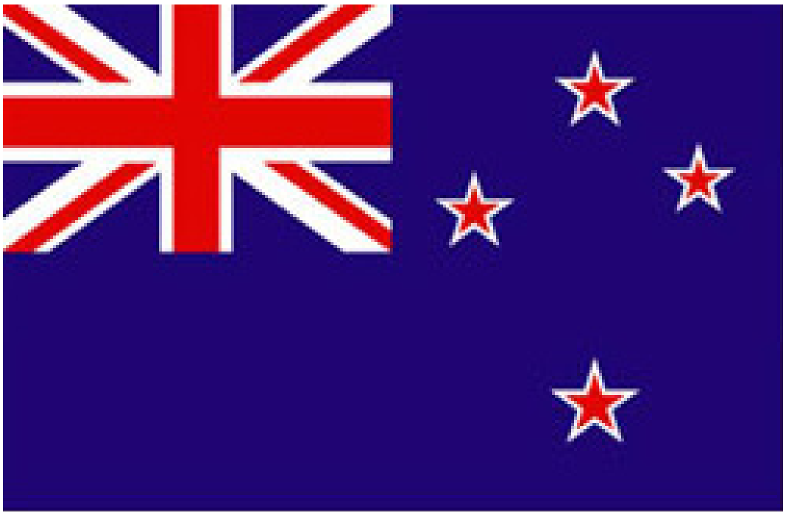
Country Pasture/Forage Resource Profiles

NEW ZEALAND



by

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CONTENTS

1. INTRODUCTION

Location and land area

New Zealand lies 2 162 km southeast of Australia, between 34ºS and 47ºS (Figure 1a). It consists of three main islands, surrounded by the South Pacific Ocean and Tasman Sea (Figure 1b). The North and South islands are separated by Cook Strait (25–30 km). The smaller Stewart Island (1 746 km^2) is located 20–30 km across Foveaux Strait to the south of the South Island. A range of smaller islands are also included as part of territorial New Zealand (CIA, 2009).

Figure 1a. Location of New Zealand

The distance from the north of the North Island to the south of the South Island is about 1 600 km and the islands range in width from 20 to 450 km with 15 134 km of coast line. The area of the North Island is 113 729 km^2, and the South Island is 151 215 km^2. Total land area is about 27 million ha (McKinnon, 1997).

The mountainous nature of the New Zealand landscape means only about one-third of the land mass is flat to rolling country (slope 0–16°). The remaining two-thirds are steep hill or mountainous (Hodgson *et al*., 2005). Over 75% of the country is at altitudes above 200 m and continued mountain building from movement of the underlying tectonic plates has resulted in a landscape dissected by fast flowing rivers, streams and lakes. Lake Taupo in the central North Island is the largest, covering 62 000 ha with a maximum depth of 163 m. Much of the North Island is rolling to steep hill country (slope >16°). In the South Island, mountain peaks in the Southern Alps feed water from glacial ice, snow melt and rainfall into fast flowing rivers which flow across alluvial floodplains.

Figure 1b. Map of New Zealand

Current population and distribution

New Zealand's population (2009) is about 4.3 million (4 213 418 was the July 2009 estimate according to the World Factbook with a 2009 growth rate of 0.935%) that gives a population density of ~16 people/km^2. However, >70% of the population live in the North Island so the population density is 28.6 people/km^2 in the North Island compared with about 6.7 people/km^2 in the South Island. In urban areas population density is 275–580 people/km^2 whereas areas classified as rural have population densities which range from <1 to 14 people/km^2. The largest city is Auckland which accounts for 31% of the total population. About 70% of the total population are classified as residents of urban areas (settlements with > 1 000 people) (Department of Statistics, 2009a).

Natural resources and the exclusive economic zone

New Zealand has limited quantities of mineral resources for commercial extraction, but larger quantities of minerals are located in unmined national parks. Consequently they contribute less to total export income and the domestic economy than agricultural products. Resources include natural gas, iron ore, sand, coal, timber, hydropower, gold and limestone (McKinnon, 1997).

The ~4.4 million km^2 exclusive economic zone surrounding New Zealand is the seventh largest in the world (CIA, 2009) and 14 times greater than the land area. This zone includes subtropical and sub-

Antarctic waters, inter-tidal estuaries, mangroves and seabed trenches and contributes about 3% of the Gross Domestic Product (GDP).

Natural hazards

Earthquakes from tectonic movements, periodic volcanic activity and flooding can cause disruption to natural and managed ecosystems. Of these hazards, periodic flooding following heavy prolonged rainfall is the most common problem. This is compounded by the location of many cities and townships near rivers on floodplains or coastal settlements near river mouths. Agriculture can also be interrupted by flooding and occasional landslides on unstable hill slopes. In most cases, weather forecasts allow movement of humans and livestock ahead of rising waters but property damage and significant economic losses can occur.

Occasional heavy snow may result in periods when power and communications are cut to households but in most cases these are repaired within 1–2 days. Other major hazards include strong winds which can deplete topsoil of newly cultivated land and cause wind throw in forest plantations. Fire in grassland and regenerating or exotic plantation (predominantly *Pinus radiata*) forest can occur in summer dry conditions, particularly in eastern districts of the two main islands.

Farming area, ruminant numbers and main breeds

About 37% of the land mass is classified as pastoral and a further 0.2% as arable and horticultural land. In 2007, the pastoral land area supported almost million ruminant livestock. Of these 77% were sheep, 11% were dairy cows, 9% beef cattle and 3% deer (see section 4).

The main sheep breeds include Romney, Corriedale, Coopworth, Perendale and Merino. Dual purpose and modern composite breeds are now most common as they allow income flexibility within farming systems. In dairy systems high milk and milk solids production is required and almost 80% of the national herd are Holstein-Friesian or Holstein-Friesian/Jersey crossbreeds. The main beef cattle breeds include Angus, Friesian, Angus/Hereford and Hereford. In the deer industry 85% of the national herd are red deer (*Cervus elaphus*) most of which are descended from feral animals captured in the 1980s. Information on the New Zealand ruminant industry and demographics is covered in Section 4.

Ruminant livestock enterprises in New Zealand are officially classified into nine farm classes. Each farm class differs in environment, soil fertility, pasture and animal production levels and the main farming operation. For example, the average South Island High Country farm had >80% steep land (>21°), a mean annual rainfall of about 740 mm/year and an effective area of 10 660 ha with 81% of their livestock being sheep (Farm Class 1; Section 4). The average North Island finishing farm had an annual rainfall of 1 190 mm/year, 15% of the 270 ha of effective area is classified as steep land and 52% of livestock are sheep (Farm Class 5; Section 4). The average dairy farm had an effective area of 128 ha on flat to rolling land (0–15°), in environments with >1 500 mm/year of rainfall or where irrigation was available. Regionally, North Canterbury has the largest average herd size of 771 cows. There is a high level of integration among production systems with feed sources and livestock frequently moved between farm classes to overcome regional feed deficits and unseasonal weather events.

Exports

New Zealand has an open economy which is focused on the production of high quality agricultural products at low cost. Total agricultural exports account for almost half of New Zealand's total exports (Department of Statistics, 2009a). Of this, ~30% is from meat and meat products and ~40% from dairy products (Table 1). Most exports are shipped, rather than air freighted offshore, due to transportation costs associated with the distance to the main export markets.

Natural history

Native flora and fauna

Podocarps (*Podocarpaceae*.) and southern beech (*Nothofagus* spp.) are the dominant tree species in native forests. In the north of the North Island native forests were dominated by the giant kauri (*Agathis australis*) while climatic and physical differences in the environments led to southern beech dominance in the South Island. Tussock grassland dominates in the subalpine regions. Shrub vegetation includes matagouri (*Discaria toumatou*) and manuka (*Leptospermum scoparium*).

Table 1. Merchandized exports from New Zealand between 2002 and 2008 for the year ending 31 March

	Year						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
	NZ$ (millions)						
Dairy products	7 834	6 308	6 057	6 266	6 807	8 405	10 478
Meat and meat products	4 526	4 341	4 309	4 796	4 541	4 953	4 565
Miscellaneous agricultural products	2 034	1 836	1 705	1 700	1 519	1 691	1 722
Wool	1 041	1 070	980	949	919	944	844
Live animals	157	141	170	264	200	157	177
Total agriculture	**15 591**	**13 695**	**13 222**	**13 975**	**13 987**	**16 149**	**17 785**
Horticultural products	1 961	1 960	1 969	2 349	2 276	2 533	2 802
Total agriculture and horticulture	**17 552**	**15 655**	**15 190**	**16 324**	**16 264**	**18 682**	**20 588**
Forestry products	3 612	3 717	3 125	3 255	3 164	3 562	2 900
Total agriculture and forestry exports	**21 164**	**19 372**	**18 315**	**19 579**	**19 428**	**22 244**	**23 488**
Other industry exports	10 362	9 796	9 189	10 135	10 276	11 250	13 169
Total New Zealand merchandised exports	**31 527**	**29 168**	**27 504**	**29 714**	**29 704**	**33 494**	**36 657**

Note: *Values are New Zealand dollars free on board (fob) and exclude re-exports. Figures may not add or reconcile due to rounding. Some figures have been suppressed to comply with Statistics New Zealand confidentiality rules after 2006.*
(Department of Statistics, 2009a; Ministry of Agriculture and Fisheries, 2009a).

New Zealand has a high proportion of endemic species due to its isolation from neighbouring land masses. In recent time (in geological terms), the islands had no native terrestrial mammals except for two species of rarely seen bats. Native fauna is dominated by insects and birds (McKinnon, 1997). A lack of mammalian predation meant that many native species were poorly adapted to attack by introduced predators. For example, many native bird species are vulnerable because they are flightless and others nest on the ground. The kiwi (*Apteryx* spp.) is a flightless, leaf-litter forager that has become one of the national symbols of New Zealand.

Maori colonization

It has been estimated that the Polynesian Maori people arrived in New Zealand about 800 years ago after travelling from the tropical islands in the South Pacific (McKinnon, 1997). Once the easily exploited large flightless birds and sea mammals (seal species) became scarce Maori became more reliant on their horticultural skills and evolved methods for growing subtropical crops such as kumara (sweet potato, *Ipomoea batatas*) and taro (*Colocasia esculenta*) in the warm temperate climate of the coastal North Island.

Post-human species introductions

In combination with human activity, introduced predators have resulted in the extinction of up to 50% of native bird species. The first human induced extinction wave was initiated after Polynesian people arrived in the thirteenth century A.D. with dogs (used for hunting and food) and the small Polynesian rat (*Rattus exulans*). The rat fed on the eggs and young chicks of smaller ground nesting birds. Polynesian (Maori) settlement resulted in many of the larger bird species, such as Moa (*Dinornis* spp.), being hunted for food. Initially, there were 10 species of Moa, some of which reached >2.5 m in height and over 270 kg in weight. These became extinct about 700 years ago. Consequently, with the loss of its primary food source the giant predatory Haast Eagle (*Harpagornis moorei*), (9–15 kg weight) became extinct shortly after the Moa.

After the Englishman Captain James Cook "discovered" and mapped New Zealand in 1769, European settlers introduced a range of species. These included rabbits (*Oryctolagus cuniculus*) followed by predatory mammalian species such as stoats (*Mustela erminea*) to try to control the exploding rabbit population. Native species were vulnerable to these predators and unable to adapt. This has resulted in extinctions and placed numerous species in an endangered category. With the development of European agriculture many species of crop and associated weed species were introduced during the late eighteenth century and through the nineteenth century. This has also reduced the habitat available for native species.

Conservation and biosecurity

Since human settlement, New Zealand's land cover has undergone dramatic alteration. Fires for hunting Moa, shifting cultivation (Maori) and creating farmland (European settlers) have reduced the native forest particularly on lowland sites with flat to rolling aspect. These areas are now predominantly used for pastoral agriculture, horticulture, cropping and urbanization. As an island nation New Zealand now has some of the strictest biosecurity and import regulation measures in the world to protect its exports of agricultural, forestry and fishery products.

These biosecurity measures reflect the isolation and therefore low pest and disease levels compared with other countries. From an agricultural perspective, the increase in movements of people and goods between countries has highlighted the vulnerability of primary industries to accidental introductions of pests/diseases from other countries. A recent example is the discovery of the Varroa bee mite (*Varroa destructor*). This initially infected bee hives in the north of the North Island (Stevenson *et al*., 2005) but has now reached the South Island. This directly affects the honey industry, and the pollination of fruit, vegetables and herbage seeds. New Zealand has remained free of foot and mouth disease due to vigilance in hygiene and inspection associated with meat or livestock imports.

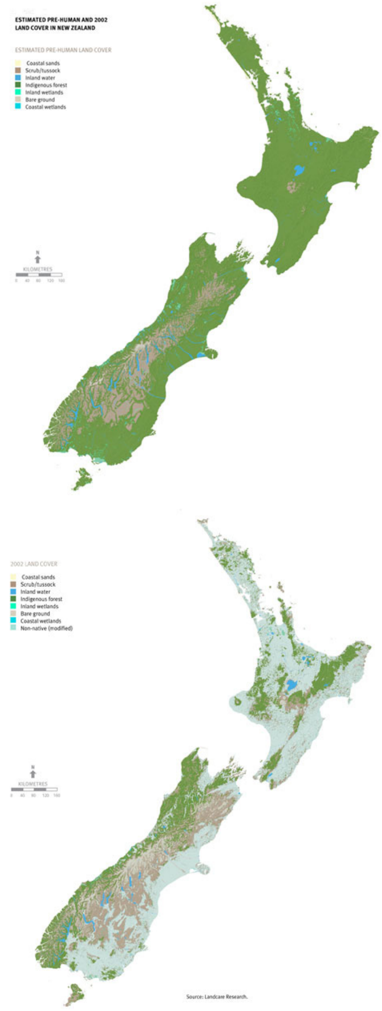


Figure 2. Change in land cover from pre-human (top) to current (2002)
(Ministry for the Environment, 2007)

Tourism

New Zealand has spectacular scenery including national parks, geothermal areas, mountains, fiords, tussock grasslands, forests and native birds. Adventure activities include bungy jumping, jet boating, skiing, canyoning, caving and mountain biking [www.newzealand.com]. Wildlife encounters include whale watching, swimming with dolphins, seals and penguins.

European colonization and agricultural development

European colonization

New Zealand was discovered twice by Europeans and lays claim to being the "youngest country" on earth as no other large land masses were subsequently discovered [Further information can be found at www.nzhistory.net.nz] . The Dutchman, Abel Tasman, mapped part of the coastline in 1642/43, but the country was not colonized by Europeans until after it was mapped more accurately by James Cook during several voyages between 1769 and 1779 (McKinnon, 1997). Whaling and sealing industries established soon after Cook's visits. The main period of organized European colonization began in 1840s following the signing of the Treaty of Waitangi between Maori and the British Crown. By 1855 the first elections for the House of Representatives were held and in 1865 the capital was moved from Auckland to Wellington. Initially, settlers purchased land from Maori. Later military conflicts (Land Wars) led to the confiscation of land under the New Zealand Settlements Act of 1863 by the colonial government and European settlers. Settlement of Treaty claims by regional iwi (tribes) against the government resulting from confiscation of lands by the Crown is on-going.

Agricultural development

New Zealand's agriculture industry has had a large and defining effect on the environment, economy and perceptions of national identity. Agricultural expansion happened rapidly between 1865 and 1915 (see section 5) as native forest was felled, burnt and introduced pasture species broadcast on cleared land. The first refrigerated exports from New Zealand to Great Britain occurred in 1882. This created new markets for meat and dairy products and led to an increase in intensive pastoral agriculture in contrast to extensive wool production.

Agricultural subsidies and regulation dominated the New Zealand economy from 1935 to 1984. Measures included subsidies for irrigation, water supply, fertilizer and lime transport, fertilizer purchase and aerial spreading costs, labour support for fencing and land development and associated loans, grants and cheap credit.

Deregulation of the agricultural industry in the mid 1980s resulted in the removal of all farm subsidies (Sandrey and Reynolds, 1990). This created many financial difficulties for farmers who had become reliant on government intervention to protect their livelihoods. The deregulation was instigated to encourage more efficient use of resources in the necessary drive to produce products which were competitive on world markets. This has been successful in the longer term, but initially those farmers who were unable to adapt, or who were burdened with large debt, left the industry. Since the 1990s agriculture has been driven by market demand. Farmers have become more flexible and rapidly change land use to adapt to changes in market and economic signals. A recent example of this responsiveness is the rapid conversion of sheep and beef farms to dairying (see section 4).

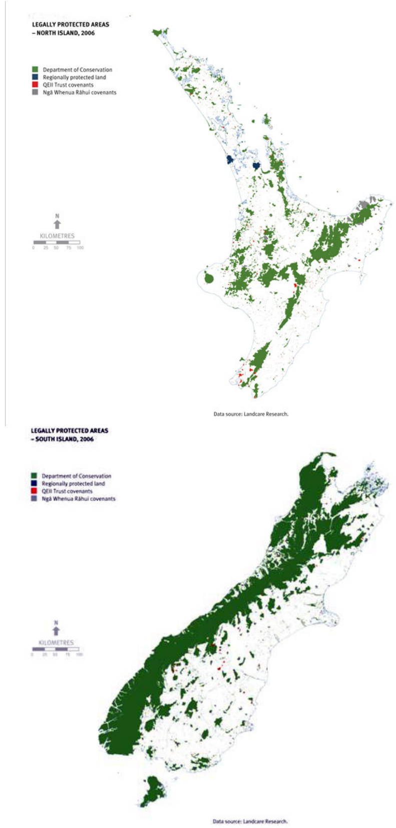


Figure 3. Department of Conservation land, which includes national parks, and other protected land areas in New Zealand *(Ministry for the Environment, 2007).*

2. SOILS AND TOPOGRAPHY

Major topographic features

New Zealand was once part of the Gondwana supercontinent. After the "Rangitata" land mass broke away, ~80 million years ago, it drifted eastwards on the Pacific tectonic plate. The majority of this land mass is now submerged, but parts of New Zealand may have managed to (periodically) stay above water. Originally flora and fauna were similar to that found on the supercontinent. However, by the time marsupials evolved, ~70 million years ago, New Zealand was surrounded by ocean. Consequently, narrow seas separated the land masses and seed and birds crossed between them but movement of larger land based animals was restricted (McKinnon, 1997).

New Zealand lies on the rather unstable boundary above the Indo-Australian and Pacific Tectonic Plates. The Alpine Fault runs the length of the South Island, below the Southern Alps, and continues up the east coast of the North Island. The Southern Alps, which geographically and climatically separates the east and west coasts of the South Island, were formed by the uplifting of the continental crust of the Pacific Plate by the underlying Indo-Australian Plate (McKinnon, 1997). Today, the Southern Alps continue to increase in height by 0.8–10 mm/year (Tippett and Kamp, 1995). Mt Cook, also known by its Maori name of "Aoraki", is New Zealand's highest mountain and rises to 3 754 m a.s.l. A further 18 mountains are >3 000 m a.s.l. Given the position of the country in relation to the underlying tectonic plates, earthquakes are common (most are minor and not felt by the majority of people) but a few have caused significant damage. Below the North Island, pressure between the two plates causes formation of magma (80–100 km deep), which rises to the surface forming a line of, occasionally active, volcanoes running in a north east direction from Mt Ruapehu (2 797 m a.s.l.) in the central North Island to White Island in the Bay of Plenty. Consequently these areas are dominated by geothermal activity which is the basis of tourism in Rotorua and has been harnessed for geothermal power generation especially in the central North Island.

Over 75% of New Zealand's land mass is >200 m a.s.l. and continued mountain building from movement of the underlying tectonic plates has resulted in a landscape dissected by fast flowing rivers and streams (see Figure 4). These feed numerous lakes. The largest is Lake Taupo in the Central North Island which covers 62 000 ha and has a maximum depth of 163 m. In the South Island, glaciers of varying size, carry away water from snow and ice melt from the mountain peaks in the Southern Alps. These glaciers are currently (2009) in a cycle of retreat. Much of the North Island is classified as rolling

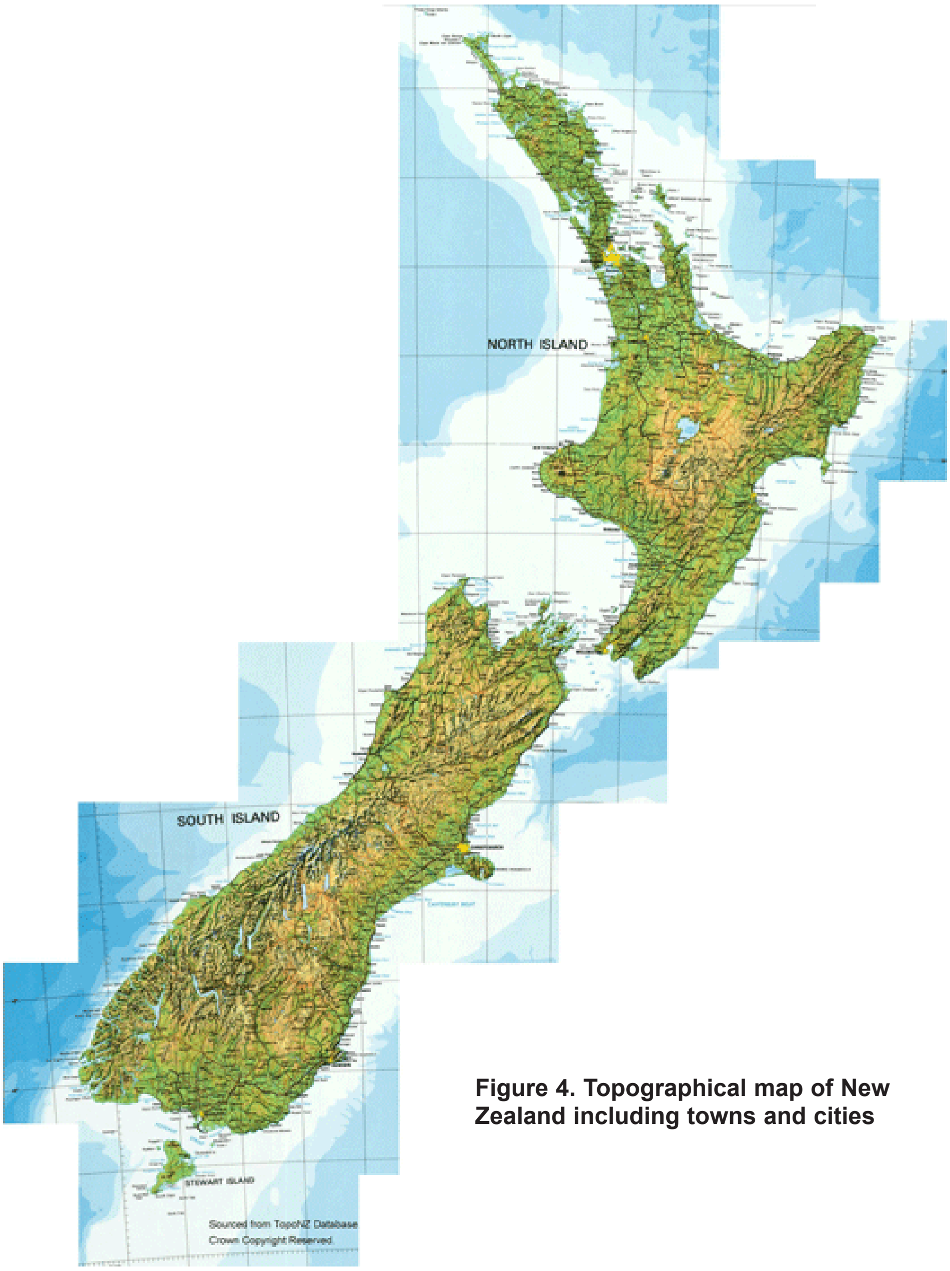


Figure 4. Topographical map of New Zealand including towns and cities

to steep hill country. Given the mountainous nature of the landscape it is important to note that only about 33% of New Zealand's land area is classified as flat to rolling country. The remaining two-thirds is steep hill or mountainous (Hodgson *et al*., 2005).

