Natural resources for Canterbury agriculture

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Overview

On 4 September 2010 a Richter 7.1 earthquake unzipped a 29 km scarp along the previously unknown "Greendale fault" about 12 km west of Lincoln. It was a powerful reminder of the dynamic geological forces that have shaped the diverse landscape of Canterbury, which is one of New Zealand's most diverse agricultural regions. For millions of years the Indo-Australian and Pacific Tectonic Plates have collided along the Alpine Fault (McKinnon 1997) to produce the dramatic Southern Alps. These dominate the Canterbury landscape and create the different climates of the east and west coasts of the South Island. Repeated re-working of the land by glacial, alluvial, water, windborne and volcanic activities has resulted in a pedologically young (<20 000 years) landscape (O'Connor 1984). Before Polynesian arrival, the region was dominated by forest which was changed by fire to mainly tussock grassland before European settlement in the early 1800s. Farming in the region commenced during the 1850s, initially by sheep grazing for wool production on the Canterbury Plains and then the hill and high country followed by arable cropping on the plains in the 1860s (Evans 2004).

The importance of agriculture to the region was reinforced by the establishment of Lincoln College in 1878, which originally had a dryland farming focus. Its expansion to a University that specialises in all aspects of land management reflects the developing social and technical sophistication of the region and its people. Climatically, the low annual rainfall (650 mm) and warm föhn north-west winds mean the provision of stock and irrigation water is essential for intensive agriculture. Water from the mountain-fed rivers or deep alluvial aquifers can treble the productive capacity of the dryland farms and 70% of New Zealand's water use for irrigation is in the region. Such intensification inevitably produces changes of land use, is associated with greater inputs of inorganic fertilisers and other agrichemicals, and can lead to environmental degradation. Tension between the growing urban and diminishing rural populations is centred especially on the ownership and use of the region's water resources. The national significance of this was highlighted recently when the government dismissed the region's elected Councillors and replaced them with appointed Commissioners. They now oversee all of the Canterbury Regional Council's functions, with a strong directive to "deal with water issues". In parallel, a major focus of the local scientific community is to assist the management of agricultural intensification along ecologically acceptable principles. Since 1990 there has been a rapid expansion of irrigation associated with the conversion of dryland sheep and forestry land to large-scale dairy farming. Water and nitrogen management, winter grazing systems, and integrated farm management are all at the forefront of research and policy questions.

The expansion of dairying has also challenged sheep, beef and deer production to intensify on more difficult hill and high country areas and put pressure on the traditional integration of store lambs from the hills finished as "Canterbury lamb" on the plains. The evolution of production systems has created a diverse range of more intensive cropping options including cereals, herbage seeds, high value vegetable seeds, forage crops to support the dairy industry, viticulture and horticulture. The complexity of farm businesses and variety of agricultural options available has also generated an experienced commercial agribusiness sector to support farm production, resource and financial management.

Climatically, summer drought is usual and in the future the region is predicted to be warmer and drier (Salinger 2003; Ministry for the Environment 2008) with benefits and opportunities accruing for those with access to irrigation. Conversely, the burnt brown appearance of the foothills and Banks Peninsula may be viewed for longer each summer as the duration and intensity of droughts increases the stress for dryland farmers. Thus, continued pressure to intensify agriculture further on the plains is inevitable. The pace and level of change will depend on how well farmers utilise current and future technologies to mitigate the associated environmental consequences to develop ecologically sustainable and socially acceptable on-farm practices.

Geology

The Canterbury region accounts for 17% or 4.53M ha, of New Zealand's total area (Wilson 2010) with 800 km of coastline as the eastern boundary. Tectonically mediated mountain building of the Southern Alps, which form the region's western boundary, in

Table 1 Areas (ha) of cereals (wheat, barley and oats) sown (1999 and 2002) or harvested (2007, 2008 and 2009) and of vegetables (potatoes, green beans and fresh and processed peas) in the Canterbury region. Dash indicates no data (Department of Statistics 2010).

