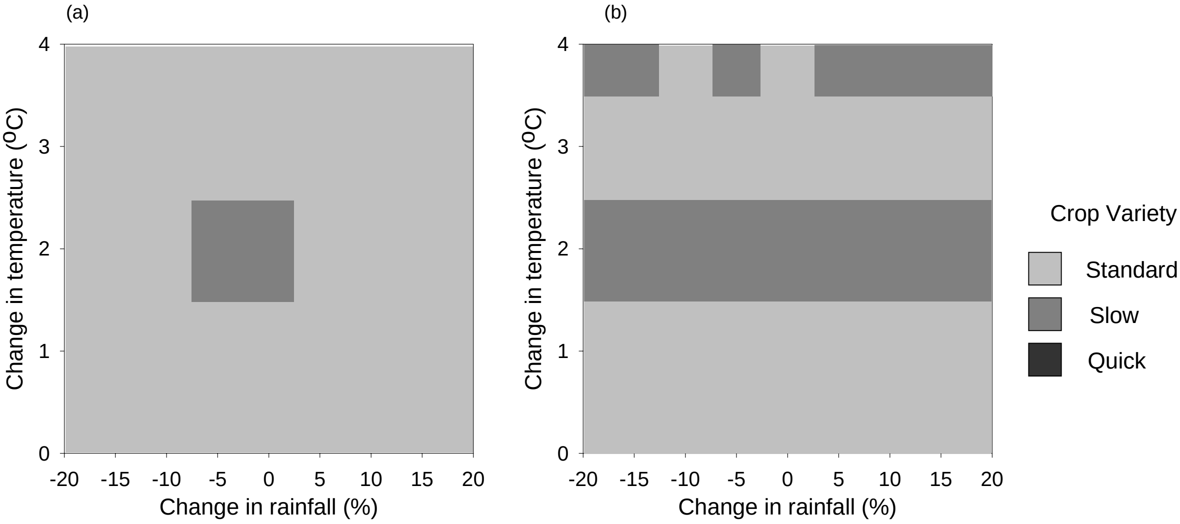


Figure 8.2: Maximum yielding crop ‘variety’ simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 10% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 8.3). The quality of the grain was actually increased (+5%) under the –20% rainfall and +4°C scenario but declined to –14% under the +20% rainfall and 1°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –1 to –10% with the most likely response –5 to –9% (Figure 8.3).

Modifying the planting window resulted in greater reductions in grain nitrogen than those under the current planting window (Figure 8.3). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -1 to -11% with the most likely response about –7 to –11% (Figure 8.3).

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $223/ha. Doubling of CO_2 alone resulted in a 6% reduction in gross margins (Figure 8.4). Gross margins increased with increased rainfall and temperature. The maximum change in

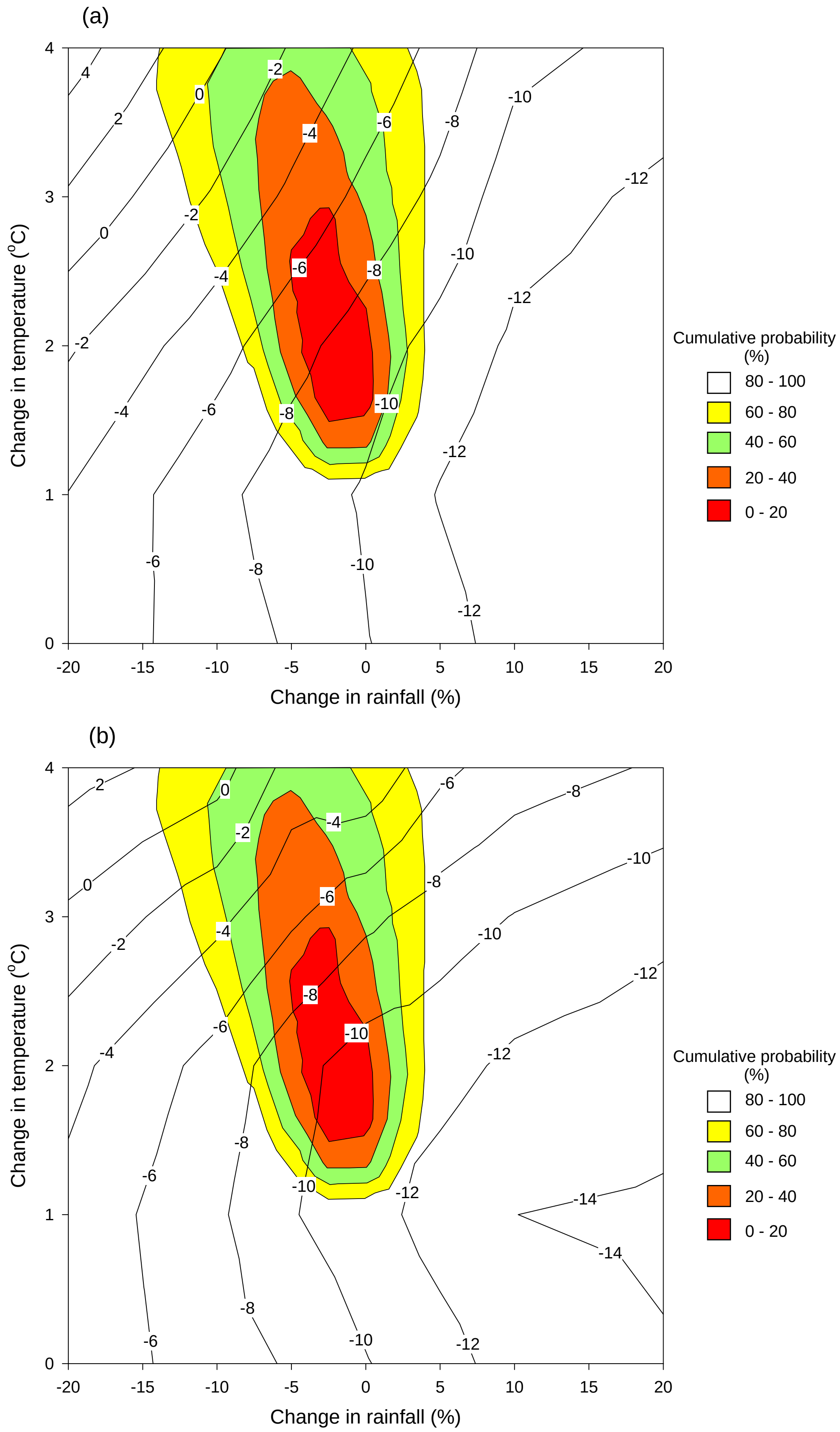


Figure 8.3: Wagga Wagga - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

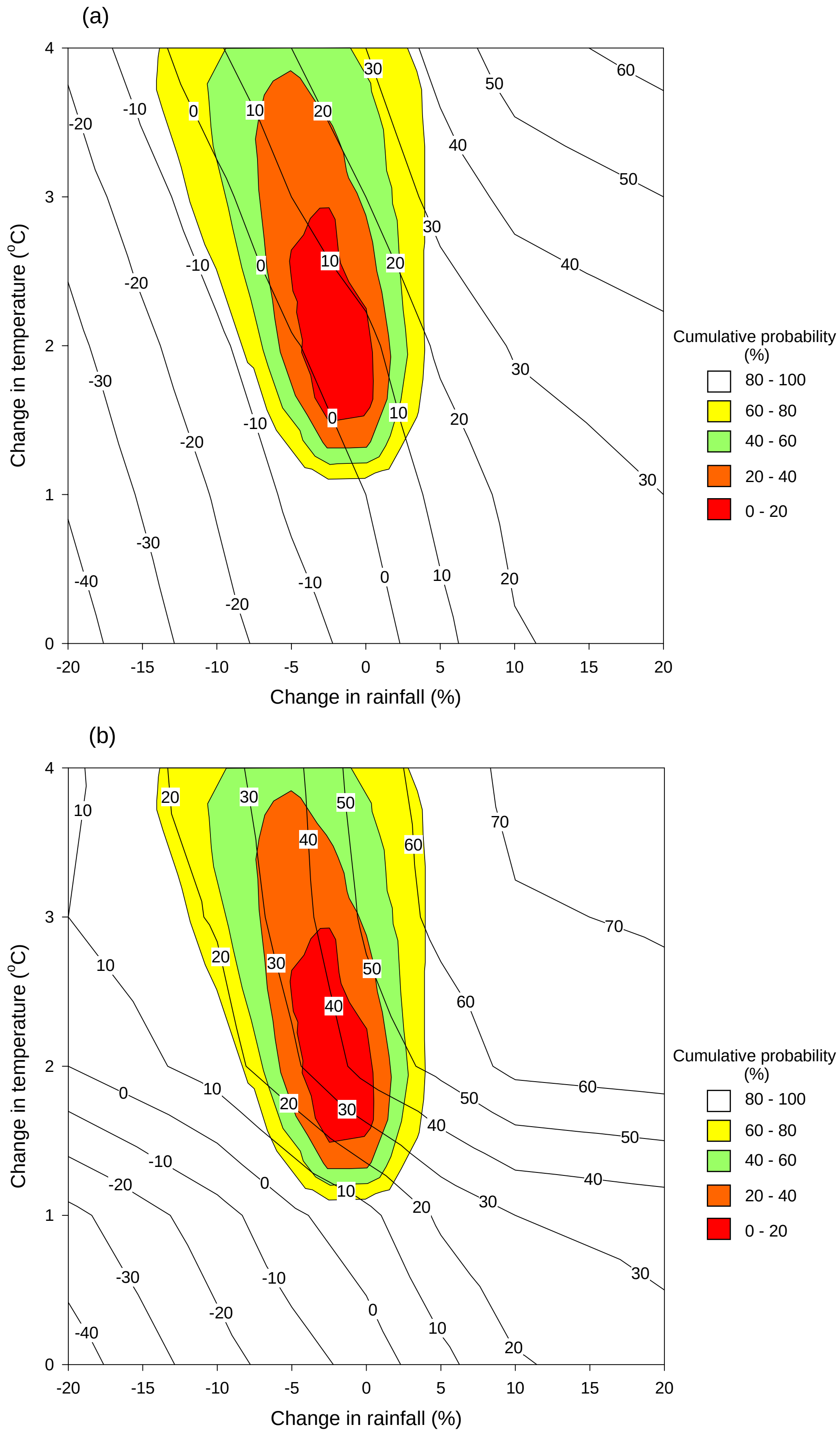


Figure 8.4: Wagga Wagga – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

GM (64%) achieved with the +20% rainfall and 4°C scenario and the lowest (-45%) occurring with the –20% rainfall and 0°C scenario (Figure 8.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about –5 to 25% with the most likely response 0-14% (Figure 8.4).

Modifying the planting window resulted in high GM than those under the current planting window (Figure 8.4). The maximum response (75%) occurring in the +20% rainfall and 4°C scenario (Figure 8.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 12-53% with the most likely response about 20-45% (Figure 8.4).

Heat Shock

The risk of heat shock in Wagga Wagga is very low. The earlier anthesis and maturity with increased temperatures actually results in a reduction in the risk of heat shock under the current planting window (Table 8.2). Modifying the planting window enabled earlier sowings, further reducing the risk of heat shock (Table 8.3). Increased rainfall also enabled earlier sowing, thus avoiding hot days later in the year. Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock will not increase and may in fact decline if the planting window is modifed (Table 8.2 and Table 8.3).

Table 8.2: Proportion of days in Wagga Wagga with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.04	0.05	0.04	0.04	0.03
-10	0.04	0.04	0.03	0.02	0.02
-5	0.04	0.04	0.04	0.02	0.02
0	0.04	0.03	0.04	0.02	0.02
5	0.04	0.03	0.03	0.02	0.02
10	0.03	0.03	0.03	0.02	0.01
20	0.03	0.03	0.03	0.01	0.01

Table 8.3: Proportion of days in Wagga Wagga with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.04	0.04	0.02	0.01	0.01
-10	0.04	0.03	0.02	0	0
-5	0.04	0.03	0.01	0	0
0	0.04	0.03	0.01	0	0
5	0.04	0.03	0.01	0	0
10	0.03	0.03	0.01	0	0
20	0.03	0.02	0.01	0	0

Forced Sowings

The frequency of years where the planting rules were not satisfied and ‘forced sowings’ occurred increased from 30% to 45% under the lowest rainfall scenario but was reduced to 25% under the highest (Table 8.4). The modified planting window reduced the number of ‘forced sowings’.

Table 8.4: Frequency of ‘forced sowings’(%) in Wagga Wagga under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window				
		0°C	**1°C**	**2°C**	**3°C**	**4°C**
-20	45	45	42	31	29	28
-10	35	35	33	25	24	23
-5	30	30	26	19	19	18
0	25	25	22	13	12	11
5	19	19	16	9	8	8
10	14	14	11	5	5	4
20	10	10	8	3	3	3

9 Dubbo – New South Wales

Background

Dubbo was chosen to represent the North Western region of New South Wales. This region is a winter cropping area with wheat the dominant crop. Smaller amounts of oats and barley are sown. In 1996 the area of cereal cropping was 962,549 ha with about 72% of this sown to wheat. Regional wheat yields were 1.55 t/ha. Over the last 17 years wheat yields for the region have averaged 1.27 t/ha.

Annual rainfall in Dubbo is about 587 mm and is uniformly distributed throughout the year. The January mean maximum temperature is 33°C and the July mean minimum temperature is 2.6°C. Temperatures range from –5.4°C to 44.2°C. Mean daily evaporation is 5.6 mm.

Soils are predominantly yellow earths with some shallow red loams.

Modified Planting Window

The risk of frost damage was present in Dubbo in all climate change scenarios. However, the warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 9.1). The ‘quick’ variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 9.1: Modified planting window for ‘standard’ and ‘slow’ varieties under different temperature scenarios for Dubbo.

Temperature Change (°C)	Standard	Slow
0	1 May - 1 Aug	1 May - 1 Aug
1	27 Apr - 1 Aug	20 Apr - 1 Aug
2	17 Apr - 1 Aug	10 Apr - 1 Aug
3	7 Apr - 1 Aug	31 Apr - 1 Aug
4	28 Mar - 1 Aug	21 Mar - 1 Aug

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in an 18% increase in potential yields (Figure 9.1). Using the current planting window, the yield response increased with increased rainfall and increased temperature up to the 3°C scenario (Figure 9.1). The maximum yield response (35%) was achieved at the +20% rainfall and 3°C temperature scenario while the lowest (-6%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 15-26% with the most likely response 20-24% (Figure 9.1).

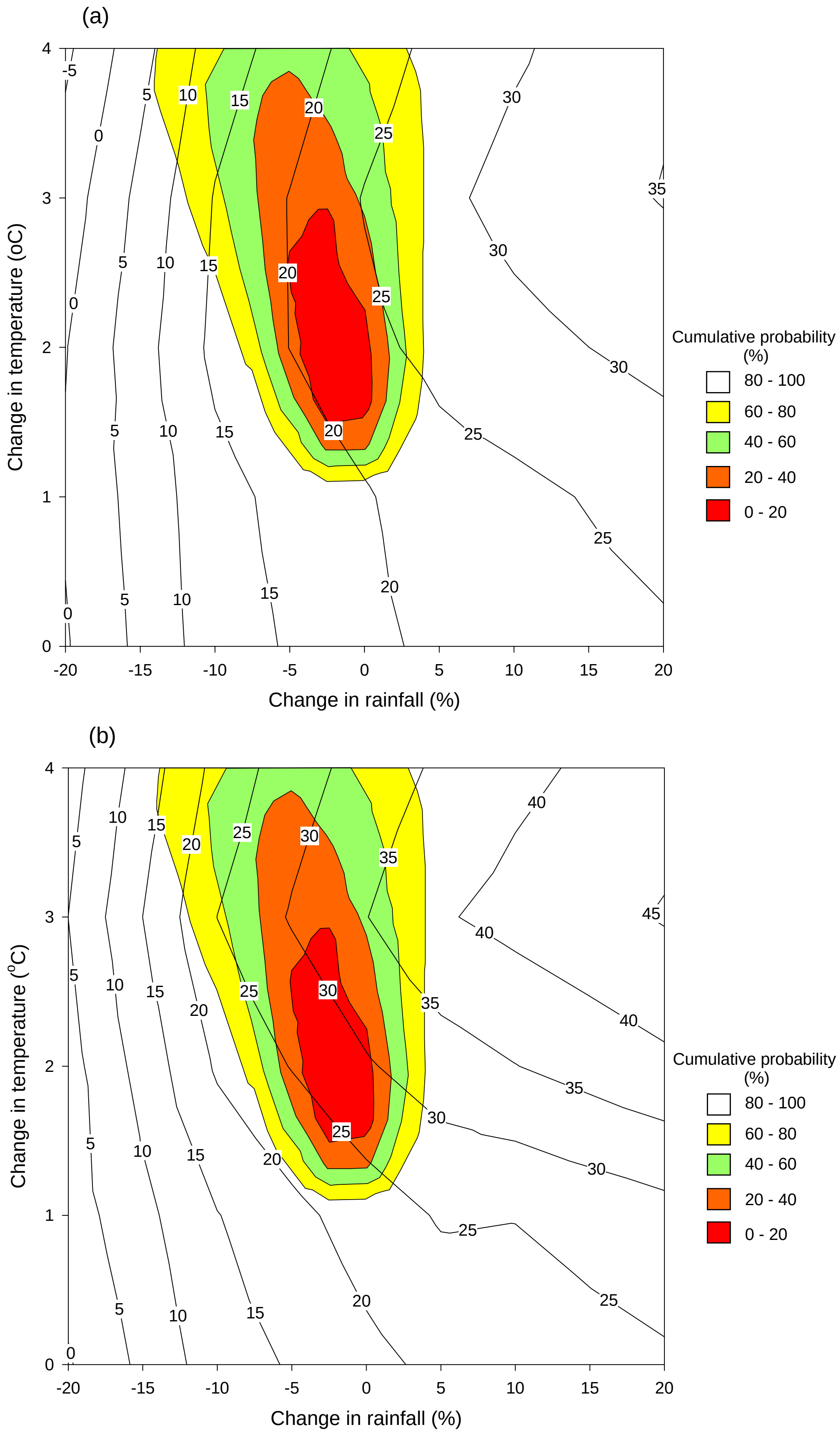


Figure 9.1: Dubbo – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Modifying the planting window resulted in higher yields under all global change scenarios with the maximum yield response (45%) achieved at the +20% rainfall and 3°C temperature scenario. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 22-36% with the most likely response about 24-32% (Figure 9.1).

Under the current planting window, the 'standard' variety had higher mean yields in most climate change scenarios. The 'standard' variety still produced higher mean yields when the planting window was brought forward (Figure 9.2).

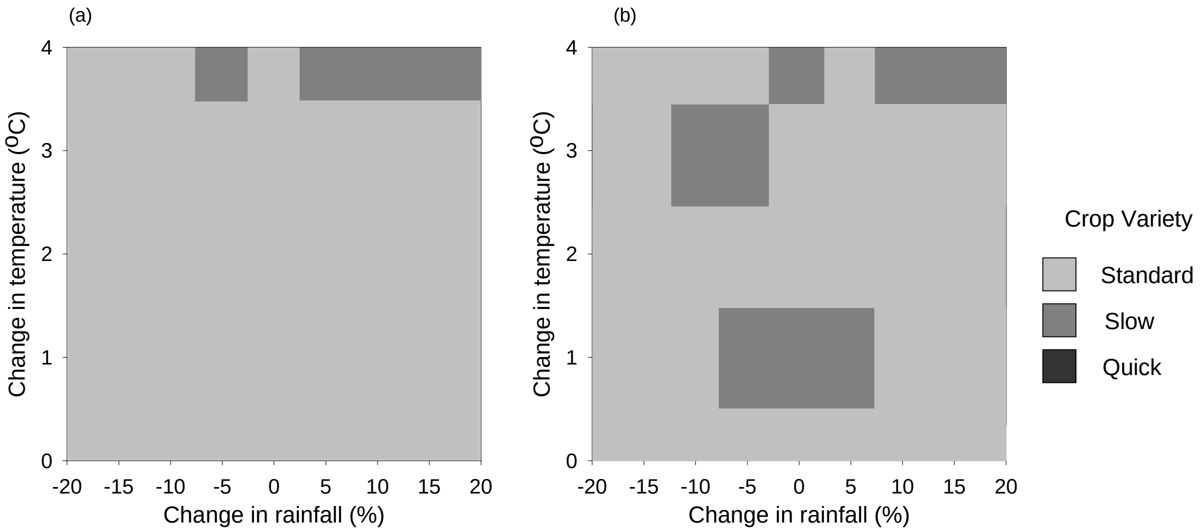


Figure 9.2: Maximum yielding crop 'variety' simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 12% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 9.3). The quality of the grain was actually increased (+4%) under the –20% rainfall and +4°C scenario but declined to –15% under the +20% rainfall and 0°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –4 to –11% with the most likely response –8 to –11% (Figure 9.3).