Soils

Pedologically, New Zealand has a young landscape formed from periods of mountain building, glaciation, volcanic activity and weathering by wind and water with no prolonged periods of landscape stability (White, 1999). However, with the exception of recent volcanic material, the majority of current landscapes were formed from reworked volcanic, sedimentary and metamorphic material from previous landscapes (O'Connor, 1984). Most soils have low to moderate native soil fertility, and are slightly acidic (pH 4.5–5.5) with low nitrogen (N), phosphorus (P) and sulphur (S) and micronutrients which include boron (B), cobalt (Co), copper (Cu), selenium (Se), iodine (I) and Molybdenum (Mo) (Kemp *et al*., 1999). Distance from the sea coast in association with topography and high rainfall reduces sodium (Na), S, B and I availability in inland regions.

Phosphate and sulphur based fertilizers with Mo and/or lime have been widely adopted in all pastoral ecosystems (flat, rolling, hill, high country), to encourage biological N fixation from pastoral legumes.

The interaction of climate, topography, parent materials and time has resulted in many different soil types (>100) with varying soil properties, native nutrient levels and soil depths to parent material (McLaren and Cameron, 1996). An example of one of the soils found on a Canterbury floodplain, and which is currently used for pastoral agriculture, is shown in Figure 5. On these floodplains, soil depth to gravel can vary from <0.5 m to >3 m and this changes greatly over small (5.0 m) distances. This reflects the underlying effect of previous river channels and river banks which have dissected the plains. The majority of pastoral topsoils are high (3–10%) in organic matter and this generally increases with the duration under pasture.

As shown by Figure 4, New Zealand is a mountainous country with the majority of its limited flat land formed from alluvial floodplains and glacial outwash fans. Its pastoral area can be divided into three categories, each of which account for about one third of the total pastoral area (Bryant and Sheath, 1987). These three grassland types are: “High country” which refers to the 4.5 M ha of pastures on land with slopes >21°, a further 5.0 M ha of “Hill country” pastures are on land with slopes of 16-20° and “Flat to rolling land” grassland (0–15° slopes) account for the remaining 4.5 M ha. More than half of all improved pastures are on easily cultivatable flat to rolling land.

Figure 5. Soil pit showing depth to alluvial gravels under a lucerne (alfalfa; *Medicago sativa*) stand in the Lees Valley (400–500 m), Canterbury, New Zealand. These soils, located on the valley bottom, are classified as Recent soils (see below)

Table 2. Major soil orders and their main diagnostic features for classification under the New Zealand soil classification system

Soil order	Main diagnostic feature
Allophanic	Soils dominated by allophane
Anthropic	Soils constructed or drastically disturbed by human activity
Brown	Aerobic soils with brown colours due to iron oxide coatings
Gley	Waterlogged, anaerobic soils with Br and/or Cr horizons
Granular	Clayey soils derived by strong weathering of ancient volcanic rocks. Usually, dominated by well-developed nutty structure throughout A and B horizons.
Melanic	Soils with dark A horizons and high base status. Subsoil contains lime or have well developed structure.
Organic	Soils consisting predominantly of organic material
Oxidic	Clayey soils dominated by oxidic horizons (Bo) containing crystalline aluminium and iron oxides.
Pallic	Soils with pale coloured subsoils with high slaking potential and high density (often in the form of a fragipan, Bx horizon)
Podzols	Strongly leached acid soils with E horizons underlain by accumulations of aluminium/iron/humus (Bs, Bh, Bsh or Bfm horizons).
Pumice	Soils dominated by pumice or pumice sand with a high content of natural glass.
Raw	Very young soils without distinct topsoil
Recent	Weakly developed soils showing minimal profile development but with distinct topsoil.
Semiarid	Dry, weakly weathered soils with high base status. Accumulations of lime and salts common in subsoils (Bk or Bky (sic was Bk) horizons).
Ultic	Strongly weathered soils with clay enriched subsoils (Bt horizons).

(Hewitt, 1992; McLaren and Cameron, 1996).

Soil classification

The New Zealand Soil Classification system was introduced in 1992 and groups soils based on the degree of similarity between observed/measured properties (Hewitt, 1992; McLaren and Cameron, 1996). The main soil properties are summarized in Table 2 and their geographic distribution is shown in Figure 6.

In the North Island the three main soils are Pumice, Allophanic (with a volcanic parent material) and Brown soils. In contrast, the west coast of the South Island is dominated by Podzols (high rainfall environments with high organic matter inputs) with Brown and Pallic soils on the east coast. In the Canterbury region, formed on an alluvial floodplain, stony Brown soils and Raw soils dominate, indicating the young age of the Plains. In Central Otago Semiarid soils occur in environments with mean annual rainfall <500 mm/year. Gravel scree and Raw soils dominate the steep upper slopes of the dividing Southern Alps. These have low native fertility as they are geologically young, and have many intergrade soils.

Sparling and Shipper (2004) reported differences in soil quality as part of the 500 Soils Project (Table 3). Soil samples (0–0.1 m) were taken from 511 sites of differing land use which represented 98% of the New Zealand land area. They analysed soil pH, N, P and C content and macroporosity.

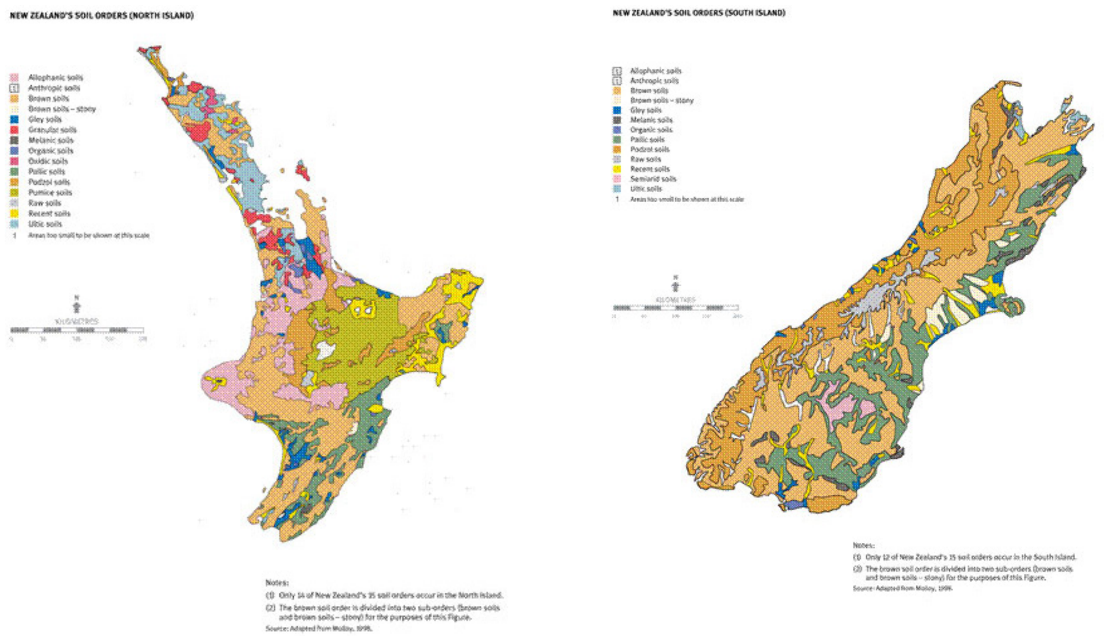


Figure 6. Geographic distribution of the dominant soil groups in New Zealand
For the purposes of this figure the Brown soil order has been divided into two sub-orders (Brown soils and Brown soils – stony). In the North Island 14 of the 15 soil orders occur. In the South Island 12 of the 15 soil orders occur *(Adapted from Molloy, 1998 in Ministry for the Environment, 2007).*

Table 3. Summary of mean soil pH (H_2O), mineralisable nitrogen (N, $\mu g/m^3$), total N (mg/cm^3), total carbon (C, mg/cm^3), Olsen P ($\mu g/m^3$) and macroporosity (%) of soil samples taken from 511 sites throughout New Zealand and grouped by land use

Soil property	Arable cropping	Mixed cropping	Dry stock pasture	Dairy pasture	Tussock grasslands	Exotic forestry	Native forests
(n)	44	17	142	127	20	67	58
pH	6.2	6.2	5.8	5.7	5.6	5.4	5.4
Mineralisable N	56	70	128	160	88	63	100
Total N	2.3	3.1	4.3	5.9	2.6	3.0	3.5
Total C	41	38	51	67	38	46	57
Olsen P	49	44	19	44	16	10	11
Macroporosity	14.7	9.3	13.3	10.1	15.6	25.6	9.3

(n) is the number of samples which contribute to the mean value in each land use category. "Dry stock pasture" includes sheep, beef and deer farming and "tussock grasslands' were mainly grazed by sheep and beef (Sparling and Shipper, 2004).

Overall, it was shown that grazed pastures had higher mean total N content (>4.6%) than all other land uses (<3.5%). Mean soil pH was lowest under native and exotic forests (<5.4) and highest in cropping systems (>6.1).

Soil erosion

Natural soil erosion occurs in the more fragile ecosystems, such as the steep hill country in the North Island. Erosion has always shaped the New Zealand landscape because 30% of the land area has slopes >25°. In some cases this process has been accelerated by the removal of native forest and replacement by low producing pasture. Consequently, when high impact rain events occur they saturate the soil on steep hill slopes which can cause mass soil movement (Ministry for the Environment, 2007). The effects are generally more common on the east coast of the North Island than in other regions. Tunnel gully erosion occurs predominantly on summer dry, low productivity grassland hill slopes of the eastern South Island. Soils in these erosion prone areas tend to have subsoils formed from poorly structured loess and contain fragipans which are dense. Subsurface water movement erodes the soil above the pan which eventually results in gully formation (McLaren and Cameron, 1996).

3. CLIMATE AND AGRO-ECOLOGICAL ZONES

Climate

New Zealand is located in the temperate climatic zone and exhibits a strong oceanic influence which results in rapidly changing and variable weather patterns. Weather is most changeable in spring (Sept-Nov) and early summer and more settled in late summer and autumn (MetService, 2008; NIWA, 2009).

Anticyclones approach from the west across the Tasman Sea and bring settled weather conditions to most of the country. Low pressure troughs (depressions) of varying strength are interspersed between the anticyclones and move up the country from the south. In winter months, these depressions can bring rain, sleet and snow. The majority of snow falls on the Southern Alps of the South Island and Central Plateau of the North Island but may occasionally fall to sea level in Southland, Otago and Canterbury.

The mountainous terrain has a strong influence on regional climates. There is a strong rainfall gradient from west to east, particularly in the South Island (Figure 7). This results from the rain shadow formed by the Southern Alps. Long-term mean annual (1951–1980) rainfall ranges from 360 mm (Alexandra, SE South Island, 45.267°S, 169.383°E) to >6 700 mm at Milford Sound (SW South Island, 44.667°S, 167.917°E). The maximum recorded annual rainfall was 18 000 mm on the West Coast of the South Island (Crop River, Hokitika catchment). Annual rainfall is between 600–1 500 mm for most of the country but large areas of both islands receive >2 500 mm/year. In most locations, long-term mean monthly rainfall may show slight seasonal variation which is insufficient to replenish the soil water used when potential evapotranspiration increases in summer months. This leads to the development of summer soil moisture deficits that restrict pasture growth. On the east coast of both the North and South Islands these deficits can develop between September and April before autumn rainfall alleviates water stress conditions.

The gradient in mean annual temperature runs north to south. Mean annual temperatures are 16–18 °C in the northern North Island and 8–10 °C in the south of the South Island. Mean annual temperatures also decrease by about 2 °C for every 300 m increase in altitude. Mean annual sunshine hours (1971–2000) are between 900 and 2 600 hours/year. The lowest sunshine hours (900 to 1 400 hr/year) occur in Fiordland and parts of the west coast of the South Island. The highest (2 200 to 2 600 hr/year) occur in the northwest of the North Island and the top of the South Island.

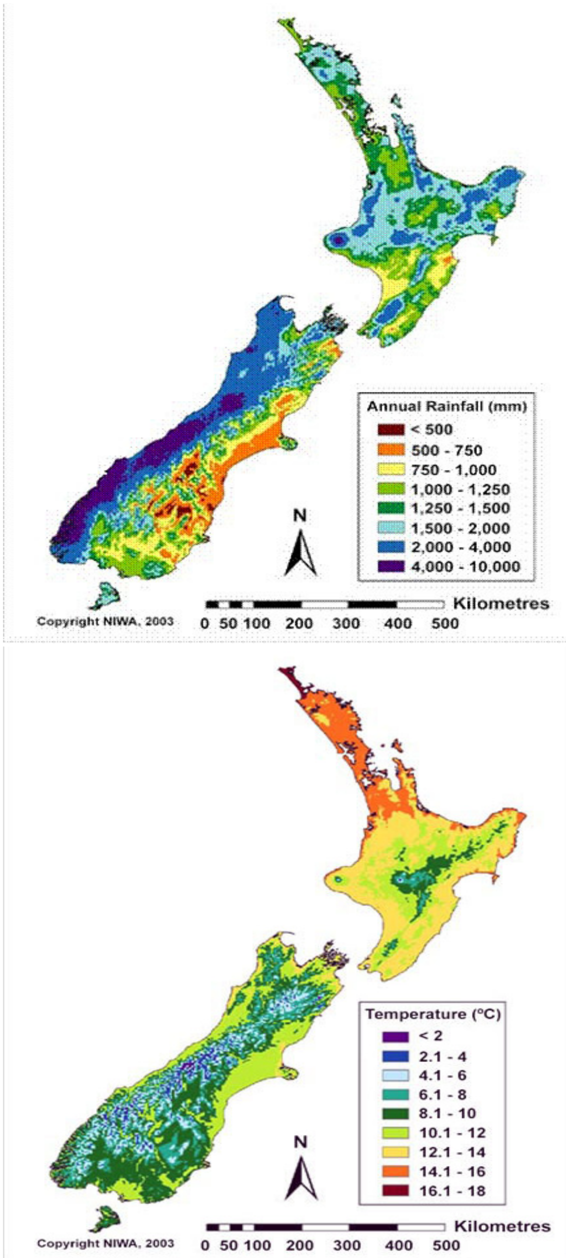


Figure 7. Long-term mean annual rainfall (bottom) and air temperature (top) in New Zealand
(NIWA, 2009)

Temperature

There is a strong seasonal variation in mean air temperature (Figure 8) which is typical of a temperate climate, but it is moderated by oceanic influence. Temperatures are highest in the summer months (Dec-Feb) and lowest in July. In eastern areas, maximum daily temperatures may be >30 °C in midsummer (1–10 days/year). Nationally, the maximum recorded daily temperature was 42 °C in

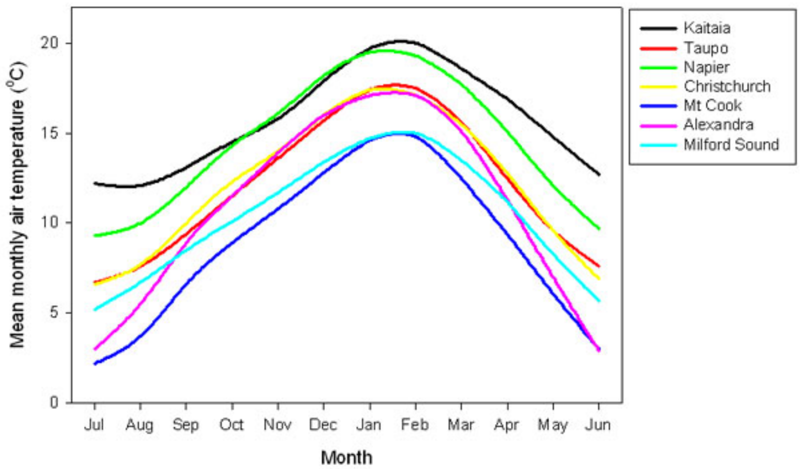


Figure 8. Monthly variation in long-term mean air temperature (°C) at selected New Zealand locations as listed
North Island sites: Kaitaia (35.135°S, 173.262°E, 35 m), Taupo (38.683°S, 176.067°E, 376 m), Napier (39.500°S, 176.917°E, 2 m). South Island Sites: Christchurch (43.533°S, 172.617°E, 7 m), Mt Cook village (43.733°S, 170.100°E, 762 m), Alexandra (45.267°S, 169.383°E, 141 m) and Milford Sound (44.667°S, 167.917°E, 3 m) (NIWA, 2009).

eastern regions of the South Island. The annual temperature range is 8–10 °C except for inland South Island (>11 °C) districts where there is a maximum difference of 14 °C in Central Otago which has a continental climate. At Ophir (Central Otago) the national maximum recorded temperature range was 55 °C being the lowest recorded of –22 °C in winter and up to 33 °C in summer.

This seasonal temperature variation affects the length of the growing season and consequently the potential production that can be achieved in specific regions. Table 4 shows the amount of thermal time accumulated above a base temperature of 0 °C from long-term data at selected locations from 1 July to 30 June. Of these, the longest growing season occurs in Kaitaia (5 730 Cd) and the shortest growing season is at Invercargill which is 40% lower (3 563 Cd) but the growth season here is severely restricted by killing frosts.

Table 4. Accumulated thermal time (above a base temperature of 0 °C) at selected locations throughout New Zealand

Location	Accumulated thermal time (°Cd)
Kaitaia	5 730
Gisborne	5 194
Napier	5 269
Wanganui	5 105
Blenheim	4 666
Westport	4 581
Christchurch	4 370
Invercargill	3 563

Data are means from sites having at least five complete years of data.

Rainfall

Geographically, the highest rainfall typically occurs on the west coast of both islands where the mountains are exposed to westerly and north-westerly winds from depressions approaching from the southwest. For a large part of the country, long-term records indicate rainfall is distributed reasonably evenly throughout the year (Figure 9). The greatest contrast is found in the north, where winter rainfall is almost double that which occurs in the summer months. The predominance of winter rainfall diminishes as you travel south but it is still discernible over the northern part of the South Island. In the southern half of the South Island, rainfall is lowest in winter months and a summer maximum occurs inland due to convectional showers. Rainfall is most reliable in spring and least reliable in summer and autumn.

Rainfall is also influenced by seasonal variations in the strength of the westerly winds. Spring rainfall is increased west of, and in, the mountain ranges as the westerlies rise to their maximum strength in

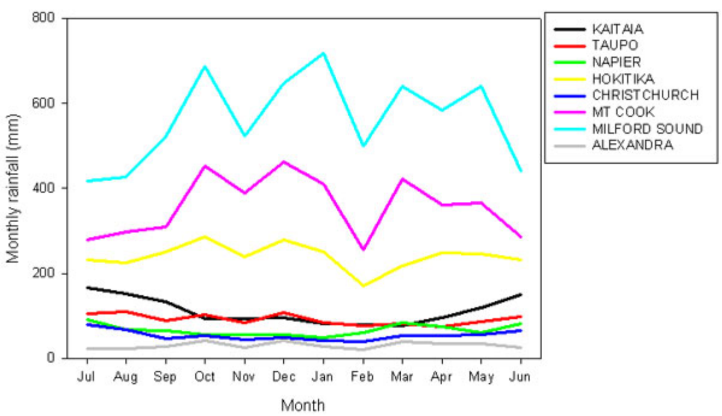


Figure 9. Long-term mean monthly rainfall (mm) at selected New Zealand locations as listed
North Island sites: Kaitaia (35.135°S, 173.262°E, 35 m), Taupo (38.683°S, 176.067°E, 376 m) , Napier (39.500°S, 176.917°E, 2 m). South Island Sites: Christchurch (43.533°S, 172.617°E, 7 m), Mt Cook village (43.733°S, 170.100°E, 762 m), Alexandra (45.267°S, 169.383°E, 141 m) and Milford Sound (44.667°S, 167.917°E, 3 m) (NIWA, 2009).

