DEPARTMENT OF
PRIMARY INDUSTRIES

The Age, 18 March 1988

Climate change – Identifying the impacts on soil and soil health

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Project MIS No 06980

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Published by: Department of Primary Industries
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November 2007

Authorised by: Victorian Government
1 Treasury Place
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Acknowledgments

The following people made suggestions or contributions to this review.

Roger Armstrong
Alan Bedggood
Glenn Fitzgerald
Mark Imhof
Richard MacEwan
Bernard Noonan
Rob Norton
Garry O'Leary
Nathan Robinson
Jennifer Smith

Executive Summary

In response to the future climate change challenge, and in recognition of the critical role that healthy soils play in agricultural production and the production of ecosystem services, DPI's Future Farming Systems Research Division undertook a study to identify some of the potential impacts of climate change on soil health.

As there is little applied research related to this area, the perspectives presented in this report are based on a combination of a review of international literature, basic desktop analyses and expert opinion from leading soil scientists. The following observations therefore represent our current knowledge, but are subject to modification as further research is conducted and trends emerge.

Climate change and soil health in Victoria

Within Victoria, the effects of climate change will be most strongly felt as drier springs (up to 14% decrease in rainfall by 2030 and 40% decrease by 2070 compared with 1996) and hotter summers (up to 2.0°C increase in temperature by 2030 and 6.0°C increase by 2070 relative to 1996). The expected reduction in spring rainfall is most extreme across all the major land use zones examined, dryland cropping, dryland pasture and public land. In contrast the most extreme temperature forecasts for summer are restricted to the dryland cropping and public land regions. As a consequence:

- Soil carbon levels are expected to decrease due to decreased net primary production. Any gains by increased plant water use efficiency, due to elevated CO_2 are likely to be outweighed by increased carbon mineralization after episodic rainfall and reduced annual and growing season rainfall. The quality of soil organic matter may also shift where the more inert components of the carbon pool prevail.

- An increased risk of soil erosion and nutrient loss due to reduced vegetation cover in combination with episodic rainfall and greater wind intensities is expected.

- A shift in land suitability for farming due to greater significance of soil texture on plant/soil water dynamics and plant available water is likely.

- Transient salinity may increase. Transient salinity ncreases as capillary rise dominates, bringing salts into the root zone on sodic soils. Leaching during episodic rainfall events may be limited due to surface sealing. Increased subsoil drying increases concentration of salts in the soil solution. Conversely, the severity of saline scalds due to secondary salinisation may abate as groundwater levels fall in line with reduced rainfall.

- Water quality may be impacted by increased bush fire frequency and intensity. Fires will reduce ground cover and soil stability,

particularly in the sub-alpine regions, and increase risk of soil and nutrient export into waterways.

- Soil biology and microbial populations are expected to change under conditions of elevated CO_2 and changed moisture and temperature regimes. As soil biology regulates nutrient dynamics and many disease risks, nutrient availability to crops and pastures could change as could the exposure to soil-borne diseases.

Recommendations

For Victoria's agricultural production systems to be viable into the future there is a need to identify farming systems that are climate change compatible, where water efficient plant production compensates for less available water. This may require a shift in management practices within current farming systems as well as changes in the farming system/enterprise. Increasing crop adaptation may also be assisted by increasing drought tolerance of crop and pastures through genetic control, although this may be a less realistic option. Identifying and adopting use of species with current natural adaptation to drier conditions is likely to be more realistic option. By maintaining crop and pasture production, this ensures the supply of organic carbon to the soil and promotes soil health. In an environment with increased evaporative demands and less rainfall, there is the need to identify farming systems that uses water more efficiently for agricultural production, while reducing financial risk and crop failure.

The importance of maintaining groundcover to protect the soil from both water and wind erosion will be greater. However, the challenge of maintaining stubble or pasture over summer will also be exacerbated under climate change conditions, unless farming systems are radically changed.

The viability of shifting land use zones, given climate change, physiographic zones and soil type also needs consideration. If arid and semi-arid regions shift southward, then does this alter the current suitability of land use? Examining the suitability of current farming systems in regions where existing climatic zones and soil types are equivalent to that predicted by climate change will provide a demonstration of the impact of changing climate on current agricultural systems.

For zones that are becoming increasingly marginal for agricultural production, the risk of annual crop failure due to poor growing seasons will increase. One method for reducing risk and financial loss associated with crop failure is to reduce variable input costs. One avenue is to reduce the use of nitrogen fertiliser, where an alternative nitrogen supply may be derived from nitrogen fixing legumes or green manuring. These systems are also compatible with maintaining soil health through the enhancement of organic matter despite changing climatic conditions. Evaluating the value of pulse crops and legume pasture species under future greenhouse climate scenarios is also important, due to the potential effect of changed water conditions on nitrogen fixing capability of legumes.

Contents Page

1. Project Background

1.1 Project Context

The inevitable changes in climate resulting from the ‘greenhouse effect’ are expected to have a major impact Victoria’s agricultural sector. The economic viability and environmental amenity of these sectors depends heavily on ‘soil health’. In order to better predict the likely impact of climate change, a better understanding of how soil health will be affected is required. This information can be used to develop appropriate adaptation measures to reduce the economic, social and environmental impacts of climate change on Victoria.

1.2 Project Rationale

Greenhouse effect

The increasing concern around the greenhouse house effect over at least the last 20 years is related to the rapid increase in anthropogenic contribution of gases including carbon dioxide, methane and nitrous oxides to the atmosphere through global industry, the consumption of fossil fuels and land clearing. This increase in atmospheric gases is likely to induce rapid global warming. Global warming, although evident within paleo-climatic oscillations, is of current concern due to the rapid rate in which change is occurring. The rapid rate allows little time for equilibrium to be maintained within natural systems, thus threatening the stability of ecosystems globally. Humans depend on ecosystem services for their survival.

Emissions scenarios – IPCC

The level of global greenhouse gas emissions into the future is difficult to predict, as the level of emissions depend on future socio-economic evolution of the world population. In response to this dilemma, the Intergovernmental Panel on Climate Change (IPCC) has developed a set of scenarios which the human populaces may evolve and so influence climate change through different rates of the greenhouse gas emissions (Nakicenovic et al 2000). The scenarios are described by 4 main categories defined as A1, A2, B1 and B2 family lines. Of these the A1 family is further subdivided into 3 sub-groups A1F1, A1T and A1B. These scenarios are described in Table 1.1 and their projected impact on atmospheric CO_2 concentrations are defined in Fig 1.1.

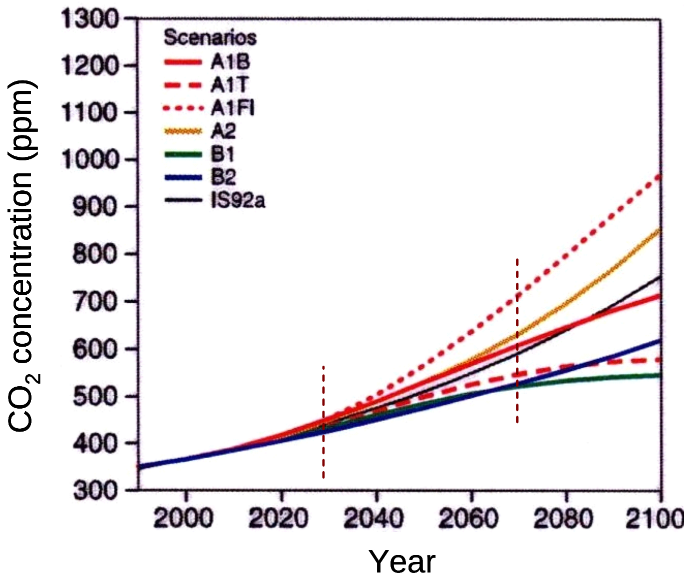


Figure 1.1 Projected atmospheric CO_2 concentration for 6 SRES scenarios and the IS92a for comparison (Albritton *et al* 2001)

The extreme scenario of A1F1 assumes little attempt is made by humanity to reduce the reliance on fossil fuels, although this scenario is considered unlikely, as government's world wide are considering the potential of alternative energy sources such as nuclear, solar and wind power generation. Recent information suggests that the rate of change is more rapid than that expected for even the worse case scenario. For the A1T scenario, it is probably unrealistic for this to occur within the next 90 years where there is negligible reliance on fossil fuels. If, at the end of this period, fossil fuels make up a small portion of energy production, the slow switch this century and the lag phase associated with CO_2 emission reduction means the A1T is unlikely to have large bearing on CO_2 emissions in the 21st century. The low emission potential scenario (B1), relies on reduction in industry and infrastructure to reduce CO_2 emissions. Industrialization in China and India is currently expanding at a rapid rate. China alone is currently commissioning two coal-fired power stations per week (Harrabin 2007) as this is currently the most cost effective source of power to service their growing industries. It is therefore unlikely that the global demand for energy derived from fossil fuels will abate in the near future.