The positive effect of increased temperature under the current window was reduced with the modified planting window (Figure 9.3), resulting in greater reductions in grain nitrogen than those under the current planting window. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of –9 to -14% with the most likely response about –13% (Figure 9.3).

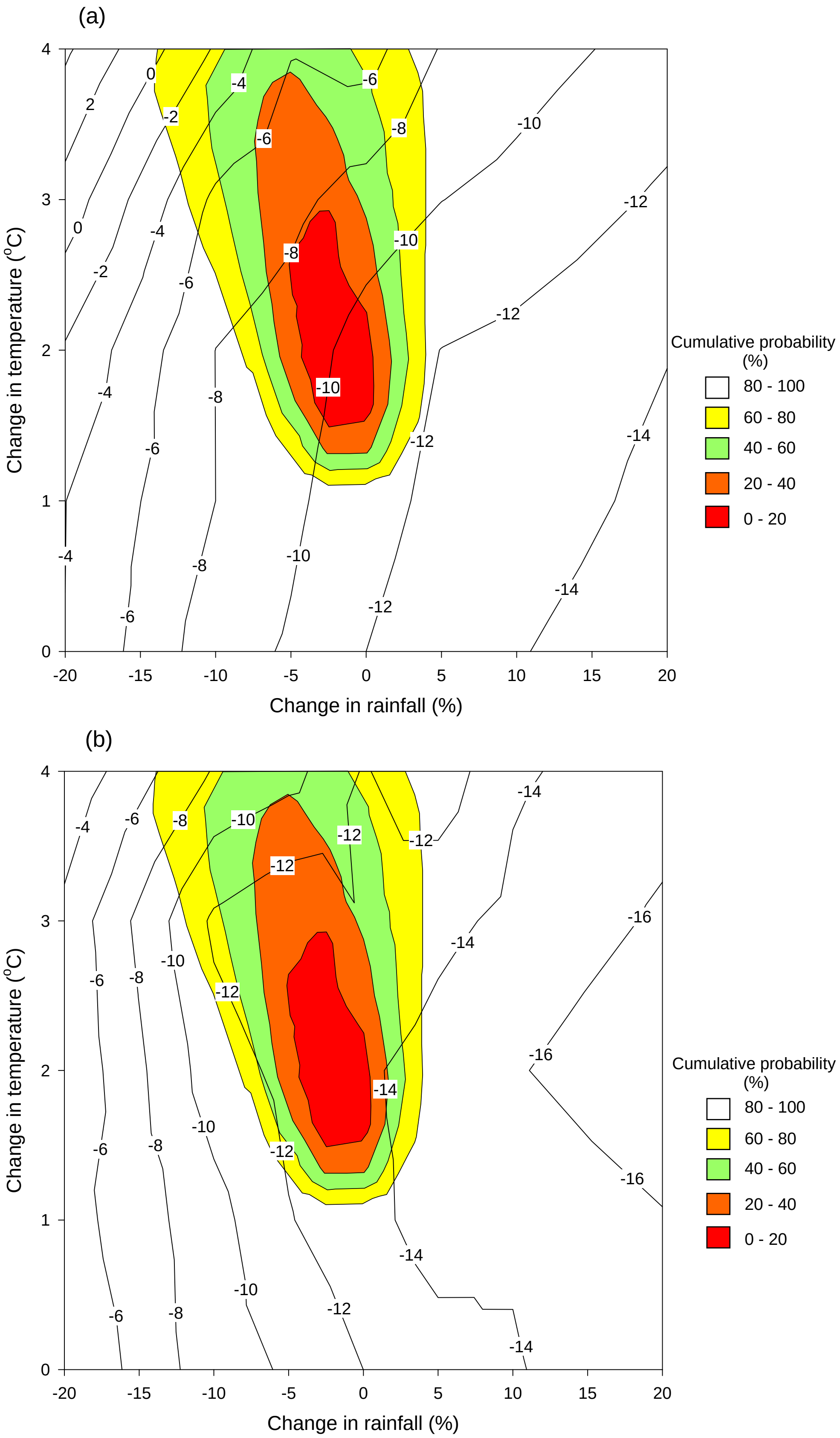


Figure 9.3: Dubbo - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $271/ha. Doubling of CO_2 alone resulted in a 11% increase in gross margins (Figure 9.4). Gross margins increased with increased rainfall, with the maximum change in GM (53%) achieved with a 20% increase in rainfall and the lowest (-39%) occurring with the –20% rainfall scenario (Figure 9.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about 12-32% with the most likely response 15-36% (Figure 9.4).

With the modification in planting window, increased temperature had a positive effect on gross margins with the maximum response (74%) occurring in the +20% rainfall and 4°C scenario (Figure 9.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 25-55% with the most likely response about 30-49% (Figure 9.3).

Heat Shock

The risk of heat shock in Dubbo is low. The earlier anthesis and maturity with increased temperatures resulted in only a small increase in the risk of heat shock under the current planting window (Table 9.2). Modifying the planting window enabled earlier sowings, and reduced the risk of heat shock (Table 9.3). Increased rainfall also enabled earlier sowing, thus avoiding hot days later in the year. Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock may increase by 37% with the current window but may decline by 37% with the modified window (Table 9.2 and Table 9.3).

Table 9.2: Proportion of days in Dubbo with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.09	0.11	0.12	0.10	0.12
-10	0.09	0.10	0.09	0.09	0.10
-5	0.08	0.09	0.09	0.09	0.12
0	0.08	0.09	0.11	0.08	0.09
5	0.08	0.08	0.08	0.08	0.11
10	0.08	0.08	0.08	0.08	0.11
20	0.07	0.08	0.07	0.07	0.10

Table 9.3: Proportion of days in Dubbo with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.09	0.10	0.08	0.06	0.05
-10	0.09	0.09	0.06	0.05	0.03
-5	0.08	0.10	0.06	0.05	0.03
0	0.08	0.10	0.05	0.04	0.03
5	0.08	0.09	0.05	0.04	0.02
10	0.08	0.08	0.05	0.04	0.03
20	0.07	0.07	0.05	0.03	0.02

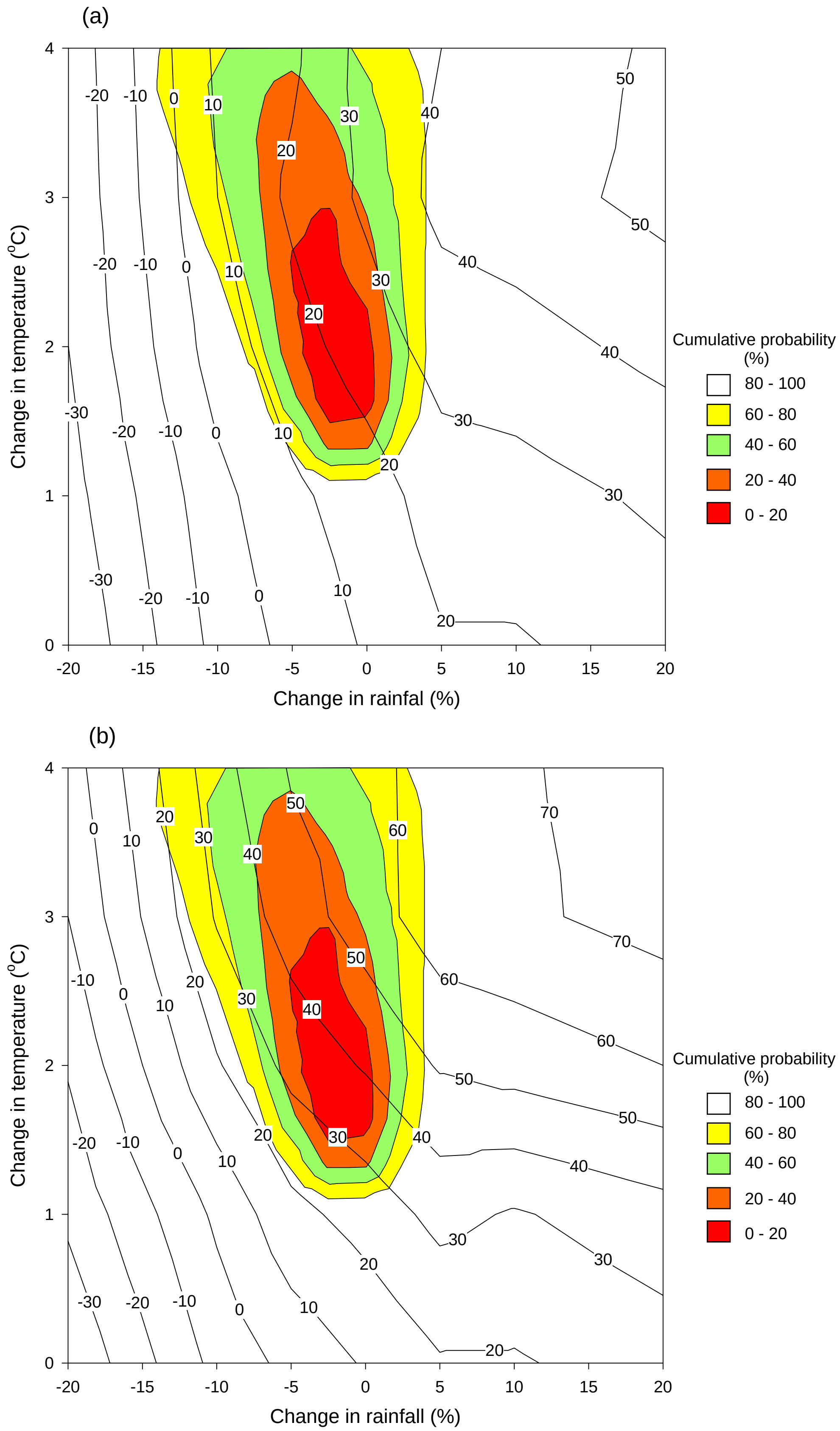


Figure 9.4: Dubbo – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and ‘forced sowings’ occurred increased from 19% to 40% under the lowest rainfall scenario but was reduced to 14% under the highest (Table 9.4). The modified planting window reduced the number of ‘forced sowings’.

Table 9.4: Frequency of ‘forced sowings’(%) in Dubbo under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window				
		0°C	1°C	2°C	3°C	4°C
-20	40	40	37	33	31	27
-10	27	27	24	20	17	15
-5	22	22	17	15	12	11
0	19	19	15	12	12	7
5	16	16	12	9	9	7
10	16	16	14	9	9	5
20	14	14	12	8	8	5

10 Moree – New South Wales

Background

Moree was chosen to represent the Northern region of New South Wales. This region is a summer and winter cropping area with wheat, barley and sorghum the main crops. In 1996 the area of cereal cropping was 943,031 ha with about 58% of this sown to wheat. Regional wheat yields were 1.76 t/ha. Over the last 17 years wheat yields for the region have averaged 1.57 t/ha.

Annual rainfall in Moree is about 579 mm and is summer dominant with 61% falling in the 6 months October-March. The January mean maximum temperature is 34.8°C and the July mean minimum temperature is 3.4°C. Temperatures range from –5.0°C to 43.9°C. Mean daily evaporation is 6.3 mm.

Soils are predominantly alluvial cracking clays

Modified Planting Window

The risk of frost damage was present in Moree in all climate change scenarios. However, the warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 10.1). The 'quick' variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 10.1: Modified planting window for 'standard' and 'slow' varieties under different temperature scenarios for Moree.

Temperature Change (°C)	Standard	Slow
0	10 May - 1 Aug	10 May - 1 Aug
1	9 May - 1 Aug	4 May - 1 Aug
2	30 Apr - 1 Aug	24 Apr - 1 Aug
3	20 Apr - 1 Aug	15 Apr - 1 Aug
4	11 Apr - 1 Aug	5 Apr - 1 Aug

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 33% increase in potential yields (Figure 10.1). Using the current planting window, the yield response increased with increased rainfall and declined with increased temperature (Figure 10.1). The maximum yield response (48%) was achieved at the +20% rainfall and 0°C temperature scenario while the lowest (-11%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 7-29% with the most likely response 17-27% (Figure 10.1).

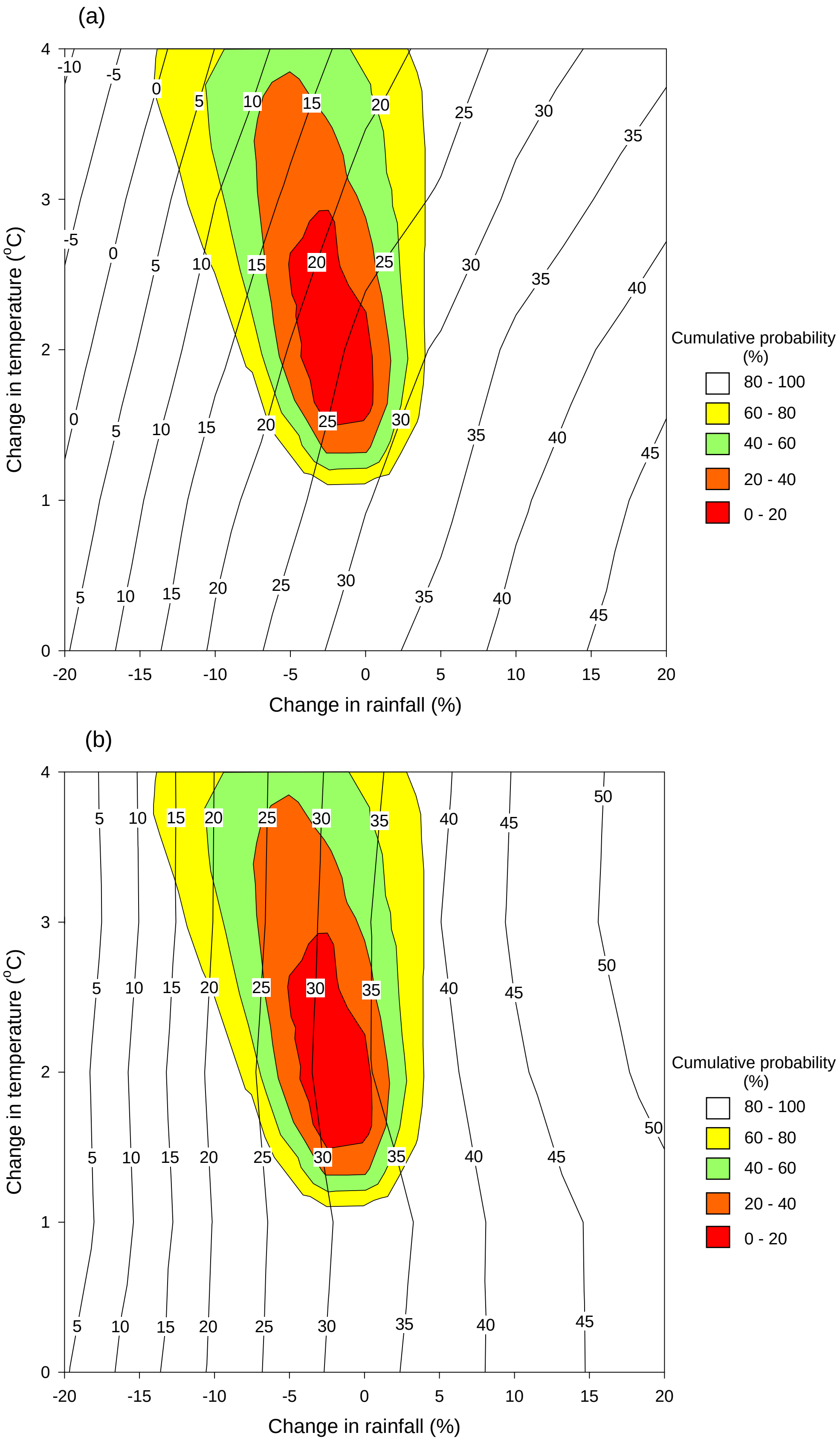


Figure 10.1: Moree – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Modifying the planting window largely removed the negative impact of increased temperature found with the current window (Figure 10.1), while rainfall change remained positively correlated with yield. Yield increased under all global change scenarios with the modified planting window. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 22-36% with the most likely response about 27-35% (Figure 10.1).

Under the current planting window, the 'standard' variety had higher mean yields in most climate change scenarios, however when the planting window was brought forward the slower maturing 'variety' began producing higher mean yields (Figure 10.2).

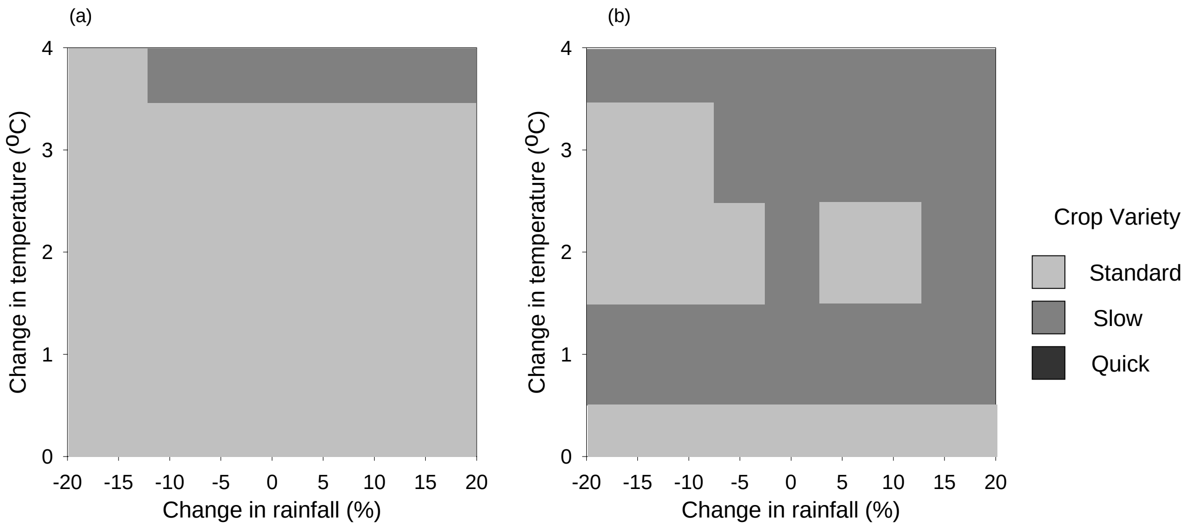


Figure 10.2: Maximum yielding crop 'variety' simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 9% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 10.3). The quality of the grain was actually increased (+4%) under the –20% rainfall and +4°C scenario but declined to –12% under the +20% rainfall and 0°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –1 to –6% with the most likely response –2 to –5% (Figure 10.3).

The positive effect of increased temperature under the current window was reduced with the modified planting window (Figure 10.3), resulting in greater reductions in grain nitrogen than those under the current planting window. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -5 to -9% with the most likely response about –6 to –8% (Figure 10.3).