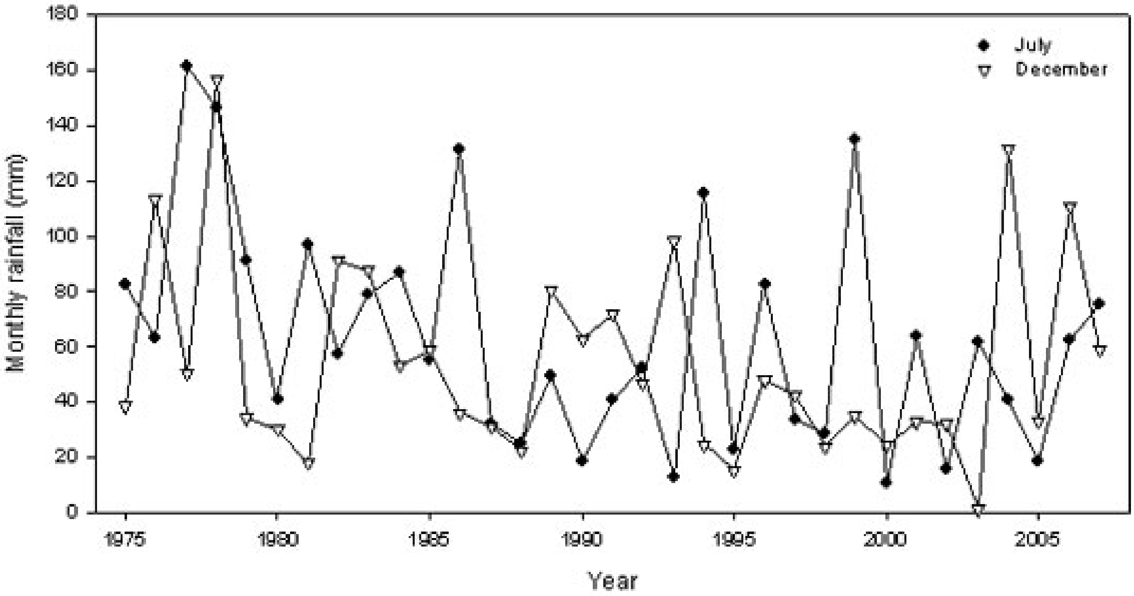


Figure 10. Total monthly rainfall (mm) in July and December from the Broadfields Meteorological Station located 2 km north of Lincoln University, Canterbury, New Zealand between 1975 and 2007
Long-term monthly rainfall, calculated for the 1975-2007 period, indicate a mean monthly rainfall of 63 mm in July (winter) and 54 mm in December (summer)

October. Consequently, there is an unavoidable but complementary decrease of rainfall in the lee of the ranges. Long-term records mask this annual variation. For example, at Lincoln, Canterbury, the long-term (1975–2007) mean annual rainfall is 627 mm/year but has ranged from a minimum of 308 mm (1988) to a maximum of 1 015 mm in 1978. Average monthly rainfall indicates a reasonably even distribution of ~50 mm/month throughout the year with slightly more rainfall in winter months. However, Figure 10 shows that in July (winter), which has a long-term mean monthly rainfall of 63 mm, the minimum rainfall was 11 mm (2000) and the maximum was 161 mm (1977). In December (summer), with a long-term mean monthly rainfall of 54 mm, the minimum was 1 mm (2003) and the maximum was 157 (1978). Thus, rain tends to fall in large (30–130 mm) events at infrequent intervals throughout any given year.

Potential evapotranspiration and potential soil moisture deficits

Daily potential evapotranspiration (PET) throughout New Zealand varies between a minimum of 0 mm/d and a maximum of about 12 mm/d. As expected, long-term mean daily PET is highest in summer and lowest in winter. For example, Figure 11 shows long-term monthly PET in winter at Gisborne increases from 1 mm/d in July to 5.2 mm/d in Dec/Jan. In Alexandra, mean daily PET is 0.1–0.7 mm/d between May and August and then increases to >4 mm/d in summer months.

A potential soil moisture deficit (PSMD) can be calculated as the difference between PET and rainfall in a July-June growing season. When potential soil moisture deficits exceed 100 mm pasture production is compromized and significant losses occur when deficits exceed 150 mm (McAneney *et al.*, 1982). In eastern New Zealand potential soil moisture deficits accumulated across the entire growing season commonly reach 300–500 mm/year. It reaches 100 mm

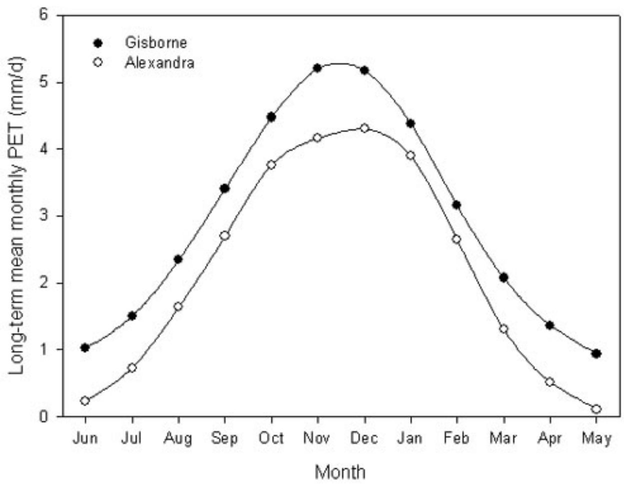


Figure 11. Mean daily potential evapotranspiration (PET) at Gisborne and Alexandra
Gisborne data is for the period 1975-1992 (38.661°S, 177.986°E, 4 m) and Alexandra data is for the period 1975-1983 (45.258°S, 169.389°E, 141 m).

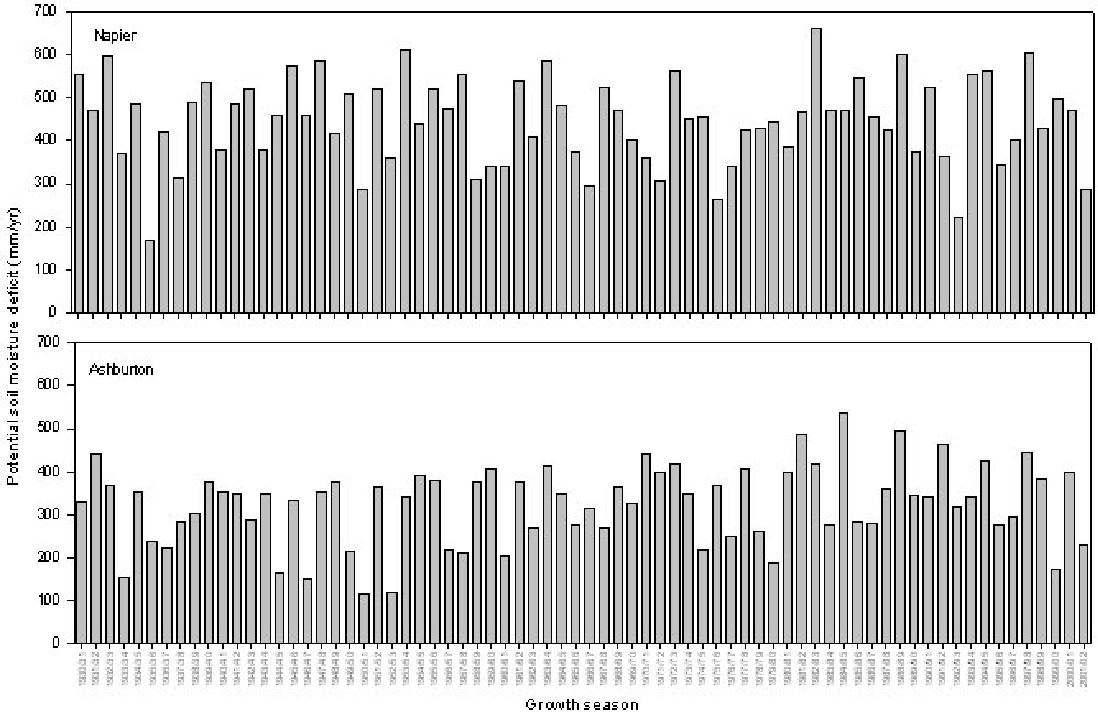


Figure 12. Potential soil moisture deficit (mm/y) accumulated over Jul-Jun growing seasons for Napier (top) and Ashburton (bottom) between 1930/31 and 2001/02 *(Salinger, 2003).*

Table 5. Magnitude of potential soil moisture deficit (PSMD, mm) at Napier and Ashburton from 1930/31 to 2001/02

	Napier		Ashburton	
PSMD	No. years	% years	No. years	% years
1 Jul-1 Dec >100	60	85	36	51
1 Jul-1 Dec >150	39	55	13	18
1 Jan-1 Mar >100	61	85	49	69
1 Jan-1 Mar >150	37	52	23	33

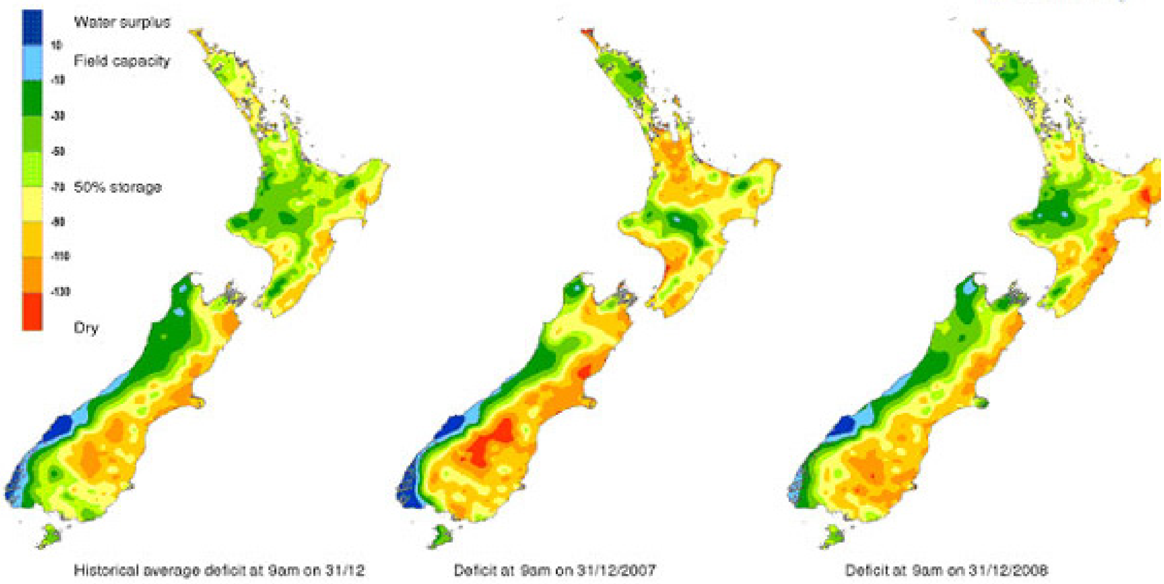
(Salinger, 2003).

by the beginning of summer and a further 120–150 mm accumulates by the end of summer (Salinger, 2003). In Napier the long-term (1930–2002) mean potential soil moisture deficit is ~450 mm/year and ranges from 170 to 660 mm/year (Figure 12). In Ashburton the long-term PSMD is ~325 mm/y and ranges from 120 to 540 mm/year. Table 5 shows that PSMD exceeded 100 mm by 1 December in 85% of years in Napier and in 51% of years at Ashburton. Severe water stress (PSMD >150 mm) occurred by 1 December in 55% of years at Napier compared with 18% of years at Ashburton.

Figure 13a shows the extent of the potential soil moisture deficit, based on potential evapotranspiration (PET) for dryland areas (no irrigation) on the 31 December (midsummer) across New Zealand. The historical average is shown for comparison with the situation in December 2007 (drier than average) and 2008 (drier than average particularly on the west coast of both islands). Note the effect of the rain shadow, from west to east, cast by the Southern Alps in the South Island and to a lesser extent the mountains in the North Island. Figure 13b shows the regional variation in the longterm median number of deficit days which occur annually. This ranges from 0–5 days/year on the west coast and at higher altitude mountainous sites to >120 days in areas on inland Otago and coastal areas on the east coast of both the North and South Islands. The soil water storage for plant growth is also affected by soil type (texture, proportion of stones, soil depth to stones or rock), plant water extraction ability (rooting depth, timing of peak seasonal demand) and local variations in rainfall. The variation in soil depth and associated presence of intergrade soils means differences occur over small (< 10 m) distances. These factors are not accounted for in potential soil moisture deficit calculations which are based on potential evapotranspiration, and represent the difference between rainfall receipts and atmospherically driven demand.

Winds

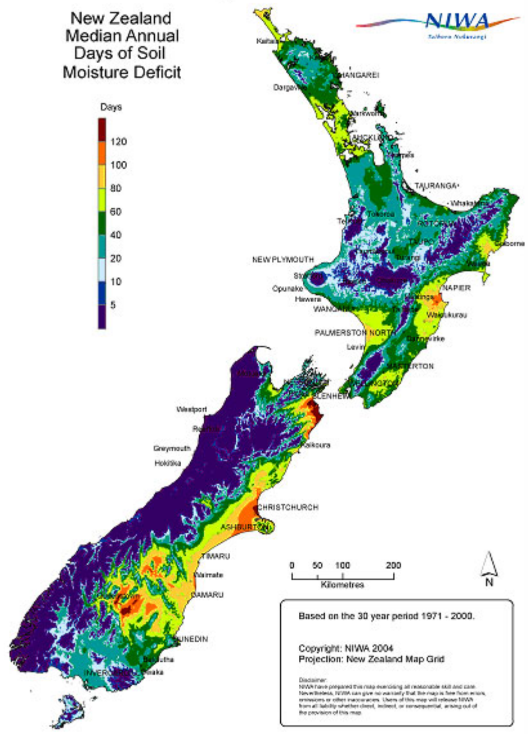
The mountain ranges also modify wind patterns but annually mean wind speed ranges between 10 and 18 km/h. The moist westerly anticyclones which result in the high rainfall on the west coast push drier westerly windflows up over the dividing ranges. This results in the development of low humidity (5–30%),



The water balance used in the calculation for deficit development within the root zone was based on an “average soil type” with a plant available soil water holding capacity of 150 mm.

Figure 13a. Potential soil moisture deficit, calculated from potential evapotranspiration assuming no irrigation is applied, on 31 December showing the historical average (left), December 2007 (centre) which was a drier than average year and in 2008 (right) which was slightly drier than average particularly on the wetter west coast
(NIWA, 2009).

warm ‘főhn’ winds which move rapidly across the eastern areas of both islands. As the wind speed increases topsoils of recently cultivated or summer dry paddocks may be blown away and in extreme cases, wind throw of plantation trees and damage to buildings may occur. New Zealand’s location in the southern ocean results in high total wind run in many locations. Figure 14 shows mean daily wind run at four locations in New Zealand tends to be highest in spring and lowest in winter months. For Wanganui the maximum daily wind gust was 111 km/hr in Feb 2004 and in Wellington the maximum recorded gust was 161 km/hr in Aug 1975. Tornadoes occur rarely but can remove roofs and cause trees and power lines to fall. These events tend to occur when moist anticyclones move across New Zealand in a northerly direction from the subtropics but this is not the dominant weather pattern.



Deficit days are defined as the number of days where the potential soil moisture deficit exceeds 75 mm with potential soil moisture deficits using an “average soil type” with a plant available soil water holding capacity of 150 mm

Figure 13b. Long-term (1971–2002) annual median number of deficit days occurring in different regions of New Zealand
(NIWA, 2009)

Frost and snow events

Annually, the average number of ground frosts increases from 1 d/year in Kaitaia (northern North Island) to >90 d/year in Invercargill (southern South Island) (Table 6). Frosts are generally rare between mid October and April but may occur at any time in some southern and elevated parts of the country. Unseasonal spring frosts can have a large economic cost particularly to the viticulture and horticultural industries. When frost warnings are put in place a range of methods which include helicopters and wind turbines are used to create air movement and prevent damage to fruit. Snow may fall to sea level

Table 6. Number of ground frosts annually at selected locations throughout New Zealand

Site	No. ground frosts
Kaitaia	1
Gisborne	33
Napier	29
Wanganui	7
Blenheim	60
Westport	26
Christchurch	70
Invercargill	94

Data are means from sites having at least five complete years of data.

for short periods of time on the east coast of the South Island and in inland Canterbury and Otago. Serious stock losses may occur in winter if farmers fail to move stock to more sheltered areas especially where grazing occurs at >330 m.

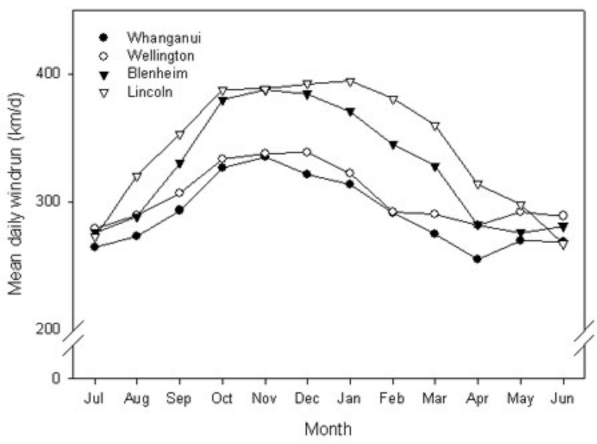


Figure 14. Long-term mean monthly wind run (km/d) at Wanganui (39.9388°S, 175.045°E, 15 m, 1996–2009), Wellington (41.286°S, 174.767°E, 125 m, 1975–1998), Blenheim (41.5231°S, 173.865°E, 35 m, 1990–2009) and Lincoln (43.62622°S, 172.4704°E, 18 m, 1975–2007)

Table 7. Dominant land use and selected land cover of New Zealand in 2004

Land-use classes	Hectares	Percentage of total land area (%)
Dairy	1 879 600	7.0
Intensive sheep and beef	3 841 100	14.3
Hill and High country sheep and beef	4 072 100	15.2
Deer	249 700	0.9
Other animals (goats, pigs, poultry, alpaca, emu, ostrich etc.)	64 900	0.2
Ungrazed	659 800	2.5
Urban	203 600	0.8
Planted forest	1 957 000	7.3
Arable & horticulture	43 460	0.2
Land-cover classes		
Tussock	2 645 200	9.9
Native forest	6 567 200	24.5
Rivers, lakes, snow and ice	2 094 200	7.8
Scrub	2 543 600	9.5
Total	**26 821 460**	**100.0**

Note: The "Arable & Horticulture" category includes cereals, fruit, vegetables and floriculture
(Ministry for the Environment, 2007)

Agro-ecological zones

Table 7 quantifies land use based on farming enterprise and dominant land cover classes through New Zealand and the total land area they cover as determined in 2004 (Ministry for the Environment, 2007). Pastoral based production accounts for 37% of the total land mass. Exotic forestry, predominantly from *Pinus radiata*, accounted for 7.3% of land area use. Agriculturally non productive native forest, tussock grasslands, scrubland, waterways and snow and ice accounted for >50% of land cover.

O'Connor (1993) summarized the main activities and identified 14 distinct landscape areas for New Zealand each of which differ in their dominant land use. More than one activity can occur within any agro-ecological zone. For example, arable production is mostly on flat to rolling land. Consequently, the majority of cereal and herbage seed production occurs in mixed cropping farm systems on the alluvial floodplains of the South Island. Most of the kiwifruit and citrus production occurs in the north of the North Island where higher rainfall and warmer temperatures are suitable for warm climate fruit production. Pastoral production occurs in parts of all landscape regions but the main farming enterprise depends on climate, topography, fertility, and the constraints these factors place on potential pasture and animal production at a specific location. Modifications to the descriptions of landscape areas note the recent increase in conversion of sheep and beef farms to dairying, plus the dramatic increase in viticulture in the South Island (Figure 15).

Within pastoral systems, about 55% of improved pastures are flat to rolling (slope 0–15°). A further 13% are hill country (16–20° slope) while the remaining area is classified as steep hill or high country (>21° slope) (Hodgson *et al.*, 2005). There are nine broad farm classes used to classify ruminant livestock production systems in New Zealand (section 4). Generally, hill and high country farm systems (Farm Classes 1-4, Section 4) include valley bottoms and/or alluvial terraces so at least 5–10%, or more, of these properties can be cultivated.

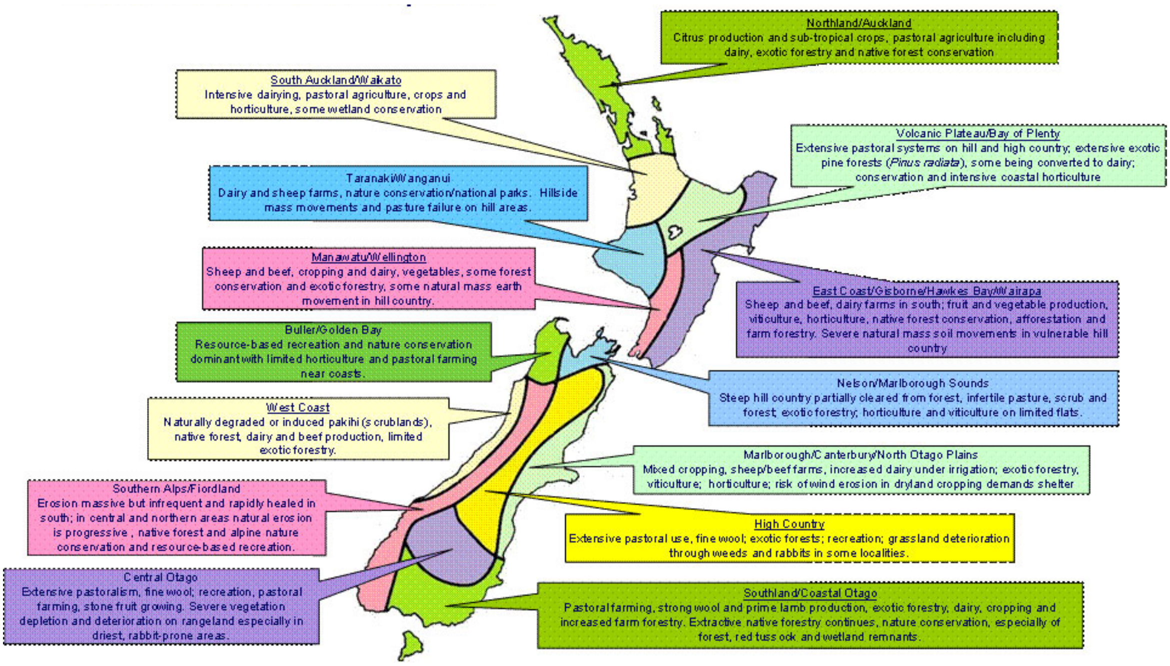


Figure 15. Major uses within the 14 landscape areas *(Modified from O'Connor, 1993).*

Arable and horticultural production

Topography is a major constraint to the area available for arable cropping, vegetable and horticultural enterprises. The Waikato landscape province has the highest proportion of high value soils suitable for food production followed by Southland. Canterbury has the most flat land but its use for arable crops is restricted because many soils are stony and have poor water holding capacity.