Story line	Description	Emission Scenarios (A1 only)	Emission Potential
A1	The future world has strong economic growth, rapid development of efficient technologies. Global population peaks ca 2050 and then declines. There are increased social and cultural interactions across regions and reduced differences in per capita income. This social and commercial construct in supported by potentially one of three energy systems.	A1F1 Fossil fuel reliant.	High
		A1T Non-fossil fuel alternatives dominate.	Low
		A1B Both fossil fuel and alternative energy sources used.	Moderate
A2	The future world tends toward heterogeneity, where countries place emphasis on self reliance. Global technological advances and economic growth variable and is not as rapid as other story lines. Global population gradually increases indefinitely.		High
B1	The future global population peaks ca 2050 and then declines, and there is increased social and cultural interaction, similar to that defined by A1 storyline. In contrast, however, there is reduction in industry/ infrastructure. Economic wealth is generated from service and information technologies.		Low
B2	The future world tends towards heterogeneity where self reliance creates modest economic growth. Shift in technological emphasis is greater than A1 and B1 where focus is on social and environmental sustainability. Global population growth is continuous, however, at a rate less than A2.		Moderate

Table 1.1 Description of the SRES story lines and 6 emission scenarios.

The A1B and B2, are classed as having moderate future emissions potential, where A1B is most concordant with the previously defined mid-case scenario, ISA92a, used by the IPCC in 1996. The estimated CO_2 emissions and resultant atmospheric concentrations for the ISA92a scenario are summarised in Table 1.2. Expected global temperature increases are also defined.

	present	2030	2070
CO_2 emissions (Gt/year)	9	13	17
CO_2 concentration (ppm)	370	425	590
Temperature increase (°C)	N/A	0.8	2.5

Table 1.2 Estimated CO_2 emissions and concentration for 2030 and 2070, using the IS92a mid-case scenario. Median global temperature increase is also defined, relative to the present (1996).

Impact of climate change
The impact of climate change is usually considered in terms of direct effects on society and infrastructure, such as threat of rising sea level on coastal occupation or changes in climate conditions on living standards. Climate change will also indirectly impact on society by altering the stability of many ecosystems, both natural and agricultural. One important example is the impact climate change will have on soil stability. If water availability, atmospheric CO_2 and temperature rapidly change then the soil processes that underpin biological systems (both agricultural and natural) will also change. These changes are likely to impact on soil health and ecosystem services provided by soil as well as on the economic viability of many agricultural systems.

Soil quality

'Soil quality' and 'soil health' have been extensively defined but remain difficult to measure in reality. Many descriptions encapsulate the soil through its function or its perceived goodness. The Soil Science Society of America (SSSA) defines soil quality as:
"The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water quality, and support human health and habitation" (Allan *et al* 1995).

Soil quality is considered in terms of function around ecological and human activity. Doran and Safley (1997) identified 6 main ecosystem service functions of soil: i) biomass production, ii) medium which filters, buffers, transforms matter to protect environment and ground water, iii) biological habitat and genetic reserve for flora and fauna, iv) physical medium to support infra structure, v) source of raw material and vi) cultural heritage. For each of these 6 functions, key attributes of the soil will determine its applicability to that function. It these attributes alter due to human activity then a shift in soil health has occurred.

In considering the interplay between soil quality and soil health the Victorian Department of Primary Industries has adopted the following definitions after MacEwan (2007). "Soil quality is the capacity of soils within landscapes to sustain biological productivity, maintain environmental quality, and promote plant and animal health whereas soil health is the condition of the soil in relation to its inherent, or potential capability, to sustain biological productivity, maintain environmental quality, and promote plant and animal health." Readers are directed to MacEwan (2007) for detailed consideration of soil health in the context of Victorian Agriculture.

'Soil quality' could, in part, be viewed as a static (qualitative) measure of the capability of soil, where as 'soil health' infers a dynamic state, where human impact causes a shift in quality. There are numerous potential indicators of soil quality/health. These indicators can be categorised broadly as visual (eg runoff, plant response, weed species), physical (eg topsoil depth, bulk density, aggregate stability, crusting, compaction), chemical (eg pH, salinity, organic matter action exchange capacity, contaminant concentrations) and biological (eg activity of micro- macro-organisms) indicators (Muckel & Mausbach 1996).

Soil health and climate change

Of the range of potential indicators used to infer soil health status, soil carbon is particularly important (Burke et al 1989, Dalal & Chan 2001). Organic matter is vital because it supports many soil processes that are associated with fertility and physical stability of soil across the various ecosystem services. In particular organic matter provides an energy source for microbes, structurally stabilizes soil particles, stores and supplied plant essential nutrients such as nitrogen, phosphorus and sulphur and provides cation/anion exchange for retention of ions and nutrients (Muckel & Mausbach 1996). Carbon within the terrestrial biosphere can also behave as either a source or sink for atmospheric CO_2 depending on land management, thus potentially mitigating or accelerating the greenhouse effect (Lal 2004). Cycling of soil organic carbon is also strongly influenced by moisture and temperature, two factors which are predicted to change under global warming. Overall, climate change will shift the equilibrium, both directly and indirectly of numerous soil processes. These include carbon and nitrogen cycling, acidification, risk of erosion, salinisation, all of which will impact on soil health.

1.3 Objectives

This report reviews the climate changes predicted across Victoria by climate models and the impacts these changes have on soil processes and soil health in Victoria. The study focuses on 3 particular land uses within Victoria, dryland cropping, dryland pasture and public land. It also identifies particular knowledge gaps that may affect these predictions.

1.4 Methods

Predictions of future climatic conditions across Victoria were based on Whettin *et al* (2002). This report was undertaken by the Victorian Department of Natural Resources and Environment and by the Climate Impact Group, CSIRO Atmospheric Research. The high resolution assessment of Victoria uses the CSIRO DARLEM model and the assumptions of CO_2 emissions and concentrations from the IS92a mid-case scenario used by the IPCC in 1996. Although this report does not contain more recent scenarios for climate change across Australia, the format was most accessible for the purpose of the current report. The broad seasonal trends in climate change defined in Whettin *et al* (2002) provided sufficient information against which to gauge soil processes that may be affected by climate change.

Land use zones of Victoria were resolved to coincide with the pixel size of the CSIRO high resolution regional assessment model (DARLAM) at a pixel resolution of 60 × 60 km. This allowed cross referencing between temperature, rainfall and water-use predictions (Whettin *et al* 2002) and land-use zones within Victoria, where information on the severity of climate change impact on each land-use zone within Victoria could be assessed.

For predicted temperature shifts, change was divided into 3 classes (2030: low 0.2 to 1.4°C, medium 0.3 to 1.7°C and high 0.3 to 2.0°C and for 2070: low 0.7 to 4.3°C, medium 0.8 to 5.2°C and high 0.8 to 6.0°C). These represent average daily temperature; however increases in daily maximums and minimums are estimated to be equivalent. For rainfall predictions seven classes, (Whettin *et al* 2002) were condensed into four, where two mid-case scenarios were combined and the 3 ‘unknown’ categories were pooled into a single class, (2030: dry: -14 to 7%; drier: -13 to 3%; driest: -14 to -3% and for 2070: dry: -40 to 25%; drier: -30 to 5%; driest: -40 to -10% and unknown). These values represent percent changes in average seasonal precipitation.