Year	Wheat	Barley	Oats	Potatoes	Beans	Peas
1999	39512	35218	5693	-	-	-
2000	-	-	-	4009	486	4611
2002	35261	51567	4631	4495	533	4820
2003	-	-	-	4792	-	-
2007	35301	36869	2925	4270	537	4705
2008	36400	45200	-	-	-	-
2009	46900	45000	-	4340	-	3800

combination with glaciations extended the floodplain into the Pacific Ocean where it reached Banks Peninsula. About 63% of the region's area is classified as mountain and hill country. Inland basins account for 13% and the volcanically-formed Banks Peninsula represents a further 3%. The coalesced fluvial megafans which formed the Canterbury Plains account for the remaining 21% of flat to gently undulating land. The plains are about 185 km long and up to 70 km wide, and rise gradually from the coast to ~300 m above sea level (a.s.l.) at the foothills (Leckie 2003).

The peaks in the Southern Alps increase in height by ~10 mm/yr (Tippett & Kamp 1995) and include 19 mountains over 3 000 m a.s.l.. They feed water from glacial ice, snow melt and rainfall into fast flowing, predominantly braided river systems which flow across the alluvial floodplains. The four main mountain-fed rivers are the Waimakariri, Rakaia, Rangitata and Waitaki. Canterbury's rivers carry a sediment load that is over 10 times the global average (Griffiths & Glassby 1985). Erosion from the western regional boundary is due to tectonic building and the subsequent rapid alluvial transport of sediment down the rivers. In eastern regions, such as near Ashburton, coastal erosion occurs at up to 1 m/yr (Gibb 1978), while the central areas are considered more stable (Leckie 1994).

Soils

In their native state the overlying soils are slightly to moderately acidic (pH 4.5-5.5) with low levels of N, P and S and several key micronutrients including B, Co, Cu, Se, I and Mo (Kemp *et al.* 1999). Brown, pallic and gley soils are dominant in the region. In the hill and high country these soils, formed under medium-high rainfalls, are free-draining with brown colours due to iron oxide coatings and pallic soils are poorly drained soils formed in low rainfall, summer-dry environments. Gley soils are exposed to periodic water-logging which causes anaerobic and reducing conditions. The brown soil group can be separated into two subgroups. The stony subgroup accounts for what are commonly referred to as "light soils". These stony and/or shallow soils account for ~465 400 ha of land on the plains (Taylor 1967). Their potential for crop, horticultural or pastoral use is restricted by their low water holding capacity in addition to temporal and spatial variability of rainfall. On the floodplains, soil depth to gravels can vary over small (5.0 m) distances. This reflects the underlying effect of previous river channels and river banks which have dissected the plains. Many plains soils hold between 60 and 90 mm/m (Morgan *et al.* 2002) of plant available water content (PAWC) but are <0.5 m deep. Rainfall in excess of storage capability, regardless of its timing, is therefore drained to groundwater or enters waterways through overland flow. These shallow soils have been favoured for recent conversion to dairy farming because of their low risk of pugging damage. However, they require careful irrigation management, with frequent small applications of water, to minimise the risk of drainage and associated leaching of nutrients. Deeper, well-drained soils may hold 150 mm/m and be over 2.0 m in depth giving >300 mm of PAWC (Brown *et al.* 2003) and are often used for high-value cropping.

P and S-based fertilisers with Mo and/or lime are used widely in all pastoral ecosystems (flat, rolling, hill, high country) to enable biological N fixation by pastoral legumes. Use of inorganic N fertiliser has increased over time, predominantly in dairy systems on the plains, to meet the increased demand for feed on the shoulders of the milking season in autumn and early spring. The majority of pastoral topsoils are high (3-10%) in organic matter and it increases with time under pasture provided soil moisture is adequate (Haynes & Williams 1993).