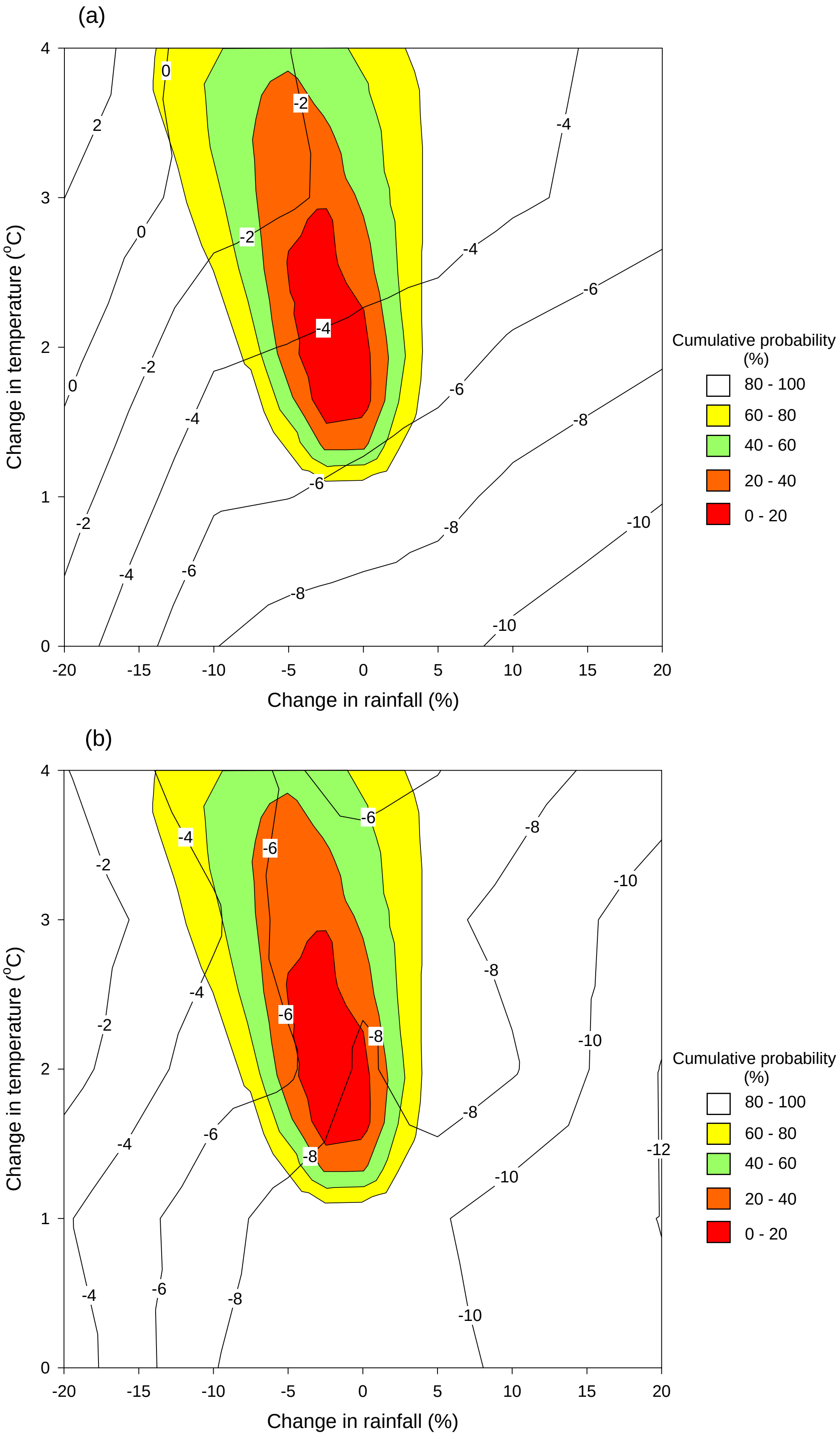


Figure 10.3: Moree - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $241/ha. Doubling of CO_2 alone resulted in a 26% increase in gross margins (Figure 10.4). Gross margins increased with increased rainfall, with the maximum change in GM (69%) achieved with a 20% increase in rainfall and the lowest (-29%) occurring with the –20% rainfall scenario (Figure 10.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about 0-35% with the most likely response 20-32% (Figure 10.4).

With the modification in planting window, increased temperature had a positive effect on gross margins with the maximum response (99%) occurring in the +20% rainfall and 4°C scenario (Figure 10.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 28-55% with the most likely response about 30-45% (Figure 10.3).

Heat Shock

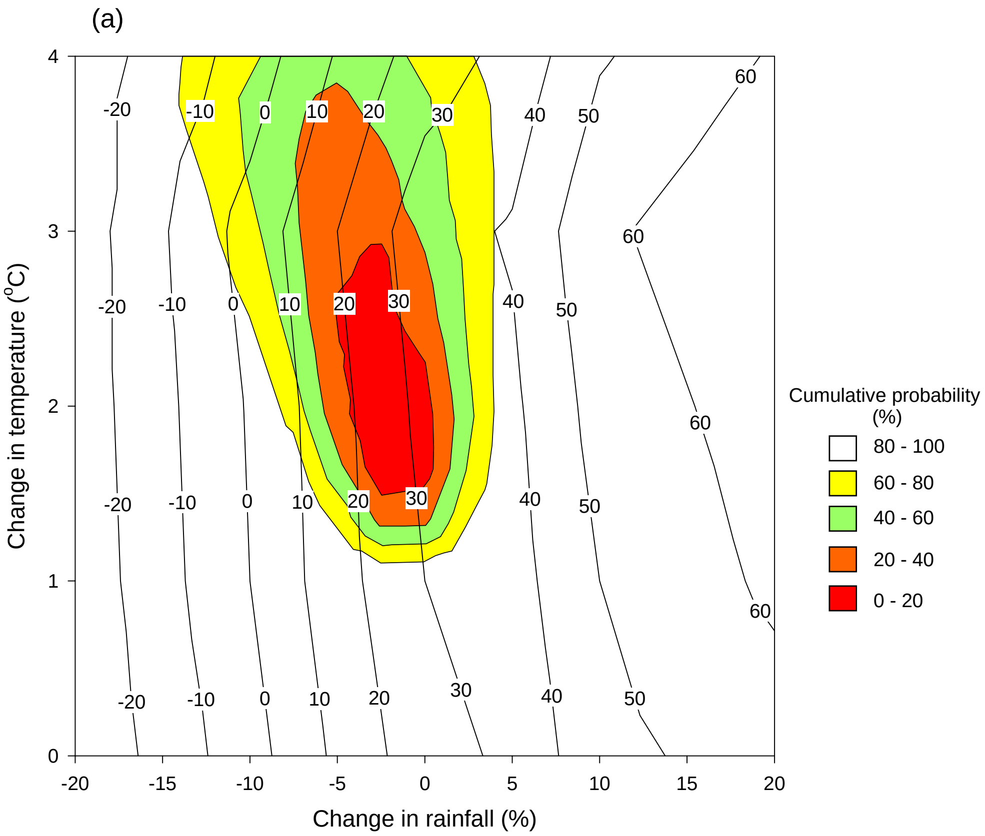
With the current planting window, the risk of heat shock increased significantly with climate change, increasing by 73% under the 4°C scenario (Table 10.2). Modifying the planting window enabled earlier sowings, and reduced the risk of heat shock (Table 10.3). Increased rainfall also enabled earlier sowing, thus avoiding hot days later in the year. Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock is most likely to increase by about 27% (Table 10.2 and Table 10.3).

Table 10.2: Proportion of days in Moree with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.24	0.27	0.31	0.33	0.38
-10	0.23	0.26	0.30	0.31	0.40
-5	0.22	0.25	0.29	0.3	0.39
0	0.22	0.24	0.28	0.29	0.38
5	0.22	0.24	0.28	0.29	0.37
10	0.21	0.23	0.27	0.28	0.36
20	0.21	0.22	0.26	0.26	0.35

Table 10.3: Proportion of days in Moree with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.24	0.28	0.28	0.28	0.28
-10	0.23	0.27	0.26	0.24	0.24
-5	0.22	0.27	0.25	0.26	0.23
0	0.22	0.26	0.27	0.25	0.22
5	0.22	0.26	0.25	0.24	0.20
10	0.21	0.25	0.24	0.23	0.19
20	0.21	0.24	0.25	0.22	0.18



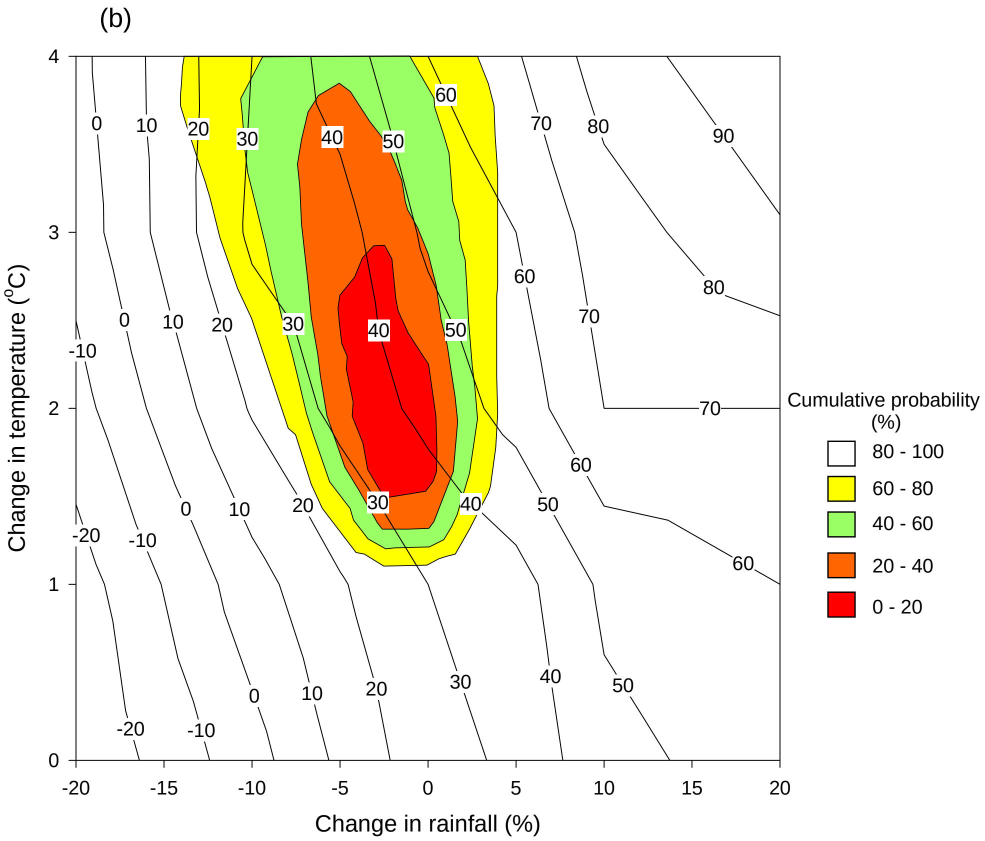


Figure 10.4: Moree – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 30% to 45% under the lowest rainfall scenario but was reduced to 25% under the highest (Table 10.4). The modified planting window reduced the number of 'forced sowings'.

Table 10.4: Frequency of 'forced sowings'(%) in Moree under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window				
		0°C	**1°C**	**2°C**	**3°C**	**4°C**
-20	45	45	41	41	39	35
-10	39	39	35	34	32	29
-5	35	35	31	31	29	26
0	30	30	28	27	25	23
5	30	30	27	27	24	23
10	26	26	23	23	22	20
20	25	25	23	23	20	18

11 Dalby – Queensland

Background

Dalby was chosen to represent the Darling Downs - Maranoa region of Queensland. This region is a summer and winter cropping area with wheat, sorghum and barley the main crops. In 1996 the area of cereal cropping was 924,221 ha with about 42% of this sown to wheat. Regional wheat yields were 0.97 t/ha. Over the last 20 years wheat yields for the region have averaged 1.34 t/ha.

Annual rainfall in Dalby is about 676 mm and is summer dominant with 67% falling in the 6 months October-March. The January mean maximum temperature is 31.6°C and the July mean minimum temperature is 4.4°C. Temperatures range from –5.8°C to 43°C. Mean daily evaporation is 5.5 mm.

Soils are predominantly heavy, deep self-mulching clays. These allow summer rain to be stored for use by winter crops, thus reducing the risk of crop failure.

Modified Planting Window

The risk of frost damage was present in Dalby in all climate change scenarios. However, the warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 11.1). The 'quick' variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 11.1: Modified planting window for 'standard' and 'slow' varieties under different temperature scenarios for Dalby.

Temperature Change (°C)	Standard	Slow
0	10 May - 1 Aug	10 May - 1 Aug
1	10 May - 1 Aug	4 May - 1 Aug
2	4 May - 1 Aug	29 Apr - 1 Aug
3	29 Apr - 1 Aug	23 Apr - 1 Aug
4	24 Apr - 1 Aug	18 Apr - 1 Aug

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 37% increase in potential yields (Figure 11.1). Using the current planting window, the yield response increased with increased rainfall and declined with increased temperature (Figure 11.1). The maximum yield response (51%) was achieved at the +20% rainfall and 0°C temperature scenario while the lowest (-8.5%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 8-32% with the most likely response 20-30% (Figure 11.1).

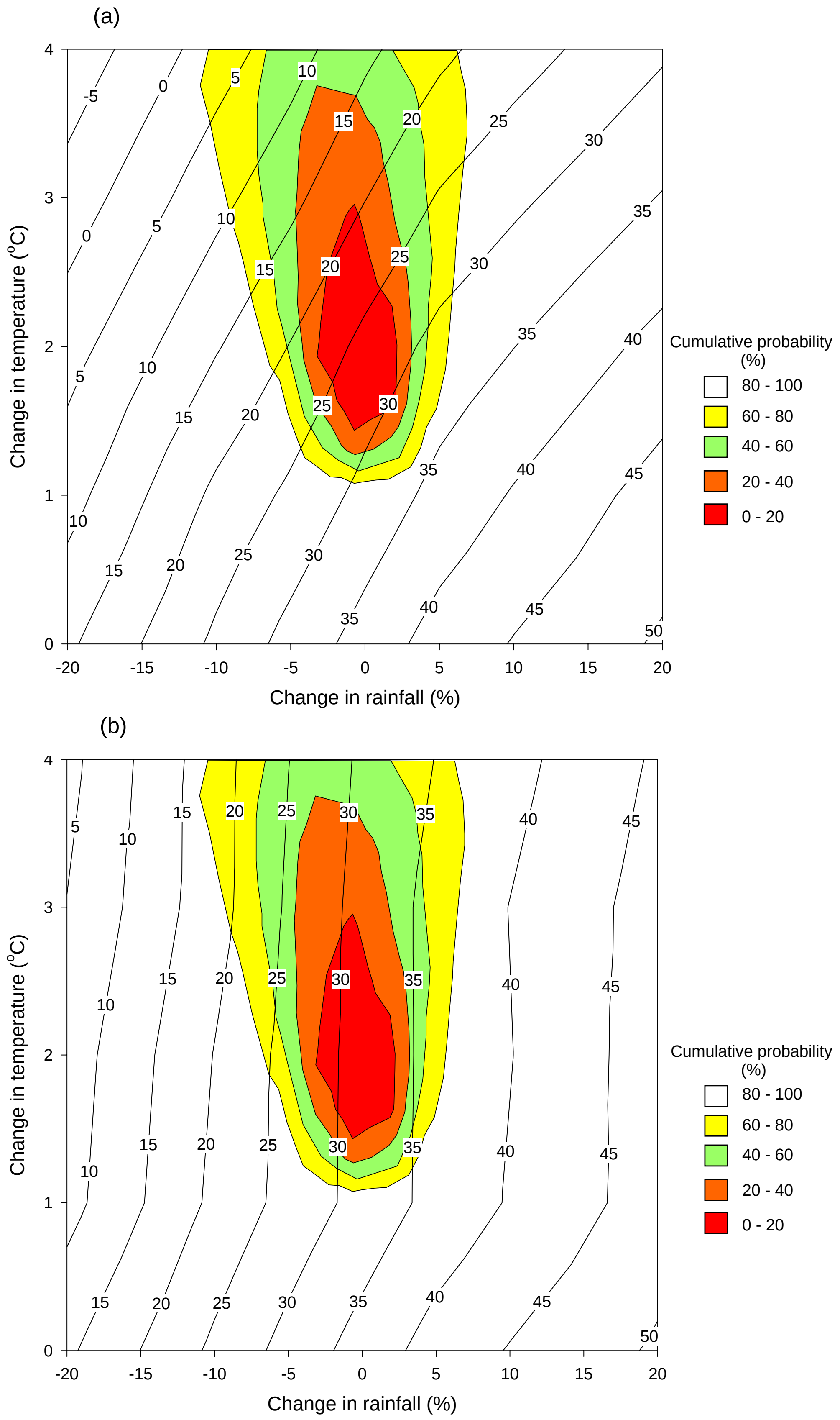


Figure 11.1: Dalby – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Modifying the planting window largely removed the negative impact of increased temperature found with the current window (Figure 11.1), while rainfall change remained positively correlated with yield. Yield increased under all global change scenarios with the modified planting window. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 25-35% with the most likely response about 28-34% (Figure 11.1).

Under the current planting window, the 'standard' variety had higher mean yields in most climate change scenarios, however when the planting window was brought forward the slower maturing 'variety' produced higher mean yields (Figure 11.2).

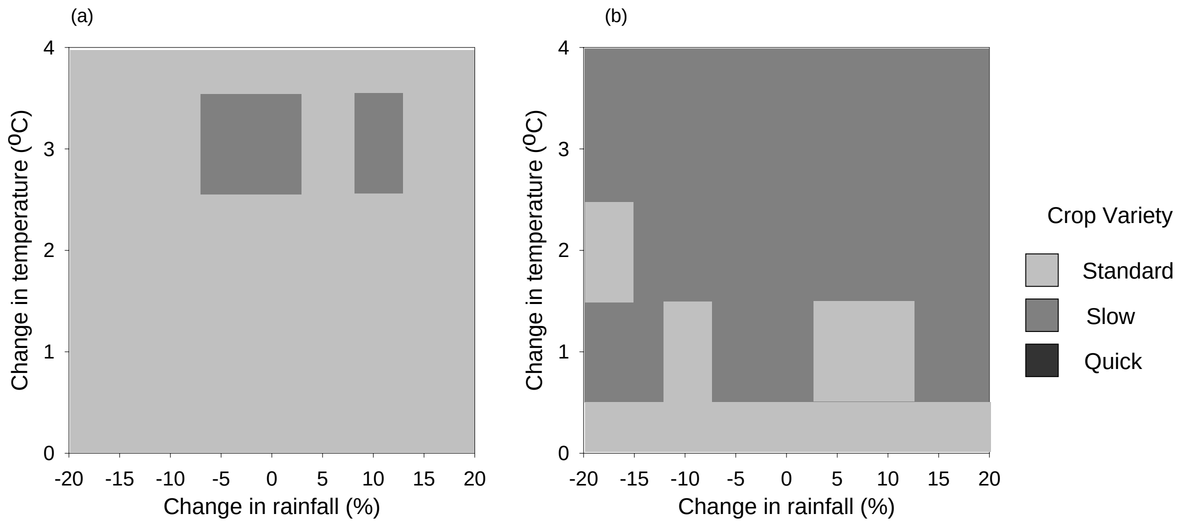


Figure 11.2: Maximum yielding crop 'variety' simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 10% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 11.3). The quality of the grain was maintained under the –20% rainfall and +4°C scenario but declined to –15% under the +20% rainfall and 0°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –3 to –9% with the most likely response –7 to –9% (Figure 11.3).

The positive effect of increased temperature under the current window was largely removed with the modified planting window (Figure 11.3), resulting in greater reductions in grain nitrogen than those under the current planting window. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -7 to -11% with the most likely response about –9 to –11% (Figure 11.3).