Estimates of annual water balance based on changes in temperature and rainfall are also defined, and were categorised into one of two classes, -

160 to -80 mm/°C increase and -80 to -40 mm/°C increase (Whetton *et al* 2002). Annual water balance integrates the net effect of increasing surface evaporation due to higher temperatures and potential deficits in rainfall where the combination of these factors reduce available water for use by plants, animals, soil water accruement and runoff to catchments. Water balance in express as mm of water lost from the system per degree Celsius increase in temperature (mm/°C). For this report we also calculated annual water balance decrease (mm), using predicted annual temperature changes and water balance values, where best and worse case scenarios define the range in possible outcomes for 2030 and 2070.

In addition to the desktop study detailed above, a review of the literature was also conducted. A summary of the potential impact of climate change on soil processes and soil health, as identified by the literature, is presented in the Appendix.

2. Results and Discussion

Climate change within Victoria

Within Victoria, it is projected that temperature and rainfall pattern will be significantly altered by the greenhouse effect. On average, temperatures over the state are estimated to rise by between 0.3 - 1.5°C by 2030 and 0.8 - 4.7°C by 2070 (Whettin *et al* 2002). These increases will not be uniform, with temperature increases being greater in the north of the state. There is less certainty for predictions of future rainfall. The average annual rainfall is estimated to change between -9% and +3% in 2030 and between -25% and +9% in 2070.

Victoria land use zones

Victoria's land use was split into 3 major categories; dryland cropping (26%), dryland pasture (32%) and public land (37%). The remaining 5% incorporates urban and agricultural irrigation districts (Victorian Resources Online Department of Primary Industries (www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome)). We converted the continuous land use boundaries to pixel elements equivalent to that generated by DARLEM (Chang 2006). Although substantial aliasing occurs for land use zone at this scale, adequate definition existed to define the main land use regions within Victoria (Fig 2.1).

Dryland cropping occurs predominantly in the north-western portion of the state (Wimmera and Mallee) where the climate is arid and semi-arid. Dryland pasture is largely restricted to the south-western part of the state (Western District), east of Melbourne (Gippsland) and also the central part of Victoria, north of Melbourne. Public land is concentrated mainly in two areas; the largest being in the Victorian uplands in the eastern portion of the state, which incorporate the sub-alpine region and in the north-west of the state, the aeolian tongues of sand which form the Wyperfield and Sunset National Parks.

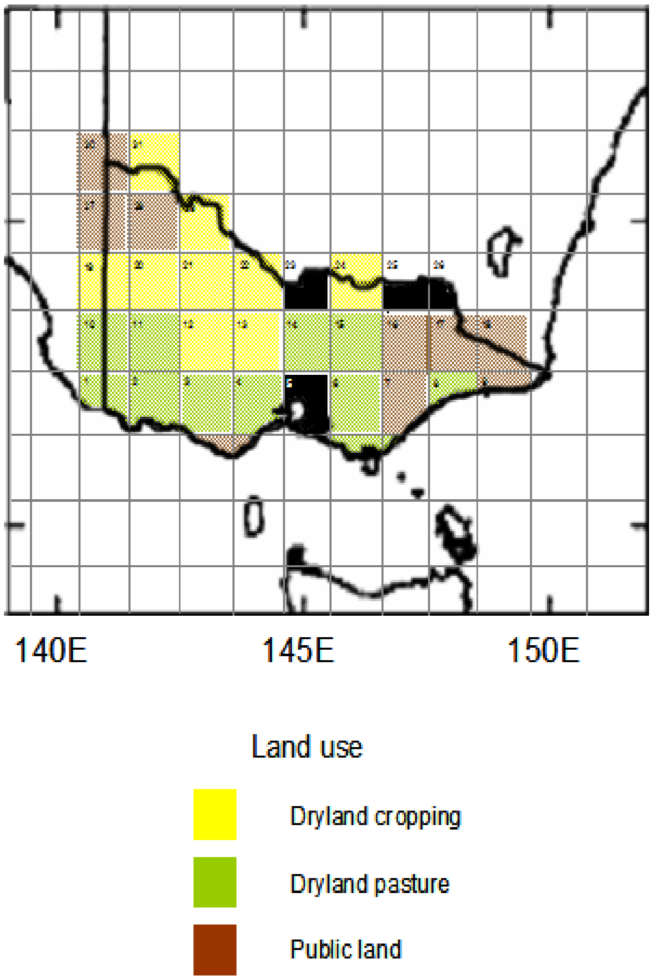


Figure 2.1 Land use zones for Victoria, Australia. Zones have been resolved to coincide with pixel size (60 × 60 km) of the CSIRO high resolution regional assessment model (DARLAM) for estimating climate change. Land use zones have been determined from Department of Primary Industries, Victoria Resources Online maps. (www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome).

Physiographic regions

For Victoria, each of the land use zones cut across various physiographic regions, thus the impact of climate change on soil health depends on the combined effects of land use and physiographic characteristics.

Physiographic zones are bound by the surficial features that define the landscape. Variation in physiographic units is largely due to geologic control, where the slope and elevation are important factors affecting landscape evolution through geomorphic processes. For Victoria eight physiographic regions are defined (Fig 2.2). Definitions are based on descriptions sourced from the Victorian Resources Online Department of Primary Industries (www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome).