Figure 16. Vineyards Wairau Valley, Marlborough *(Photo: W.R. Scott).*

Over the last decade, greater diversification of land use has been evident, especially for horticultural land. As an example, the area of land in vineyards increased by 28% from 1997 to 2002 with large areas converted in Gisborne and Marlborough (Figure 16) with additional expansion into parts of Canterbury and Otago. Table 8 shows the area harvested (ha) for the year ending 30/6/2007 of selected outdoor vegetable, fruit, major cereals and herbage seeds (Department of Statistics, 2007).

Table 8. Area harvested (ha) of the selected outdoor vegetable, fruit, cereal and herbage seed crops for the year ending 30/6/2007

Crop		Area harvested (ha)				Area harvested (ha)		
		North Island	South Island	New Zealand		North Island	South Island	New Zealand
Vegetables	Broccoli	1 624	623	2 247	Green beans	66	658	724
	Cabbage	598	171	768	Lettuce	1 134	175	1 309
	Carrots	684	635	1 320	Tomatoes (outdoor)	734	23	757
	Cauliflower	648	212	860				
Fruit	Kiwifruit	12 632	618	13 250	Stone fruit	1 077	1 216	2 294
	Wine grapes	8 303	21 313	29 616	Berry fruit	270	431	1 222
	Apples	6 004	3 244	9 247	Citrus	453	9	1 834
	Pears	357	337	694				
Cereal and seed	Wheat	1 737	38 801	40 538	Oats	147	5 626	5 773
	Barley	5 772	45 710	51 481	Herbage seeds	424	26 904	27 329
	TOTAL	42 664	146 706	191 263				

Note: Data may not sum due to suppression of confidential data. "Stone fruit" includes peaches, nectarines, plums, cherries and apricots; "Berry fruit" includes: raspberries, strawberries, boysenberries and blueberries; "Citrus" includes oranges, lemons, grapefruit, mandarins and tangelos.(Department of Statistics, 2007).

4. RUMINANT LIVESTOCK PRODUCTION SYSTEMS

New Zealand is recognized for its year round grazing systems with a heavy reliance on perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pastures. Livestock systems are pasture based with forage crops and/or conserved feed used to fill in periods when pasture supply is below animal demand. The distance between New Zealand and its main export markets, combined with an environment suitable for pastoral production, has resulted in a focus on efficient sheep, beef and dairy production systems (Hodgson *et al.*, 2005). Table 9 shows the change in stock numbers from 1994–2007. In 1996 there were over 66 000 farms of which 25% were dairy farms, 36% were sheep and beef, 5% had mixed livestock, 17% were horticultural enterprises, 2% cropping and 15% allocated to the category "Other" which includes small (0.5–20 ha) "lifestyle" blocks and the equine industry.

Ruminant livestock systems in New Zealand are based on differences in environment, soil fertility, pasture and animal production levels and the main farming operation. There is a high level of integration between production systems with feed sources and livestock frequently moved between them to overcome regional feed deficits and unseasonal weather events.

Table 10 compares the environmental and farm structure differences in the eight farm classes used by Meat & Wool New Zealand Ltd (Matthews

Table 9. Total livestock numbers (M) from 1994 to 2007 for the main classes of ruminant livestock commercially farmed in New Zealand

Year	Beef cattle	Dairy cattle	Sheep	Pigs	Deer
1994	5.05	3.84	49.47	0.42	1.23
2002	4.49	5.16	39.57	0.34	1.65
2003	4.63	5.10	39.55	0.38	1.69
2004	4.45	5.15	39.27	0.39	1.76
2005	4.42	5.09	39.88	0.34	1.71
2006	4.44	5.17	40.08	0.36	1.59
2007	4.39	5.26	38.46	0.37	1.40

(Department of Statistics, 2009b).

Table 10. Sheep and cattle farm structure for an average farm separated by farm class

Farm Class	Rainfall (mm)	Steep land (%)	No. farms	Effective area (ha/ farm)	Labour (persons/ farm)	stock units1 (s.u./ ha)	s.u. as sheep (%)	Wool (kg/s.u.)	Lambing (%)	Calving (%)	Fawning (%)
1) South Island High Country	739	82	250	10 660	3.3	1.1	81	4.7	85	81	87
2) South Island Hill Country	766	61	900	1 600	1.9	4.0	76	4.7	114	85	85
3) North Island Hard Hill Country	1 520	77	1 550	790	1.9	8.7	60	4.5	115	76	79
4) North Island Hill Country	1 408	45	4 500	400	1.6	10.2	56	5.1	120	80	75
5) North Island Intensive Finishing	1 190	15	2 900	270	1.4	10.1	52	4.6	120	84	-
6) South Island Finishing Breeding	780	23	4 100	450	1.7	9.3	82	5.0	128	88	78
7) South Island Intensive Finishing	927	14	2 600	240	1.4	12.5	94	5.3	148	86	100
8) South Island Mixed Finishing	685	0.7	900	355	2.6	7.5	76	5.0	127	71	-
9) Dairy	>1 500	0	11 436	126		2.83a		307 b	-	74 c	-

Notes: dairy information is for the 2007/08 season. Rainfall for dairy systems includes irrigated properties in lower rainfall environments a = cows/ha; b = kg milksolids/cow; c = total number of calves born alive (3.5 M) divided by the total number of dairy cows and heifers in calf, in milk or empty but intended for milk production (4.7 M) as at 30/6/2008.

[1] s.u./ha = stock unit/ha. Stocking units are standardised rates which allow direct comparison of stocking rate regardless of stock class. A stocking rate of 1 s.u./ha is equivalent to one breeding ewe which rears one lamb. Feed allocation is 550 kg DM/y with an average metabolisable energy (ME) content of 10.5 MJ ME/kg DM. The allocation includes lamb feed consumed to weaning at 14 weeks. Ewes weighing 65 kg/head weaning 120% are equivalent to 1.2 s.u./ha. A 300 kg dairy cow with a milksolids yield of 280 kg is equivalent to 6.3 s.u; a 400 kg beef cow weaning 83% is equivalent to 4.4 s.u.; and an adult male red deer is equivalent to 2.1 s.u.. Stocking rate of a farm is usually based on the number of stock wintered on a farm. Specific details can be sourced from the Lincoln University Farm Technical Manual (Fleming, 2003).

Data for rainfall, steep land, number of farms and stock units (s.u.) as sheep were sourced from 1996 data (adapted from the New Zealand Meat and Wool Board Economic Survey, 1997) (Matthews et al., 1999). Data for effective area, stock units per hectare, wool yield, lambing, calving and fawning percentages are for the 2007/08 season (Meat & Wool New Zealand Economic Service, 2009b) and information for dairy systems is for 2007/08 (DairyNZ and LIC, 2009).

et al., 1999; Hodgson *et al.*, 2005) plus a ninth class to describe dairy farms. Descriptions of each farm class follow.

South Island high country

The South Island high country farms systems are extensive and dominated by high altitude tussock grassland (Figures 17 and 18). Improved pastures are limited to flat and rolling land on a limited area of valley bottoms and old river terraces. Approximately 80% of feed produced comes from the 20% area of improved pastures on the property (Matthew *et al*., 1999). Properties can range in size from 3 000 to 40 000 ha. Traditionally, these are fine wool producing properties. The average farm size for farms in this class is 10 660 ha (Table 10). Stocking rates are generally low (1 s.u./ha) but the contribution of improved pastures is marked. Carrying capacity of these properties is strongly influenced by the area of improved pastures present which may carry up to 4 s.u./ha. Consequently, farms with larger areas of improved pastures may have a higher carrying capacity.

Figure 17. An extensive South Island high country property in the Lindus Pass with native tussock grasslands
(Photo: W.R. Scott).

Steep hill and mountainous terrain combined with a short growing season means annual pasture production is low and intensification may not be economically viable. Pasture production on high country varies depending on position in the landscape and level of pasture improvement. For example, in a 600–900 mm/year rainfall environment production from unimproved pastures ranges from 0.3–1.0 tonnes DM/ha/year; improved pastures on shady faces can yield 2.5–5.5 tonnes DM/ha/year; on sunny faces improved pastures can produce 2.0–5.0 tonnes DM/ha/year. Improved pastures on flat land (terraces and valley bottoms) can yield between 4.0–10.0 tonnes DM/ha/year (Matthews *et al.*, 1999). Farms are stocked with a combination of merino sheep, beef cattle and deer, all of which are seasonally set stocked. Ratios between stock classes are altered depending on the season and commodity prices.

Figure 18. Sheep grazing tussock grasslands near Lake Tekapo in late winter/early spring
(Photo: W.R. Scott).

Historically, the main source of revenue has been wool (60–70% of farm income) but recent low wool prices have resulted in a shift to store lamb and calf production to increase farm income. Currently farm incomes are 51% from wool, 21% from lamb and 15% from beef (Figure 19) with a gross farm income of NZ$ 59/ha. Some farms have also run deer to sell weaners for finishing (venison) and for immature antlers (velvet) from a stag herd.

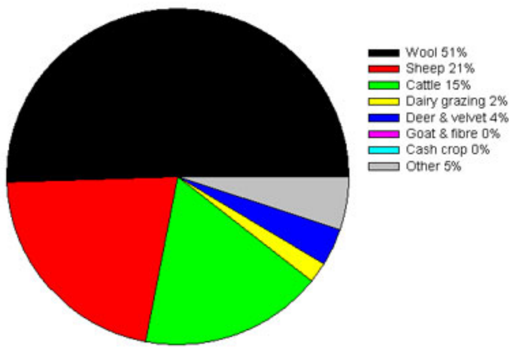


Figure 19. Percentage of gross farm revenue per hectare from different sources for a South Island High country property (Farm Class 1) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

Appropriate stock management in winter and spring is essential in these systems due to the short growing season and harsh environmental conditions for production. Frost can occur throughout the year and snow may lie at altitudes above 1 000 m for several months. Within a grazing area, pasture production is highly variable because of variations in slope, aspect and altitude. In winter months animals grazing at high altitude may be lost due to snow if appropriate measures are not taken to protect vulnerable stock. Long (4–5 month), cold winters mean the active growing season is short. Therefore, these properties are highly reliant on forage crops (e.g. swedes, *Brassica napus*) and conserved feed from lucerne (alfalfa; *Medicago sativa*) or pasture based hay or silage, which is generally grown in spring on the limited flat land available in river valleys and old river terraces. These flatter areas are well subdivided and break fenced for feeding out during critical periods when feed demand exceeds supply.

Previously, about 80% of land grazed by high country farms was under pastoral lease from the Crown (i.e. owned by the government). These properties have been the subject of recent "Tenure Review" (see below). The process negotiates for landscapes of value to the nation. Large areas of higher altitude tussock grasslands have been returned to government management (Department of Conservation) and withdrawn from grazing. In the current review cycle higher value is placed on the lower altitude landscapes within this property class. In return, lease holding farmers are able to freehold lower altitude land which is less vulnerable to erosion.

Rangeland on these properties is dominated by native tussock species. These include: *Chionocloa* spp. (tall tussock or snow grass), *Festuca novae-zelandiae* (fescue or hard tussock) and *Poa cita* (silver tussock) interspersed with introduced low yielding but persistent browntop (*Agrostis capillaris*). Invasion by *Hieracium* species over the last 50 years has reduced the productivity of unimproved tussock grasslands. The most prostrate of these perennial daisies, *Hieracium pilosella*, has the greatest effect on productivity. Introduced woody weeds, gorse (*Ulex europaeus*), broom (*Cytisus scoparius*), sweet brier (*Rosa rubiginosa*) and conifers (wilding *Pinus* spp. from exotic forestry plantations) are also difficult to control under these extensive grazing systems.

South Island hill country

Pasture production is constrained by low temperatures in winter and by soil moisture deficits which develop in late spring and summer. This is compounded by shallow, weakly developed soils that dominate on the eastern foothills of Marlborough, Canterbury and Otago. Unreliable pasture growth in summer months reflects seasonal variation in the rainfall distribution combined with high evapotranspiration and low soil water holding capacity due to a high proportion of stones within the profile and/or shallow depth to underlying gravels. Annual pasture production is 1.0–6.0 tonnes DM/ha/year (Matthews *et al.*, 1999).

Properties within this land class (Figure 20) produce wool and breed lambs and cattle which are then sold to lowland intensive finishing properties (Farm Class 6). Mid micron sheep (merino x coarse wool cross breeds or Corriedale) are the dominant breeds and they graze modified tussock grasslands. Typically, about 75% of the stock wintered are sheep and 25% are beef cattle at about 4 s.u./ha. These properties are being forced to intensify as dairy conversions displace the intensive sheep and beef finishing properties on the more fertile lowland plains. The gross revenue for farms in this class in 2007/08 was NZ$ 211/ha and contributions from different sources are shown in Figure 21.

Figure 20. South Island hill country property near Hawarden (North Canterbury) showing improved pastures in foreground on cultivatable land and lower producing mixed species pasture on steeper hill country in the background
(Photo: W.R. Scott).

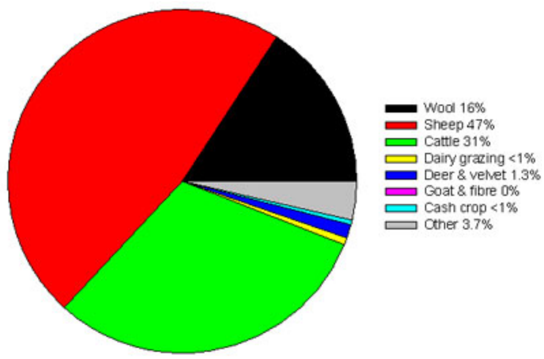


Figure 21. Percentage of gross farm revenue per hectare from different sources for a South Island Hill country property (Farm Class 2) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

Low input pastures are a mix of low fertility tolerant and lower yielding pasture species which include *Notodanthonia* spp., browntop, sweet vernal (*Anthoxathum odoratum*), silver tussock, Yorkshire fog (*Holcus lanatus*), adventive annual legumes such as suckling (*Trifolium dubium*) and haresfoot (*T. arvense*) clovers. Development of improved pastures, which includes grass/legume pastures, areas of lucerne for hay and brassicas for winter feed, depends on the level of investment for improvements. Soils tend to be naturally acidic (pH 4.5–5.5) and fertility can be improved by the application of lime and superphosphate fertilizers on river flats, terraces and easier lower slopes. Improved pasture species include perennial ryegrass, cocksfoot (*Dactylis glomerata*) white and subterranean (*T. subterraneum*) clovers. Supplements (predominantly brassicas) are grown on cultivatable land to provide winter feed. Clovers can be introduced to hill slopes by aerial broadcasting of inoculated seed followed by heavy stocking with sheep and cattle to trample in the seed.

North Island hard hill country

These properties are steep hill country (>16° slopes, see Figure 22) with low fertility soils on the east and west coasts and Central Plateau of the North Island. Properties were cleared from native forest in the late 19^{th} Century by burning and broadcasting seed. Further pasture improvement was possible from 1950 with the widespread use of aerial topdressing of superphosphate fertilizer and oversowing with improved pasture species, particularly white clover. These low fertility soils are maintained by regular aerial topdressing with lime and superphosphate when this is financially viable but applications cease if farm returns drop in relation to fertilizer prices. Woody weeds such as gorse and manuka (*Leptospermum scoparium)* can reduce the productive grazing area and weed control is made difficult by the terrain. Woody weed reversion can be avoided by maintaining intensive grazing management through subdivision.

Annual rainfall for farms in this class is usually >800 mm and temperatures allow year round pasture production although lower rates occur in winter months. Steep hills are prone to soil erosion by mass movement following high intensity, saturating rain events and this is compounded when pastures are overgrazed.

Pasture yields are 2.0–6.0 tonnes DM/ha/year and properties are stocked at about 8–9 s.u./ha with dual purpose sheep breeds and beef cattle (about 60:40 sheep:beef s.u.). The majority of farm income is from the sale of store lambs, wool, cast-for-age ewes and beef weaners (Matthews *et al.*, 1999; Hodgson *et al.*, 2005). In the 2007/08 season, 63% of total gross farm income (NZ$ 351/ha) was from wool and sheep with a further 31% from cattle (Figure 23).

Low fertility, low producing species which include browntop, Yorkshire fog, sweet vernal, crested dogstail (*Cynosurus cristatus*), white clover and adventive annual legumes dominate pasture production. Significant fertility transfer of nitrogen, phosphorus and sulphur (Gillingham and During, 1973; Saggar *et al.*, 1990) can occur on a micro-scale from slopes to sheep tracks and camps (section 5) where perennial ryegrass and white clover can dominate.

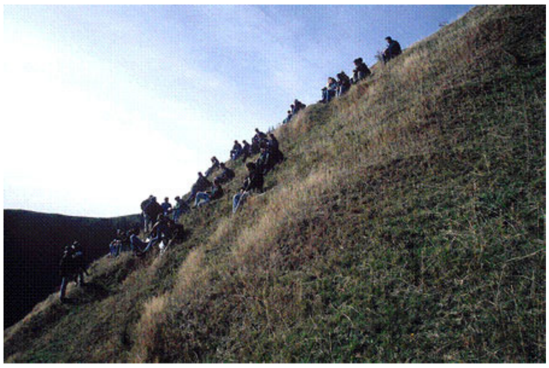


Figure 22. Example of a North Island hard hill country property visited by Lincoln University students on a field trip
(Photo: W.R. Scott).

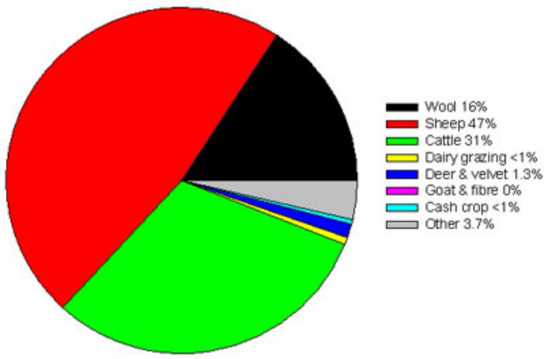


Figure 23. Percentage of gross farm revenue per hectare from different sources for a North Island Hard Hill Country property (Farm Class 3) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

North Island hill country

These properties are smaller in area than those on hard hill country and are more productive per unit area. Soils are moderate to high fertility resulting from lime and fertilizer inputs over time. Feed deficits may occur in summer months as pasture production is compromised when summer soil moisture deficits develop.

Lower slopes and flat land are easily cultivated to introduce improved pasture species (Figure 24). Predominantly these are perennial ryegrass and white clover but subterranean clover and cocksfoot use is also widespread. In stock camps high fertility weed species dominate. These include Californian (*Cirsium arvense*), scotch (*C. vulgare*) and nodding (*Carduus nutans*) thistles, barley grass (*Hordeum murinum*) and nettle (*Urtica urens*). Nitrogen deficiency often compromises potential pasture production and this is addressed by management to encourage pasture legumes and some use of inorganic N fertilizer when it is economic.

Annual pasture production is 5.0–8.0 tonnes DM/ha/year (Matthews *et al.*, 1999) from improved species and stocking rates can be 10+ s.u./ha. A high proportion of stock are sold in forward store or prime condition. Income from cattle accounted for 38% of total gross farm income (NZ$ 550/ha) in 2007/08 and a further 41% was from sheep production (Figure 25).

Figure 24. Example of a North Island hill country property
(Photo: W.R. Scott)...

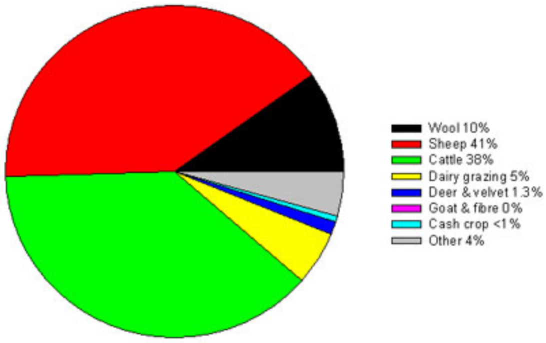


Figure 25. Percentage of gross farm revenue per hectare from different sources for a North Island Hill country property (Farm Class 4) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

North Island intensive finishing systems

This farm class can be found throughout the North Island. Farms are high fertility, flat to rolling properties that produce 10–16 tonnes DM/ha/year from predominantly perennial ryegrass/white clover pastures (Figure 26). These persist for 10–15 years before they undergo renewal. Endophyte status (see section 5) of the perennial ryegrass is determined by the requirements of the systems and the number of life cycles pests such as Argentine stem weevil (*Listronotus bonariensis*) complete during a year. Recently, novel endophytes such as AR1 and AR37 have been introduced to protect against pasture pests without causing the animal health issues (e.g. ryegrass staggers) associated with use of wild type endophyte infected ryegrass. Leaf turnips are sown as part of the pasture renewal programme (see section 5) and provide supplementary feed during periods of summer or winter feed deficit.