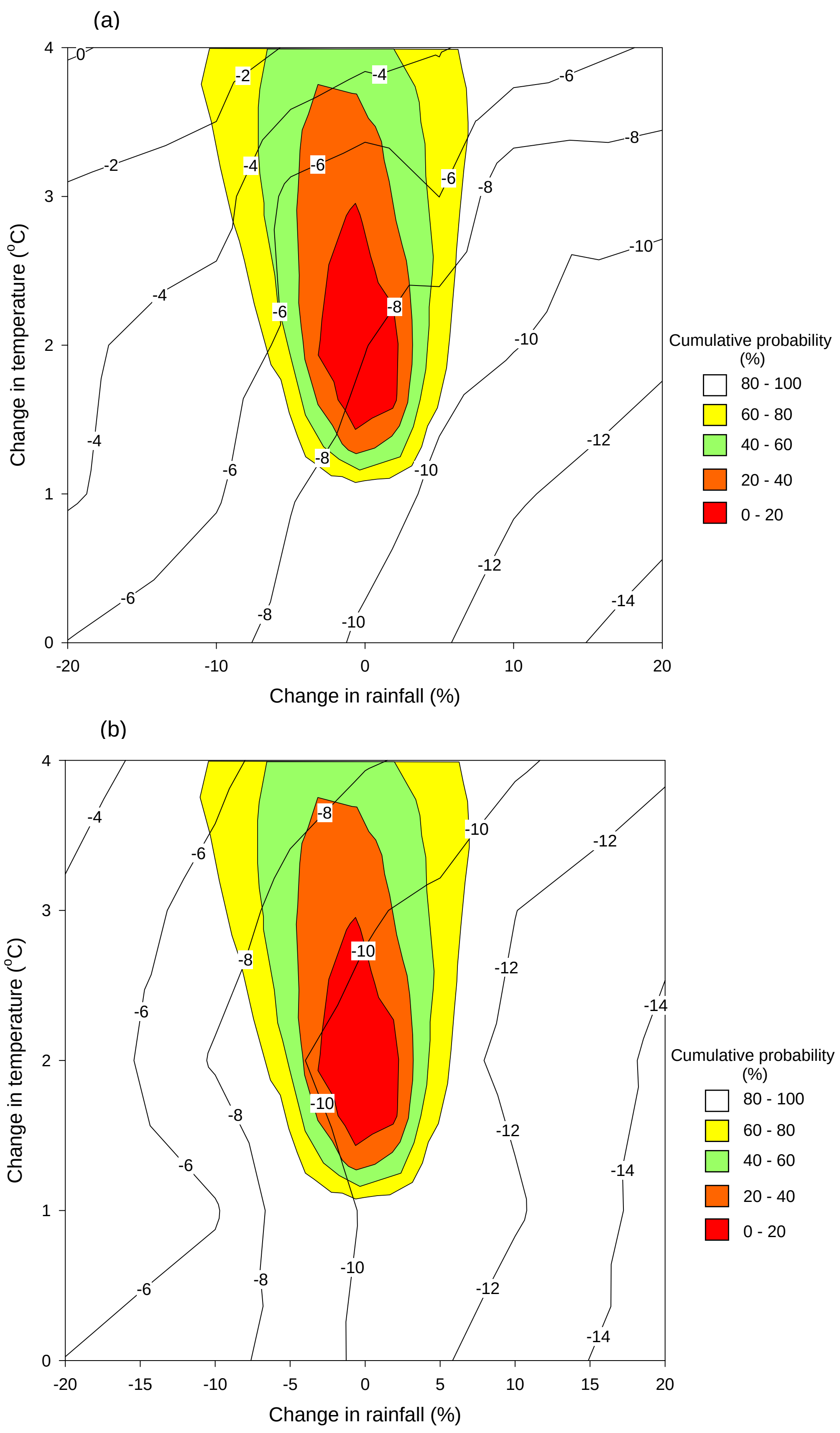


Figure 11.3: Dalby - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be \$207/ha. Doubling of CO_2 alone resulted in a 31% increase in gross margins (Figure 11.4). Gross margins increased with increased rainfall, with the maximum change in GM (70%) achieved with a 20% increase in rainfall and the lowest (-23%) occurring with the –20% rainfall scenario (Figure 11.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about 10-39% with the most likely response 20-35% (Figure 11.4).

With the modification in planting window, increased temperature had a positive effect on gross margins with the maximum response (96%) occurring in the +20% rainfall and 4°C scenario (Figure 11.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 28-60% with the most likely response about 32-45% (Figure 11.3).

Heat Shock

The risk of heat shock increased significantly under the climate change scenarios. Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock is most likely to increase by about 60% (Table 11.3). Modifying the planting window enabled earlier sowings, reducing the risk of heat shock slightly (e.g. about 60% compared with a doubling for the current window under the 4°C scenario). Increased rainfall also enabled earlier sowing, thus avoiding hot days later in the year.

Table 11.2: Proportion of days in Dalby with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.15	0.19	0.23	0.26	0.31
-10	0.14	0.18	0.22	0.25	0.29
-5	0.14	0.17	0.21	0.26	0.28
0	0.13	0.17	0.21	0.25	0.27
5	0.13	0.16	0.20	0.22	0.26
10	0.13	0.16	0.19	0.25	0.25
20	0.12	0.16	0.19	0.20	0.24

Table 11.3: Proportion of days in Dalby with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.15	0.20	0.21	0.25	0.27
-10	0.14	0.18	0.22	0.23	0.24
-5	0.14	0.19	0.21	0.22	0.22
0	0.13	0.18	0.20	0.21	0.21
5	0.13	0.16	0.20	0.20	0.20
10	0.13	0.16	0.19	0.19	0.20
20	0.12	0.16	0.19	0.18	0.19

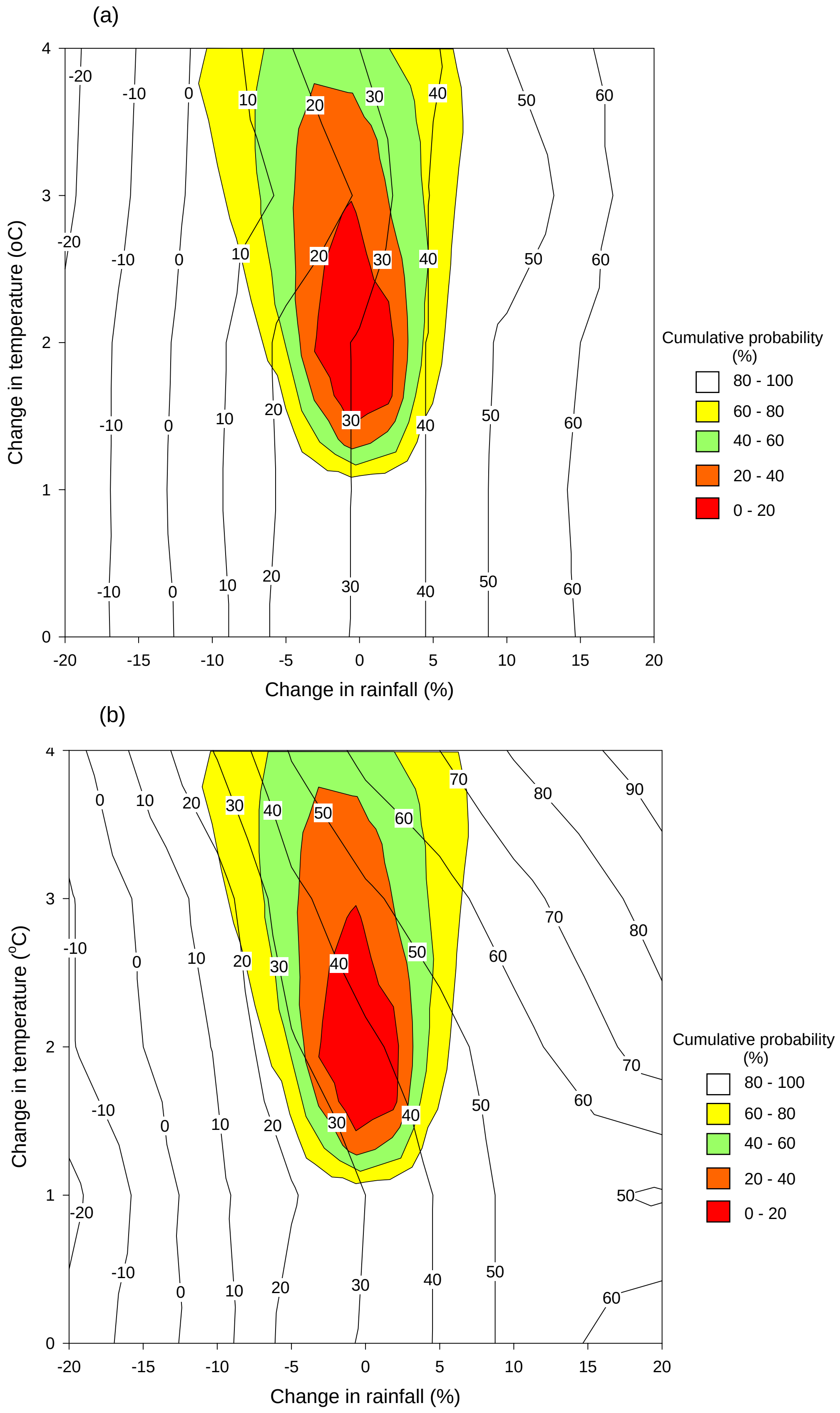


Figure 11.4: Dalby – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 35% to 45% under the lowest rainfall scenario but was reduced to 23% under the highest (Table 11.4). The modified planting window reduced the number of 'forced sowings'

Table 11.4: Frequency of 'forced sowings'(%) in Dalby under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window				
		0°C	1°C	2°C	3°C	4°C
-20	45	45	45	45	43	40
-10	40	40	40	39	38	34
-5	36	36	36	34	32	28
0	35	35	33	32	30	26
5	32	32	32	30	28	25
10	28	28	28	26	23	21
20	23	23	27	21	18	17

12 Burenda – Queensland

Background

Burenda in the Murweh shire was chosen to an area where cropping is currently not a viable industry but may become so under some scenarios of climate change. In 1996 the area of cereal cropping was 2,919 ha with about 41% of this sown to wheat. Regional wheat yields were 1 t/ha.

Annual rainfall in nearby Charleville is about 483 mm and is summer dominant with 68% falling in the 6 months October-March. The January mean maximum temperature is 34.9°C and the July mean minimum temperature is 4.1°C. Temperatures range from –5.2°C to 46.4°C. Mean daily evaporation is 7.6 mm.

Soils are predominantly deep cracking clays.

Modified Planting Window

The risk of frost damage was present in Burenda in all climate change scenarios. However, the warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 12.1). The 'quick' variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 12.1: Modified planting window for 'standard' and 'slow' varieties under different temperature scenarios for Burenda.

Temperature Change (°C)	Standard	Slow
0	10 May - 1 Aug	10 May - 1 Aug
1	1 May - 1 Aug	25 Apr - 1 Aug
2	25 Apr - 1 Aug	19 Apr - 1 Aug
3	18 Apr - 1 Aug	13 Apr - 1 Aug
4	12 Apr - 1 Aug	7 Apr - 1 Aug

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 50% increase in potential yields (Figure 12.1). Using the current planting window, the yield response increased with increased rainfall and declined with increased temperature (Figure 12.1). The maximum yield response (87%) was achieved at the +20% rainfall and 0°C temperature scenario while the lowest (-10%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 15-47% with the most likely response 29-45% (Figure 12.1).

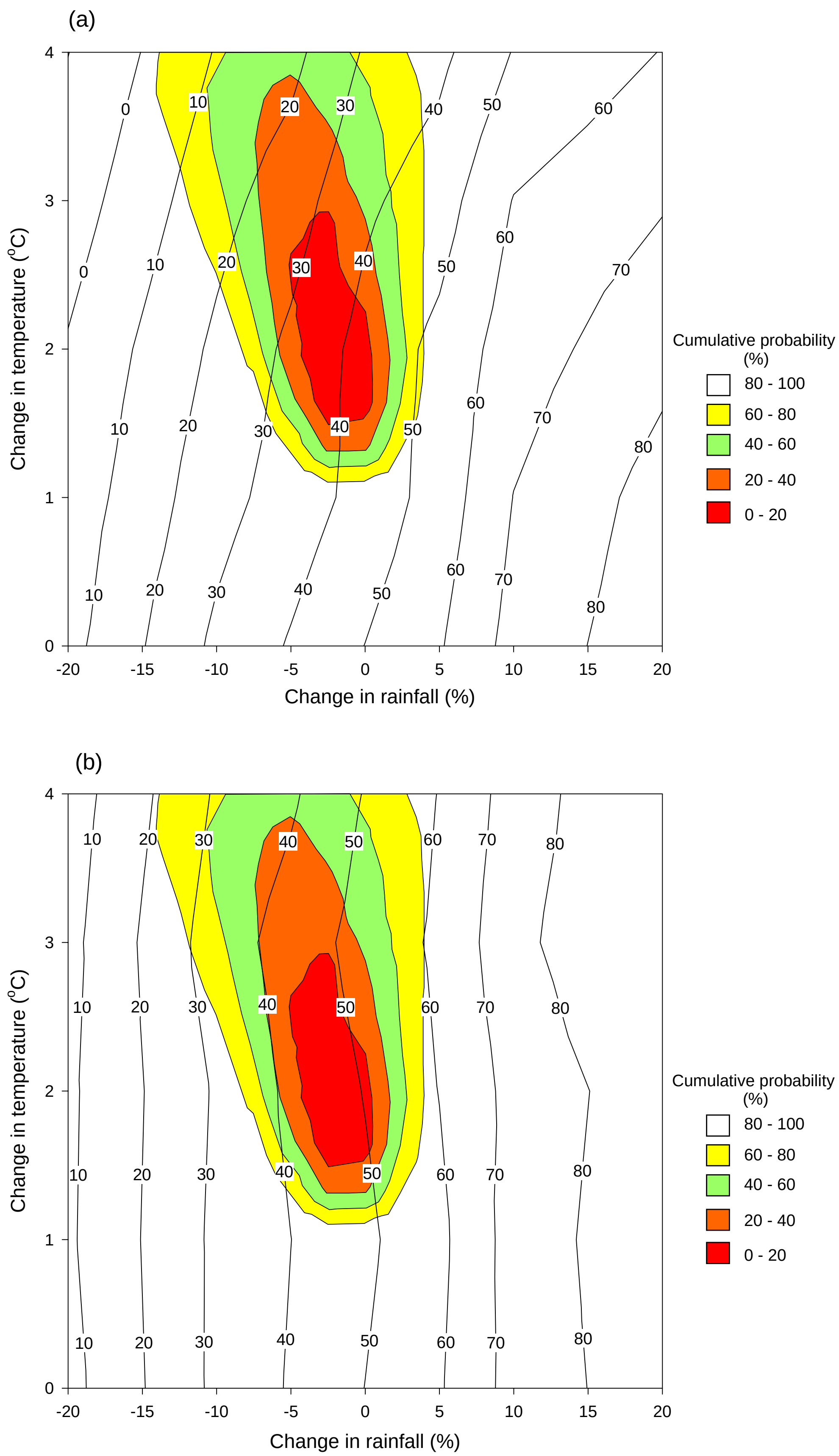


Figure 12.1: Burenda – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Modifying the planting window largely removed the negative impact of increased temperature found with the current window (Figure 12.1), while rainfall change remained positively correlated with yield. Yield increased under all global change scenarios with the modified planting window. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 35-55% with the most likely response about 43-50% (Figure 12.1).

Under the current planting window, the 'standard' variety had higher mean yields in most climate change scenarios. Modifying the planting window had little impact on the 'variety' producing the highest mean yields (Figure 12.2).

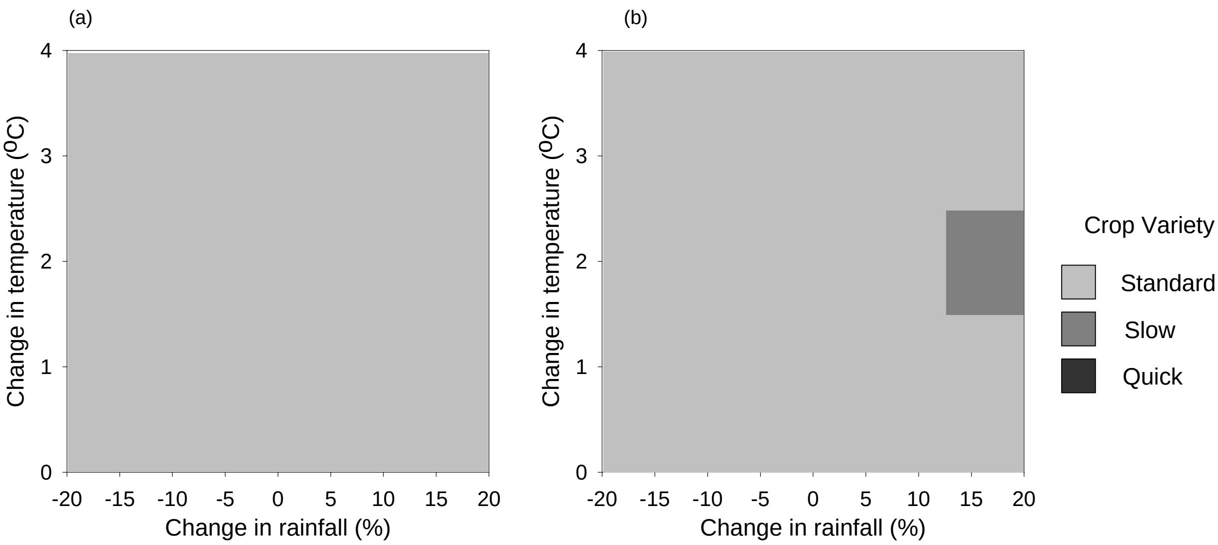


Figure 12.2: Maximum yielding crop 'variety' simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 11% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increase temperature (Figure 12.3). The quality of grain was actually increased (+8%) under the –20% rainfall and +4°C scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –1 to –9% with the most likely response –4 to –8% (Figure 12.3).

Modifying the planting window resulted in further small reductions in grain nitrogen (Figure 12.3). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -2 to -9% with the most likely response about –5 to –9% (Figure 12.3).