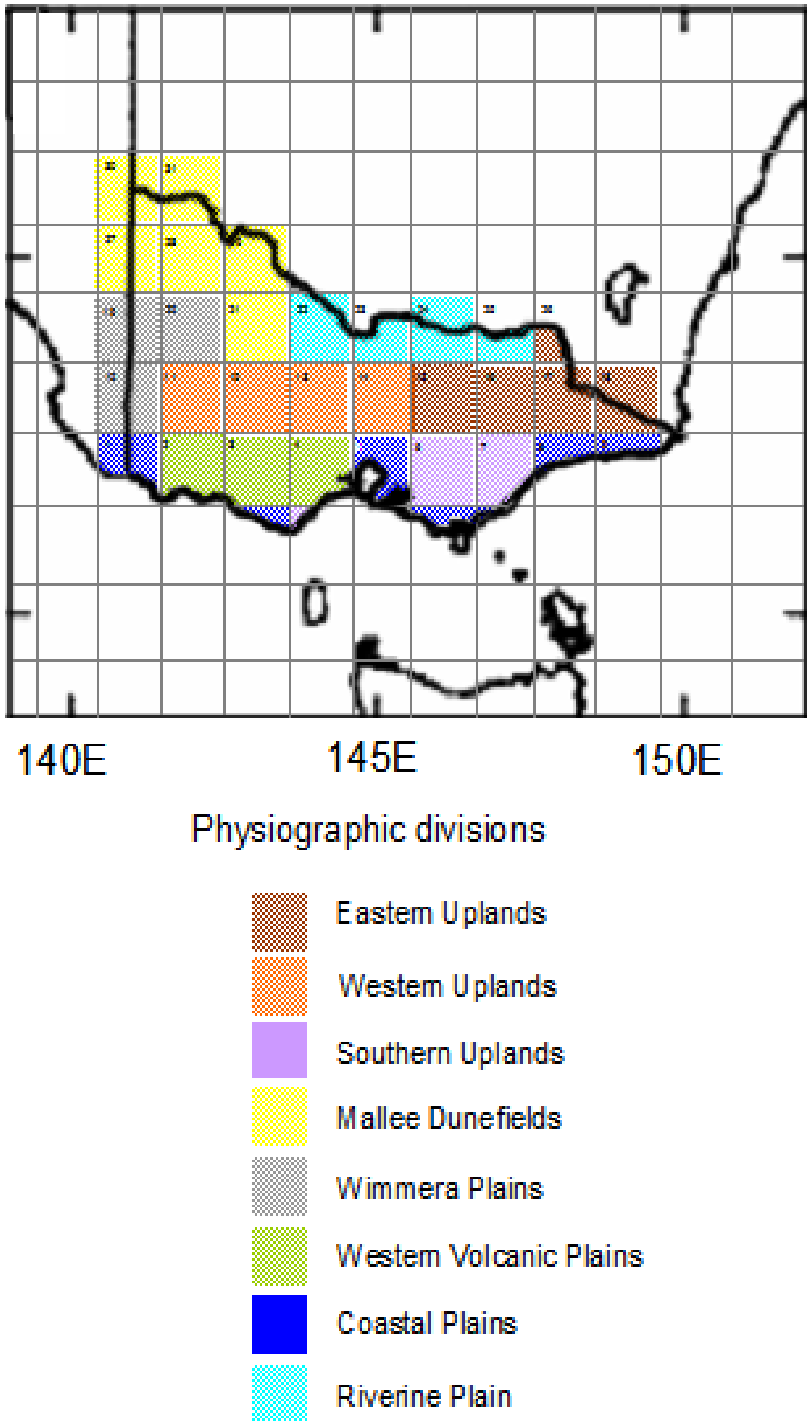


Figure 2.2 Physiographic divisions of Victoria, Australia. Zones have been resolved to coincide with pixel size of the CSIRO high resolution regional assessment model (DARLAM) for estimating climate change. Physiographic divisions are sourced from: Victorian Resources Online (www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/vrohome).

1.) Eastern Uplands – are characterised by rugged, highly dissected terrain and incorporate all of the land above 1220 metres which comprise the sub-alpine regions. During winter the mountain peaks are snow covered and snow prevails for around four months each year. The eastern uplands provide the catchments for major tributaries that feed south to Gippsland and north to the Murray River.

2.) Western Uplands – are part of the same mountain belt at the eastern uplands, however, are less elevated and not as rugged. The landscape is characterised by undulating hills.

3.) Southern Uplands – The Otway Ranges, west of Melbourne and the Strzelecki Ranges east of Melbourne constitute a highly dissected undulating terrain that was formed by geologic uplifting processes.

4.) Riverine plain – constitutes a large alluvial plain, where sediment was derived from the Victorian Highlands. The landscape is flat and low relief ranging 50 to 200 m above sea level and is dissected by the Goulburn, Campaspe, Loddon and Avoca rivers, which flow northwards into the Murray River.

5.) Mallee Dunefield – is a region that is encompassed by the Murray-Darling basin and was formed by consecutive phases of alluvial, marine, lucustrine and aeolian conditions. The current landscape is defined by a combination of smaller east-west sand dunes formed by recent aeolian processes, although strand line ridges which were formed by retreating oceans (4 million years) remain as permanent features on today's landscape as ridges running NNW-SSW. This region is arid to semi-arid.

6.) Wimmera Plains – are positioned in the southern portion of the Murray Darling basin and share a similar geological history to the Mallee dune fields. In contrast, however, is the current land surface which is a flat terrain covered dominantly by aeolian derived clays.

7.) Western Volcanic plains – Tertiary volcanics have formed the low relief plains west of Melbourne which are confined by the Otway Ranges in the south and western Highlands in the north. Numerous volcanic vents form low relief hills across the landscape.

8.) Coastal plains are low relief regions confined to the Victorian coast line. They constitute a combination of marine sediments and alluvial and aeolian deposits.

For this report, these eight physiographic units have been condensed into 3 classes, related to terrain. The uplands include the physiographic divisions that have rugged or steeply dissected terrain (Eastern, Western and Southern uplands). In contrast, the Riverine, Wimmera and Coastal plains have been grouped based on flat or low relief and the Mallee dune fields fall into a distinct category, defined by a low undulating land surface. For these physiographic classes, dryland cropping and pastures are confined largely to the plains, where as public land occurs either within the uplands or dune fields (Table 2.1).

Land use (%)	Uplands	Plains	Dune fields
Dryland crop	20	50	30
Dryland pasture	38	64	0
Public land	44	22	33

Table 2.1 Distribution of land use across 3 physiographic classes.

In terms of climate change, these physiographic divisions provide an important division in determining the impact of climate change on soil. For example, different physiographic zones will have varying erosion risk. If increased episodic rainfall events due to climate change occur, there may be increased risk of soil erosion by water on a highly dissected terrain, whereas for plains this may not be the case. Alternatively, higher wind speeds may increase the risk of wind erosion of fine soils on plain country.

Climate change over land use zones
Dryland cropping
Summer months (December to February) are going to become substantially hotter within the cropping zone across Victoria (Fig 2.3). It is estimated 70% of this zone will be exposed to 0.3 to 2.0°C increased by 2030 and 0.8 to 6.0°C increases by 2070. It is likely that the autumn and winter seasons will experience only minor impact with projected temperature increases of 0.2 to 1.4°C and 0.7 to 4.3°C by 2030 and 2070 respectively.

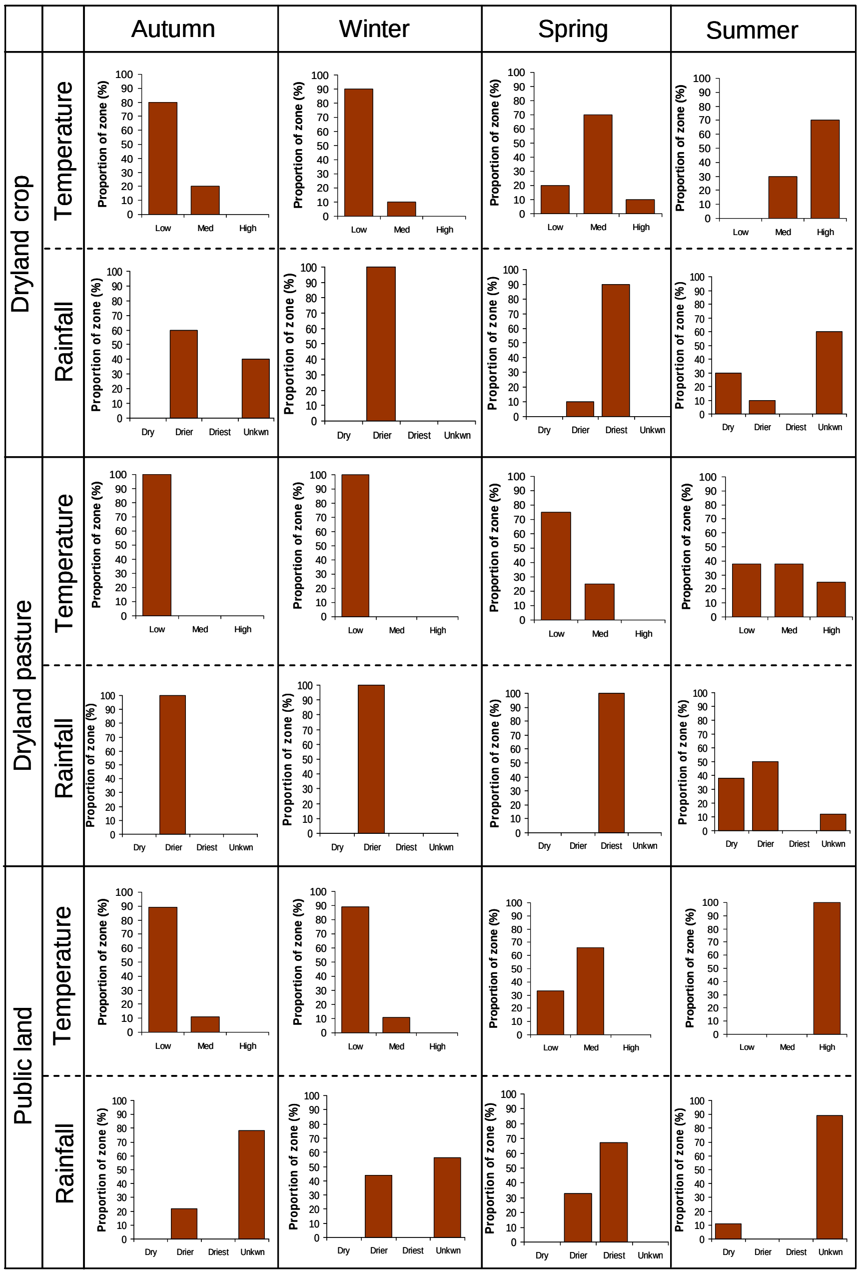


Figure 2.3 Projected changes in seasonal temperature and rainfall relative to 1996 for three land use zones in Victoria under the IS92a scenario. Temperature increase by 2030; low: 0.2 to 1.4°C, med: 0.3 to 1.7°C, high: 0.3 to 2.0°C; and by 2070; low: 0.7 to 4.5°C, med: 0.8 to 5.2°C, high: 0.8 to 6.0°C by 2070. Rainfall change; dry: -14 to 7%; drier: -13 to 3%; driest: -14 to -3% by 2030 and dry: -40 to 25%; drier: -30 to 5%; driest: -40 to -10% by 2070; Unk, unknown.