Figure 26. Example of a North Island intensive finishing farm
(Photo: W.R. Scott).

Stocking rates may reach 12–13 s.u./ha with the majority sold in prime condition to the freezing works. In favourable environmental conditions pasture production allows purchase and finishing of replacement ewes and store lambs obtained from surrounding hill country farms (Farm Classes 3 and 4). Income is from a combination of beef (including bull beef from the dairy industry) and prime lamb production. Gross revenue was NZ$ 799/ha in 2007/08. Providing grazing for dairy cattle and cash crops provided about 13% of gross farm income (Figure 27).

South Island finishing-breeding farms

Sheep and beef finishing and breeding farms may be >300 ha in size and this is the dominant farm class in the South Island. Properties are intensively managed for finishing and breeding stock. Pastures may be irrigated in drier areas.

Perennial ryegrass/white clover pastures dominate under irrigation while specialist forages such as lucerne and brassicas are sown to ensure the supply of high quality feed particularly on the dryland properties exposed to summer moisture limitations. Perennial ryegrass is generally infected with wild type or a novel endophyte to ensure pastures persist due to combined effects of pest load and periodic exposure to drought. Cocksfoot is more suited to these environments but yields can be below potential due to nitrogen deficiency, which can have a greater effect on total annual pasture production than the periodic summer drought (Mills *et al*., 2006). In dryland systems, where soil water stress compromises pasture production, white clover also fails after loss of the taproot 12–18 months after sowing. Weed species include browntop, twitch (*Elymus repens*), barley grass, vulpia (*Vulpia* spp.), dock (*Rumex obtusifolius*) and thistles. Pastures are renewed at 6–10 year intervals depending on the level of weed and pest infestation and the need for land to grow winter forage crops. Typically, about 10% of the property is renewed annually to maintain production of high quality forage and ensure winter feed supply. Lucerne can represent 30–40% of the effective farm area and cultivars need to be resistant to blue green aphid (*Acyearthosiphon kondoi*) and resistant/tolerant of stem nematode (*Ditylenchus dipsaci*) to ensure production and persistence. Lucerne stands are rotationally grazed to ensure optimum animal performance and stand persistence, and may be conserved as hay or silage.

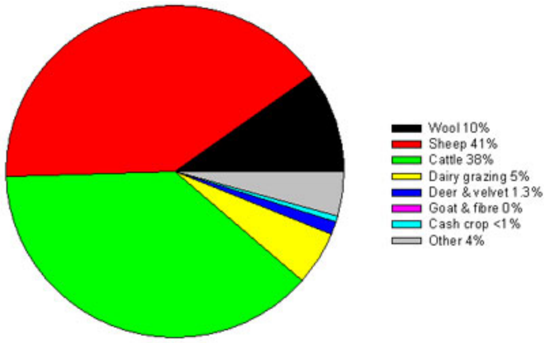


Figure 27. Percentage of gross farm revenue per hectare from different sources for a North Island Intensive Finishing property (Farm Class 5) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

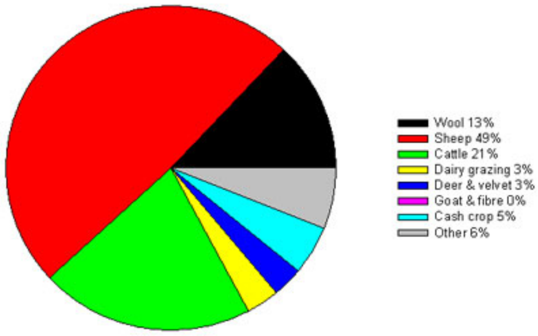


Figure 28. Percentage of gross farm revenue per hectare from different sources for a South Island Finishing-Breeding property (Farm Class 6) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

Perennial ryegrass based pasture yields are generally 7.0–10.0 tonnes DM/ha/year in the Canterbury and Otago regions. This increases in years with above average summer rainfall. This allows stocking rates on dryland properties to be maintained at 9–10 s.u./ha and replacements are generally bred on-farm. Irrigated pastures may produce 15.0 tonnes DM/ha/year and carry up to 20 s.u./ha.

Of the NZ$ 670/ha gross income almost half (Figure 28) is generated from sheep production and income may be supplemented by using a limited farm area for vegetable or arable cash crops sown for either processing or seed production. Conversion of suitable sheep and beef farms to dairying occurs when irrigation is available and commodity prices provide a financial incentive.

South Island intensive finishing farms

These farms are mostly found in summer safe environments in Southland (Figure 29) and parts of Otago where sufficient summer rainfall precludes severe droughts but winters may be severe. Typically, in these farm systems, about 85% of gross farm income is from sheep, 7% from cash crops and about 2% from beef cattle (Matthews *et al*., 1999). However, in 2007/08, farms in this class actually generated gross farm incomes of NZ$ 1091/ha of which 7% was from cattle and only 2% from cash crops (Figure 30). High production rates (>65 kg DM/

Figure 29. South Island intensive finishing property near Gore. Note areas sown in brassica left and central mid distances for winter feed
(Photo: W.R. Scott).

ha/d) occur consistently from late spring and through summer with annual yields of 10.0–15.0 tonnes DM/ha/year capable of carrying 12 s.u./ha. The climate provides reliable rainfall year round but cool temperatures restrict winter pasture growth. Nil endophyte perennial ryegrasses are used as the basis for pasture mixes with white clover because pest incidence is reduced in cooler climates. This avoids potential for animal heath issues. Other pasture species used in these systems include annual and hybrid ryegrasses, timothy (*Phleum pratense*), red clover (*Trifolium pratense*) and chicory (*Cichorium intybus*). Weed species include browntop, crested dogstail and Californian thistle. Pasture renewal intervals depend on management strategies but are usually at least 10 years. Forages such as bulb brassicas (swedes) are essential to provide winter feed (Figure 31). These are sown in late spring to accumulate 15.0–20.0 tonnes DM/ha over summer/autumn before being grazed off behind an electric fence in winter. This outdoor feed supply in the coldest regions of New Zealand means animals are not housed. Equally, the perennial grass pastures are grazed hard in late summer before being left to accumulate pasture cover in autumn that may also be break-fed in winter months (Figure 32), or utilized in spring for lambing.

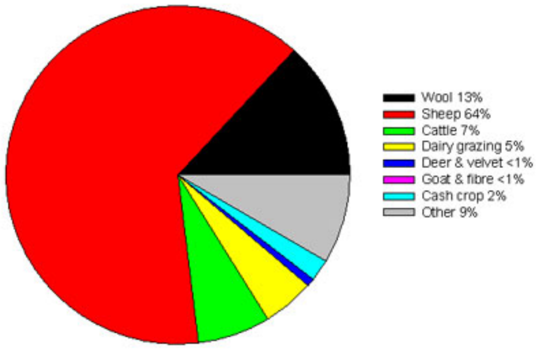


Figure 30. Percentage of gross farm revenue per hectare from different sources for a South Island Intensive Finishing property (Farm Class 7) for the 2007/08 season

(Meat & Wool New Zealand Economic Service, 2009b).

Figure 31. Winter grazing of a swede crop in Southland

(Photo: W.R. Scott).

Figure 32. Example of 'all grass wintering' in Southland. Break fencing ensures development of a feed wedge and back fencing is important when re-growth production is expected

(Photo: W.R. Scott).

South Island mixed cropping and finishing farms

These farms are mainly in Canterbury on flat land with deep soils. Irrigation is usually available. The main crops are cereals; wheat *(Triticum aestivum)*, barley (Hordeum vulgare), oats (*Avena sativa)*, herbage seed (ryegrasses, white clover (Figure 33), cocksfoot and tall fescue (*Festuca arundinacea)*, vegetable seeds and process crops such as peas (*Pisum sativum*), beans (Phaseolus vulgaris); potatoes (*Solanum tuberosum*) and carrots (*Daucus carota*). Many run a breeding sheep flock and/or finish bought in lambs which fit into the crop/pasture rotations.

About 70% of gross farm income is derived from grain and small seed production. Revenue sources and contributions to farm income per hectare for 2007/08 (NZ$ 2 348/ha) are shown in Figure 34. The remainder is split between stock finishing and process crops. In these systems specialist finishing pastures of lucerne or red clover, chicory and annual (*Lolium multiflorum*) or hybrid ryegrass may be used to maximize animal liveweight gains. Permanent pastures are uncommon because the pasture phase is part of the cropping rotation used to increase soil organic matter levels and restore soil structure.

Dairy farms

Most dairy farms are in 'summer safe' areas which include South Auckland, Waikato and Taranaki in the North Island and Southland and the West Coast of the South Island which have a favourable growing environment. These regions usually experience >1 500 mm of annual rainfall and periods of water stress are uncommon. There has been recent expansion in dairying (see below) into traditional sheep and beef regions on the east coast of the South Island where irrigation is available (Figure 35). This is due to higher returns from milk than from meat and wool in recent years. These systems may need to provide 450 mm of irrigation water to overcome PSMD in summer.

Dairy systems are high input, and high fertility farms which are intensively managed. Perennial ryegrass pastures dominate with some white clover. Supplementary feed is required (pasture and maize (*Zea mays*) silage, palm kernel, brassicas) for winter months to complement perennial ryegrass pasture production curves. In the North Island turnips (*Brassica rapa*) and maize (for silage) dominate supplementary feed which may also be used to supplement pasture in summer. In the South Island, kale (*B. oleracea* spp. *acephala*) is the dominant forage crop for winter grazing. Dry stock are often wintered on other properties (e.g. mixed cropping properties described in Farm Classes 6 and 8) off the "milking platform", particularly in the South Island.

Figure 33. Example of a white clover herbage seed crop grown in Canterbury
(Photo: W.R. Scott).

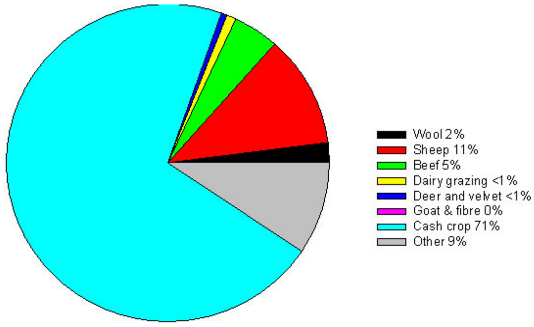


Figure 34. Percentage of gross farm revenue per hectare from different sources for a South Island Intensive Finishing property (Farm Class 7) for the 2007/08 season
(Meat & Wool New Zealand Economic Service, 2009b).

Figure 35. Dairy cows grazing irrigated perennial ryegrass dominant pasture on the Lincoln University Dairy farm, Lincoln, Canterbury
(Photo: W.R. Scott).

Ruminant sector demographics, products and exports

The sheep industry

New Zealand sheep meat has been exported to international markets since 1882. It accounts for 6% of global production but 38% of international sheep meat trade (2006/07). The majority is destined for markets in the European Union. Prime lambs tend to receive the highest prices, and are sold before Christmas to meet market demand. A benefit of this for those farmers that can procure lambs at this time is that they are sold prior to summer dry conditions which compromise pasture production on the east coast of both islands. Currently the average carcass weight is 17.7 kg/hd (Meat & Wool New Zealand Economic Service, 2009a) and the majority of lambs are slaughtered at ~100 days of age.

Total sheep numbers (Figure 36) have decreased from 70.3 million in 1982 to ~50 million in 1994 (MAF, 2009) and declined further to an estimated 34 million in 2008 (Department of Statistics, 2009b). This decrease represents the dynamic nature of the livestock industry which has responded to low sheep meat prices and an east coast drought. The drought reduced the national lambing percentage by 5.3% to 113% because ewes were in a poorer condition than usual at mating. Changes in land use included conversion of sheep farms to dairying, viticulture and cropping which offered higher returns than meat. Breeding ewe numbers decreased almost 10% in 2008, and the greatest reduction (almost 15%) was in Marlborough/Canterbury (Meat & Wool New Zealand Economic Service, 2009a). Dairy conversions occurred on 330 sheep and beef properties in 2008 which displaced 1.3 M sheep and beef stock units. Total conversions in 2008 were second only to the 360 properties converted in 1996/97. In contrast, only 70 farms underwent dairy conversion in 2007.

Despite the >30% decline in sheep numbers since 1990 (MAF, 2009), total national lamb meat production has increased by 12% over the same period. This reflects improvements in on-farm management practices, genetic gains for animals, higher quality pastures, animal and pasture based research and uptake of new knowledge by pastoral farmers.

In June 2000 it was estimated that 58% of all sheep were the dual purpose Romney. This was the dominant breed in the North Island and south of the South Island. In Canterbury, Marlborough and Otago the main breeds were Corriedale and Half breed dual purpose sheep which accounted for 6% and 4% of the national flock. South Island high country properties favour merinos (7% of all sheep) for their fine wool production. The other two major breeds are the Coopworth and Perendale which accounted for 10% and 7% of the national flock. The remaining 8% consists of crossbreeds, composites, Texel, Suffolk, Borderdale, Dorper, Poll Dorset and others. As producers move towards dual purpose flocks, genetics from Texel, Finn and East Friesian are being used to increase fertility and the meat production potential of the existing Romney, Perendale and Coopworth based flocks.

Half of New Zealand lamb exports in 2007/08 (volume) and 64% of lamb export receipts (value) were to the European Union. Of this, 30% was chilled lamb and 70% frozen. For the 2007/08 year (Sept) lamb exports accounted for NZ$ 2.52 billion (Meat & Wool New Zealand Economic Service, 2009a).

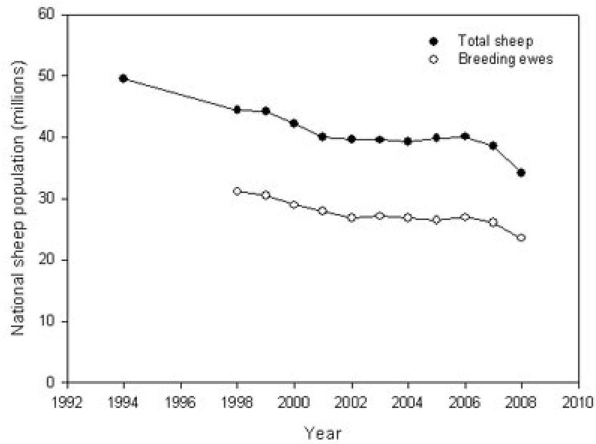


Figure 36. Total sheep and breeding ewe population changes in New Zealand between 1994 and 2008
(Meat & Wool New Zealand Economic Service, 2009a).

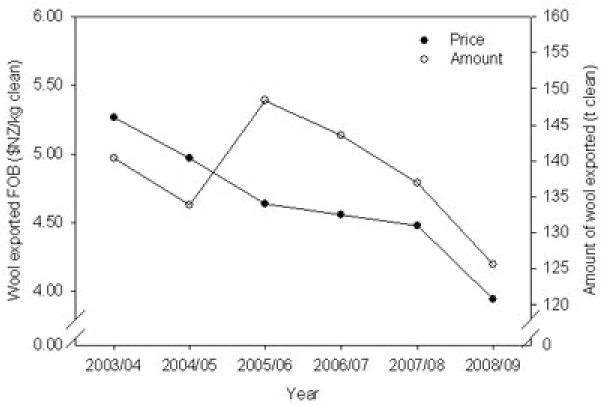


Figure 37. Change in wool price and quantity of wool produced between 2003/04 and 2008/09
(Meat & Wool New Zealand Economic Service, 2009a).

Wool

New Zealand wool is used in the production of 45% of the world's wool carpets (Meat & Wool New Zealand, 2008). In New Zealand fleece weights are 4.5–5 kg/hd (clean) compared with a global average of 1.2 kg/hd. In 2006, 14% of global wool production was from New Zealand and this indicates that 89% of all New Zealand wool was exported. Of this, 7% of the wool sold at auction was fine (<24 micron), 6% was medium (25–32 micron) and 87% was strong wool (>32 micron). Clean wool exports totalled NZ$ 613 M for the 2007/08 year, and the price was at its lowest in more than 20 years (Meat & Wool New Zealand Economic Service, 2009a). The majority of New Zealand wool is sent to China (37 300 tonnes clean) which included >40% of the total fine wool. A consequence of the decrease in wool prices since 2005/06 (Figure 37) has been a shift by farmers towards composite sheep breeds to increase income from meat production with the wool component contributing less to total farm income.

The Beef Industry

Over 99% of beef produced in NZ is grass fed and about 70% of the national beef herd is in the North Island. Bull beef is mainly sold for slaughter at 260–300 kg carcass weight (500–580 kg liveweight/hd) when stock are 14–18 months old (Hodgson *et al*., 2005).

In June 2008, total beef cattle numbers were 4.3 M which was a 3.2% decrease from June 2007 (Figure 38) and 31% of these were breeding cows and heifers. Over 2.0 M head are slaughtered annually with 200 000 tonnes of beef and veal meat exported to North America (54% of total beef exports) and 100 000 tonnes to North Asia (28%). At 30 June 2008, the main beef breeds were Angus (~20%), Friesian (~23%), Angus/Hereford (8%) and Hereford (~8%) and mixed breed (32%).

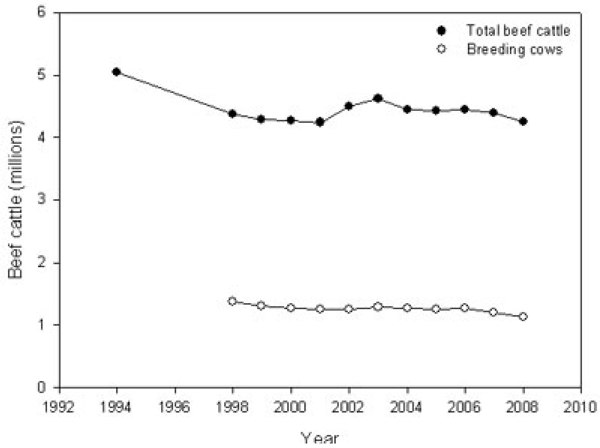


Figure 38. Changes in the total number of beef cattle and the number of breeding cows (subset of total herd number) in New Zealand between 1994 and 2008
(Meat & Wool New Zealand Economic Service, 2009a).

About 70–80% of all beef cattle are farmed in the North Island (Farm Classes 3, 4 and 5). In Taranaki/Manawatu the 5.6% decrease in beef cattle numbers between 2007 and 2008 was a result of drought and dairy conversion whereas beef cattle numbers on the east coast of the North Island increased 5.3%. In the South Island, dairy conversion of finishing properties in Southland and Canterbury resulted in a 1.2 M head reduction between 2007 and 2008. This decreased weaner cattle numbers by almost 30% in Southland. However, breeding cow numbers increased 6–8% in Southland and Otago. The majority of the increase in breeding cow numbers occurred on Farm Class 2 (South Island Hill Country) properties in Otago, Farm Class 6 (South Island Finishing-Breeding) in Southland and retention of weaners on Farm Class 1 (South Island High Country) land in Marlborough/ Canterbury regions.

The Deer industry

New Zealand is now the major exporter of deer products globally and accounts for about 50% of the worldwide farmed deer numbers. The major product is venison meat (~84%) followed by antler velvet (10%) and other co-products including hides and leather with 90% of all venison produced being exported. The majority of venison produced is sent to European markets while velvet and co-products are exported to Asia. Animal welfare regulations on the removal of velvet are strict. Only veterinarians or farmers who have been appropriately trained may administer the local anaesthetic and remove immature antlers.

The NZ Deer Industry Industry was developed from aerial capture of wild red deer from the South Island high country. Deer were initially released in the Southern Alps and foothills of the Canterbury Plains in the mid 1800s for sport. Lack of predation and a suitable environment resulted in significant increases in the feral population. These animals are considered pests that destroy native vegetation. Aerial eradication programmes were used to control numbers in the wild and export of feral venison began in the 1960s.

In the 1970s live capture of feral red deer was initiated and these bloodlines form the basis of the deer industry. Red deer account for over 85% of the national herd with the remainder from Wapiti (Elk; *Cervus canadensis*) and red deer/wapiti crosses. A small number of fallow deer (*Dama dama*) are also commercially farmed. Genetic improvements have been made through the import of genetic material from Eastern Europe, the UK and North America.

The total number of farmed deer decreased 28% between 2005 and 2008 to 1.2 M (Figure 39) in response to product prices. About 70% of farmed deer are in the South Island (Department of Statistics, 2009b). In 2002, the total export value of the deer industry was NZ$ 375 M.