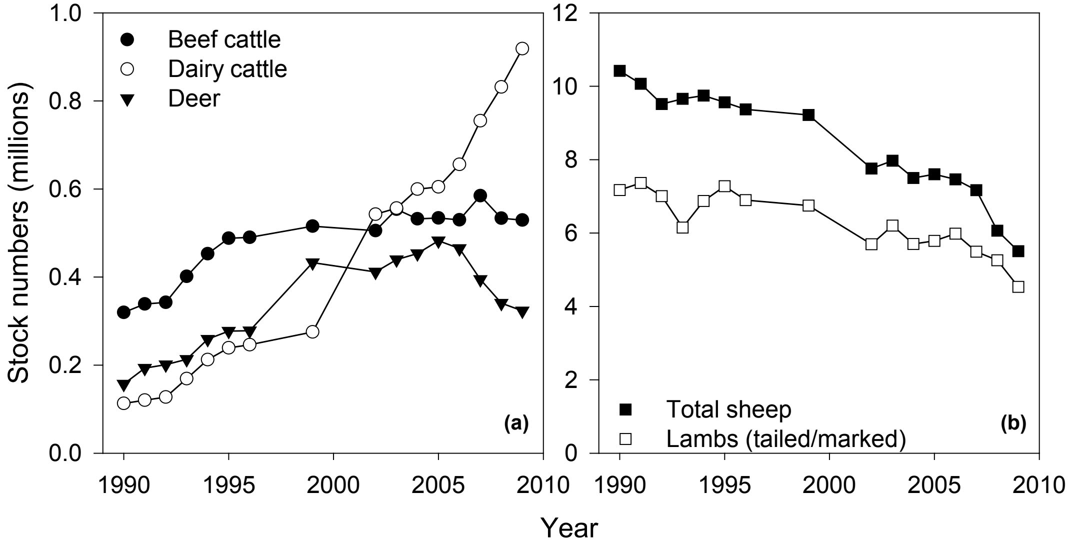
Climate

The South Island's climate is dominated by high pressure systems that approach from the west across the Tasman Sea. In Canterbury, they bring settled weather conditions with periods of strong drying northwest winds and mean summertime potential evapotranspiration (PET) rates of 4-6 mm/d. Near the coast and inland from Banks Peninsula, northeast winds prevail (McKendry 1983). Low pressure troughs

Table 2 Area (ha) sown for seed production of the seven main herbage species grown for seed in five seasons. Data from Foundation for Arable Research.

Species	1995/96	1999/00	2004/05	2008/09	2008/09
Perennial ryegrass	10950	15035	11915	14465	11050
Italian ryegrass	3070	2460	6260	5535	6510
Hybrid ryegrass	1140	2010	2640	1625	1725
Tall fescue	197	1030	1030	749	576
Cocksfoot	1175	348	668	958	1080
White clover	13915	10055	8340	5915	8420
Red clover	1130	1270	579	380	413

Figure 1 Changes in the number (millions) of (a) beef and dairy cattle and deer and (b) sheep (rams, ewes and wethers) and lambs in Canterbury between 1990 and 2009 (Department of Statistics 2010).



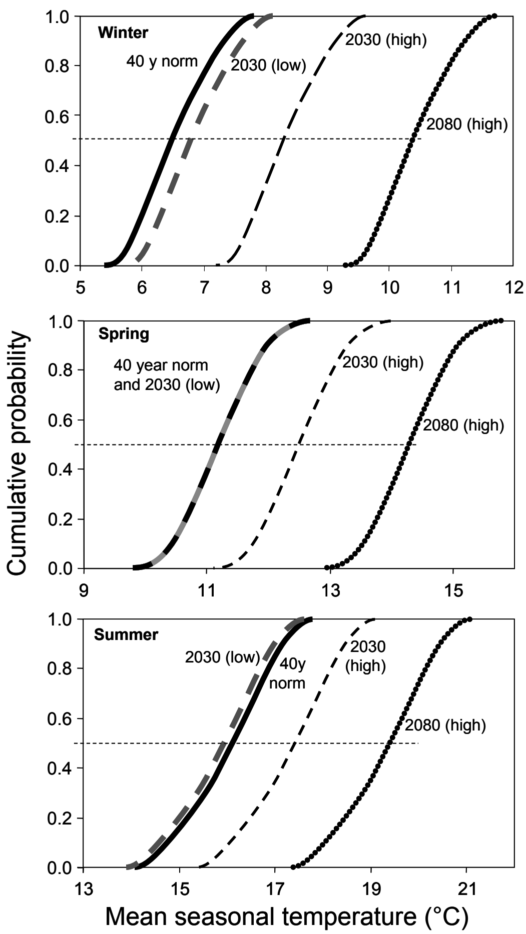
(depressions) of varying strength also move across the country from the west. In winter months these depressions, on passing to the east, can bring rain, sleet and snow, with the snow occasionally settling at sea level. The Southern Alps have a major influence on the impact of these systems including the amount and location of consequent precipitation.