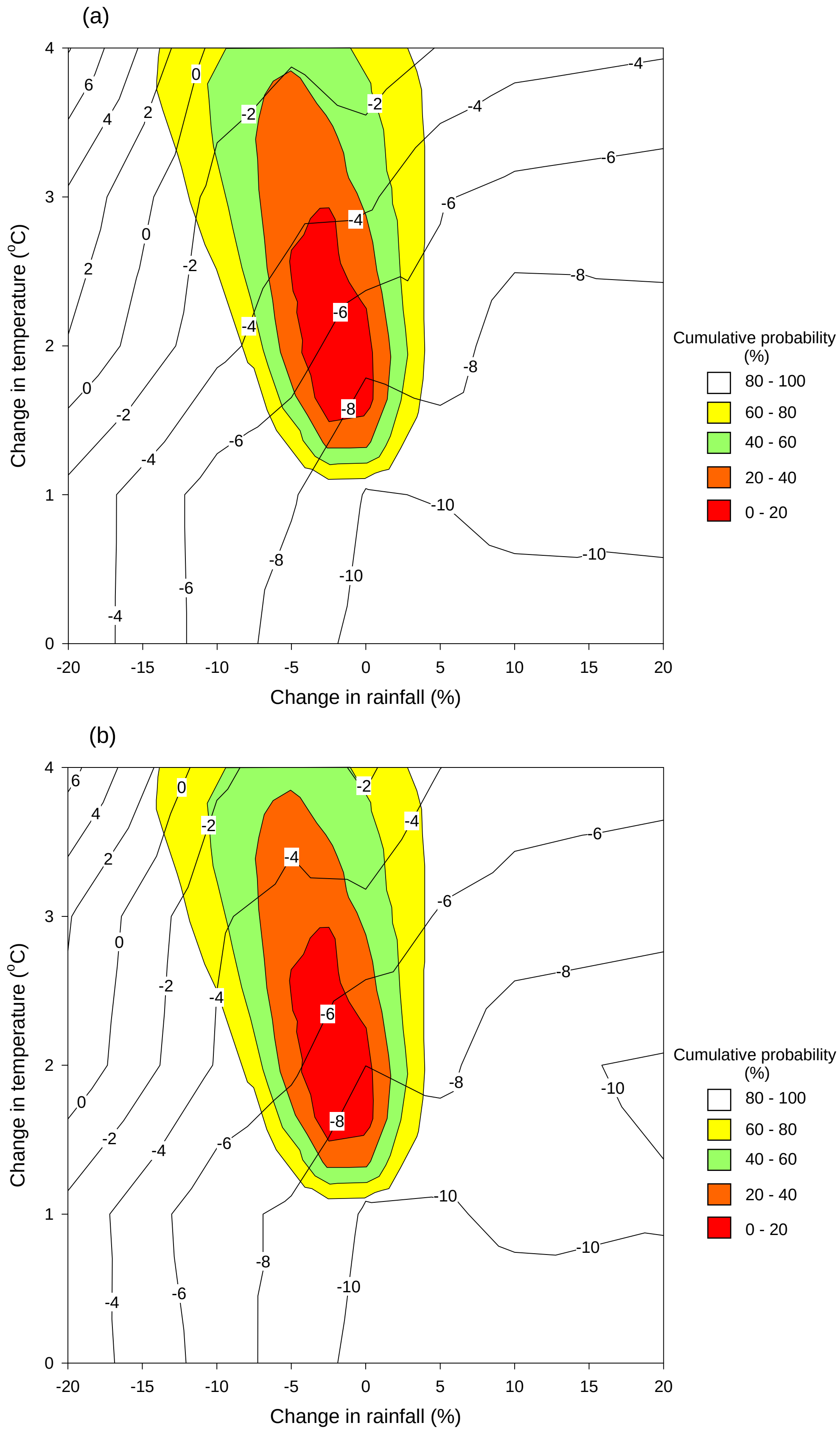


Figure 12.3: Burenda - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $-61/ha. Doubling of CO_2, while increasing gross margins by 80%, still results in negative gross margins (-13$/ha) (Figure 12.4). Gross margins increased with increased rainfall, with the maximum GM (47$/ha) achieved with a 20% increase in rainfall and the lowest (-65$/ha) occurring with the –20% rainfall scenario (Figure 12.4). Based on the CSIRO 1996 climate change scenarios, it is likely that gross margins will remain negative in this region (Figure 12.4).

With the modification in planting window, increased temperature had a positive effect on gross margins with the maximum GM (75$/ha) occurring in the +20% rainfall and 4°C scenario (Figure 12.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that GM with the modified window will be in the range of –9 to 15$/ha with the most likely amount about –5 to 10$/ha (Figure 12.3).

Heat Shock

The risk of heat shock increased significantly under the climate change scenarios. Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock is most likely to increase by about 57% (Table 12.3). Modifying the planting window enabled earlier sowings, reducing the risk of heat shock slightly (e.g. about 170% compared with a 300% increase for the current window under the 4°C scenario). Increased rainfall also enabled earlier sowing, thus avoiding hot days later in the year.

Table 12.2: Proportion of days in Burenda with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.20	0.21	0.29	0.54	0.65
-10	0.16	0.17	0.24	0.48	0.58
-5	0.16	0.17	0.24	0.48	0.58
0	0.14	0.14	0.22	0.46	0.56
5	0.14	0.14	0.22	0.46	0.55
10	0.14	0.14	0.22	0.44	0.52
20	0.12	0.12	0.21	0.42	0.51

Table 12.3: Proportion of days in Burenda with temperatures greater than 32^{o}C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.20	0.19	0.24	0.44	0.50
-10	0.16	0.14	0.21	0.36	0.40
-5	0.16	0.14	0.21	0.35	0.40
0	0.14	0.12	0.21	0.34	0.38
5	0.14	0.12	0.21	0.32	0.33
10	0.14	0.12	0.20	0.31	0.33
20	0.12	0.12	0.20	0.27	0.28

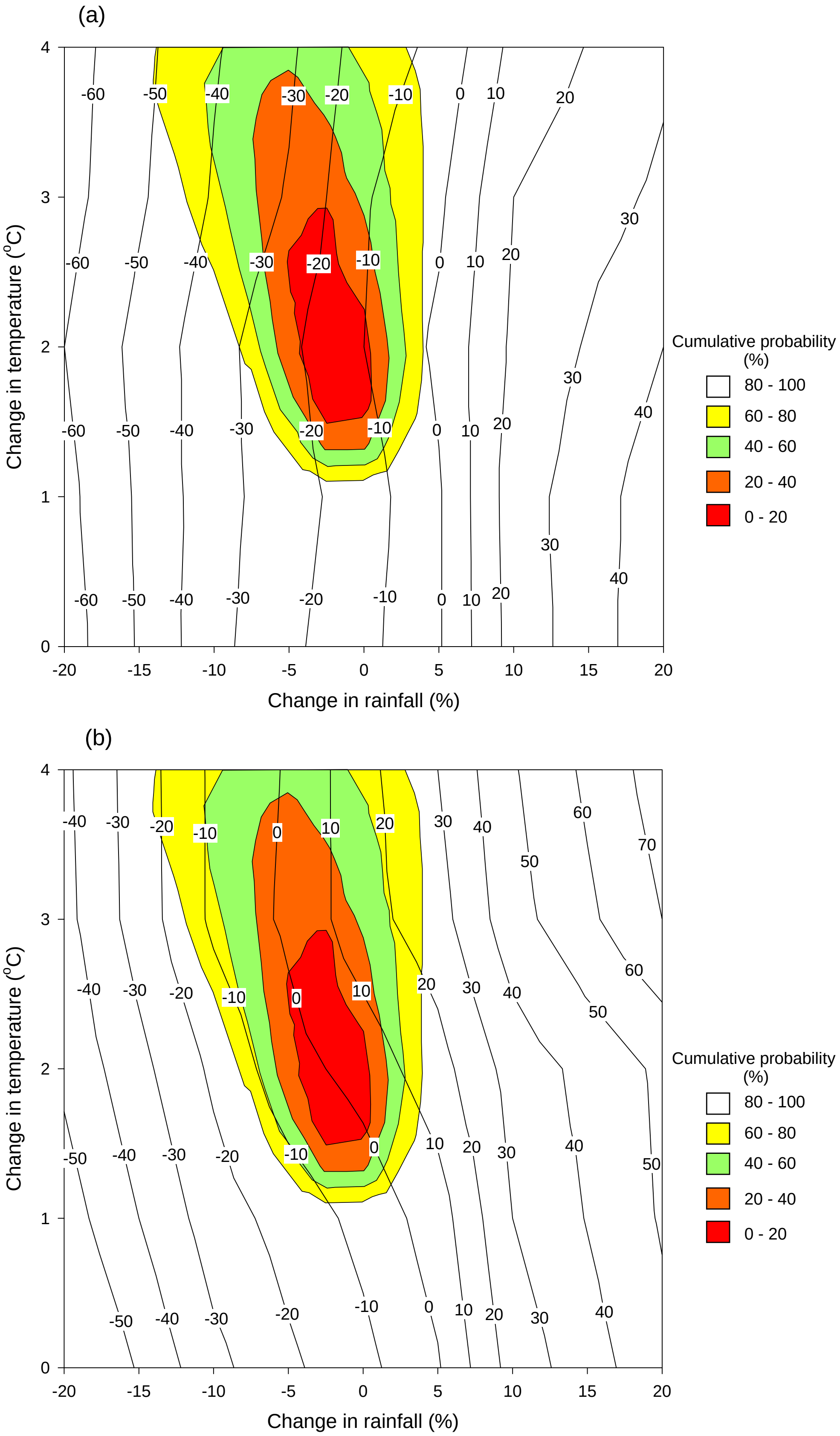


Figure 12.4: Burenda – Gross margins ($/ha) under doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and 'forced sowings' occurred increased from 36% to 51% under the lowest rainfall scenario but was reduced to 30% under the highest (Table 12.4). The modified planting window reduced the number of 'forced sowings'.

Table 12.4: Frequency of 'forced sowings'(%) in Burenda under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window 0°C	1°C	2°C	3°C	4°C
-20	51	51	49	47	46	44
-10	43	43	40	37	37	35
-5	40	40	37	35	35	33
0	36	36	35	32	32	30
5	36	36	35	32	32	30
10	33	33	32	30	30	28
20	30	30	29	27	27	25

13 Emerald – Queensland

Background

Emerald was chosen to represent the Fitzroy region of Queensland. This region is a summer and winter cropping area with sorghum, wheat and barley the main crops. In 1996 the area of cereal cropping was 290,446 ha with about 31 % of this sown to wheat. Regional wheat yield were 0.54 t/ha. Over the last 20 years wheat yields for the region have averaged 1.38 t/ha.

Annual rainfall in Emerald is about 640 mm and is summer dominant with 72 % falling in the 6 months October-March. The December mean maximum temperature is 34.7 °C and the July mean minimum monthly temperature 7.2 °C. Temperatures range from –2.3°C to 44.6°C. Mean daily evaporation is 6.6 mm.

Soils are predominantly alluvial cracking clays.

Modified Planting Window

The risk of frost damage was only present in Emerald in the 0-2°C scenarios. The warmer scenarios moved the period of risk allowing progressively earlier sowing (Table 13.1) with water availability restricting sowing in the 3-4°C scenarios. The 'quick' variety was not evaluated in this region as preliminary simulations showed it was unlikely to be consistently higher yielding than the other varieties under any of the scenarios.

Table 13.1: Modified planting window for 'standard' and 'slow' varieties under different temperature scenarios for Emerald.

Temperature Change (°C)	Standard	Slow
0	20 Apr - 10 Jul	20 Apr - 10 Jul
1	18 Apr - 10 Jul	11 Apr - 10 Jul
2	9 Apr - 10 Jul	2 Apr - 10 Jul
3	17 Mar - 10 Jul	17 Mar - 10 Jul
4	17 Mar - 10 Jul	17 Mar - 10 Jul

Results

Yield

The doubling of CO_2 alone (i.e. 0°C and 0% rainfall change scenario) resulted in a 43% increase in potential yields (Figure 13.1). Using the current planting window, the yield response increased with increased rainfall and declined with increased temperature (Figure 13.1). The maximum yield response (58%) was achieved at the +20% rainfall and 0°C temperature scenario while the lowest (-10%) occurred in the –20% rainfall and 4°C temperature scenario. Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the yield response will be in the range of about 8-36% with the most likely response 22-34% (Figure 13.1).

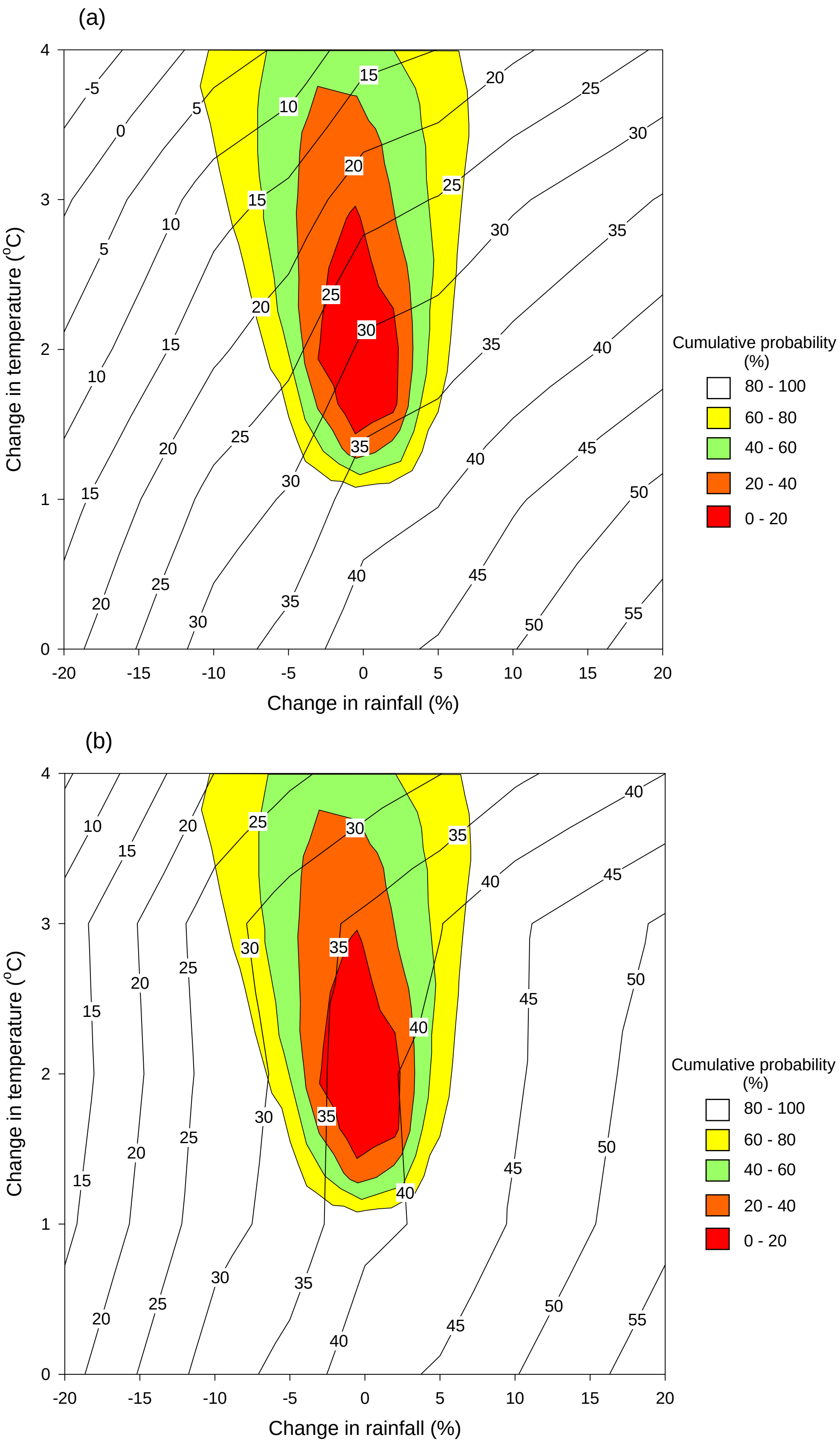


Figure 13.1: Emerald – Yield response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Yields increased under all global change scenarios with the modified planting window. Modifying the planting window largely removed the negative impact of increased temperature found with the current window (Figure 13.1). However, once temperature change had exceeded 3°C, the yield response began to decline. Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the yield response with the modified window will be in the range of 26-40% with the most likely response about 35-40% (Figure 13.1).

Under the current planting window, the ‘standard’ variety had higher mean yields in most climate change scenarios, however when the planting window was brought forward the slower maturing ‘variety’ begans to produce higher mean yields (Figure 13.2).

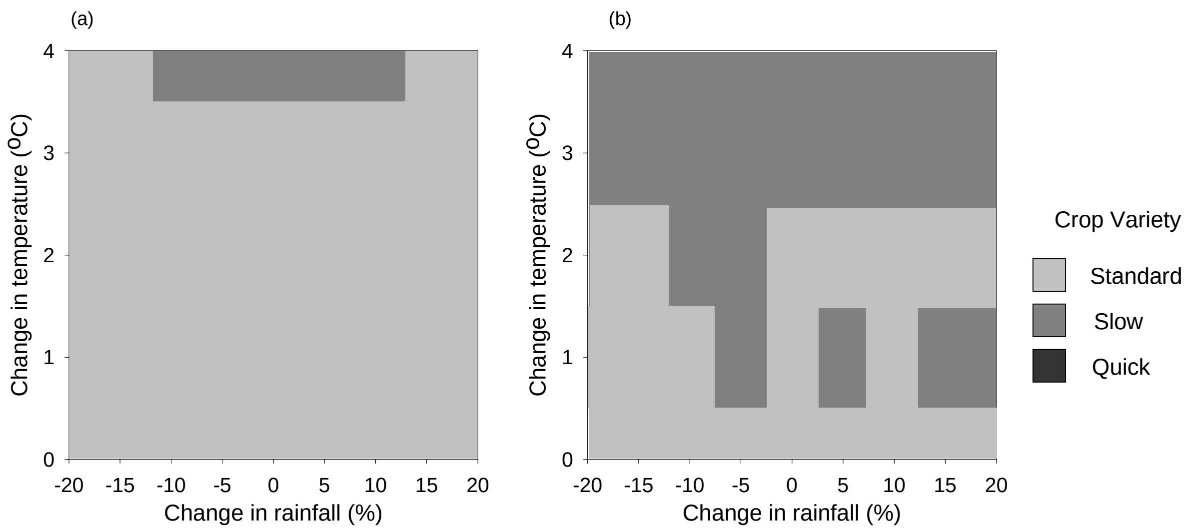


Figure 13.2: Maximum yielding crop ‘variety’ simulated under global change scenarios for (a) current planting window and (b) modified planting window.

Grain Nitrogen

The nitrogen content of the grain was reduced by about 11% with the doubling of CO_2. Using the current planting window, this declined further with increased rainfall but improved with increased temperature (Figure 13.3). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the decline in grain nitrogen will be in the range of about –7 to –10% with the most likely response –8 to –10 (Figure 13.3).

The modified window resulting in greater reductions in grain nitrogen than those under the current planting window (Figure 13.3). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the decline in grain N with the modified window will be in the range of -7 to -11% with the most likely response about –9 to –11% (Figure 13.3).

Gross Margins

Average gross margins (GM) under current climate and CO_2 levels were estimated to be $88/ha. Doubling of CO_2 alone resulted in a 70% increase in gross margins (Figure 13.4). Gross margins increased with increased rainfall, with the maximum change in GM (135%)

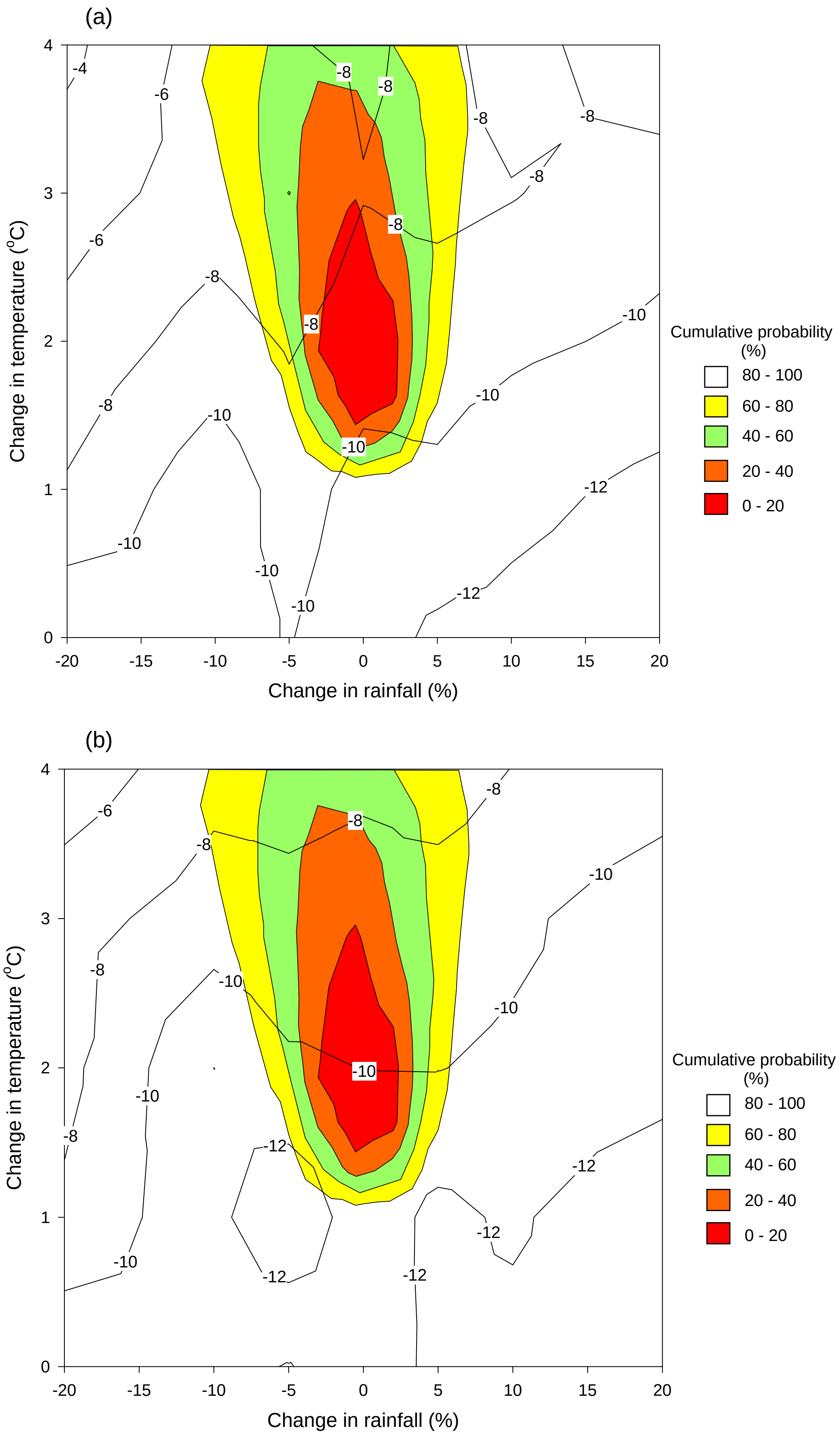


Figure 13.3: Emerald - Response of grain nitrogen (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

achieved with a 20% increase in rainfall and the lowest (-44%) occurring with the –20% rainfall scenario (Figure 13.4). Based on the CSIRO 1996 climate change scenarios, there is a 50% probability that the increase in GM will be in the range of about 0-70% with the most likely response 40-70% (Figure 13.4).