Deer farming occurs in a range of farming systems from small herds on lifestyle blocks (10–20 ha) to large herds grazing on extensively managed high country farms (Farm Class 1). In these larger farming systems deer are usually part of a diversified stock portfolio which includes sheep and beef cattle (Deer Industry New Zealand, 2009). Farming systems may focus on 1) breeding, 2) venison finishing or 3) velvet production, but commonly farms run a combination of operations to spread the economic risk. In

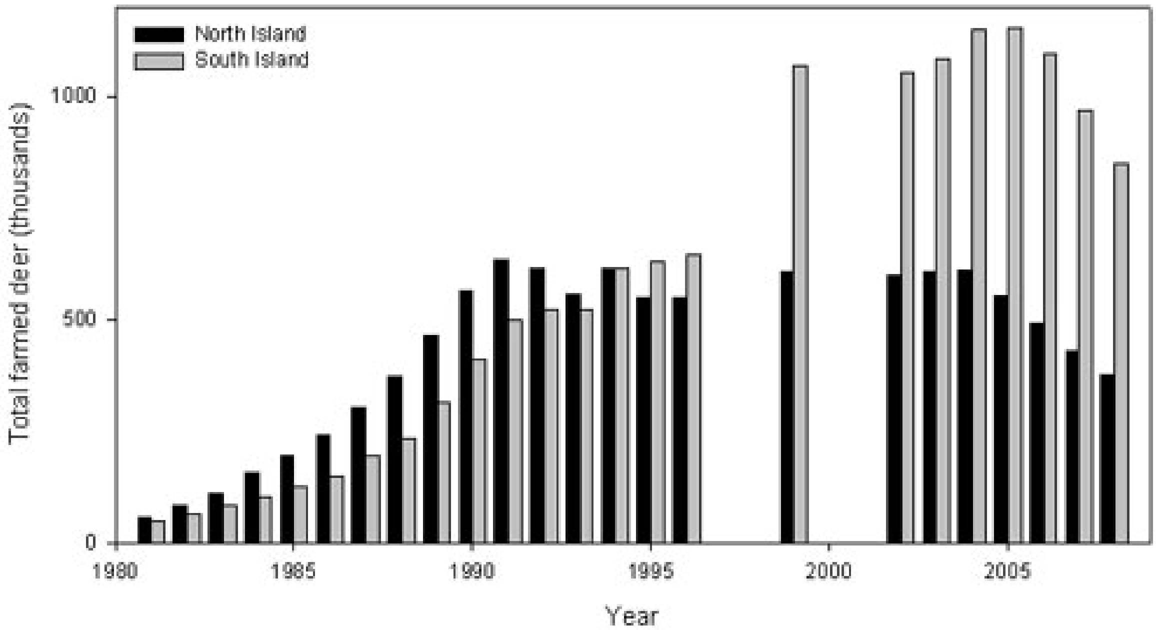


Figure 39. Total farmed deer numbers at 30 June between 1981 and 2008 in the North and South Islands of New Zealand.
Note: data were not collected in 1997, 1998, 2000 and 2001
(Department of Statistics, 2009b).

Table 11. Target liveweights (kg/head) at different ages for stags and hinds of commercially farmed deer breeds in New Zealand

Class	Breed	4 months (weaning)	9 months (winter end)	16 months (end summer)	2 years	Mature (summer)
Stags	NZ Red	53	67	109	145	200
	Half bred Wapiti/red	75	107	160	180	300
	Canadian Wapiti	140	168	260	320	400
Hinds	NZ Red	48	60	85	95	100
	Half bred Wapiti/red	66	95	130	180	220
	Canadian Wapiti	120	150	220	270	330

(Fleming, 2003).

2002/03, deer contributed >50% of farm revenue on 2 300 farms nationwide and these farms accounted for 63% of the farmed deer population (Ministry of Agriculture and Fisheries, 2009b).

The red deer gestation period is ~233 days with fawning in November/December. This timing does not match traditional ryegrass/white clover pasture production curves which peak a month earlier in most dryland systems. Feed demand by this class of stock is also highly seasonal. Consequently, the majority of farmed deer sold for venison are slaughtered at 12–15 months of age by which time they have achieved 50–60 kg carcass weight. Target liveweights for commercially farmed stags and hinds of different breeds are presented in Table 11. Velvet production ranges from 1 kg/head from young animals (2 years age), 2.5 kg/head from stags aged 5–8 years) with a 4.5 kg/hd maximum (Hodgson *et al*., 2005).

Most herds graze perennial ryegrass based pastures but specialist pastures of herbs and legumes such as chicory, red clover and lucerne are used to promote high liveweight production. During periods of feed deficit hay, silage and grain may be fed out to maintain feed supply.

The Dairy industry

New Zealand's dairy industry has expanded rapidly over the last 20 years. Traditionally, dairy farming was restricted to 'summer safe' flat to rolling land in the west of the North Island where mean annual rainfall is ≥2 000 mm/year. Recent expansion into high risk regions that receive 600–1 000 mm rainfall has occurred in Canterbury, Otago and the eastern North Island. These regions are highly reliant on access to irrigation in summer months. The conversion of sheep/beef properties to dairy has been fuelled by an increase in dairy commodity prices as international demand has increased. Dairy products now account for 37% of the countries merchandized agriculture and forestry exports With the increased potential incomes from dairy products, land prices have increased dramatically from NZ$ 5 013/ha in 1988 to NZ$ 28 035/ha in 2007 (DairyNZ and LIC, 2009).

New Zealand dairy systems are based on year round outdoor pastoral grazing. Direct grazing contributes about 90% of the animal feed demand and means production costs are low by international standards (Hodgson *et al*., 2005). When pasture production is insufficient to meet stock demand, due to low winter temperatures, or summer drought conditions, or when pasture quality is insufficient to meet the animals' energy requirements, supplements such as hay, silage, concentrates and/or forages fed *in situ* are included. The primary pasture is perennial ryegrass/white clover which is high producing in environments with adequate rainfall (annual and seasonal) or where there is access to irrigation. Dairy systems are intensively managed with rotational grazing, twice a day shifts (which are often back fenced) which coincide with milking. Recently some farmers have begun 'once a day' milking programmes.

Farms are generally run as either 1) owner operated 2) contract milk or 3) share-milking farm structures. Owner operators account for 63% of the national herd (DairyNZ and LIC, 2009). The majority of owner operator and contract milk structures dominate with smaller herd sizes (<200 cows). Almost 80% are based in the North Island. Share-milking is a farm structure in which there is a partnership between a farmer (landowner) and a share-milker (herd owner). Partnerships vary depending on the resources contributed by each of the partners. The 50/50 share milking structure accounts for a further 22% of the national herd while 10% are managed under a <20–29% share-milking structure and <2% are >54% share-milkers. Share-milking is the dominant farm operating structure when herd size is 200–449 cows and reflects the inputs necessary to manage larger herds.

The national dairy herd is >4 M milking cows/heifers and has increased by more than 50% since 1992/93. During this time the average herd size has increased from 180 cows/herd to 351 cows/herd while the number of herds has declined by 20% to 11 436 (DairyNZ and LIC, 2009). The average on-farm stocking rate has increased from 2.5 to 2.8 cows/ha and varies regionally from 2.2 cows/ha in Northland to 3.3 cows/ha in North Canterbury.

Herd sizes varied in 2007/08, with ~3% having <100 cows and ~3% having >1000 cows. About 52% of all national herds have 150–349 cows. The majority of dairy farms (79%) are located in the North Island of which 32% are in the South Auckland/Waikato region and 16% in Taranaki. Farm sizes in the South Island (526 cows/herd and 186 effective ha) are larger than those in the North Island (305 cows/herd and 110 effective ha) with the largest average herd size in Canterbury (>700 cows/herd).

Increased production by the New Zealand dairy industry is a reflection of improvements in on-farm management and genetic gain. Over 70% of the national herd undergo herd testing which allows low producing or disease prone (predominantly mastitis) animals to be identified and culled. The best performing stock are then used for breeding. Since 1998/99 the total amount of milk processed from the national herd has increased 40% from 10.6 billion litre/year to 14.7 billion litre/year. Milk solids (MS) production has increased by ~3.9 kg MS/cow/year from 653 (1992/93) to 934 kg MS/cow/year in 2006/07. Figure 40 shows the changes in annual milk solids production in New Zealand between 1992/93 and 2008/08 on a per cow and per hectare basis.

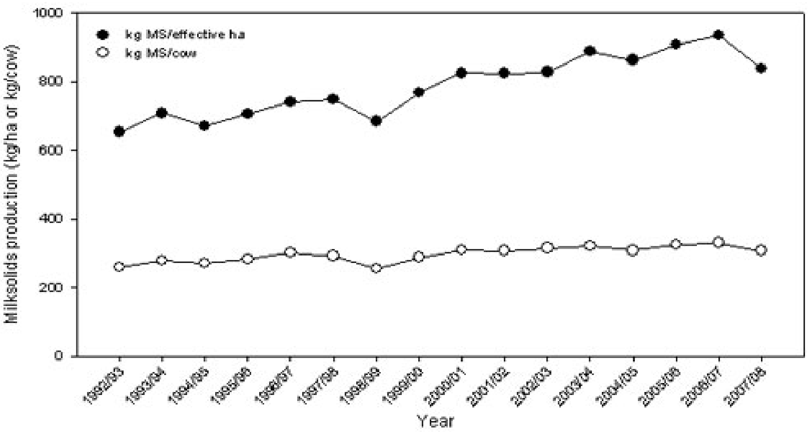


Figure 40. Milk solids production per hectare (excludes runoff) and average per cow milk solids production in New Zealand between 1992/93 and 2007/08
(DairyNZ and LIC, 2009).

Main breeds and production differences. In all regions except Taranaki, Holstein-Friesian is the dominant breed and accounts for almost 45% of the national herd. Holstein-Friesian/Jersey crossbreeds account for ~33% (DairyNZ and LIC, 2009). Other breeds include Jersey (14%), Ayearshire (<1%) and "Other" (7%). The Holstein-Friesian dominates because of its higher average milk production (4 043 litre milk/cow/year) which is 12–43% more than the other breeds and consequently gives higher levels of protein (144 kg/cow/year) and milk solids (318 kg/cow/year). The average cow is in milk for ~250 days with Holstein-Friesian/Jersey crossbreeds having the highest average milkfat production (176 kg/cow/year) while Jersey cows have the highest average milk solids (9.75%) and protein (4.03%) content.

Average cow liveweights differ with age and breed with 2 year old cows having an average weight of 322–405 kg/cow. Across the three main breeds and all age groups (2->10 years) average liveweights range from 385 kg (Jersey) to 487 kg (Holstein-Friesian).

Since 1999/00, over 75% of the national herd has been mated using artificial insemination (AI). Successful AI requires on average 1.25–1.35 inseminations/cow. Bulls may be put out with the herd post AI with 1 bull/75 cows for a period of 4–5 weeks. To maintain a 365 d cycle all cows must be mated about 80 d after calving with a target body score condition of 5.0. The start of calving varies regionally due to environmental conditions. In Northland the start of calving is in mid July compared with early August in the South Island.

Animal health and welfare

Monitoring, prevention and control of disease and disorders in ruminant livestock is critical to the success of New Zealand pastoral farming systems. The impact and spread of many diseases and disorders which can affect production, and thus income, can be prevented by ensuring livestock are provided with feed of adequate quantity and quality to meet their growth and reproductive requirements.

Prevention is more desirable than control. For example, introducing new feed sources slowly allows the rumen to adapt and can reduce the risk of acidosis, bloat, diarrhoea and photosensitivity (Fleming, 2003). Shearing sheep to remove dags (wool contaminated with faeces) reduces potential for fly-strike. Culling of poor performing or susceptible stock is common practice to ensure the genetic structure of the herd/flock is suited to the system and environment.

Fortunately New Zealand's isolation, border inspection and quarantine measures have ensured that economy crippling diseases such as Bovine Spongiform Encephalopathy (BSE) and foot and mouth disease (FMD) are not present. The Ministry for Agriculture and Fisheries (MAF) has protocols in place to allow rapid containment of any potential outbreak. Hydatids eradication programmes have been highly successful and an eradication programme for sheep measles which involves dosing working dogs and preventing access to raw sheep meat is in progress.

Parasites

Internal parasites, especially gastrointestinal parasites are a major cause of decreased production, especially in young stock (<20 months). Liveweight gain may be reduced by 50% and wool production by 25% from stock grazing heavily infested pastures. Widespread use of anthelmintics since their release in the 1960s has lead to the development of resistant populations in some areas. Consequently, an integrated approach is required to reduce infestation. This requires grazing grass based pastures with different stock classes (e.g. sheep then cattle), different ages of stock (e.g. production sheep >20 months in age is less affected than younger stock), providing access to 'safe pastures' with reduced infestation (e.g. forage crops, hay or silage) plus strategic anthelmintic applications to reduce development of resistant populations.

External parasites are treated with organo-phosphate dips or synthetic pyearethroids and insect growth regulators. Wool withholding periods following treatment range from 60 d for coarse wool breeds to 180 d for fine wool breeds. Prevalence of fly-strike has increased since the Australian green blowfly (*Lucilia cuprina*) arrived in New Zealand in 1982 but *Lucilia sericata*, *Calliphora stygia* and *Chrysomya rufifacies* also commonly initiate fly-strike. Ensuring diets have adequate fibre (reduced diarrhoea), and removal of faeces contaminated wool (shearing –crutching) are critical to reducing risk of fly strike. Animals which do become fly-blown require immediate treatment and this is highly successful when affected stock are identified early.

Facial eczema

Facial eczema occurs most commonly in grazing sheep but can also affect cattle. It is caused by the saprophytic fungus *Pithomyces chartarum* which survives in the base of pastures. Ryegrass, cocksfoot, browntop, Yorkshire fog or dogstail grass dominant pastures have high facial eczema risk from Jan-Apr in regions where warm, humid conditions result in rapid increases in spore numbers. Heavy grazing to low residual yields can exacerbate the scale of the disease and severely affected animals can die within 3–4 weeks. There is no treatment for animals which suffer severe liver damage from the toxins released. Symptoms may be clinical (visual symptoms observed) or sub-clinical (no visual symptoms) so if animals show clinical signs all stock should be removed from the pasture and moved to a 'safe' pasture with adequate shade provided. Production levels of affected livestock may be reduced for the rest of their productive lives if not removed immediately. When ingested by grazing animals spores release a toxin (sporidesmin) which damages bile ducts and the liver and stock become photosensitive. In severe cases animals die.

Although the fungus is found in grazed pastures worldwide the most severe problems occur in New Zealand. Exposed skin of infected animals develop weeping dermatitis and scabby skin and these areas can become infected or fly-blown. Furthermore, infected animals can have reduced fertility levels and reduced immunity levels to other diseases. A range of fungicide sprays can be applied to pastures but for control they must be applied before spore numbers increase. When spore numbers reach >200 000/g fungicides are unable to reduce them to safe levels so the risk of infection remains high.

Breeding programmes that use disease resistant genetics are a major management tool to reduce prevalence of this disease. Use of rams tolerant to FE will not result in 100% of progeny showing tolerance but fewer progeny will be susceptible which will reduce incidence within the flock. Rams are tested using the Ramguard FE tolerance testing Service. Other management tools to control the disease infected animals include treatment with zinc salts which can help protect susceptible animals as the zinc binds with the toxin which can then not damage the liver or bile ducts. Controlled release zinc treatments are more expensive but offer protection for up to six weeks compared with drenches which do not offer protection for as long. Zinc can also be applied to pasture prior to grazing. Alternative pastures which have high legume content, tall fescue and/or chicory are recommended for grazing during periods of high risk. Forage crops are also a safe option. Spore levels are highest in regrowth from urine patches (more litter and a higher N content).

Johnes disease

Johnes Disease is a chronic disease caused by *Mycobacterium paratuberculosis* which affects the intestines of grazing ruminants. The disease causes wasting, loss of condition, diarrhoea and thickening of the small intestine. There is no treatment but a vaccine is available. The disease appears to be contracted while stock are young and incubates for 18 months before symptoms appear. Diagnosis is by faecal examination or blood test, but there is no reliable test available. Consequently this disease and its prevention are very difficult. Infected stock should be removed and culled immediately to prevent distress to the animal as the disease develops. Furthermore, the disease can be passed to foetuses and suckling young. Pastures may remain infective for up to 12 months but this is less than the time the disease incubates prior to symptoms being observed.

Footrot

This is an infectious bacterial infection of the hoof caused by *Dichelobacter nodosus* but *Fusobacterium necrophorum* bacteria must also be present. Prevalence increases in warm, wet and humid conditions. High stocking rates facilitate the spread so it is important to ensure unaffected stock are prevented from accessing areas where infected stock have been within the previous 10 days. Hooves of infected animals can be pared to increase airflow and footbaths containing formalin or zinc sulphate are used. Culling of susceptible stock is a viable option as it also reduces genetic predisposition to footrot which may carry through progeny. Increasing genetic tolerance in stock is a major breeding objective. Rams can be tested for tolerance with the Lincoln University Footrot Gene-marker test.

Scabby mouth

A viral infection which infects sheep through breaks in the skin. Scabs mainly form on the lips, nostrils and face. Production declines because of reduced feed intake but the disease usually clears within 2–4 weeks. Vaccines are only used on properties where the disease is present as the virus can last for long periods on the ground. Carrier sheep facilitate spread of the disease within flocks. Antibiotics can be administered when secondary infection occurs.

Liver fluke

This disease can cause severe liver damage but infection is limited to damp areas where *Lymnaea columella* snails are found which allow completion of the fluke's life cycle. Flukicides are available to treat infected livestock but reducing snail numbers or preventing grazing in wet areas are alternative management strategies to reduce disease incidence.

Dairy herd diseases

Herd testing is used to identify the best genetics for production and to monitor dairy animals for diseases which include Enzootic Bovine Leucosis (EBL). This is a viral disease which affects the immune system and can cause fatal cancer. Tuberculosis (Tb) can also be fatal and may infect humans. Milk companies impose demerit points for a range of required milk quality tests if standards are not met.

Two herds tested positive for EBL in the 2007/08 season and were culled while another two herds were treated (DairyNZ and LIC, 2009). Incidence of EBL is considered low by international standards. Nationally, herd incidence of EBL was <0.17% and no detections occurred in the North Island. For Tb testing, the prevalence of host species which include possums and ferrets determines the vector status of an area. Legally, all movement of cattle must be documented in case of an outbreak. Almost 3.1 M dairy cows were tested in 2007/08 of which 402 tested positive. Most animals (299) were identified in the South Island and 82% of these were found in areas with a known risk. The industry as a whole is proactive in monitoring, treating and preventing the infection and spread of disease.

Socio-economic limitations of pastoral agriculture

The New Zealand economy has relied on pastoral production for over 150 years. Initially wool, skins and tallow were exported but with the introduction of refrigerated shipping meat and dairy products have been major exports since the late nineteenth century. Consequently government policy has normally been favourable to pastoral farmers.

Currently legislation to control pastoral use of land relates to limitations being applied to some high altitude (above 900 m) tussock grasslands and to the extremely erosion prone soils in some steep hill country where tree planting is encouraged.

Land tenure of pastoral farms is mainly freehold. There are however some large areas of Maori land in the North Island which are farmed successfully as incorporations on behalf of iwi (tribal groups). Much of the South Island high country is Crown (Government) owned land which is leased for grazing to individual pastoralists. Some of those leases are currently being renegotiated. There are no communal pastures as flocks or herds are owned by individual farmers or commercial companies. These privately owned livestock do not graze any pasture or natural rangeland in common with domesticated livestock owned by other farmers.

The land tenure systems and lack of communal grazing mean that the New Zealand pastoral landscape is characterized by post and wire fences to maintain individual farm boundaries to avoid mixing privately owned livestock. Subdivision fences within farms form separate paddocks (grazed fields) so that different classes of livestock (species, age, sex) on a farm may be grazed separately. This provides a high degree of farmer control on when and where animals graze. The specific grazing management requirements of pasture species (e.g. lucerne) are more easily achieved with this acceptance of the need for fenced paddocks.

Because most products from pastoral production are exported, market access is an issue of national importance. New Zealand strongly advocates international free trade and the removal of agricultural subsidies in developed countries. The New Zealand government does not subsidize farm production. This ensures that scarce resources of land, capital and labour are used efficiently. This has led to New

Zealand pastoral products being able to compete on world markets. However, the profitability of the New Zealand pastoral exports is vulnerable to exchange rate fluctuations and the use of rural subsidies by its trading partners.

More recently (2008/09) the extreme distance of New Zealand from its main markets has resulted in its pastoral products being challenged on the basis of their total energy content when delivered to northern hemisphere consumers. The suggestion that the concept of food miles should disqualify New Zealand pastoral products in environmentally sensitive western markets was shown to be false when the energy cost of livestock production in New Zealand plus its transportation was compared with competing subsidized UK and European local meat and dairy products (Saunders *et al*., 2006). New Zealand lamb was produced four times more efficiently and milk solids production efficiency was double compared with UK lamb and milk solids production. The greater use of N fertilizers, grain feeding and the need to house animals in winter in northern hemisphere production systems results in higher energy costs of production than the imported New Zealand livestock products. The low energy cost of production of the NZ products are related to the high reliance on N fixation by pasture legumes, relatively low use of N fertilizers, little grain feeding and the fact that grazing livestock are outside all year without winter housing. These production efficiencies allow New Zealand pastoral products to have lower total energy cost even when the cost of delivery to export markets is included.

New Zealand has a declining area in pastoral production. With marginal land being excluded from grazing and the encroachment of urban development the only way to increase pastoral production will be through intensification.

Crown pastoral land act 1998

About 10% of the land area of New Zealand, the remnants of which are predominantly in the South Island High Country, is government owned and leased to farmers for grazing. These leaseholds have tenure in perpetuity and are renewed every 33 years. During the tenure review process, which is initiated by the farmer or occurs when a Crown leased property is sold, the land resource is evaluated and some land may be sold to the Crown. The farmer may then have the opportunity to purchase back, as freehold, the more productive lower altitude land. The high altitude land which is valued for recreation and conservation may be retired (Swaffield and Hughey, 2001) and taken over for management purposes by the Department of Conservation. The ability of the farmer to freehold land means the restrictions set on land use which were part of the leasehold tenure are voided. Tenure review is a contentious process as it affects the farmer's ability to manage their land and public access, nature conservation, wildlife, anglers and game hunting groups.

The resource management act (RMA) 1991

In the mid-1980s government agencies were reformed and this was followed by a major revision of legislation and local government (Ministry for the Environment, 2006). The RMA was the first policy of its type in the world and replaced almost 60 previous resource and planning statutes. The RMA is concerned with the environmental impacts of human activities on land, air, water, coastal, geothermal resources and pollution management. Specifically, it manages the environment while encouraging social, economic and cultural well-being of the people and communities within that environment.

The Act is intended to provide sustainable management plans that will protect the environment for future generations. The RMA states that every New Zealander, resource user and developer has obligations/responsibility to prevent, remedy or mitigate the effects of their actions on the environment.

5. THE PASTURE RESOURCE

The description of dominant farm classes within a specified agro-ecological environment was presented above in section 4.