The number of summer days over 35°C will increase on average between 1 to 8 days by 2030 and 3 to 28 days by 2070 compared with 1996 for regional centres within the dryland cropping zone (Table 2.2) (Anon 2004).

Zone	Town	Present	2030	2070
Dryland cropping	Mildura	23	24 - 33	27 - 56
	Ouyen	24	25 - 32	27 - 57
	Swan Hill	20	20 - 30	24 - 55
	Donald	12	13 - 19	15 - 38
	Horsham	15	16 - 22	18 - 38
	Echuca	16	17 - 25	20 - 49
Dryland pasture	Bendigo	9	10 - 16	12 - 34
	Ballarat	4	4 – 7	5 - 17
	Ararat	6	6 – 10	7 - 23
	Hamilton	6	6 – 9	7 - 19
	Benalla	13	14 - 22	16 - 47
	Sale	4	5 – 7	6 - 16
	Wonthaggi	3	3 – 6	4 - 13
Public land	Beechworth	2	3 – 6	4 - 22
	Omeo	2	2 – 5	3 - 20
	Orbost	5	6 – 9	7 - 21
Other	Lakes Entrance	3	3 – 5	4 - 9
	Tatura	8	9 – 16	11 - 41
	Wangaratta	15	16 - 25	20 - 56
	Melbourne	8	9 – 12	10 - 20

Table 2.2 Number of summer days over 35°C for Victorian towns and cities, across different land use zones. Values are for present and projected changes in annual temperatures defined by the CSIRO high resolution regional assessment model (DARLAM) (Anon 2004).

Spring months (September to November) are going to become significantly drier (Fig 2.3), where 90% of the current dryland cropping zone will experience a 3% to 14% decrease in rainfall by 2030 and 10 to 40% reduction by 2070. Winter (June to August) rainfall over the entire cropping region is estimated to change between -13% and +3% by 2030 and -30% and +5% by 2070. Overall the dryland cropping zones will experience drier conditions in the winter and spring followed by substantially hotter summers. It is unclear on whether summer rainfall will increase or decrease. The number of winter days below 0°C will decrease on average between 1 to 4 days by 2030 and 3 to 5 days by 2070 compared with 1996 for regional centres within the dryland cropping zone (Table 2.3).

Zone	Town	Present	2030	2070
Dryland cropping	Mildura	4	1 – 3	0 - 1
	Ouyen	5	1 – 3	0 - 2
	Swan Hill	3	1 – 2	0 - 1
	Donald	7	2 – 6	0 - 4
	Horsham	7	3 – 6	0 - 5
	Echuca	10	3 – 8	0 - 5
Dryland pasture	Bendigo	6	1 – 4	0 - 3
	Ballarat	10	5 – 8	0 - 6
	Ararat	14	7 - 12	1 - 10
	Hamilton	8	3 – 6	0 - 5
	Benalla	17	7 - 14	0 - 11
	Sale	11	4 – 9	0 - 7
	Wonthaggi	2	0 – 1	0
Public land	Beechworth	17	6 - 14	0 - 9
	Omeo	44	29 - 40	7 - 35
	Orbost	3	0 – 2	0 - 1
Other	Lakes Entrance	1	0	0
	Tatura	15	6 - 13	0 - 9
	Wangaratta	18	8 - 15	0 - 12
	Melbourne	1	0 – 1	0

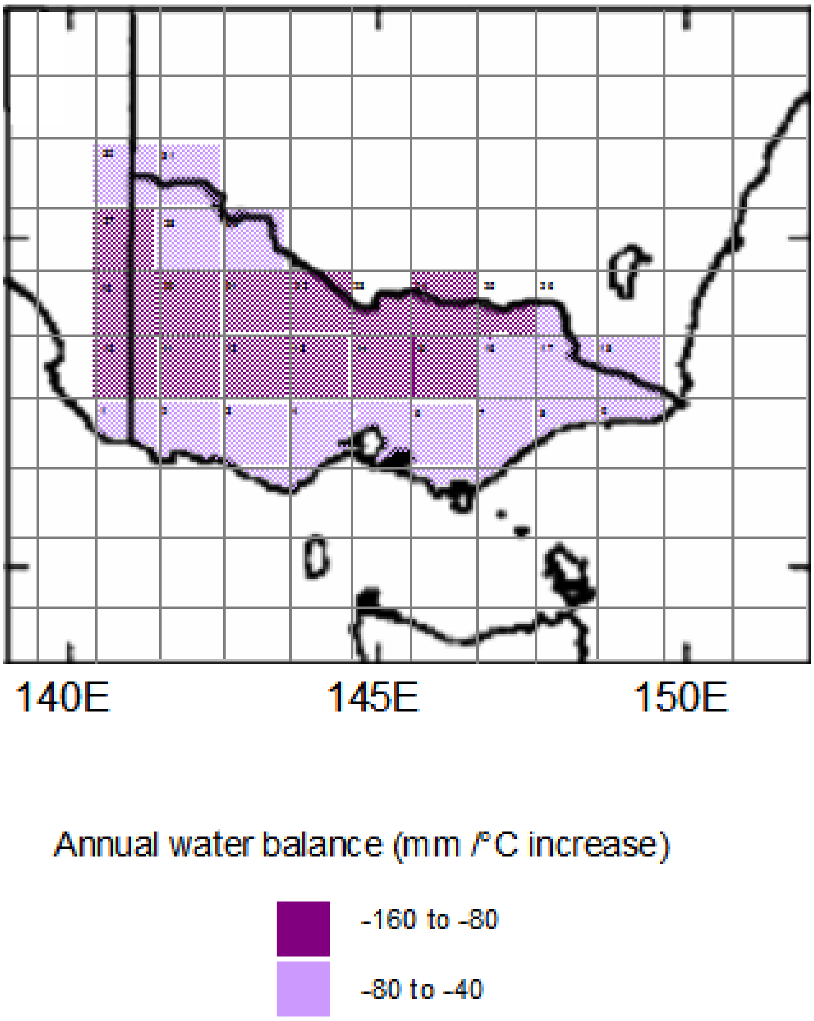
Table 2.3 Number of winter days below 0°C for Victorian towns and cities, across different land use zones. Values are for present and projected changes in annual temperatures defined by the CSIRO high resolution regional assessment model (DARLAM) (Anon 2004).

Annually 80% of the cropping zone will have a 4 to 6% increase in evaporation per degree increase in temperature. This translates to between an 80 to 160 mm decrease in available water per degree Celsius increase (Table 2.4 & Fig 2.4). If the latter rate is calculated against expected temperature increases, then the majority of the cropping zone will experience between 16 and 224 mm less water by 2030 and 56 and 688 mm less water by 2070 (Fig 2.5).

Land use (%)	Annual water balance	
	-160 to -80 mm/°C	-80 to -40 mm/°C
Dryland crops	80	20
Dryland pasture	50	50
Public land	22	78

Table 2.4 Distribution of 2 predicted annual water balance outcomes across Victorian land use.