With the modification in planting window, changes in temperature up to 3°C had a positive effect on gross margins with the maximum response (167%) occurring in the +20% rainfall and 3°C scenario (Figure 13.4). Based on the CSIRO 1996 climate change scenarios there is a 50% probability that the increase in GM with the modified window will be in the range of 60-120% with the most likely response about 70-110% (Figure 13.3).

Heat Shock

With the current planting window, the risk of heat shock increased significantly with climate change, more than doubling under the 4°C scenario (Table 13.2). Temperature changes based on the CSIRO 1996 scenarios suggest that the frequency of heat shock is most likely to increase by about 37-57% (Table 13.3). Modifying the planting window enabled earlier sowings, and reduced the risk of heat shock significantly (Table 13.3). Increased rainfall also enabled earlier sowing, thus avoiding hot days later in the year. For the modified window the CSIRO 1996 scenarios suggest that the frequency of heat shock will only increase by about 16%.

Table 13.2: Proportion of days in Emerald with temperatures greater than 32°C during grain filling

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.22	0.26	0.32	0.35	0.44
-10	0.21	0.25	0.30	0.33	0.47
-5	0.20	0.24	0.29	0.33	0.46
0	0.19	0.23	0.30	0.31	0.44
5	0.18	0.22	0.26	0.30	0.43
10	0.17	0.21	0.25	0.29	0.42
20	0.16	0.19	0.24	0.27	0.33

Table 13.3: Proportion of days in Emerald with temperatures greater than 32°C during grain filling with modified planting window

Rainfall	**Temperature Change** (°C)				
Scenario (%)	**0**	**1**	**2**	**3**	**4**
-20	0.22	0.25	0.25	0.13	0.17
-10	0.21	0.23	0.23	0.12	0.16
-5	0.20	0.25	0.23	0.12	0.16
0	0.19	0.22	0.22	0.11	0.14
5	0.18	0.22	0.22	0.10	0.13
10	0.17	0.20	0.21	0.09	0.12
20	0.16	0.20	0.19	0.08	0.11

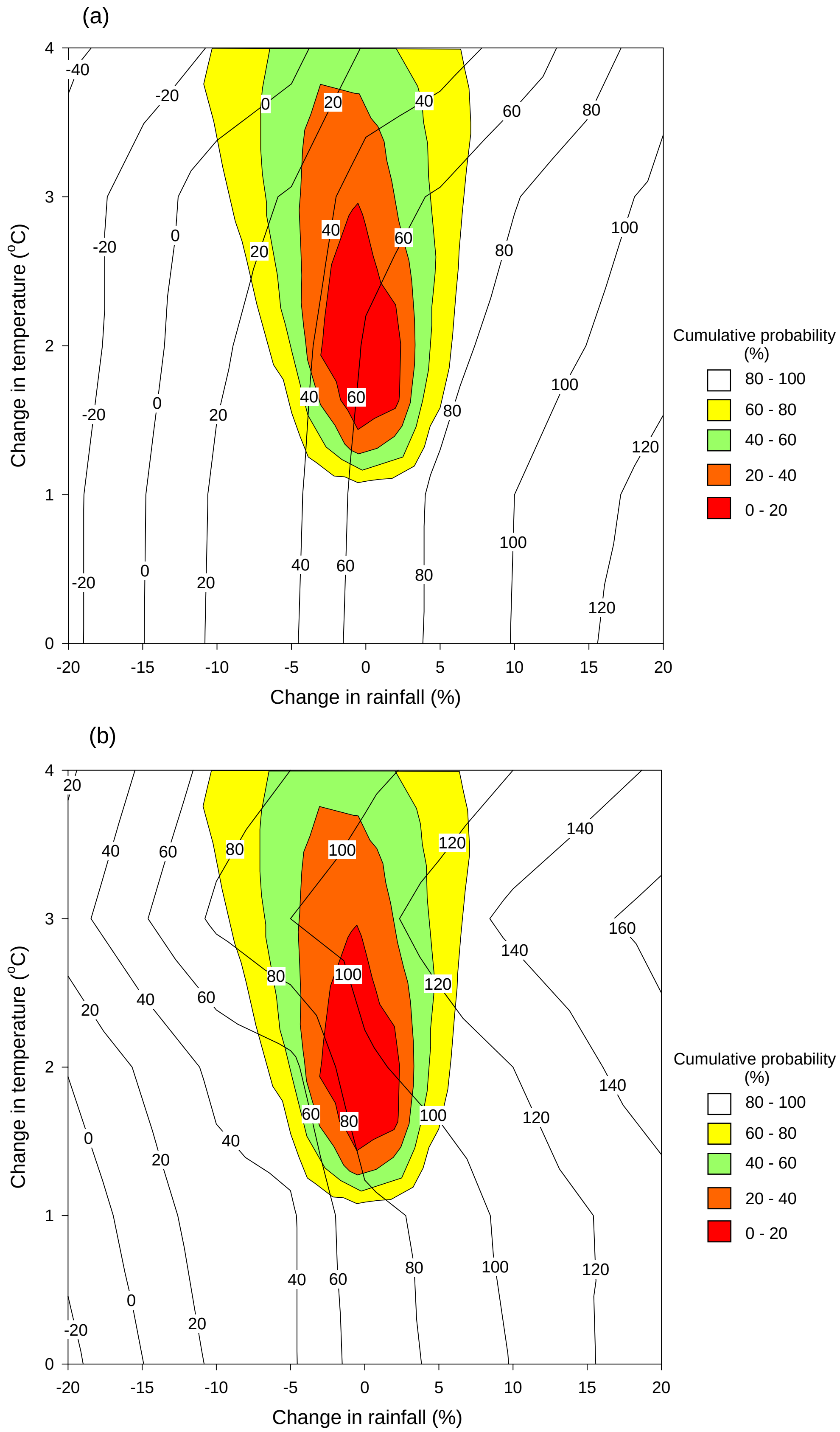


Figure 13.4: Emerald – Gross margin response (% change from baseline) to doubled CO_2 and a range of climate change scenarios with (a) current planting window and (b) modified planting window. The cumulative probability of climate change is shown in the shaded areas.

Forced Sowings

The frequency of years where the planting rules were not satisfied and ‘forced sowings’ occurred increased from 32% to 42% under the lowest rainfall scenario but was reduced to 25% under the highest (Table 13.4). The modified planting windows reduced the number of ‘forced sowings’

Table 13.4: Frequency of ‘forced sowings’(%) in Emerald under different rainfall and temperature scenarios

Rainfall Scenario (%)	Current Window	Modified Planting Window				
		0°C	1°C	2°C	3°C	4°C
-20	42	42	40	36	24	24
-10	37	37	36	30	21	21
-5	36	36	33	30	21	21
0	32	32	31	28	19	19
5	30	30	27	26	17	17
10	28	28	27	25	17	17
20	25	25	23	22	14	14

14 Aggregated Results

Yields

Table 14.1: Mean yield response (% change from baseline) to doubled CO_2 (700ppm) and 'most likely' climate change (ie the area of the response surface with the highest probability density) based on CSIRO 1996 climate change scenarios.

	Double CO_2 Only	**'Most likely' Climate Change** Current window	Modified window
Geraldton	27	15	-
Wongan Hills	31	21	32
Katanning	26	37	45
Minnipa	24	14	-
Horsham	18	17	23
Wagga	5	9	13
Dubbo	19	22	27
Moree	33	23	32
Dalby	37	25	32
Burenda	50	37	46
Emerald	43	30	37

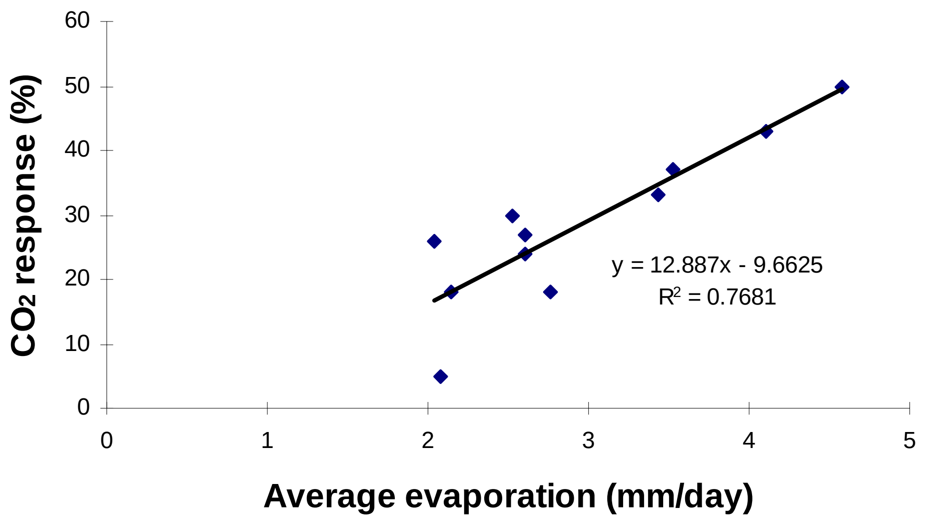


Figure 14.1: Mean yield response (% change from baseline) for the 11 sites compared with average daily evaporation thorough the vegetative growth stage of the wheat.

Adaptation

Varieties

As a general rule the 'optimum' yielding varieties switched from the faster to slower maturing varieties as temperature and rainfall increased. The importance of the slower maturing varieties increased with the modification of the planting window.

Modification of planting window

Modifying the planting window resulted in higher yields than using the current planting window (Table 14.1).

Scaling Up

Table 14.2: Australian wheat production ('000 t) by State during the period 1986-1996 compared with mean yields simulated under doubled CO_2 (700ppm) for the existing wheat belt areas (ie this assumes no increase in the area of wheat production under global change). NSW includes ACT and Victoria includes Tasmania.

	Baseline ('000 t)	**CO_2** ('000 t)	**Difference** ('000 t)	(%)
Queensland	960	1332	372	39
New South Wales	3878	4561	683	18
Victoria	1842	2169	328	18
South Australia	2067	2560	493	24
Western Australia	5338	6854	1516	28
TOTAL	14085	17477	3392	**24**

Table 14.3: Change in Australian wheat production ('000 t) by State with doubled CO_2 (700ppm) and the 'most likely' climate change based on CSIRO 1996 climate change scenarios when compared with current (1986-1996) production. Scenarios included either existing planting windows or modified planting windows. The analysis extrapolates changes in yield from the existing wheat cropping areas only. NSW includes ACT and Victoria includes Tasmania.

	Current Window		**Modified Window**	
	('000 t)	(%)	('000 t)	(%)
Queensland	253	26	320	33
New South Wales	694	18	912	24
Victoria	313	17	423	23
South Australia	289	14	289	14
Western Australia	1334	25	1762	33
TOTAL	2883	**20**	3706	**26**

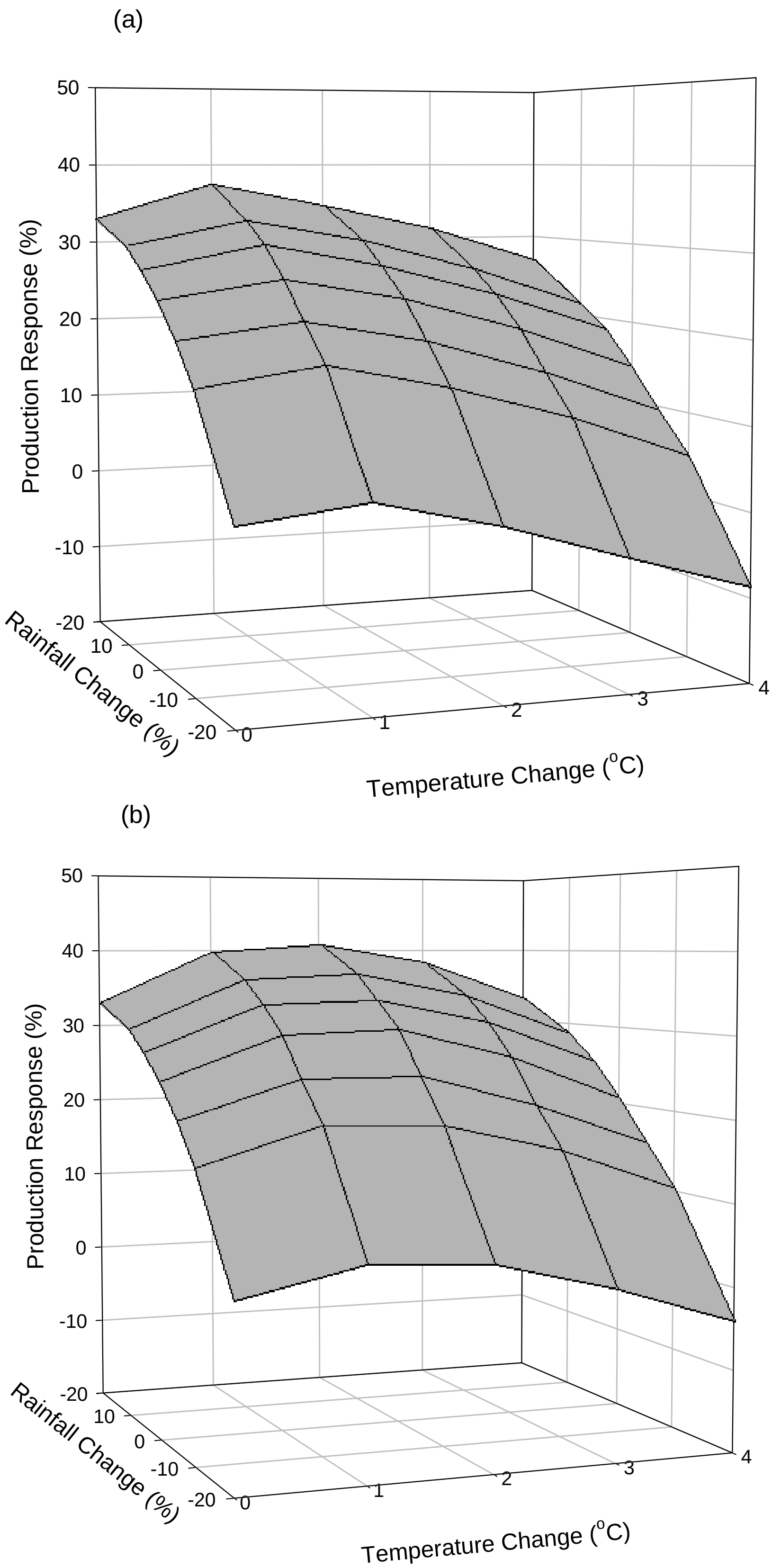


Figure 14.2: Effect of doubling CO_2 (700ppm) and a range of climate change scenarios on mean Australian wheat production (% change from 1986-1996 baseline) with (a) current planting window and (b) modified planting window. The analysis assumes no change in the area of wheat production under global change.

Aggregate national wheat production under doubled CO_2 (700ppm) was simulated to increase slightly with 1^{o}C warming and then decline when varietal adaptation was used with the current planting window. Adoption of earlier planting windows with climate change resulted in the yield plateau extending by 2^{o}C before declining. The scaling up was based on existing cropping areas, however, expansion of cropping into the drier margins may occur thus expanding the cropping zone and thus national yields. An opposing factor is that increases in areas affected by land degradation may result in removal of areas currently cropped thus tending to reduce national yields.

Grain Nitrogen

Table 14.4: Grain nitrogen response (% change from baseline) to doubled CO_2 (700ppm) and 'most likely' climate change based on CSIRO 1996 climate change scenarios.

	Double CO_2 Only	**'Most likely' Climate Change**	
		Current window	Modified window
Geraldton	-15	-11	-
Wongan Hills	-14	-10	-14
Katanning	-14	-8	-10
Minnipa	-13	-5	-
Horsham	-14	-6	-11
Wagga	-10	-7	-9
Dubbo	-12	-9	-13
Moree	-9	-4	-7
Dalby	-10	-8	-11
Burenda	-11	-6	-6
Emerald	-11	-9	-10

Gross Margins

Table 14.5: Gross margin response (% change from baseline) to doubled CO_2 (700ppm) and 'most likely' climate change based on CSIRO 1996 climate change scenarios.

	Double CO_2 Only	**'Most likely' Climate Change**	
		Current window	Modified window
Geraldton	19	5	-
Wongan Hills	32	20	45
Katanning	23	50	80
Minnipa	33	17	-
Horsham	8	17	28
Wagga	6	5	39
Dubbo	11	22	40
Moree	26	26	40
Dalby	31	30	40
Burenda	80	75	100
Emerald	70	60	95

Heat Shock

For sites where the risk of heat shock was currently less than 10% (Geraldton, Wongan Hills, Katanning, Minnipa, Horsham, Wagga and Dubbo) there was generally no increase in risk with the 'most likely' climate changes scenarios and in some instances there was even a reduction in risk due to anthesis occurring earlier in the cooler months due to more rapid crop development with increased temperatures or earlier planting with modified planting windows. The risk of heat shock increased significantly under the 'most likely' climate change scenarios for sites which currently have a greater than 10% risk of heat shock (ie. Moree, Dalby, Burenda and Emerald). Modifying the planting window did moderate the increase in risk although in all cases the risk remained higher than the current climate scenario.

15 Discussion

Yields

Doubling of CO_2 concentration to 700ppm without climate change was simulated to increase yield within the current wheat belt by 5 to 43% compared with the simulated 100-year historical mean. Yields were increased from 0.85 t/ha to 1.3 t/ha (50% increase) at the Burenda site in south-western Queensland outside the current wheat belt. The relative increase was least at sites where evaporative demand and hence soil moisture stress was least and tended to be greater at drier and warmer sites as found in experimental situations (eg Gifford 1979, Kimball *et al.* 1995). The site results were consistent with previous assessments where they have been made (Wang *et al.* 1992).

Thus there is a possibility that cropping can continue to expand into drier margins where soils are suitable as it has over the past decades (eg Hammer *et al.* 1987, Verrell and O'Brien 1996). The geographical extent of this expansion could be very considerable with sites such as Burenda perhaps forming the new margins to cropping provided that climate changes are not substantially negative (Reyenga *et al.* 1998, 1999a). However, at a national level the increase in cropped area may be only moderate as in many regions the soils beyond the current dry margins of cropping are generally unsuitable (eg Reyenga *et al* 1998, 1999a). Changes in landuse from grazing to cropping could also occur on the wetter margins due to alterations in the relative productivity of the two industries with global change (Howden *et al.* 1999). Changes in landuse of these types at either margin will have impacts on many factors including regional viability, degradation issues, rural infrastructure requirements and biodiversity. They are also likely to be associated with major emissions of greenhouse gases arising from land-clearing, loss of perennial grass biomass and soil carbon loss.