Development of the pasture resource

Pre 1850 settlement

The earliest changes in land cover occurred about 800 years ago when fire was used by Maori to hunt flightless birds such as Moa (see section 1) and to clear land for cultivating root crops. Multiple burning events were the likely cause of a change in vegetation from montane forest to montane tussock grassland because forests were unable to regenerate in the period between fire events. With European settlement the vegetation in the last 170 years has had a second period of rapid change with forest clearance and exotic plant introduction. In the mid 1800s extensive grazing of indigenous tussock grasslands began (White, 1999).

Post 1890 settlement by Europeans

Sheep numbers increased rapidly and production (mainly wool) from cleared forest to grazing pastoral systems peaked in the 1870s. Stock numbers then declined as grazing, burning and declining soil fertility reduced production from these unimproved soils. Increased rates of lowland forest clearance for introduced pasture species were triggered by industry expansion when refrigeration opened export markets to meat and dairy products in the late 19th Century. By 1925, it was estimated that >500 exotic plant species (pastoral, arable, horticultural and ornamental) had become established and 3.2 M ha of native, predominantly lowland rainforest, had been converted to pasture. Initially, lowland areas and dissected uplands (Daly, 1990) in the North Island underwent conversion followed by areas in the South Island. As demand for land by settlers grew, increasing areas of broadleaf montane forest were also claimed for pastoral agriculture. About 4.9 M ha of podocarp-broadleaf forest have been converted to grassland since European settlement (Daly, 1990).

From 1920 onwards innovation in science and technology allowed intensification of farming systems. Improvements included mechanization, amelioration of soil fertility through improved understanding of nutrient requirements for plants and animals, advances in plant and animal breeding and health issues. More recently diversification and improvements in the quality of products produced has dominated. These improvements have been made while maintaining or improving agricultural efficiency to allow production to remain competitive in international markets.

Initially, new pastures were developed from forest by felling of timber which was then left to dry. It was then burnt and pasture seed was broadcast by hand over the ash. Multiple species seed mixes (containing up to 10 different grass and legume species) were recommended for ‘bush burn’ pasture establishment into the 1950s at total seed rates of 20–40 kg/ha. Once established, pasture and regenerating native seedlings were grazed by sheep and cattle and pastures were fully stocked within 12 months of initial tree felling. Later any large tree trunks, which remained after felling, would be hauled out and burnt. This removal of tree stumps may not occur for up to 20 years after the initial tree felling.

Post clearing “Bush sickness” after forest clearing

In the volcanic plateau of the North Island, after initial pasture establishment, livestock showed severe symptoms of ill thrift known as “bush sickness” even when pastures produced adequate feed. In the mid 1930s, cobalt deficiency in livestock grazing pastures sown into soils formed from volcanic parent materials (e.g. pumice) was identified as the cause. Cobalt is required for synthesis of vitamin D in ruminants. This is now rectified by soil fertilizer applications or a mineral drench to livestock.

Development through improved soil fertility

On occasion the initial pasture establishment failed and/or cleared areas of forest began to revert to scrub and forest vegetation. A combination of hard grazing, subdivision, application of lime and superphosphate fertilizers was used to reclaim these areas. This enabled improved pasture plants to be introduced. Where cultivation was possible pasture improvement was more reliable and lime, superphosphate fertilizer and seed were able to be applied. In the 1950s the widespread use of aircraft to apply lime, superphosphate and seed (mainly perennial ryegrass/white clover) to steep hill country was pioneered.

Because of the large proportion of pastures on land with slopes >16° much research was conducted to determine the effects of slope and aspect on pasture production. Important aspects of this work included the effects of stock behaviour in nutrient transfer, seasonality of production (see below) and differences in aerial fertilizer distribution patterns. This information has been used since the 1970s to develop on-farm grazing management systems, aid subdivision decisions and stratify fertilizer applications. Superphosphate applications totalled 794 000 tonnes in 1981 and increased to 1 270 000 tonnes in 2007 while lime applications were 1 355 000 tonnes in 1981, decreased to 561 000 tonnes in 1987 following agricultural reforms, but have increased to 1 487 000 tonnes in 2007.

Hill country development

On some extensively grazed steep hill country (Farm Class 3, Section 4) reversion to manuka and kanuka (*Kunzea ericoides*) continues to occur. Some farms are encouraging this reversion on marginal land so native species can be re-introduced through planned plantings. Motivation for what is effectively a voluntary retirement of less productive land varies from farm to farm, but is usually a result of cost, ecological sustainability or a combination of the two. For example, the cost involved with retaining marginal areas as productive grassland may not be financially viable, while exotic tree or encouraging native forest reversion in gullies and on steep slopes could be beneficial to stabilize the ground. This means more productive pastures downstream from the steeper slopes are protected from the effects of soil erosion. Further, both plant and animal (native/endemic bird) biodiversity can be increased. Where possible the focus is shifting to tree planting along waterways and fencing off planted areas to prevent grazing livestock from accessing waterways. Deep rooted tree (or pasture) species are encouraged in riparian strips to reduce eutrophication of waterways by capturing nutrients at depth to reduce nitrate leaching and control movement of phosphorus rich topsoil. Farmers also currently anticipate the possibility of gaining carbon credits from converting steep, eroding pasture land back into indigenous or exotic forest.

Nitrogen use for pasture production

Nitrogen fertilizer was rarely used on New Zealand pastures up to the 1980s and nitrogen fixation from white clover was the main source of nitrogen for companion pasture grasses. The use of N fertilizer (mainly as urea - 46% N) has increased dramatically over the last 30 years particularly associated with the intensification in dairy systems. For example, nationally across all agricultural industries, the quantity of urea applied in 1981 was 17 000 tonnes and this had increased to 433 000 in 2007. Nitrogen fertilizer is also used by some sheep and beef farmers to boost grass production in late autumn and early spring. The consequence of N fertilizer use is a reduction in clover content of pastures. Dairy pastures may receive up to 200 kg N/ha/year applied in split applications of 25–50 kg N/ha. Intensively managed, high fertility pastures are expected to produce about 10 kg DM/kg N applied, while on less intensive pastures responses up to 30 kg DM/kg N applied have been reported. Many regional councils restrict the total amount of nitrogen fertilizer that can be applied.

Irrigation

Access to irrigation depends on factors including topography, cost and ability to obtain a resource consent which dictates the timing and quantity of permitted applications. Across all farm types, which includes horticulture, floriculture, viticulture, agriculture and forestry industries, <3% of New Zealand total land area is irrigated (~620 000 ha). Of this, 16% is in the North Island and 84% in the South Island (Department of Statistics, 2007). Of the irrigated pastoral area, spray irrigation is the dominant method (74%) and flood irrigation accounts for a further 18%.

Dairy farms account for 235 000 ha of the total irrigated land and 111 000 ha of pastoral land used for sheep farming can be irrigated. About 62 000 ha of irrigated land occurs in cropping and mixed cropping systems and a further 51 000 ha on cattle or mixed sheep and cattle farms.

Pasture growth patterns

In the 1970s and 80s a major government initiative quantified New Zealand pasture production rates in a series of 21 papers on "Seasonal distribution of pasture production in New Zealand" which were published in the New Zealand Journal of Experimental Agriculture (e.g. Radcliffe, 1974). Data were predominantly collected from 30 sites throughout New Zealand for an average of 11 years (range: 8–27 years). The results enabled the pasture production profile to be generated for most regions and are now used as a reference for individual farms. Nationally, mean annual pasture production from perennial ryegrass/white clover based pastures was reported as 10.0–12.0 tonnes DM/ha/year. Regionally, perennial ryegrass based pasture yields ranged from 5.2 to 17.2 tonnes DM/ha/year. The variation in seasonal growth rates primarily reflects differences in temperature and rainfall.

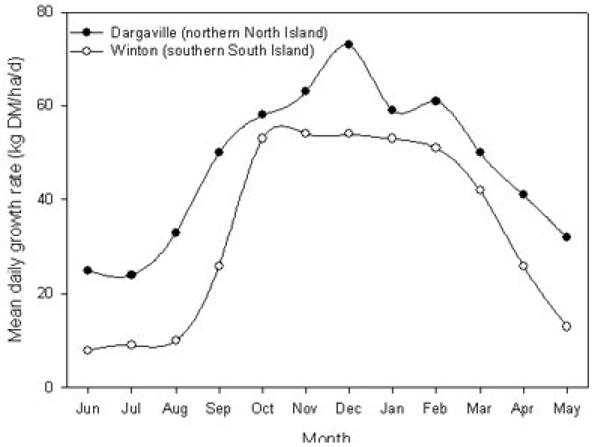


Figure 41. Monthly mean daily growth rates (kg DM/ha/d) of perennial ryegrass/white clover based pastures at Dargaville (northern North Island) and Winton (southern South Island) in New Zealand

Temperature effects on production in summer moist regions

In summer safe environments, where soil moisture deficits are uncommon, the effect of seasonal temperature variation can be quantified. Figure 41 shows that the mean daily pasture growth rates in Dargaville and Winton are lowest in winter and highest in summer and have similar seasonal production patterns. Both sites receive >1 100 mm/year rainfall. However, the annual yield in Dargaville (northern North Island) was 17.2±3.6 tonnes DM/ha/year which was 40% more than from Winton in the southern part of the South Island (12.0±2. tonnes DM/ha/year). The main cause of the difference was higher winter production in Dargaville. Spring production was also almost 60% higher than in Winton. Mean air temperatures (1951–1980) for Dargaville were 11.3 °C in winter and 13.9 °C in spring compared with 6.0 °C in winter and 8.1 °C in spring for Winton. These differences mean the annual amount of thermal time (°Cd) accumulated, above a base temperature of 5 °C, was 3 385 °Cd for Dargaville compared with 1940 °Cd for Winton (McKenzie *et al*., 1999).

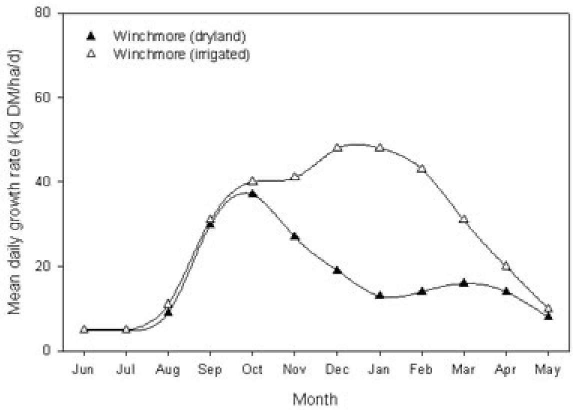


Figure 42. Mean daily pasture growth rate (kg DM/ha/d) of irrigated and dryland pastures at Winchmore, Canterbury, New Zealand

Production in summer dry regions

In regions where soil moisture deficits develop, such as Canterbury, it is unusual for production in winter and early spring months to be constrained by insufficient moisture. However, as soil moisture deficits develop between September and April, mean daily growth rates fall below potential (Figure 42). Annual yields from an irrigated pasture were 10.2±1.0 tonnes DM/ha/year compared with 5.9±1.1 tonnes DM/ha/year from adjacent dryland pastures (Rickard and Radcliffe, 1976). The dryland pasture was perennial ryegrass, subterranean clover, with cocksfoot, browntop and white clover. The irrigated pasture was perennial ryegrass/white clover with some cocksfoot, browntop, and *Bromus* spp. Summer drought can reduce pasture production rates on dryland properties on the east coast to zero which may be less than the temperature constrained winter growth rates. For example, in Canterbury, January (summer) mean monthly dryland pasture production is 13±14 kg DM/ha/d.

Seasonal variation in mean daily growth rates

Figure 43 shows the upper and lower pasture production variability of mean monthly growth rates (kg DM/ha/d) at a North Island hill country site (Wairakei, Farm Class 4; Section 4) and flat dryland South Island site in Central Otago (Otago Plateau, Alexandra; Farm Class 1, Section 4). Grey lines show one standard deviation in monthly growth rates measured at each site. The greatest absolute variation occurs in summer and reflects the effect of differences in summer rainfall and consequently soil moisture availability. The least variation occurs in winter months when growth rates are solely limited by temperature. It should be noted that dry matter production from unimproved hill country pasture may be only half that of an improved hill country pasture. Much of this is due to lower DM production in winter months from swards which become dominated by browntop and flat weeds. Low legume content compounds the degradation of improved pastures over time and N fixation and transfer to companion grasses is decreased. Improved grasses which require higher fertility conditions, such as ryegrass, fail to persist in competition with species suited to lower fertility conditions such as browntop.

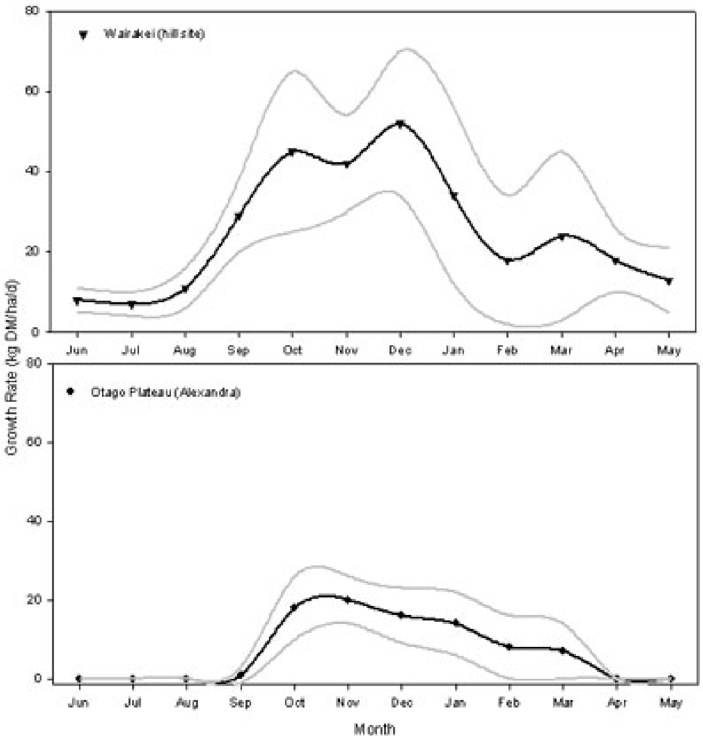


Figure 43. Mean daily growth rates (kg DM/ha/d) of pastures on a hill site at Wairakei (▼; top) in the North Island and on the Otago Plateau (●; bottom) at Alexandra in the South Island. Grey lines are ± one standard deviation and production falls within that range in two out of three years

Effects of topography

Because a large proportion of intensive pastoral production is conducted on hill country in New Zealand the effects of altitude and aspect on pasture production have been quantified in several studies.

Altitude

Temperature decreases as altitude increases (about 2 °C/300 m) while rainfall may increase (McKenzie *et al.*, 1999). For improved hill country in Central Otago, this resulted in a 450 kg DM/ha/year yield reduction per 100 m increase in altitude. Because of low temperatures constraining production in winter months, the majority of production in dryland systems is limited to spring months before water stress develops and limits production in summer. At Poolburn (430 m) annual pasture production was 2.8 tonnes DM/ha from a mean annual rainfall of 400 mm. The growing season (Sept-May) accumulates 1500 °Cd above a base temperature of 5 °C. At an adjacent irrigated site annual production was 8.7 tonnes DM/ha. During the cold five- month winters growth is negligible. Conserved feed from any irrigated pastures is therefore essential for farmers in the Poolburn district (South Island High country; Farm Class 1, Section 4).

Aspect and slope

Differences in total annual production between sunny and shady slopes varies from site to site depending on whether temperature or soil moisture is the major constraint to production (McKenzie *et al.*, 1999). At a high rainfall North Island site, Gillingham (1973) reported yields on N facing slopes were 10% higher than from S facing slopes. He also showed that slope accounted for 22% of the observed variation in pasture growth rates. Annually yield decreased by 109±26 kg DM/ha/year for every degree increase in slope. The remaining variability was attributed to differences in microclimate, soil fertility and pasture utilization. In Canterbury hill country where summer soil moisture deficits are common, Radcliffe *et al.* (1977) reported annual DM yields of browntop dominant pasture from a shady (SW) slope (20-30° at 290–440 m) over a three year period of 7.4 tonnes DM/ha/year. This compared with 6.1 tonnes DM/ha/year produced on sunny (N-NW) slopes at the same location.

Animal behaviour

Animal behaviour is also modified by slope and aspect with consequent effects on nutrient transfer particularly within large (>20 ha) un-subdivided hill and high country blocks. These are usually set stocked for long periods each year. Livestock camp in areas that offer the most protection from environmental conditions (Lambert and Roberts, 1978). Gillingham (1980a, 1980b) reported livestock camped on land with slopes of 0–10°. In these camps pasture production was dominated by perennial ryegrass. Yields decreased from 11.0 tonnes DM/ha in stock camps to 5.0 tonnes/ha on slopes of 45°. This was equivalent to a reduction of ~850 kg DM/ha per 5° increase in slope. Faecal P transfer from slopes to stock camps meant soil P levels that were 2–3 times greater than the annual pasture requirement. Saggar *et al.* (1990) reported 60% of faecal P returns were made to the land with slopes <12° which accounted for 30% of the land area in their study.

Botanical composition of pastures on and near stock camps is strongly influenced by increased N and P fertility and the degree of soil moisture deficit at different sites. At Ballantrae in the Manawatu, annual DM yield production of unimproved pasture was 2.8 on the north aspect, 3.0 on the west, 9.7 on the east and 3.6 tonnes DM/ha on south facing aspects (Lambert and Roberts, 1978). Botanical composition was dominated by native *Notodanthonia* grass species on the north aspect; perennial ryegrass and mouse-eared chickweed (*Cerastium glomeratum*) on the south; Yorkshire fog on the east and south and *Nertera setulosa* in the west and south aspects. Browntop and sweet vernal had similar cover at all sites probably due to their wider tolerance of soil fertility and environmental conditions.

Grass endophytes

Perennial ryegrass endophytes

Endophyte (*Neotyphodium lolii)* was first identified in perennial ryegrass in New Zealand in 1940 but its detrimental effects were not recognized until Fletcher and Harvey (1981) linked it to ryegrass staggers in livestock. Gallagher *et al.* (1981) identified the causal agent as the tremorgenic neurotoxin lolitrem B, one of several alkaloids produced by the endophyte. Ergovaline was identified soon after as the cause of heat stress in grazing livestock while the peramine alkaloid was shown to deter invertebrate pests.

The presence of endophyte is vital to maintaining long-term productivity and persistence of ryegrass based pasture due to the protection it offers against pests. The presence of wild type endophyte has been shown to deter black beetle (*Heteronychus arator*), cutworm (*Graphania mutans*), root aphid (*Aploneura lentisci*), porina (*Wiseana cervinata*) and pasture mealy bug (*Balanacoccus poae*) (Easton, 1999). Another major pest affected by endophyte is Argentine stem weevil which has been estimated to cost the pastoral industry NZ$ 46–200 M annually through pasture damage (Prestidge *et al.*, 1991).

To maintain protection from insects and minimize livestock health issues novel strains of endophytes, such as AR1 and NEA2, have been developed. These endophytes are non-existent in the neurotoxic lolitrem and ergovaline but contain high levels of peramine, an alkaloid to which Argentine stem weevil is very sensitive.

However, peramine is not a broad spectrum pesticide and consequently further development of novel strains continues. The recently released AR37 endophyte does not produce peramine, lolitrem or ergovaline alkaloids. It does produce epoxy-janthitrem compounds which confer pest deterrence to a wider range of invertebrate pests than the AR1 endophyte. Some staggers may still occur in livestock grazing AR37 infected ryegrass. Farmers in the warmer areas of New Zealand, where there is the greatest pest challenge to ryegrass productivity and persistence are encouraged to sow AR37 ryegrasses. AR1 is recommended where there is sporadic insect pest attack in more temperate areas and nil-endophyte seed may be safely sown in cool southern or high altitude regions.

Tall fescue endophytes

Similar novel endophyte technology has been applied to tall fescue in recent years and has led to the release of the MaxP endophyte (*Neotyphodium coenophialum*). Severe heat stress and necrosis can occur in livestock grazing wild type endophyte infected pastures in other countries (e.g. U.S.A.). However, in New Zealand wild type endophyte infected tall fescue is only found on roadsides. Tall fescue in grazed pastures has always been endophyte free. Thus, the development of this novel endophyte was primarily focused on use in international markets. It is likely to increase persistence in New Zealand environments compared with the current endophyte free lines. Development of loline producing endophytes (Ball and Tapper, 1999) particularly for tall fescue and meadow fescue is a current research area (Patchett *et al.*, 2008). These loline producing endophytes show evidence of wound induced alkaloid redistribution by increasing concentrations in areas of tissue under insect attack.

Research is continuing to develop novel endophytes. The aim is to ensure pasture yield and persistence from ryegrass and tall fescue based pastures is maintained at levels comparable to wild type endophyte infected pastures but avoidance of adverse effects on livestock.

Pasture species

Major species

New Zealand farmers have a large range of improved grass, legume and forage crop cultivars to select from. For perennial ryegrass there are different endophyte options (nil, wild type or modified 'novel'; see above) available in over 60 different perennial/long rotation cultivars. These cultivars also differ in flowering time, cool season activity and ploidy level. In addition there are 20+ Italian, annual and short rotation ryegrasses. There are at least 15 cultivars of tall fescue, cocksfoot, bromes (*Bromus* spp.) and timothy. The most commonly sown pasture legume is white clover with 20+ cultivars that vary in leaf size and stolon density. There are several cultivars of red and subterranean clovers and 10+ lucerne cultivars commercially available or registered for use. Subterranean clover seed is imported from Australia and cultivars vary in flowering date (early, mid or late) and hardseededness rating. There are also pasture herbs, namely chicory and plantain (*Plantago lanceolata*) available (Caradus, 2008).

The development of new pasture and forage cultivars is ongoing and commercial companies often work in association with Government owned Crown Research Institutes during breeding, selection and development. Locally bred, pest and disease resistant cultivars which are suitable for grazing or conservation are most widely sown but some cultivars bred in Europe, North America, Argentina or Australia are also sown. These cultivars may have cool season activity or may tolerate more frequent grazing.