Reduced growing season water will induce higher likelihood of poor or failed crops. It will also limit the capacity to accrue soil water over the summer months for following crops to benefit. Overall, reduced rainfall in these regions will translate to less biomass production. If larger episodic rainfall events trigger significant mineralization and decomposition then these factors may result in net reduction in soil organic carbon.



nnual water balance (mm/°C increase) for Victoria, Australia as predicted by CSIRO high resolution regional assessment model (DARLAM) for estimating climate change Whetton *et al* (2002)

Agronomic management that places emphasis on conservation cropping practices are required if current soil organic carbon levels are to be maintained under drying conditions due to climate change. Farm enterprises that currently prepare fields by removing crop residues by bailing or burning have the opportunity to maintain or enhance soil organic carbon levels by retaining crop residue. The adoption of conservation tillage practices with enhanced crop residue management will assist in maintaining soil structure and reducing surface evaporation, runoff and the risk of erosion. These actions are likely to maintain soil health under increasingly extreme conditions due to climate change. Where cropping systems currently use conservation tillage systems, there may be less opportunity to adapt to climate change and some reduction in organic carbon may occur due to not being able to sustain current levels of biomass accruement.

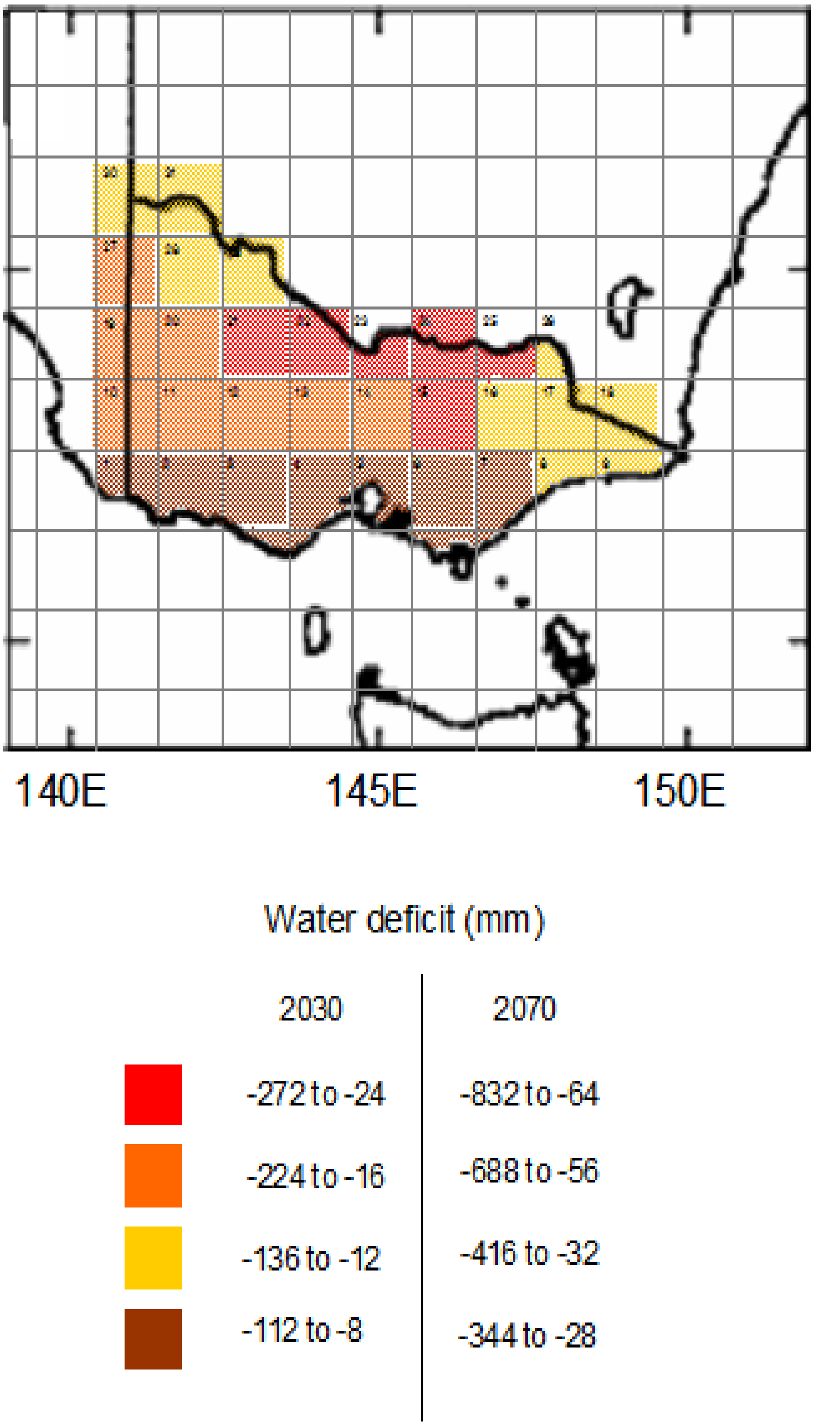


Figure 2.5
Estimated annual water deficit increase (mm) for Victoria, Australia in 2030. Divisions are calculated using predicted annual temperature change and water balance values derived from the CSIRO high resolution regional assessment model (DARLAM) for estimating climate change. Whetton *et al* (2002).

Dryland pastures
Those regions of the state which are currently used predominately for pasture production to support livestock enterprise are predicted to experience lower temperature increases compared to cropping zones (Fig 2.3). During summer it is estimated that 25% of the area used for dryland pasture will experience a 0.3 to 2.0°C increase by 2030 and 0.8 to 6.0°C increase by 2070. This portion corresponds to east Gippsland and that north central region of Victoria. In contrast, dryland pasture in the western district is less likely to be affected from temperature increases with expected rises of 0.2 to 1.4°C by 2030 and 0.7 to 4.3°C by 2070. It is also estimated that these temperature increases will apply to the entire dryland pasture region during autumn and winter. Greatest reduction in rainfall will occur in spring across the entire dryland pasture zone where precipitation will drop by 3 to 14% by 2030 and 10 and 40% by 2070.

Accordingly, evaporation will increase between 6 % and 8 % per degree increase in the north-eastern and central part of the state which translate to an 80 to 160 mm decrease in annual available water per degree increase in temperature (Fig 2.4). Evaporation in the remaining pasture lands in the south-western portion of the state is estimated to increase between 4 and 6% per degree increase in temperature, which equates to a 40 to 80 mm decrease in annual available water per degree increase in temperature.

Dryland pasture east of Seymour is likely to be impacted substantially by climate change. This region is where eastern highlands transect those zones estimated to have a substantial increase in annual water deficit. Accordingly, reduced biomass quality and quantity for stock feed will limit both carrying capacity of this system and reduce soil organic carbon input. This will expose these soils to higher risk of erosion by water given expected increases in episodic rainfall events.

For pasture systems to successfully adapt to drier conditions, particularly during the spring months, optimal management strategies for grazing will be required, which cause least damage to pasture and soil structure through the effect of livestock traffic and trampling. A major challenge is the feed supply gap between summer and autumn if dry and hot conditions become increasingly protracted over the spring and summer period. Under future climate predictions pasture systems may become more reliant on imported feed. Marginal cropping zones may be able to provide this feed if the predicted increase in the number of failed crops is harvested for fodder. Other pasture management options may include cell grazing and lighter grazing through reduced stocking pressure. Selection of pasture species that show high adaptation to increasingly arid conditions may be another alternative ie. suitability of exotic grasses/pasture legumes (C3) compared with native grasses (C4). In extreme cases, highly erodible land may have to be retired to perennial native vegetation. Within the pasture zone, climate change also offers the potential of positive impacts. For example, soils in the higher rainfall zone (HRZ) near Hamilton may be at less risk of secondary salinisation. Drier condition may cause locally shallow water tables to abate, thus increasing the effective root zone of pastures. Increases in soil temperature due to higher ambient warmth may also increase biomass production in late autumn and winter. On acid soils, reduced leaching and loss of cations may also slow acidification rates and reduce the dependence on lime.