Adaptations

Under the 'most likely' climate change (derived from probabilistic assessment of the CSIRO 1996 scenarios) combined with doubling of CO_2, yields increased by 9-37% when planting practices were maintained as at present. However temperature increases are likely to result in a reduction in the duration of the annual frost period, thus allowing earlier planting in some sites. Modifying the planting window to take advantage of this opportunity resulted in yield increases of 13-46% when compared with simulated 100-year historical baseline yields. Key varietal adaptations in response to changing conditions are a switch from fast-maturing to slower maturing varieties particularly with increased temperature and rainfall and under the modified planting windows. Systematic analysis of the full range of phenological development stages, such as the approach developed by Wang and Connor (1996) could be used to further investigate the phenological characteristics required to optimise yield responses.

Scaling Up Yields

When yields were scaled up across the continent based on currently cropped areas (mean of 1986-1996 values), doubling CO_2 increased national yields by 24% (3.4Mt) with the greatest increase in Queensland (39%) and least in NSW and Victoria (18%). If climate change was included in the assessment the yield changes were 20% using the current planting window or 26% if planting windows were modified (increases ranged from 14% in South Australia to 33% in Queensland and WA). This analysis suggests that this adaptation strategy alone is worth at least 1M tonnes wheat per year nationally; other adaptations such as choice of variety are already built into the analysis. This scaling up of yields is an underestimate of the possible change as it does not include the possible expansion of cropping areas as noted above (eg. Reyenga *et al* 1999a). However, there are likely to be opposing influences arising from potential increases in pest and disease incidence with global change (eg Sutherst 1995) and the substantial losses in productivity expected through continuing land degradation processes such as dryland salinity, soil structural decline and acidification. Elevated CO_2 is also likely to increase soil moisture content during the growing period, which in some environments may increase waterlogging hazard. These effects have not been included in this analysis.

Longer Term Responses

It is important to note that this is an analysis of one point in time (approximately year 2100 when CO_2 is anticipated to rise to 700ppm) and that the impacts on yields may differ both before and after this point. Analysis of this issue would require transient simulation runs which have not yet generally been made. A general response is developed instead which displays possible climate and CO_2 trajectories and their combined impact on yield (Fig 15.1).

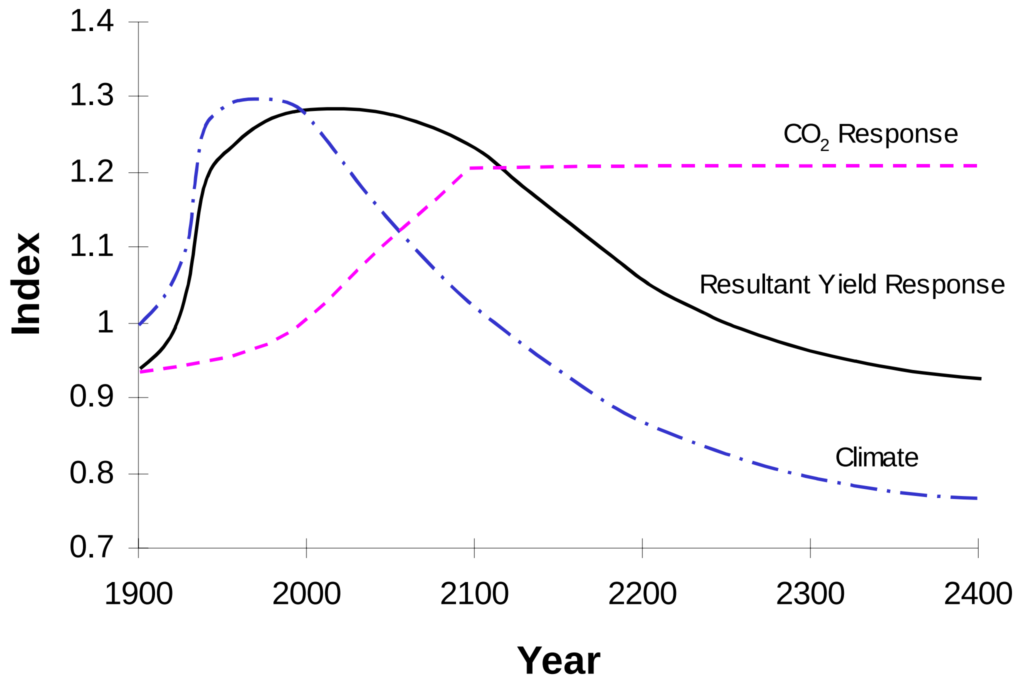


Figure 15.1: Conceptual long-term interactions between CO_2 (photosynthetic index current value = 1) and a climate change index. CO_2 levels follow historical trends to the current date with mid range IPCC scenarios to 2100 and stabilisation at 700ppm. The CO_2 response is a combination of this increase in CO_2 concentrations and the CO_2 photosynthetic response (Reyenga *et al*. 1999b). The resultant is the approximate change in yield due to the combination of CO_2 and climate impacts.

This general response is based on recorded historical changes in CO_2 and climate in Australia to which wheat yield changes are already attributed (Nicholls 1997) combined with future trajectories of impacts of CO_2 change (Houghton *et al.* 1996) and climate change (McKeon *et al.* 1999). The climate trajectory of increasing yields followed by decreasing yields is due to 1) temperatures being on-average sub-optimal during the historical period, with small rises in temperature increasing yield but warming greater than 1-2^{o}C decreasing yield (Figure 14.2) and 2) general increases in rainfall over the historical period observed (Suppiah and Hennessy 1998) and simulated (McKeon *et al.* 1999) but these steadily declining over time to be considerably below present values (McKeon *et al.* 1999). If these representations are adequate, then yields now (ie 1990s) through to the end of the next century are about as high as they are likely to get. This analysis is supported by a transient CO_2 long-term climate simulation running from 1736 onwards for Emerald, Queensland which shows a distinct upturn in yields over the past four decades with predicted yields in 2100 being slightly lower than those simulated in the 1990s (Howden *et al.* 1999b). Hence, it appears that the longer term implications (post 2100) are for declining yield.

A further caveat relating to long-term increases in yields relates to the approach used to represent climate changes. This results in maintenance of the current structure, variability and seasonality of the climate. However, there is a growing expectation that climate change will result in increased incidence of El Niño events (eg Meehl and Washington 1996, Wilson and Hunt 1997, Timmermann *et al.* 1999) which are known to adversely affect crop production, particularly in north-east Australia (eg Stone *et al.* 1993, 1996b). Whilst some of these effects will be accounted for in the rainfall scenarios, the detail will undoubtedly differ. Similarly, increases in rainfall intensity are widely anticipated with climate change (eg Whetton *et al.*1993) and would occur also with more frequent La Niña events (Timmermann *et al.* 1999). Increases in intensity of rainfall will increase erosion risks and are likely to result in hastened run-down of productive potential (Littleboy *et al.* 1992).

Grain Nitrogen

Whilst grain yields are generally simulated to increase over the next 100 years when compared with the historical mean, this is likely to occur at the cost of reducing grain protein (or nitrogen) contents (eg Rogers *et al.* 1996, Wolf 1996). Mean reductions in grain nitrogen of 9-15% with doubled CO_2 and 4-14% with CO_2 change and climate change are likely to be quite significant in downgrading grain quality (this represents a reduction in one to two quality classes). The simulations presented here all include fertiliser additions at the rate of 80kg N/ha/year - somewhat higher than recent regional norms (McLeish and Flavel 1996) but adequate to ensure that nitrogen inputs at least balance outgoings; a strategy now adopted by many farmers (Hayman and Alston 1999). To maintain grain nitrogen contents at simulated historical levels, there will be a need to increase application rates by 40 to 220 kg/ha depending on the future scenario (data to be presented in a later report). There could be significant environmental (eg river eutrophication) and financial costs associated with such increases. Furthermore, this could be a significant source of greenhouse gas emissions as production, packaging and distribution of nitrogenous fertiliser generates about 5.5 kg CO_2 per kg N (Leach 1976) and as increased application rates will increase emission of nitrous oxide (NGGIC 1996).

Gross Margins

Changes in gross margins were calculated from grain yields and nitrogen content. Doubling CO_2 by itself increased calculated gross margins by 6 to 70% in the existing wheat belt and by 80% at the Burenda site outside the existing wheat belt. Whilst this increase was largely driven by increases in mean yields, it was also due to a reduction in the coefficient of variation of yields by about 15 to 20% (data not shown) due to the buffering effect of high levels of CO_2 during dry years (Gifford 1979, Reyenga *et al.* 1999b). Modifying planting windows in combined CO_2/climate change scenarios had substantial benefits, with gross margin increases ranging from 28 to 95% in the current wheat belt whereas using the current planting window this range was 5 to 60%. In Burenda, outside the current wheat belt, there was a 100% increase in simulated gross margin compared with the historical record, changing gross margins from -$61/ha to $4/ha. Given these low returns, it is apparent that the relative costs of inputs and the prices received with be critical in determining the viability of cropping in this region.

However, all these gross margin calculations assume that wheat prices, the grain nitrogen/price relationship and input prices will be the same in the year 2100 as they currently are whereas it is obvious that these will vary. Several studies of the potential impacts of climate change on food supply have been made, mostly revolving around the comprehensive study of Rosenzweig *et al.* (1994). This study suggested prices in 2060 will increase by 10 to 100% compared with current prices if minor adaptation is globally adopted to -5 to 35% if major adaptation strategies are used, with the variation dependent on the climate change scenario. In all but one scenario they suggest that there will be an increasing imbalance between demand and supply of crop products leading to increases in the number of people at risk of hunger. This would suggest that the assumed prices received for Australian wheat cropping are likely to be conservative.

Heat Shock

Increased risk of heat shock in wheat grain with climate change has been raised as a concern (eg Blumenthal *et al.* 1991, Stone *et al.* 1996a). Heat shock occurs from high temperatures during early grain-filling and it can substantially reduce the doughmaking qualities of the grain. We undertook a risk assessment of heat shock incidence under all scenarios for all sites. For those sites where the risk of heat shock is already low (<10% chance of an event in any year), increased rates of crop development with warmer temperatures resulted in anthesis and maturity occurring earlier, in the cooler part of the year, resulting in no significant increase in heat shock risk. In some cases there was even a reduction in risk, particularly in the higher rainfall scenarios and where the planting window was brought forward. However, for Moree, Dalby, Burenda and Emerald where the risk of heat shock was already greater than 10%, increased rates of crop phenological development were not sufficient to counteract the effects of increases in numbers of days over the 32^{o}C threshold used. Without modification of planting windows, heat shock increased markedly, approximately doubling with the 4^{o}C warming scenario. Modifying the planting window enabled earlier sowings, offsetting some of the increased risk (range of 0 to 50% increase risk). At Burenda, even with planting window modification, there was a three-fold increase in heat shock risk with a 4^{o}C temperature rise, with about 38% of years likely to have at least one event. This would suggest that development of heat-tolerant varieties would be needed for this site to become a viable producer of high quality wheat.

16 References

Bates, B.C., Jakeman, A.J., Charles, S.P., Summer, N.R. and Flemming, P.M. (1996). Impacts of climate change on Australia's water resources. In: Bouma, W.J., Pearman, G.I. and Manning, M.R. (eds) *Greenhouse Coping with Climate Change,* CSIRO, Melbourne, pp. 248-262.

Blumenthal, C.S., Bekes, F., Batey, I.L., Wrigley, C.W., Moss, H.J., Mares, D.J. and Barlow, E.W.R. (1991). Interpretation of grain quality results from wheat variety trial with reference to high temperature stress. *Australian Journal of Agricultural Research* **43:**325-334.

Carter, J., Flood, N., Danaher, T., Hugman, P., Young, R. and others (1996) Development of data rasters for model inputs. Development of a National Drought Alert Strategic Information System, Vol. 3. Final Report to LWRRDC.

Cure, J.D. and Acock, A. (1986). Crop responses to carbon dioxide doubling: A literature survey. *Agricultural and Forest Meteorology*, **38**:127-145.

Gifford, R.M. (1979). Growth and yield of CO_2-enriched wheat under water-limited conditions. *Australian Journal of Plant Physiology* **6**, 367-378.

Hammer, G.L., Woodruff, D.R. and Robinson, J.B. (1987). Effects of climatic variability and possible climatic change on reliability of wheat cropping — A modelling approach. *Agricultural and Forest Meteorology,* **41**:123-143.

Hayman, P.T. and Alston, C.L. (1999). A survey of farmer practices and attitudes to nitrogen management in the northern New South Wales grain belt. *Australian Journal of Experimental Agriculture*, **39**:51-63.

Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell K. (eds) (1996). *Climate Change 1995. The Science of Climate Change*, IPCC 1996.

Howden, S.M., McKeon, G.M., Walker, L., Carter, J.O., Conroy, J.P., Day, K.A., Hall, W.B., Ash, A.J. and Ghannoum, O. (1999). Global change impacts on native pastures in south-east Queensland, Australia. *Environmental Modelling and Software*, **14**:307-316.

Howden, S.M., McKeon, G.M., Reyenga, P.J., Entel, M., Meinke, H and Flood, N. (1999b). Past and future competitiveness of wheat and beef cattle production in Emerald, NE Queensland. In: *MODSIM 99 Proceedings of the International Congress on Modelling and Simulation*, December 6-9 1997, Hamilton, New Zealand. (in press)

Jones, R.N. (1998). Climate change scenarios, impact thresholds and risk. In: *Proceedings of the Impacts of Global Change on Australian Temperate Forest Workshop*, Canberra, 25-27 February 1998, pp.14-28.

Kenny, G., Howden, S.M. and Aalbersberg, B. (1995). The impacts of climate change on agricultured in Oceania: A review and assessment of future research needs. *Asia Pacific Journal on Environment and Development*, **2**:1-29.

Kimball, B.A., Pinter, P.J., Garcia, R.L., La Morte, R.L., Wall, G.W., Hunsaker, D.J., Wechsung, G., Wechsung, F. and Kartschall, T. (1995). Productivity and water use of wheat under free-air CO_2 enrichment. *Global Change Biology,* **1**:429-442.

Leach, G. (1976). *Energy and Food Production*, IPC Science and Technology Press, Guildfor, Surry U.K.

McLeish, R. and Flavel, N. (1996). Managing the Liverpool Plains: 1995 survey. Liverpool Plains Land Management Committee, Gunnedah, Australia.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., Freebairn, D.M. (1996). APSIM: a novel software system for model development, model testing, and simulation in agricultural research. *Agricultural Systems,* **50**:255-271.

McKeon, G.M., Howden, S.M., Silburn, D.M., Carter, J.O., Clewett, J.F., Hammer, G.L., Johnston, P.W., Lloyd, P.L., Mott, J.J., Walker, B., Weston, E.J. and Wilcocks, J.R. (1988). The effect of climate change on crop and pastoral production in Queensland. In: Pearman, G.I. (ed) *Greenhouse: planning for climate change*. CSIRO, Melbourne, Australia. pp. 546-563.

McKeon, G.M., Hall, W.B., Carter J.O., Howden, S.M. and Crimp, S. (1999). Learning from history. Climate change in Australia's rangelands. Final report to the Australian Greenhouse Office. (in prep)

Meehl, G.A. and Washington, W.M. (1996). El Niño-like climate change in a model with increased atmospheric CO_2 concentrations. *Nature,* **382**:56-60.

Meinke, H., Hammer, G.L. Van Keulen, H. and Rabbinge, R. (1998). Improving wheat simulation capabilities in Australia from a cropping systems perspective III. The integrated wheat model (I_WHEAT). *European Journal of Agronomy,* **8**:101-116.

Morison, J.I.L. and Gifford, R.M. (1984). Plant growth and water use with limited water supply in high CO2 concentrations. II. Plant dry weight, partitioning and water use efficiency. *Australian Journal of Plant Physiology,* **11**:375-384.

NGGIC (1996). *National Greenhouse Gas Inventory 1996.* National Greenhouse Gas Inventory Committee, Canberra

Nicholls, N. (1997). Increased Australian wheat yield due to recent climate trends. *Nature* **387**, 484-485.

Reyenga, P.J., Howden, S.M., Meinke, H. and Hall, W.B. (1999a). Global change impacts on wheat production along an environmental gradient in South Australia. In: *MODSIM 99 Proceedings of the International Congress on Modelling and Simulation,* December 6-9 1997, Hamilton, New Zealand. (in press).

Reyenga, P.J., Howden, S.M., Meinke, H. and McKeon, G.M. (1999b). Modelling global change impacts on wheat cropping in south-east Queensland, Australia. *Environmental Modelling and Software,* **14**:297-306.

Reyenga, P.J., Howden S.M., Meinke, H. and Robinson, B. (1998). Global change impacts on the wheat 'cropping frontier' in northern New South Wales. *Climate Change Newsletter*, **10**(2):11-12.

Rogers, G.S., Milham, P.J., Gillings, M and Conry, J.P. (1996). Sink strength may be the key to growth and nitrogen response in N-deficient wheat at elevated CO_2. *Australian Journal of Plant Physiology*, **23**:253-264.

Rosenzweig, C. and Parry, M.L. (1994). Potential impacts of climate change on world food supply. *Nature*, **367**:133-138.

Semenov MA and Barrow EM (1997). Use of a stochastic weather generator in the development of climate change scenarios. *Climatic Change*, **35**:397-414

Stone, P.J., Nicolas, M.E. and Wardlaw, I.F. (1996a). The influence of recovery temperature on the effects of a brief heat shock on wheat. II. Fraction protein accumulation during grain growth. *Australian Journal of Plant Physiology* **23**:605-616.

Stone, R.C., Hammer, G.L. and Marcussen, T. (1996b). Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. *Nature* **384**:252-255.

Stone, R.C., Hammer, G.L. and Woodruff, D. (1993). Assessment of risk associated with climate prediction on management of wheat in north-eastern Australia. In: *Proceedings 7th Australian Agronomy Conference*, Adelaide. Pp. 174-177.

Suppiah, R. and Hennessy, K.J. (1998). Trends in total rainfall, heavy rain events and number of dry days in Australia, 1910-1990. *International Journal of Climatology*, **18**:1141-1164.

Sutherst, R.W. (ed) (1995). *Impacts of Climate Change on Pests, Diseases and Weeds in Australia. Report of an International Workshop, Brisbane 9-12 October 1995*, DEST, RIRDC.

Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M. and Roeckner, E. (1999). Increased El Niño frequency in a climate model forced by future greenhouse warming. *Nature*, **398**:694-697.

Verrell, A.G. and O'Brien, L. (1996). Wheat protein trends in northern and central NSW, 1958 to 19993. *Australian Journal of Agricultural Research*, 47:335-354.

Wang, Y.P. and Connor, D.J. (1996). Simulation of optimal development for spring wheat at two locations in southern Australia under present and changes climate conditions. *Agricultural and Forest Meteorology*, **79**:9-28.

Wang, Y.P., Handoko, Jr. and Rimmington, G.M. (1992). Sensitivity of wheat growth to increased air temperature for different scenarios of ambient CO_2 concentration and rainfall in Victoria, Australia — a simulation study. *Climate Research*, **2**:131-149.

Whetton, P.H., Fowler, A.M., Haylock, M.R. and Pittock, A.B. (1993). Implications of climate change due to the enhanced greenhouse effect on floods and droughts in Australia. *Climatic Change*, **25**(3/4):289-317.

Wilson, S.G. and Hunt, B.G. (1997). *Impact of Greenhouse warming on El Niño/Southern Oscillation behaviour in a high resolution Coupled Global Climate Model*. Report to the Department of Environment, Sport and Territories, Australia.

Wolf, J. (1996). Effects of nutrient supply (NPK) on spring wheat response to elevated atmospheric CO_2. *Plant and Soil*, **185**:113-123.