There is a strong rainfall gradient from west to east across the plains with >1 000 mm on the western foothills on the eastern side of the Southern Alps and ~600 mm on the eastern seaboard (Morgan *et al.* 2002; NIWA 2010a). In most locations rainfall is distributed evenly throughout the year, on average, but in eastern areas it is well short of PET demand, so there are regular summer soil water deficits. These restrict pasture and crop growth between October and March (NIWA 2010a). Salinger (2003) summarised the current climate using Ashburton as typical of dryland Canterbury. Long-term weather records (1930-2002) give a mean potential soil moisture deficit (PMSD) of 325 mm with a range from 120 to >560 mm. A significant PSMD of ≥100 mm was found to occur by 1 December in 50% of years and by 1 January in 70% of years. Mean daily total solar radiation is 22.5 MJ/m^2/d in mid-summer when daily mean air temperature is above 16°C, but it declines to 4.4 MJ/m^2/d in mid-winter when frequent ground frosts and daylength of 9 h reduce the daily mean air temperature to 6.1°C.

Land use

The indigenous ecosystems of the lowland plains contained kanuka (*Kunzea ericoides*) shrubland (Molloy & Ives 1972) which regenerated freely after periodic fires before and after Polynesian colonisation ~1 000 years ago (McGlone 1989). At higher altitudes fescue tussock (*Festuca novae-zelandiae*) with clumps of matagouri (*Discaria toumatou*) or native broom (*Camichaelia sps*) and Danthonia (*Rytidosperma clavatum*) grassland dominated. The expansion of agriculture means remnants of these native sites are

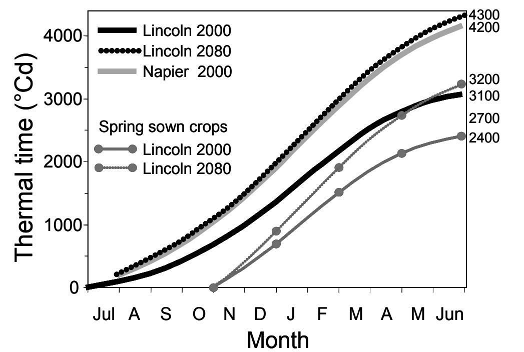
Figure 2 Cumulative probabilities of mean seasonal temperatures* for 1970-2010, solid line, and broken lines for future scenarios based on data from Wratt *et al*. (2004) including 2030 low temperature rise, 2030 high temperature rise and 2080 high temperature rise for Canterbury. Horizontal broken lines indicate the median temperatures where they intersect the curves (* temperature data from Lincoln-Broadfields climate records, NIWA 2010b).



rare.