Although potentially beneficial in HRZ, the increase in subsoil drying under pasture systems is not without complications. For example, on vertic clay soils, with significant shrink/swell characteristics, increased dewatering of the subsoil by perennial pasture (lucerne) has caused the development of deep subsoil cracks. In combination with episodic rainfall events, topsoil has slumped into subsoil voids (pers. comm. B Noonan) (Fig 2.6). As a result, agricultural land becomes dissected by steep sides 'sink holes' which create difficulty with machine traffic ability, stock husbandry and agronomic management due to topsoil heterogeneity.

Figure 2.6 Topsoil slumping into subsoil voids on Vertosol soils, after extended perennial pasture Longerenong, Victoria. Images courtesy B. Noonan, DPI.

Overall, a substantial risk to soil health by climate change within pasture systems is structural degradation and loss of topsoil on highly erodible upland regions where potential reduction in ground cover and greater stock pressure destabilize soil.

Public land

Temperature increases will be greatest during summer across all public land in Victoria, where estimated increases are 0.3 to 2.0°C by 2030 and 0.8 to 6°C by 2070 (Fig 2.3). Autumn and winter temperatures will be least affected where 90 % of public land will have average temperature increases of 0.2 to 1.4°C by 2030 and 0.7 to 4.3°C by 2070. During summer the effect of global warming on rainfall is unknown, although over 70% of public land, spring rainfall will reduce by 3 to 14% by 2030 and 10 to 40% by 2070. The sub-alpine regions within Victoria's eastern uplands will have substantially drier springs that precede hotter summers, creating greater annual evaporative demands (6-8 % per degree increase). The water balance in this region will decrease between 40 and 80 mm per degree increase in temperature.

Public land in eastern Victoria is almost exclusively in the southern and eastern highlands. These regions are important as both a carbon sink (forests) and as catchments for water (for both urban consumption and environmental flows into waterways such as the Murray River). The effect of climate change on summer autumn and winter is largely unknown (Whetton *et al* 2002), however, the development of substantially dryer spring periods and hotter summers is more certain. This will increase net annual evaporative losses and increase water stress of perennial vegetation. Moreover, fire risk (Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI)) will increase where hotter and drier conditions will be the precursor to increasing the average number of days where very high or extreme fire danger exists (Hennessy *et al* 2005). Within increasing risk of fire storms comes the consumption of large carbon reserves (timber/understorey) thus destabilizing the soil environment. On heavily dissected country, water erosion of unprotected soil will remove nutrients and soil organic matter and redistribute them in water ways and catchments thus reducing water quality.

Soil Health

Across all the land use zones, dryland cropping, dryland pasture and public land, the maintenance of the organic carbon pool is crucial for maintaining soil health. Preservation of soil carbon depends on the balance between that material created through biomass accumulation and that which breaks down through decomposition/mineralization. Climate change is likely to reduce biomass production due to reduced growing season rainfall for current land use distribution and farming systems. This is likely to override any possible increase in biomass production due to elevated CO_2 levels driving greater water use efficiency (Chandler 2007). The link between climate change and soil health impact is schematically presented in figure 2.7

Identifying best management practices for soil maintenance across the various land uses is crucial to balance any degradation effects climate change may impose on current soil health. The following is a list of potential research gaps that will assist in identifying best management practices within the agricultural industries across Victoria in context of reducing the impact of climate change on soil health.

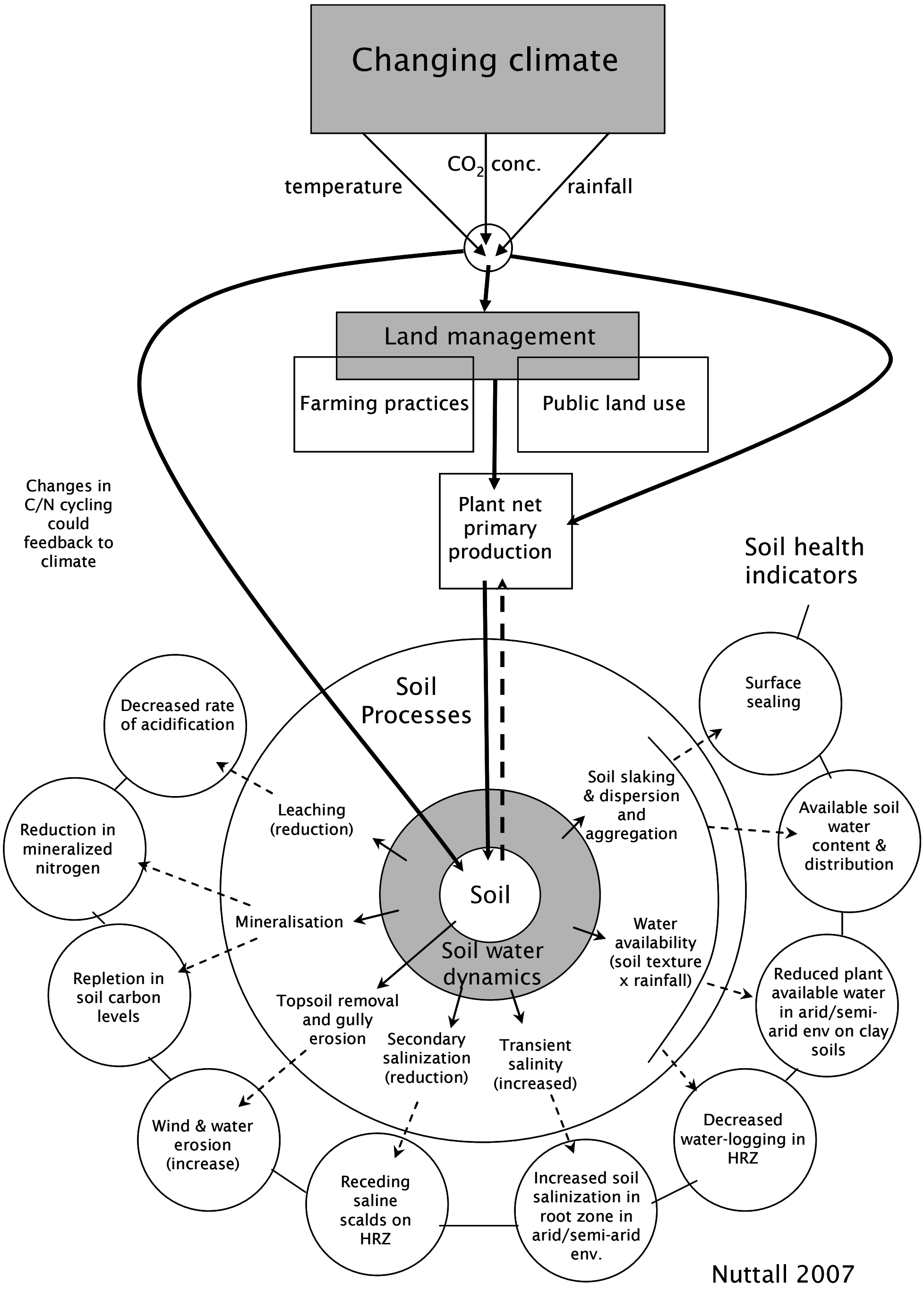


Figure 2.7 Schematic representation of the potential links between climate change and soil health.

3. Conclusions and Recommendations

Information gaps

Climate change compatible farming systems

Identify farming systems that use water more efficiently, conserve organic carbon and are more resilient to climate change. In an environment characterised by increased evaporative demands and less rainfall, determine the optimal system which budgets water and reduces risk to farming failure - (soil/water/temperature management). Because seasonal variability will occur against a background of climate change these 'opportunity farming' systems will need to flexible enough to allow rapid adaptation to seasonal circumstances (based on improved seasonal forecasting tools). Is it a matter of changing management practices within current farming systems or changing the entire farming system?

Drought proof crops

Identify drought proof crops by utilizing genetic variation across a range of dryland crops to improve adaptation to soil water deficits. Increasing crop adaptation to increasingly drying conditions will maintain productivity and the financial viability of otherwise marginal rain-fed farming systems and an opportunity to sustain carbon cycling in these soils.