Appendix

Geraldton

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 3.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 2.5     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 68  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  =  100   200   200   200   200   200     ! layer depth mm soil
ll15    =  0.05  0.05  0.05  0.05  0.06  0.08    ! lower limit mm water/mm soil
dul     =  0.12  0.12  0.12  0.12  0.12  0.12    ! drained upper limit mm water/mm soil
sat     =  0.13  0.13  0.13  0.12  0.12  0.12    ! saturation mm water/mm soil
sw      =  0.10  0.10  0.10  0.10  0.10  0.10    ! initial soil water/mm soil
bd      =  1.30  1.30  1.40  1.40  1.50  1.60    ! bulk density gm dry soil/cc moist soil
swcon   =  0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry =  0.04  0.05  0.05  0.05  0.06  0.08    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   200   200   200   ! layer depth mm soil
oc      =    0.90  0.50  0.02  0.01  0.01  0.01 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    5.00  4.00  2.50  1.20  1.20  1.20 ! trt10 ppm nitrate
bd      =    1.30  1.30  1.40  1.40  1.50  1.60 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   11.6 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   19.4 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Quick

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -2.7 * day + 954
   man_phylo           = -0.6 * day + 176

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 20-apr
End planting window = 10-jul
rain required = 15 mm accumulated over 2 day
soil moisture required = 0%
dry down required = 1 days
```

Wongan Hill

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 3.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 2.5     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 68  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer =  100   200   200   200   200   200     ! layer depth mm soil
ll15   =  0.05  0.05  0.05  0.05  0.06  0.08    ! lower limit mm water/mm soil
dul    =  0.12  0.12  0.12  0.12  0.12  0.12    ! drained upper limit mm water/mm soil
sat    =  0.13  0.13  0.13  0.12  0.12  0.12    ! saturation mm water/mm soil
sw     =  0.10  0.10  0.10  0.10  0.10  0.10    ! initial soil water/mm soil
bd     =  1.30  1.30  1.40  1.40  1.50  1.60    ! bulk density gm dry soil/cc moist soil
swcon  =  0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry=  0.04  0.05  0.05  0.05  0.06  0.08    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   200   200   200    ! layer depth mm soil
oc      =    0.90  0.50  0.02  0.01  0.01  0.01 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    5.00  4.00  2.50  1.20  1.20  1.20 ! trt10 ppm nitrate
bd      =    1.30  1.30  1.40  1.40  1.50  1.60 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   13.3 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   17.9 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()   ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()   ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Quick

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -2.7 * day + 954
   man_phylo           = -0.6 * day + 176

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 20-apr
End planting window = 10-jul
rain required = 15 mm accumulated over 2 day
soil moisture required = 0%
dry down required = 1 days
```

Katanning

Soil Water Parameters

```
runoff_filename = blank
insoil        = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u             = 3.0     ! stage 1 soil evaporation coefficient (mm), guess
salb          = 0.13    ! bare soil albedo, guess
cona          = 2.5     ! guess
crop_cover    = 0.0     ! guess
diffus_const = 88.0     ! coeffs for dbar, guess
diffus_slope = 35.4     ! guess
cum_eos_max   = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare      = 68  ()! runoff curve number for BARE soil at AMC2
cn_red        = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov        = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   200   200   200   5     ! layer depth mm soil
ll15    = 0.06  0.06  0.06  0.06  0.08  0.12    ! lower limit mm water/mm soil
dul     = 0.12  0.12  0.12  0.12  0.12  0.13    ! drained upper limit mm water/mm soil
sat     = 0.13  0.13  0.13  0.12  0.12  0.13    ! saturation mm water/mm soil
sw      = 0.10  0.10  0.10  0.10  0.10  0.12    ! initial soil water/mm soil
bd      = 1.30  1.30  1.40  1.40  1.50  1.60    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.05  0.06  0.06  0.06  0.08  0.12    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   200   200    5    ! layer depth mm soil
oc      =    0.90  0.50  0.02  0.01  0.01  0.01 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    5.00  4.00  3.50  1.40  1.20  1.20 ! trt10 ppm nitrate
bd      =    1.30  1.30  1.40  1.40  1.50  1.60 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   12.0 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   15.9 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()   ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()   ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Quick

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -2.7 * day + 954
   man_phylo           = -0.6 * day + 176

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 20-apr
End planting window = 10-jul
rain required = 15 mm accumulated over 2 day
soil moisture required = 0%
dry down required = 1 days
```

Minnipa

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 3.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 2.5     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 68  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   200   200   200   5     ! layer depth mm soil
ll15    = 0.06  0.06  0.06  0.06  0.07  0.14    ! lower limit mm water/mm soil
dul     = 0.14  0.14  0.14  0.14  0.14  0.15    ! drained upper limit mm water/mm soil
sat     = 0.15  0.15  0.15  0.15  0.14  0.15    ! saturation mm water/mm soil
sw      = 0.11  0.11  0.11  0.11  0.11  0.14    ! initial soil water/mm soil
bd      = 1.30  1.30  1.40  1.40  1.50  1.60    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.05  0.06  0.06  0.06  0.07  0.14    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   200   200   5    ! layer depth mm soil
oc      =    0.90  0.50  0.02  0.01  0.01  0.01 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.30  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    2.00  1.50  1.10  1.00  0.90  0.60 ! trt10 ppm nitrate
bd      =    1.30  1.30  1.40  1.40  1.50  1.60 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   12.0 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   17.0 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Quick

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -2.7 * day + 954
   man_phylo           = -0.6 * day + 176

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 20-apr
End planting window = 10-jul
rain required = 10 mm accumulated over 1 day
soil moisture required = 0%
dry down required = 1 days
```

Horsham

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 3.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 2.5     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 83  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer =  100   200   200   300   300   300     ! layer depth mm soil
ll15   =  0.32  0.35  0.36  0.36  0.36  0.39    ! lower limit mm water/mm soil
dul    =  0.49  0.49  0.48  0.48  0.46  0.44    ! drained upper limit mm water/mm soil
sat    =  0.53  0.53  0.50  0.50  0.47  0.45    ! saturation mm water/mm soil
sw     =  0.39  0.39  0.38  0.38  0.38  0.40    ! initial soil water/mm soil
bd     =  1.20  1.25  1.30  1.30  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon  =  0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry=  0.26  0.33  0.36  0.36  0.36  0.39    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   300   300   300    ! layer depth mm soil
oc      =    2.20  2.00  1.00  0.50  0.20  0.20 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    10.00 8.00  6.00  3.00  2.00  1.50 ! trt10 ppm nitrate
bd      =    1.20  1.25  1.30  1.30  1.40  1.45 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   13.4 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   14.8 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 1-may
End planting window = 31-jul
rain required = <25-may 16 mm accumulated over 3 days
                >25-may 16 mm accumulated over 6 days
soil moisture required = 0%
dry down required = 3 days
```

Wagga Wagga

Soil Water Parameters

```
runoff_filename = blank
insoil        = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u             = 3.5     ! stage 1 soil evaporation coefficient (mm), guess
salb          = 0.13    ! bare soil albedo, guess
cona          = 2.5     ! guess
crop_cover    = 0.0     ! guess
diffus_const = 88.0     ! coeffs for dbar, guess
diffus_slope = 35.4     ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare      = 78  ()! runoff curve number for BARE soil at AMC2
cn_red        = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov        = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   200   300   300   300     ! layer depth mm soil
ll15    = 0.19  0.20  0.22  0.22  0.26  0.28    ! lower limit mm water/mm soil
dul     = 0.35  0.34  0.34  0.33  0.32  0.30    ! drained upper limit mm water/mm soil
sat     = 0.38  0.37  0.37  0.34  0.33  0.31    ! saturation mm water/mm soil
sw      = 0.28  0.27  0.27  0.27  0.27  0.29    ! initial soil water/mm soil
bd      = 1.25  1.30  1.35  1.35  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.15  0.19  0.22  0.22  0.26  0.28    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   300   300   300    ! layer depth mm soil
oc      =  1.00  0.60  0.10  0.05  0.02  0.02   ! organic carbon %
ph      =  7.00  7.00  7.00  7.00  7.00  7.00   ! default values
nh4ppm  =  1.00  0.50  0.30  0.20  0.20  0.20   ! ppm ammonia
no3ppm  =  4.00  3.00  2.00  0.70  0.40  0.30   ! trt10 ppm nitrate
bd      =  1.25  1.30  1.35  1.35  1.40  1.45   ! bulk density gm dry soil/cc moist soil
fbiom   =  0.05  0.02  0.01  0.01  0.01  0.01   ! default values
finert  =  0.35  0.40  0.50  0.70  0.90  0.90   ! default values

amp     =    16.0 ! temperature amplitude (oC) - difference between highest and
                  ! lowest mean monthly air temperatures, calc. from long. met
tav     =    15.4 ! mean annual air temperature (oC), calc. from long. met
dmod    =     1.0 ! weighting factor to adjust the rate of humus mineralization
                  ! for soils in which organic matter is chemically or
                  ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 530
   man_tt_sow2em       = 130
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 15-apr
End planting window = 1-aug
rain required = 25 mm accumulated over 2 days
soil moisture required = 0%
dry down required = 2 days
```

Dubbo

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 4.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 3.0     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 78  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   200   300   300   300     ! layer depth mm soil
ll15    = 0.19  0.20  0.22  0.22  0.26  0.28    ! lower limit mm water/mm soil
dul     = 0.35  0.34  0.34  0.33  0.32  0.30    ! drained upper limit mm water/mm soil
sat     = 0.38  0.37  0.37  0.34  0.33  0.31    ! saturation mm water/mm soil
sw      = 0.28  0.27  0.27  0.26  0.27  0.29    ! initial soil water/mm soil
bd      = 1.25  1.30  1.35  1.35  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.15  0.19  0.22  0.22  0.26  0.28    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   300   300   300    ! layer depth mm soil
oc      =    1.50  1.00  0.70  0.20  0.10  0.05 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    5.00  3.80  2.00  1.00  1.00  1.00 ! trt10 ppm nitrate
bd      =    1.25  1.30  1.35  1.35  1.40  1.45 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   15.9 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   17.2 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 595
   man_tt_sow2em       = 140
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 595
   man_tt_sow2em       = 140
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 1-may
End planting window = 1-aug
rain required = 25 mm accumulated over 2 days
soil moisture required = 30%
dry down required = 2 days
```

Moree

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 4.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 3.0     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 73  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   200   300   300   300     ! layer depth mm soil
ll15    = 0.27  0.30  0.33  0.36  0.38  0.40    ! lower limit mm water/mm soil
dul     = 0.50  0.50  0.48  0.48  0.46  0.42    ! drained upper limit mm water/mm soil
sat     = 0.53  0.53  0.51  0.50  0.47  0.43    ! saturation mm water/mm soil
sw      = 0.44  0.45  0.42  0.42  0.41  0.41    ! initial soil water/mm soil
bd      = 1.20  1.25  1.30  1.35  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.22  0.29  0.33  0.36  0.38  0.40    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   300   300   300    ! layer depth mm soil
oc      =    2.20  2.00  1.50  1.00  0.50  0.20 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    8.00  6.50  4.00  2.30  1.00  1.00 ! trt10 ppm nitrate
bd      =    1.20  1.25  1.30  1.35  1.40  1.45 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   14.9 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   18.4 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 660
   man_tt_sow2em       = 150
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 660
   man_tt_sow2em       = 150
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 10-may
End planting window = 1-aug
rain required = 25 mm accumulated over 2 days
soil moisture required = 30%
dry down required = 4 days
```

Burenda

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 4.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 3.5     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 73  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   100   300   200   200   100     ! layer depth mm soil
ll15    = 0.26  0.20  0.22  0.22  0.19  0.19    ! lower limit mm water/mm soil
dul     = 0.42  0.35  0.35  0.30  0.30  0.30    ! drained upper limit mm water/mm soil
sat     = 0.45  0.38  0.38  0.33  0.31  0.31    ! saturation mm water/mm soil
sw      = 0.36  0.30  0.29  0.24  0.24  0.24    ! initial soil water/mm soil
bd      = 0.91  1.27  1.30  1.35  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.12  0.12  0.12  0.12  0.12  0.12    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   100   300   200   200   100    ! layer depth mm soil
oc      =    0.60  0.50  0.40  0.40  0.30  0.20 ! organic carbon %
ph      =    7.80  7.80  7.80  7.80  7.80  7.80 ! default values
nh4ppm  =    0.27  0.13  0.08  0.08  0.12  0.20 ! ppm ammonia
no3ppm  =    8.00  6.00  2.80  0.92  0.60  1.00 ! trt10 ppm nitrate
bd      =    0.91  1.27  1.30  1.35  1.40  1.45 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values


amp     =   16.0 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   20.6 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 660
   man_tt_sow2em       = 150
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 660
   man_tt_sow2em       = 150
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5           = man_p5
   i_wheat.tt_sow2em    = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo        = man_phylo
endif
```

Planting Rules

```
Start planting window = 10-may
End planting window = 1-aug
rain required = 25 mm accumulated over 2 days
soil moisture required = 30%
```

dry down required = 4 days

Dalby

Soil Water Parameters

```
runoff_filename = blank
insoil       = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u            = 4.0     ! stage 1 soil evaporation coefficient (mm), guess
salb         = 0.13    ! bare soil albedo, guess
cona         = 3.5     ! guess
crop_cover   = 0.0     ! guess
diffus_const = 88.0    ! coeffs for dbar, guess
diffus_slope = 35.4    ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare     = 73  ()! runoff curve number for BARE soil at AMC2
cn_red       = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov       = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   200   300   300   300     ! layer depth mm soil
ll15    = 0.27  0.30  0.33  0.36  0.38  0.40    ! lower limit mm water/mm soil
dul     = 0.50  0.50  0.48  0.48  0.46  0.42    ! drained upper limit mm water/mm soil
sat     = 0.53  0.53  0.51  0.50  0.47  0.43    ! saturation mm water/mm soil
sw      = 0.44  0.45  0.42  0.42  0.41  0.41    ! initial soil water/mm soil
bd      = 1.20  1.25  1.30  1.35  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.22  0.29  0.33  0.36  0.38  0.40    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer      1     2     3     4     5     6
dlayer  =  100   200   200   300   300   300    ! layer depth mm soil
oc      =    2.20  2.00  1.50  1.00  0.50  0.20 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    1.00  0.50  0.30  0.20  0.20  0.20 ! ppm ammonia
no3ppm  =    8.00  6.50  4.00  2.30  1.00  1.00 ! trt10 ppm nitrate
bd      =    1.20  1.25  1.30  1.35  1.40  1.45 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   18.9 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   13.5 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   14.5 ! C:N ratio of soil, guess
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()  ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()  ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5              = 660
   man_tt_sow2em       = 150
   man_tt_em2endjuv    = -3.0 * day + 1060
   man_phylo           = -0.6 * day + 195

   i_wheat.p5            = man_p5
   i_wheat.tt_sow2em     = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo         = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5              = 660
   man_tt_sow2em       = 150
   man_tt_em2endjuv    = -3.3 * day + 1166
   man_phylo           = -0.7 * day + 215

   i_wheat.p5            = man_p5
   i_wheat.tt_sow2em     = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo         = man_phylo
endif
```

Planting Rules

```
Start planting window = 10-may
End planting window = 1-aug
rain required = 25 mm accumulated over 2 days
soil moisture required = 30%
dry down required = 4 days
```

Emerald

Soil Water Parameters

```
runoff_filename = blank
insoil        = 2.00    ! indicator for initial soil water (0=ll15, 1 = dul, >1 = input by
user)
u             = 5.0     ! stage 1 soil evaporation coefficient (mm), guess
salb          = 0.13    ! bare soil albedo, guess
cona          = 3.5     ! guess
crop_cover    = 0.0     ! guess
diffus_const = 88.0     ! coeffs for dbar, guess
diffus_slope = 35.4     ! guess
cum_eos_max  = 10 (mm) ! cumulative eos at which decomposition of surface residues cease (mm)
hydrol_effective_depth = 450 (mm) !
cn2_bare      = 73  ()! runoff curve number for BARE soil at AMC2
cn_red        = 20  ()! reduction in CN2 for "cn_cov" increase in cover
cn_cov        = 0.8 ()! frac. cover for "cn_red" reduction in cover & max. cover for reduction

!layer     1     2     3     4     5     6
dlayer  = 100   200   300   300   200   200     ! layer depth mm soil
ll15    = 0.30  0.33  0.35  0.37  0.38  0.40    ! lower limit mm water/mm soil
dul     = 0.50  0.50  0.48  0.48  0.46  0.42    ! drained upper limit mm water/mm soil
sat     = 0.53  0.53  0.51  0.50  0.47  0.43    ! saturation mm water/mm soil
sw      = 0.44  0.45  0.42  0.42  0.41  0.41    ! initial soil water/mm soil
bd      = 1.20  1.25  1.30  1.35  1.40  1.45    ! bulk density gm dry soil/cc moist soil
swcon   = 0.20  0.15  0.05  0.01  0.01  0.01    ! guess
air_dry = 0.24  0.31  0.35  0.37  0.38  0.40    ! airdry mm water/mm soil, guess
```

Soil Nitrogen Parameter

```
!layer     1     2     3     4     5     6
dlayer  =    100   200   300   300   200   200    ! layer depth mm soil
oc      =    2.20  2.00  1.50  1.00  0.50  0.20 ! organic carbon %
ph      =    7.00  7.00  7.00  7.00  7.00  7.00 ! default values
nh4ppm  =    0.25  0.13  0.07  0.05  0.05  0.05 ! ppm ammonia
no3ppm  =    2.00  1.25  0.75  0.60  0.25  0.25 ! trt10 ppm nitrate
bd      =    1.20  1.25  1.30  1.35  1.40  1.45 ! bulk density gm dry soil/cc moist soil
fbiom   =    0.05  0.02  0.01  0.01  0.01  0.01 ! default values
finert  =    0.35  0.40  0.50  0.70  0.90  0.90 ! default values

amp     =   12.2 ! temperature amplitude (oC) - difference between highest and
                 ! lowest mean monthly air temperatures, calc. from long. met
tav     =   21.4 ! mean annual air temperature (oC), calc. from long. met
dmod    =    1.0 ! weighting factor to adjust the rate of humus mineralization
                 ! for soils in which organic matter is chemically or
                 ! physically protected, guess
rt_fom  = 1000.0 ! root residues as biomass (kg/ha), guess
rt_cn   =   40.0 ! C:N ratio of root residues, guess
soil_cn =   11.7 ! C:N ratio of soil, guess was 14.5 in original noaa.sol SMH from Clarkson
root_cn =   40.0
root_wt =  100.0
enr_a_coeff = 7.4
enr_b_coeff = 0.2
profile_reduction = off
```

Residue Parameters

```
pot_decomp_rate   =    0.05  ()
residue_wt        =  500.0   ()   ! surface residues as biomass (kg/ha)
residue_cnr       =   80.0   ()   ! cn ratio of surface residues
residue_type      =  wheat
report_additions  =  yes
```

Varietal Strategies

Standard

```
if (sow_today = 1) then
   man_p5                = 660
   man_tt_sow2em         = 150
   man_tt_em2endjuv      = -3.0 * day + 1060
   man_phylo             = -0.6 * day + 195

   i_wheat.p5             = man_p5
   i_wheat.tt_sow2em      = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo          = man_phylo
endif
```

Slow

```
if (sow_today = 1) then
   man_p5                = 660
   man_tt_sow2em         = 150
   man_tt_em2endjuv      = -3.3 * day + 1166
   man_phylo             = -0.7 * day + 215

   i_wheat.p5             = man_p5
   i_wheat.tt_sow2em      = man_tt_sow2em
   i_wheat.tt_em2endjuv = man_tt_em2endjuv
   i_wheat.phylo          = man_phylo
endif
```

Planting Rules

```
Start planting window = 20-apr
End planting window = 10-jul
rain required = 25 mm accumulated over 2 days
soil moisture required = 30%
dry down required = 4 days
```