The addition of fertility and grazing along with the soil, climate and water resources now support diverse farm types. Wheat and barley are produced on up to 100 000 ha (Table 1) for local human and livestock consumption with limited opportunity for export. The favourable climate enables potential yields of over 15 t/ha for wheat and 13 t/ha for barley, with mean district yields between 5.2 and 12.7 t/ha depending on input levels (Foundation for Arable Research). Seed production of herbage grasses covers ~15 000 ha (Table 2) with variable yields that may exceed 2.5 t seed/ha. Red and white clovers for seed production

Figure 3 Thermal time (°Cd, base temperature 3 °C) or heat accumulation from 1 July for Lincoln 2000, 2080 and Napier 2000, and from 1 November for Lincoln 2000 and 2080. (Air temperature data from NIWA CliFlo climate database, NIWA 2010b; projected temperature increases from Wratt *et al*. 2004).



cover ~10 000 ha annually with yields of up to 1.5 t seed/ha (Mather *et al.* 1995). High value, specialist vegetable and brassica seed production has increased over the last 15 years, much for northern hemisphere markets. Some of these seed crops provide high quality feed for lamb finishing and now arable farmers may also grow pasture and crop-based forages that support dairy operations in summer or winter. Animals are commonly wintered on shallow, stony soils where they primarily break-fed brassica crops or ryegrass and cereal greenfeeds supplemented by crop residues and silage (maize, cereal and pasture). Cropping farmers have some annual flexibility in the mix of crops sown, but strict quarantine and certification requirements limit some options and future land use. Fresh vegetable production occurs on the outskirts of Christchurch, and there is also an expanding processed vegetable industry. Canterbury has 60-70% of the total national area of green beans, ~60% of the fresh and processed peas and 30-40% of the potatoes. Processed potato production is increasing mainly to supply growing markets in Asia. There are also large areas of onions grown for export and viticulture is centred in north Canterbury.

The mountainous high country is home to fine wool merino sheep with deer numbers waxing and waning (Fig. 1a) in response to price signals. On the region's foothills and Banks Peninsula breeding ewes with store lambs dominate and beef cows assist to maintain pasture quality and diversify farm income. Livestock numbers over the last 20 years reflect the rapid reduction in breeding ewe flocks displaced by an extra 800 000 dairy cows. There were over 10M sheep in Canterbury in 1990 but this has declined almost linearly to 5.5M by 2009 (Fig. 1b). Since 2005 the area of plantation forest has decreased by about 12% to 109 800 ha (Forestry Owners Association and MAF 2010) with most converted to pasture in response to government policy and changing commodity prices.

For pastoral farmers, traditional ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) dominate where irrigation or adequate rainfall (>800 mm) is available with average yields of 12-15 t DM/ha. In dryland areas, cocksfoot (*Dactylis glomerata*), tall fescue (*Festuca arundinacea*) or *Bromus* spp. are the main grass species sown in a mix that could include subterranean clover (*Trifolium subterraneaum*), chicory (*Cichorium intybus*) or plantain (*Plantago lanceolata*) to produce 6.0-8.0 t DM/ha. Lucerne (*Medicago sativa*) is returning to the plains for grazing by sheep, beef cattle or deer and to be conserved for use as a supplementary feed in all livestock operations.

Irrigation

Irrigation development has occurred steadily in Canterbury since the early 20th century. However, there has been a dramatic expansion recently because irrigation is essential for intensive dairy production, especially to guarantee pasture growth in the usual dry period from late spring to autumn. In the recent expansion, modern centre-pivot and lateral-spray irrigation technology have replaced old border-dyke systems and have also extended onto large areas of previously unirrigated land. The demand for irrigation water continues to increase and already covers an estimated 364 000 ha in Canterbury which represents ~70% of the nation's irrigated land (National Infrastructure Unit 2010). With competing stakeholders, the allocation and use of water is currently the most contentious issue facing agriculture and society in general. To address this, the Canterbury Water Management Strategy (CWMS) was implemented. The Stage 1 report dealt with water quantity matters (Morgan *et al.* 2002) and concluded that, with development of storage to capture water during periods of high flows from Canterbury's large alpine rivers, there is sufficient water to meet a likely future demand to irrigate up to 1.0M ha. This was based on the assumption that ~90% of the demand for water would be from irrigation and that some redistribution would be required to alleviate over-allocation pressure on the region's smaller lowland streams. The Stage 2 report (Dark *et al.* 2009) was then commissioned to examine the possibility of meeting irrigation, social and environmental aims through different water storage options. It concluded that suitable storage sites were the scarcest resources and the current *ad hoc* approach to water development was an inefficient method to maximise stakeholder acceptance and infrastructure development.