Environmentally friendly nitrogen

Assess the viability of nitrogen neutral farming systems, where the value of pulse crops and green manuring are defined, compared with nitrogen derived from fertilizer. Defining the value of pulse crops under future greenhouse climate scenarios is particularly important, due to the potential impact of changed water conditions on nitrogen fixing capability.

Changes in soil carbon from Murray River to Bass Strait

Soil carbon drives many soil processes which underpin soil health. Understanding the extent that climate change will impact soil carbon quantity and quality is vital for gleaning the knock-on effect to soil health. Computer simulation in combination with knowledge on soil type and processes against ground truthing could elucidate the impact of climate change on soil health from the Murray to Bass Strait. This information would form the basis for decision making about land suitability for future use and how best to maintain soil carbon and health into the future.

Robustness of current farming systems

The viability of shifting land use zones, given climate change, physiographic zones and soil type also needs consideration. If arid and semi-arid regions shift southward, then does this alter the current suitability of land use? Examining the suitability of current farming systems in regions where existing climatic zones are equivalent to that predicted by climate change will provide demonstration of the impact of changing climate on agricultural systems.

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5. Appendix

Summary of impact of climate change on soil processes and soil health.

Component	**Possible process**	**Outcome**	**Reference**	**Effect on soil health**	**Management**
Soil carbon and C:N ratio	Increased temperature and episodic rainfall stimulates microbial activity (mineralization/ decomposition).	Reduced biomass accumulation Depletion of soil carbon and decrease C:N ratio.	Rosenzweig & Hillel 2000 Skjemstad etal 1996 Anderson 1992 Kirschbaum 2000 Neilson 1993 Lal 2004	**-ve** Soil carbon reduction due to decreased net primary production of biomass. Any gains by increased plant WUE are out weighed by increased mineralization and reduced GSR, crop failure and perennial plant death.	Conservation tillage practices. These systems consider components such as crop residue management, green manuring, intercropping. These assist in increasing soil aeration and decreasing soil temperatures and bacterial decomposition of SOM.
	Increased atmospheric CO_2 increases plant WUE	Increased biomass production per mm of available water	Kimball 2003		
	Decomposition rates are greater than net primary production under increased water deficit.	Drier conditions favour OC reduction			
	Drought induced losses of biomass (annual and perennial).	Reduction in annual and perennial vegetation.			
Nitrogen	Increased temperature in combination with aerobic conditions increases nitrification.	Aerobic conditions- increased mineral nitrogen.		**-ve/+ve** In semi arid environments with increased episodic rainfall, greater N mineralization. This may accelerate OC losses. Reduced capacity to fix atmospheric N_2, using legumes, producing greater long-term reliance on commercial fertilizers. In HRZ, less nitrogen loss.	
	Episodic rainfall in arid/semi arid regions increasing risk of loss due to leaching	Decreased plant available nitrogen			
	If anaerobic, denitrification will also increase.	Anaerobic conditions - decreased mineral nitrogen.			
	Increased temperature has depressing effect on symbiotic nitrogen fixing bacteria.	Reduced nitrogen fixation and increase dependence of artificial N sources.			

Component	**Possible process**	**Outcome**	**Reference**	**Effect on soil health**	**Management**
Soil biota (macro-fauna)	Reduced soil moisture creates unfavourable environment for earth worms etc.	Reduced macrofauna population. Correspondingly, macro porosity decreases		**-ve** Decease in soil porosity and water infiltration	Surface organic matter and trash cover to reduce evaporation
Water erosion of soil	Drought induced losses of biomass (annual and perennial) less protective cover.	Removal of topsoil and loss of fertility due to nutrient export.		-ve Decreased plant cover combined with episodic rainfall events and greater wind intensity increases risk of soil erosion and nutrient loss.	Better grazing management- a) Cell grazing. b) Light grazing rather than heavy. c) No grazing Retiring highly erodible land from cultivation. Use of perennial pastures.
	Changes in precipitation where increased rainfall intensities increase chance of run-off and sheet/ rill erosion on crop and pasture land. Increased severities in storm fronts trigger erosion events.	Creation of dissected landscapes.			
Wind erosion of soil	Increased risk of fires during summer periods destroys vegetation cover.	Rapid defoliation and conversion of carbon stores to atmospheric carbon.	Hennessy *et al* 2005		
	Changes in wind regimes where increased winds increase chance of soil erosion, particularly on fine textured cropping soils.	Removal of topsoil and loss of fertility due to nutrient export.			Establishing shelter belts and wind breaks. Stubble retention and direct drill.
Soil structure	Decreased microbial activity, reduced root growth and exudates reduce aggregate stability. Increased rainfall intensities where rain droplet impact causes surface sealing on sodic soils	Poor crop/pasture emergence and growth. Increases chance of surface runoff.		**-ve/+ve** Degradation of surface structure, inhibiting initial plant growth. Increased aeration of clay subsoils in HRZ allows greater root penetration of plants.*	

Component	Possible process	Outcome	Reference	Effect on soil health	Management
	Reduced saturation and less water logging in HRZ.	Make subsoil environment more habitable for root exploration.			
Soil acidity	Less net leaching of bases slows soil acidification process.	Reduced acidification		**+ve** Slower rate of acidification and less reliance on lime application.	None
Transient salinity	Increased dewatering of subsoil increases concentration of salts in the soil solution inducing osmotic stress.	Increased osmotic stress in the root zones on soil in arid and semi arid environments.	Maas (1986)	**-ve/+ve** In semi-arid environments the impact of *in-situ* salts will increase as overall subsoil drying occurs, thus reducing plant available water (osmotic stress) and rooting depth. In HRZ, possible reduction in saline scalds associated with secondary salinization.	Surface organic matter and trash cover.
	Increased evaporative losses increase capillary rise of salt relative to leaching, bringing salts closer to surface.		Rengasamy (2002)		
Secondary salinity	Reduced recharge and discharge of aquifers.	Reduction of saline scalds in HRZ			
Waterlogging	Reduced water logging and likelihood of reducing conditions.	Reduced Mn toxicity within plants. Reduced loss of phosphorous and nitrogen (denitrification)		**+ve** In HRZ, reduced chance of water logging	None
Soil contamination	Prolonged dry conditions slow breakdown of residual pesticides/ herbicides (eg SU herbicides).	Extended plant back periods and increased change of crop damage. Release of pesticides/herbicides into water ways.		**-ve** Increased risk of carryover damage on agricultural land and reduced spraying options for pest/weed control. Increased threat to water quality	Avoid use of products with residual properties.

Component	Possible process	Outcome	Reference	Effect on soil health	Management
Soil water dynamics	The suitability of soil type may alter for particular land uses if rainfall pattern shift, based on the water holding characteristics.	Lighter textured soils more favourable for plant growth in dry environments compared with clay.		**-ve/+ve** Shift in viability of soil type for land use based on textural class × rainfall interaction.	Farm management based on soil type. eg fallow heavy non-saline soils and continuously cropped lighter soils.
	Greater episodic rainfall events, greater chance for soil profile recharge and increase in effective rainfall	Increase potential for accruing soil water during fallow phases and in-season, particularly on vertic clay soils		Increase opportunity for soil water accruement, although benefit likely to be restricted to vertic soils.	
Weeds/disease	Distribution and prevalence of weeds alter. If better natural adoption to drier conditions will they compete more successfully than crops/pastures/understorey Will root disease in crops and pasture be more prevalent	Increased weed infestation. Increase/decrease in incidence of disease and pathogens.		-ve Competitive nature of weeds will required increased use of herbicides for control.	Need for increased chemical control
Mirco-topography	Development of sinkholes associated with slumping on vertic clay soils. Increased subsoil drying and development of large cracks in combination with episodic rainfall events causes topsoil slumping into subsoil voids	Agricultural land becomes disseminated with sink holes that create difficulty with machine traffic ability and stock husbandry.		**-ve** Increase is surface soil heterogeneity and agronomic management.	Continual infilling of holes. Avoid use of perennial such as lucerne that dewater the subsoil, particularly on vertic soils.