Water quality

The Stage 3 multi-stakeholder report of the CSWMS (Whitehouse *et al.* 2007) concluded that rigorous scientific and public consideration was required of 1) the impacts of land use intensification and its effects on water quality, 2) mitigation and management systems for water quality, and 3) methods for maintaining or improving flow variability and low flows in major rivers. Many lowland rivers and streams now disappear completely each summer due to changes in weather patterns and water use. Further studies have subsequently investigated storage options in detail (Dark *et al.* 2009), assessed the effects of rural land use on water quality (Davies-Colley *et al.* 2003) and examined impacts of nitrate discharge to groundwater. In summary, pastoral land use is highlighted as having the greatest impact on water quality through 1) decreased visual quality from the displacement of fine sediments into waterways, 2) nutrient (N and P) application being beneficial to productivity on land but causing eutrophication and largely negative impacts for waterways and 3) microbes from faecal contamination directly affecting untreated drinking water. An initial assessment (Bidwell *et al.* 2009) of nitrate discharge from agricultural land indicates that there is potential for concentrations in shallow (<20 m) groundwater to exceed safe drinking water standards. They suggest that due to the contribution of low-nitrate river recharge to the groundwater beneath the plains, groundwater quality generally improves with depth. This means high quality drinking water is expected to be attainable almost anywhere on the plains, although the depth to it will differ at a local level. Furthermore, average nitrate concentrations from some agricultural land uses are higher than allowable indicating a mix of land uses is desirable.

To mitigate the impacts of rural land use on water quality two broad strategies have been recommended (Davies-Colley *et al.* 2003). The first is to reduce pollution at the source and will require on-farm adoption of available technologies. These include matching fertiliser demand to crop and pasture requirements, which has been aided by the provision of decision support systems such as 'Sirius' (Jamieson *et al.* 1998). Recommendations are to avoid grazing in periods of water-logging and wet weather to minimise nitrate leaching and run-off, particularly on shallow soils. For dairy systems, this may require changes in grazing management, particularly on winter feed crops, greater use of stand off pads or development of shelters for indoor feeding. Nitrification inhibitors have been shown to reduce greenhouse gas emissions and nitrate leaching (Di *et al.* 2007; Di *et al.* 2009) from dairy farms but debate over their impact on pasture production appears to have limited uptake by the industry. Irrigation calculators have also been developed. They are increasingly used by arable farmers but their current uptake by pastoral farmers is low. The second strategy focuses on interception of pollutants on land by fencing rivers and streams, and riparian planting to create a buffer zone that can trap pollutants, before they enter the waterways.

Climate change

For Canterbury, climate change scenarios for the future indicate that the prevailing westerly circulation is likely to strengthen bringing warmer and drier conditions on the plains (Wratt *et al.* 2004). A warming of 0.2-1.4°C, relative to 1990, is likely by 2030 and 0.5-3.4°C by 2080. The warming is expected to be greatest in winter and accompanied by an average annual reduction in precipitation of 10%.

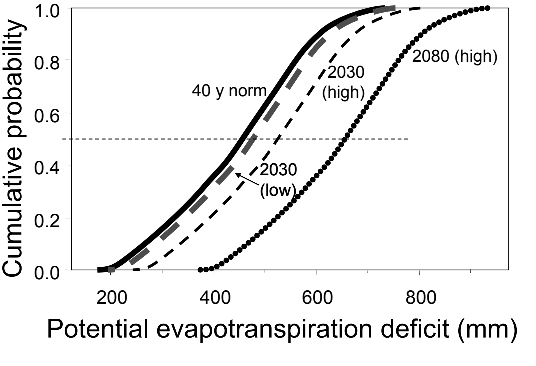
Fig. 2 shows how we might experience future temperatures compared with recent seasonal means and probabilities of departures from the median temperatures. For example, winter temperatures, even with the low temperature rise estimate for 2030, are expected to exceed the recent winter means for about 65% of the time. For the 2030 high temperature scenario the coolest winter in future may be warmer than the recent means. By 2080 the lowest winter temperatures could exceed the highest temperatures currently experienced. The contrasts are not as large for spring or summer but the milder winter temperatures will enable crops and pastures to be grown earlier in the year with significantly increased winter and annual forage growth possible in coastal and low inland Canterbury. The curves in Fig. 2 assume the same frequency distribution of temperature means for the future as calculated for the present. However, Wratt *et al*. (2004) recognise that climate warming will also result in more variability in the temperature extremes which would stretch the range of temperatures experienced for future scenarios.

Warmer temperatures will mean more rapid heat accumulation than at present (Fig. 3) with faster plant growth, shortened times between physiological stages and earlier crop maturity, provided water is not limiting. By 2080 Canterbury could experience a temperature profile similar to that of Napier now. This also means that fewer spring frosts could allow earlier sowing of crops such as maize that would benefit from the warmer climate. Warmer, drier late summer conditions also provide ideal conditions for combine harvesting, so lower crop losses and less sprouting, staining, bleaching of seed can be expected to improve seed quality.

Accompanying these changes in mean temperature and annual rainfall, scenarios also suggest potentially greater changes in the extremes. Sensitivity analyses based on high greenhouse gas emission scenarios predict a decrease in the number of frosts by 50% but 25 more days with temperatures above 25°C. These changes will affect pasture and crop water requirements with an increased occurrence of 1 in 20 year droughts to 1 in 5 years by the 2080s (Mullan *et al.* 2005) and an increase in PSMD of 90 mm (Salinger 2003). Managing additional background variability induced by interdecadal oscillations, El Niño and La Niña, will add complexity to dryland farming and increase the pressure on irrigation systems. Potential ET deficit (PED) is a suitable indicator of the amount of water required in addition to rainfall to grow pastures or crops without drought stress. As for temperature (Fig. 2) the median and frequency distribution of PED values for a season will increase and by 2080 the median PED could be as high as any experienced in the last 40 years (Fig. 4).

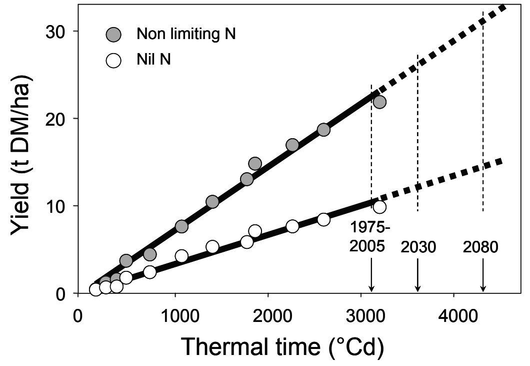
Taking climate change scenarios and looking at the implications for pasture production highlights the expected differences for dryland and irrigated situations. Grass-based pastures fully supplied with water and N can yield over 20 t DM/ha per year (Mills *et al.* 2006). A simple addition of growth provided by the warmer temperatures leads to an estimate that

Figure 4 Cumulative probabilities of potential evapotranspiration deficit (PED, mm) for 1970-2010, solid line, and broken lines for future scenarios based on data from Mullan *et al.* (2005) including 2030 low increase in PED, 2030 high increase and 2080 high increase in PED for Canterbury. Horizontal broken line indicates the median PED where it intersects the curves.



potential production could increase to ~30 t DM/ha (Fig. 5). However, this is unlikely to be obtained with temperate grass-based pastures due to N deficiency and hot temperatures restricting their growth. The predicted N requirement, from all sources (soil and fertiliser), to achieve such a yield is ~1 000 kg N/ha/yr. This is based on a critical N concentration of 3.3% required for non-limited growth to 3.0 t DM/ha and 10 harvests/yr (Mills *et al.* 2009). Similar amounts of N are returned to the

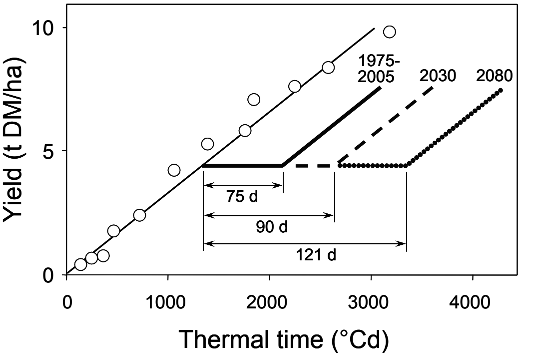
Figure 5 Accumulated cocksfoot yield, determined with non-limiting amounts of water and supplied with either non-limiting or nil N fertiliser (Mills *et al.* 2006). The solid line is the estimated potential yield based on thermal time calculated using mean monthly air temperatures at Lincoln (Broadfields Meteorological station, 1975-2005) and a non-limited growth rate of 7.2 kg DM/ha/°Cd or 3.2 kg DM/ha/°Cd in the N deficient pasture above a base air temperature of 3°C. The broken lines indicate the yield expected under climate change scenarios (Wratt *et al.* 2004).



soil in a urine patch by dairy cows. However, it would be risky and inadvisable to apply N fertiliser at the high rates needed to top up the N contributed from the soil and via animal returns to maintain maximum pasture growth rates.

A similar temperature scenario for dryland pasture induces an extended period of drought in mid-summer. A dryland cocksfoot pasture with no fertiliser N produced only 7.5 t DM/ha/yr in response to a summer drought of 75 days and a thermal time of 3 100°Cd (Fig. 6). Scenarios for 2030 and 2080 show there is no growth during an extended summer drought and that the autumn growth is constrained by the mean annual thermal time accumulation of 3 600 and 4 300°Cd for 2030 and 2080, respectively. This produces about 7.5 t DM/ha across all scenarios. This assumes that the 'average' drought for each scenario starts at about 1 340°Cd and that full growth rate of 3.2 kg DM/ha/°Cd resumes immediately at the end of the drought. Moot *et al*. (2008) noted the recovery to full potential growth rate can be delayed for several weeks while the canopy regenerates thus the effect of drought can, and does, last longer than the actual period of drought. For crops, Jamieson & Cloughley (2001) ran several scenarios and predicted early maturity of winter and spring wheat crops but an increase in yield due to the additional fertilisation effect of increased CO_2. Predictions for horticulture and viticulture are also positive provided there is adequate control of pests and diseases.

Figure 6 Effect of summer drought on cocksfoot grown without fertiliser N for current (75 d of drought) and future scenarios of 90 and 121 d of drought. A regression line through circles represents growth of 3.2 kg DM/ha/°Cd, accumulated above a base air temperature of 3°C, under N deficient and non-limiting water conditions (Mills et al. 2006). It is assumed the growth rate returns to 3.2 kg DM/ha/°Cd at the end of drought period.



Conclusions

The natural resources of Canterbury have been developed and have contributed to the economic and social prosperity of the region largely through the utilisation of water and intensification of agricultural production. The recent dairying phenomenon has resulted from compelling economic drivers that have enabled rapid expansion of irrigation to overcome the constraints of low water holding capacity of soils and hot dry summers. International experience, for example in California and Spain, suggests the diversity of land use on the plains is likely to increase along with the development of irrigation. In particular, plant-based food production that uses water more efficiently, and poses less risk of adverse environmental impacts, is likely to displace intensive pastoral agriculture in the long-term. This change will be driven by increased temperatures associated with climate change, greater competition for scarce water resources as its value increases and competition from alternative land uses to dairying as economic drivers change. On the hills and in the high country more extensive livestock production is expected to remain but alternative plant species, management strategies and livestock classes are required to cope with the diversity of soil types and impacts of climate change.

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