Minor species

Cultivars of browntop, Yorkshire fog, Caucasian clover (*T. ambiguum*), *Lotus pedunculatus*, *L. corniculatus*, alsike clover (*T. hybridum*) and sulla (*Hedysarum coronarium*) have been developed for use in New Zealand but are rarely sown. Recently, interest in *Lotus* spp. and sulla has been revived because of their tannin content which may reduce bloat incidence, gut parasites and methane gas production by ruminants while increasing protein absorption. Adoption of annual legumes other than subterranean clover, to produce high quality spring feed and nitrogen fixation in dryland regions has increased. Seed is mainly imported from Australia. Persian (*T. resupinatum*) and balansa (*T. michelianum*) clovers are tolerant of wet soils in winter. Arrowleaf (*T. vesiculosum*) clover is very late flowering and may complement white and subterranean clovers in permanent pastures.

Use of alternative pasture species, which have definite advantages in specific environments, is often restricted due to difficulty in establishment, perceived high cost of new species and widespread promotion of ryegrass/white clover pasture technologies. For example, Caucasian and strawberry (*T. fragiferum*) clovers are perennial legumes suitable for some New Zealand pastures. However, their use is limited by high seed costs and availability of seed. Slow establishment further limits uptake of these two species because of excessive sowing rates (20-25 kg/ha) of vigorous perennial ryegrass. The clovers are suppressed and fail to establish. Consequently, farmers consider slow establishing species to be failures.

Species selection

Selection of the appropriate pasture species depends on the environment where it is to be sown. Table 12 shows that ryegrasses are highly suitable for inclusion in moist lowland environments (Farm Class 5, Section 4) but are less suitable for South Island High Country properties (Farm Class 1, Section 4). In moist hill country (Farm Class 4, Section 4) recommended grasses include ryegrass, cocksfoot and grazing bromes (*Bromus stamineus* and *B. valdivianus*) while lotus, white and red clovers are the most suitable legumes. Species suitable for use in farming systems which experience periodic water stress ("dryland") include; cocksfoot, bromes, tall fescue, lucerne and subterranean clover.

Pastures for warm, summer moist regions

In warm, summer moist environments in New Zealand, perennial ryegrass/white clover is the preferred pasture combination. These pastures can be easily established and are tolerant of a wide range of management practices. They can be set stocked in spring during lambing and calving and then rotationally grazed throughout the remainder of the year. Typically, these pastures are spring or autumn sown into a firm and fine seedbed with 10–20 kg/ha of perennial ryegrass and 1–3 kg/ha of white clover seed. Timothy, chicory, plantain and/or red clover may be added to this basic mix. A clean, weed free seedbed is particularly important when herb species are included in pasture mixes as the use of herbicides for control of broadleaf weed species is restricted if chicory or plantain are included.

Table 12. General guide to suitability f common improved pasture species for New Zealand environments where 1=low suitability and 5 = highly suitable.

	Environment				
	Dryland	Moist lowland	Moist hill country	North Island dry hill country	South Island high country
Grasses					
Ryegrasses					
Perennial	3	5	3	2	1
Italian	1	5	1	1	1
Hybrid	2	5	2	1	1
Cocksfoot	5	2	5	5	4
Tall fescue	5	5	1	1	2
Prairie grass	5	4	1	1	1
Grazing brome	5	3	5	4	3
Smooth brome	2	1	3	3	5
Phalaris	5	4	2	3	2
Timothy	2	5	3	1	5
Legumes					
White clover	2	5	4	3	2
Red clover	3	5	2	4	4
Caucasian clover	3	4	3	2	5
Subterranean clover	5	1	4	5	1
Lucerne	5	3	1	1	3
Lotus	2	1	5	1	4
Birdsfoot trefoil	5	3	1	2	4
Alsike clover	1	2	1	1	4
Sulla	4	4	3	4	1
Herbs					
Chicory	5	5	2	2	1
Plantain	2	3	3	2	4

(Charlton and Belgrave, 1992; Adapted for use in "The AgResearch Grasslands Range of Forage and Conservation Plants" (2001)).

Subtropical C_4 grasses such as paspalum (*Paspalum dilatatum*) and Kikuyu (*Pennisetum clandestinum*) may dominate pastures in moist northern areas of the North Island when perennial ryegrass has lost vigour after stress periods (insect damage, summer drought, winter pugging). These aggressive C_4 grasses are vigorous in the warm summer and autumn but have lower production in winter and spring when temperatures are outside their optimum ranges. Their quality is inferior to perennial ryegrass. Frequent pasture renovation is often required to control Kikuyu particularly in the Northland region. Glyphosate is used to control C_4 grasses prior to overdrilling perennial ryegrass. Insect damage in the warmer North Island regions is more severe than farther south and suitable novel endophytes (see above) in ryegrass and tall fescue cultivars are therefore recommended.

Cool, summer moist regions

The Southland district, in the south of the South Island, has the best examples of perennial ryegrass/white clover pastures in cool summer moist environments (see the Winton production curve in Figure 41). Pasture insect pests develop more slowly in this cooler environment and their populations seldom reach pest proportions (e.g. Argentine stem weevil completes only one generation/year). Nil endophyte ryegrass can thus be sown with relative safety. Timothy is well adapted to the climate and is more sociable with clovers than the more competitive ryegrass. White and red clovers are productive during summer months. In poorly drained and lower fertility areas Yorkshire fog and browntop become dominant in older pastures. Brassicas (swedes and kale) and annual ryegrass forage crops are grown for winter feed, as part of pasture renewal programmes (see below), to complement silage made in summer from cereals and pasture.

Dryland pasture options

In summer dry areas, pastures may be sown after a summer fallow (see below) which provides opportunity for thorough weed control and accumulation of soil moisture.

These environments develop summer soil moisture deficits because of combinations of low annual or seasonal rainfall (<700 mm/year), high warm season evapotranspiration, and shallow, stony soils with low waterholding capacity. Cocksfoot is the second most commonly sown grass in New Zealand and is used for these regions. It is less affected by drought than perennial ryegrass and persists and recovers leaf area and growth more rapidly than perennial ryegrass.

White clover performs poorly in these dry environments especially after the loss of its taproot 12–18 months after sowing. Subterranean clover cultivars imported from Australia are recommended as the main companion legume in cocksfoot based pastures. The annual life cycle of subterranean clover means that it produces high quality spring feed before and during flowering and it then buries its seed burrs in November/December to complete its life cycle. This nullifies competition for scarce water between the grass and legume in summer months. At "Tempello", a dryland hill country farm in Marlborough, pre-weaning lamb growth rates on a dryland subterranean clover dominant hill country property have increased with improved subterranean clover management from 227 g/hd/d in 2001 to 328–402 g/hd/d (Grigg *et al*., 2008). Meat produced from the 2 800 ha of effective land (4 800 ha total area) has increased from 60 to 76 tonnes liveweight/year despite a 12% drop in total ewe numbers. Lamb weaning weights have increased from 27 kg LW/hd (2001) to 32.5 kg LW/hd in 2006. In years with moist summers, volunteer white clover may be a valuable component of dryland pastures. Other annual clovers are currently being tested on dryland farms and several adventive clovers, medics and lotus species are common in lower fertility dryland pastures.

Lucerne

Lucerne is used on the dry east coast of New Zealand for direct grazing and conserving as hay or silage. The area of lucerne sown decreased from 220 000 ha in 1975 to 180 000 by 1979 (Department of Statistics, 1979; Purves and Wynn-Williams, 1989). The rapid change in area was primarily a result of the accidental introduction of the blue green aphid. The cultivars available at the time were decimated as they were not tolerant/resistant to attack. The total area in lucerne in 1992 was only 72 000 ha as stand production and persistence were compromised by pests, diseases and poor management (Purves and Wynn-Williams, 1994). The need for rotational grazing combined with the perception that it is more expensive to grow compared with ryegrass/white clover resulted in a reluctance to grow lucerne. The cultivars currently sown differ in levels of winter activity and pest and disease resistance.

The area in lucerne is rapidly expanding with recent demonstrations of high productivity and profitability. For example, in Marlborough at "Bonaveree" farm with a mean annual rainfall of 530 mm, the area in lucerne has more than doubled from 120 to 300 ha between 2003 and 2009. This lucerne was direct grazed with only true surplus herbage conserved. The economic farm surplus has increased from NZ$ 30/ha to almost NZ$ 140/ha even though annual rainfall decreased over the same period. In 2006/07, lambs averaged 396 g/hd/d from birth to weaning and over 80% of lambs were finished and sent for slaughter by mid December at 13–14 weeks of age (Avery *et al*., 2008).

Increasingly, where water is scarce for growth, this deep rooting, high quality species is sown on the deepest soils to extract moisture from depths that are inaccessible for grasses. Yields vary throughout the country which reflects differences in environment, soils and management. Annually yields can range from <3.0 to >28.0 tonnes DM/ha.

The quality, particularly crude protein and metabolisable energy, of lucerne herbage is strongly affected by regrowth duration because of changes in the leaf:stem ratio (Brown and Moot, 2004). Recent changes in lucerne grazing management have been critical for maintaining stand production and persistence (Moot *et al*., 2003). Failure to allow adequate partitioning of carbohydrates to roots by allowing adequate regrowth duration (>5 weeks) between grazing events and preventing flowering in late summer or autumn reduces potential production in the following year (Teixeira *et al*., 2008). In New Zealand lucerne is rarely sown in mixtures because of its need to be rotationally grazed throughout the year. However, some farmers may sow lucerne in mixes with prairie grass to produce cool season feed while in cool dry areas cocksfoot is useful to combat wind erosion.

Alternative pasture grasses

Tall fescue (nil endophyte or novel non toxic types), prairie grass (*Bromus willdenowii)*, grazing bromes, timothy and phalaris (*Phalaris aquatica*) are all available for use in permanent pastures in

New Zealand. In higher fertility lowland sites, tall fescue with novel endophyte is likely to be more persistent than ryegrass and could have increased summer grass production as the optimum temperature for photosynthesis of tall fescue is higher than that of ryegrass. Tall fescue is also likely to be more legume friendly to clovers in mixed species pastures than ryegrass because of its greater thermal time requirement for field emergence and less vigorous seedling growth compared with perennial ryegrass (Moot *et al.*, 2000).

Bromus species provide greater cool season production than perennial ryegrass but tend to be vulnerable to insect pests and perform poorly on acid soils or poorly drained sites. Timothy has very small seed (~0.4 g/1 000 seeds) compared with perennial ryegrass (2.0 g/1 000 seeds), thus establishment can be compromised when sown too deep. Furthermore, field emergence is slow for timothy (230 °Cd) compared with 160 °Cd for ryegrass so timothy seedlings are out-competed at establishment (Moot *et al.*, 2000). Timothy is a late flowering grass which retains nutritive quality later into the season, and is less competitive with companion legumes, than ryegrass. It is frequently used in hay crops. Phalaris is valued as a minor component of multiple species pasture mixes as it tolerates root attack by grass grub (*Costelytra zealandica*) but is rarely used as the primary grass species because it may cause irreversible staggers in livestock.

Low fertility pastures are frequently browntop dominant. This mat forming perennial tends to exclude more desirable species through its ability to compete for water and nutrients, predominantly scarce phosphorus. In moist hill country it may be suppressed by mob stocking at high rates in winter. Heavy trampling then tends to favour ryegrass/white clover. Other introduced grasses which may invade improved pastures over time include: sweet vernal, crested dogstail and Yorkshire fog.

Weeds

About 50% of total plant species are exotic and some have become invasive weeds. As gaps open in pastures after drought, flooding, pest damage or overgrazing, annual and perennial weed species may invade. Purchase of certified seed has restricted the level of contamination in recent times. In many cases initial weed introductions occurred from seed sown when pastures were first broken out of scrub and forest over 100 years ago from contaminated seed imported into the country. In pastures which are not normally exposed to water stress, giant buttercup (*Ranunculus acris*), docks, ragwort (*Senecio jacobaea*) and dandelion (*Taraxacum officinale*) are the main weed species. In swampy areas species such as rushes and sedges may be present whereas in high country bracken fern, hawkweeds (*Hieracium*) and browntop may invade improved pastures if soil fertility levels are not maintained. Perennial rhizomatous species such as browntop, twitch, Californian thistle and yarrow (*Achillea millefolium*) are common weeds which invade dryland pastures.

Annual weed grasses are *Poa annua*, barley grass and *Vulpia* spp. In addition, C_4 annuals such as barnyard grass (*Echinochloa crus-galli*) and summer grass (*Digitaria sanguinalis*) are common in warmer, summer dry regions (northern North Island). Annual ripgut brome (*Bromus diandrus*) and the perennial Chilean needle grass (*Nassella neesiana*) are major grass weeds in hill country which are capable of creating serious livestock health issues and contamination of wool, skins and carcasses which may be rejected during processing.

Pasture renewal (see below) is required as pasture productivity and quality declines. Species such as *Poa annua*, shepherd's purse (*Capsella bursa-pastoris*), chickweed (*Stellaria media*), fathen (*Chenopodium album*), nightshade (*Solanum nigrum* and *S. physalifolium*) speedwell (*Veronica persica*), twin cress (*Coronopus didymus*), cleavers (*Galium aparine*), mallow (*Malva* spp.), horehound (*Marrubium vulgare*), hawksbeard (*Crepis capillaris*), hawkbit (*Leontodon taraxacoides*), catsear (*Hypochaeris radicata*), dandelion, thistles (scotch, nodding, Californian), *Hieracium* spp., gorse and broom (*Cytisus scoparius*) are all common pasture weeds. The woody weed species such as gorse, broom and sweet brier are particularly expensive to control while horehound may present significant problems in lucerne stands. In dairy pastures giant buttercup and ragwort are major weeds in some districts.

Weed control

Weed control in New Zealand pastoral agriculture uses an integrated approach. Combinations of cultural, chemical, mechanical and biological practices are implemented to reduce the impact of least desirable weed species on pasture and animal production. Ensuring pasture cover is maintained by a healthy and vigorous sward minimizes invasion by less desirable species. Chemical spraying of fence lines and road verges reduces invasion into surrounding paddocks. Topping, burning and chemical herbicides are targeted methods to prevent seed set of weed species. The decision to employ chemical control or to enter into pasture renewal depends on the species, plant population and the potential for the infestation to reduce farm income.

In most cases, crop rotations, fallow periods, cultivation and grazing management are the most common methods of weed control. Use of pest and disease resistant cultivars and timing farming operations to minimize potential for pest attack or disease are also common practice. Use of chemical control for weeds, pests and diseases is common in susceptible arable and horticultural crops and, when necessary, in establishing pastures and forage crops.

In established pasture chemical control methods are only triggered when failure to control the degradation caused to the pasture will result in an economic loss. For example, annual dicotyledonous weeds may be tolerated in established pastures but ingress of perennial rhizomatous weeds such as Californian thistle triggers a combination of control methods. In spring and summer, thistles are permitted to form seedheads but these are topped before the seed matures. This depletes reserves in rhizomes. In autumn, as the plant begins allocating carbohydrate below ground, a systemic herbicide is applied which is also translocated throughout the root system. Herbicide selection depends on whether the thistle has invaded a monoculture or mixed species pasture. A broad spectrum broadleaf herbicide is applied to grass or cereal monocultures. In a mixed species pasture containing grass and legumes the broadleaf herbicide should be selective so legumes are not killed.

Pest control

Pasture and crop pest control must be cost effective and timed to ensure maximum control is achieved. Where possible, if a pest is a known problem in a region, farmers select species or cultivars which are tolerant or resistant to attack. An integrated approach to pest management is recommended because total reliance on chemicals can result in development of resistant pest populations. Other management strategies include: crop rotations, cultivation, ensuring time of sowing does not coincide with peak pest incidence, removal of crop residues, mob stocking and irrigation. Pest thresholds are developed as the levels beyond which yield and/or economic losses are likely. For example, in susceptible established pastures action is recommended at infestation rates of 100 grass grubs/m^2 or 20–40 porina caterpillars/m^2. These two major native pests of pasture have thrived with the development of productive grazed pastures.

Several successes have been achieved with biological control of pest insects. Notable examples include the introduction of the parasitoid wasp (*Microctonus hyperodae*) to control Argentine stem weevil and *Microctonus aethiopoides* as a parasitoid for *Sitona discoideus* a weevil which caused serious damage to lucerne.

Disease

Plant disease control is not usual practice in grass based pastures but may be required in herbage seed crops and supplementary forage crops. One of the major objectives of plant breeders is to select for disease tolerance in pasture species. Cultivars that are susceptible to diseases tend to be less productive and are usually rapidly replaced with newer genetic material. Methods of disease control in crops and pastures fall into four main categories. These are to reduce or eradicate the source of disease, use resistant cultivars, protect the host plant and/or alter the environment (soil, crop and storage). Spread of disease may require an insect vector; thus by controlling the insect (e.g. aphids) the potential for infection can be reduced.

Pasture renewal programmes

Crop rotations within New Zealand pastoral agriculture are essential to ensure long-term technical and financial sustainability of the pasture resource (Moot *et al.*, 2007). There are multiple objectives of the cropping phase between periods of pasture. These include to:

1. Maximize short- and long-term income,
2. Provide feed of adequate quantity and quality to meet seasonal requirements of grazing livestock,

3. Manipulate soil fertility levels by complementary use of depletive and/or restorative crops,
4. Ensure mobile nutrients are prevented from winter leaching as they are retained in plant tissue of the 'green manure',
5. Break life cycles of pests and diseases and allow appropriate weed control,
6. Spread seasonal demand for on-farm labour and machinery and,
7. Minimize idle land.

In any pasture renewal programme it is undesirable to replace the existing run-out pasture directly with new pasture, because such a sequence fails to address why the vigour of the existing pasture declined. It is recommended that 10% of a farm undergoes renewal every year although this may vary from 5–20% depending on the farming system.

Maize in pasture rotations

Maize is one of the crops which can be used in pasture renewal as it tolerates a wide range of herbicides to control problem weeds and may also provide useful income through the sale of grain or forage for silage production. There are at least 40 different hybrids of maize available which differ in maturity rating and disease resistance. Typically, maize silage yields, when grown with adequate moisture and nutrients, range from 16.0–25.0 tonnes DM/ha depending on the environment.

As a C_4 species, maize is commonly grown in the warmer North Island areas of New Zealand where sowing can commence in mid October. Over 90% of the area sown in maize, for silage or for grain, is in the North Island. Canterbury is the southern limit for maize production due to potential for frosts at both ends of the growing season in more southern regions. In cooler areas sowing does not occur until mid-November and hybrids with lower comparative maturity ratings, which require accumulation of less thermal time to reach maturity, must be used or there is a risk of crop failure.

With both conventional cultivation and direct drilling the first herbicide is applied about one month prior to sowing maize and the pasture is grazed about 10 days later. The paddock is then cultivated and maize is sown. If necessary, the area is given a second herbicide application prior to direct drilling. Where problem grass species such as browntop, Kikuyu and summer grass are present these may be sprayed out the previous autumn and the paddock sown in Italian type ryegrass for feeding *in situ* over winter and early spring.

For successful pasture establishment it is desirable to harvest the maize for silage in mid March (autumn) rather than for grain that may not mature until May or June. Following harvest the paddocks are then sown back into pasture using either conventional cultivation or direct drilling. In some cases two or more maize crops may be grown prior to establishing a new perennial pasture. Cereal crops for grazing *in situ* may be sown in the period between the maize crops.

Brassicas in pasture rotations

There are also 40+ forage brassica cultivars commercially available and over 300 000 ha of brassicas are sown annually in New Zealand farm systems. Of these around 20% will be considered failures (de Ruiter *et al.*, 2009) due to poor preparation/sowing or inadequate control of pests and diseases during establishment. Leaf or bulb turnips (*Brassica rapa* syn. *B. campestris*) and rape (*B. napus* spp. *biennis*) are the main brassicas used to provide supplementary forage in the summer/autumn months while winter feed deficits are filled by swedes (*B. napus* spp. *napobrassica*) or kale.

If a brassica crop fails to establish then a winter greenfeed cereal, such as oats or barley, can be oversown into the paddock in April to minimize yield losses. Cereals are established at a rate of 80–120 kg/ha and can produce 2–4 tonnes DM/ha of winter feed depending on soil fertility and time of sowing. Break-grazing using back fencing is essential if regrowth is required.

In most North Island Hill country properties (Farm Classes 3 and 4; Section 4) about 5–10% of the farm area can be cultivated. This area can be used to incorporate forages into the farming system. The rotations employed depend on financial considerations and the identification of expected periods of feed deficit. Where high quality summer feed is required for lamb and beef finishing (Farm Classes 5, 6 and 8, Section 4) a leaf turnip such as 'Pasja' is used. Kale, sown in late spring, allows transfer of feed from summer to winter months. The area available for summer grazing is reduced by establishing kale in spring but the bulk of dry matter produced by the crop is available as standing feed to meet stock demand in winter months.

When kale is used rotations are usually:

old grass pasture → kale (1-2 crops) →spring sown new pasture.

In environments with over 800 mm rainfall/year kale can be sown in November (late spring) and can, with appropriate management, accumulate >20.0 tonnes DM/ha by the following winter. However, yields can be highly variable (Table 13) depending on nutrient availability, environmental conditions and establishment and management practices. For example, in Canterbury, kale yields were 23.0 tonnes DM/ha from an October sowing (8 months after sowing) and 17.0 tonnes DM/ha for the December sowing (6 months) (Brown *et al.*, 2007) and grew at a rate of 8 kg DM/ha/°Cd above a base temperature of 0 °C. Kale is grazed '*in situ*' and break fenced so stock are allocated a daily feed allowance. If two successive kale crops are grown in the rotation, yields from the second crop are generally lower than the first.

Table 13. Kale yields in trials at eight locations in diverse climates with different levels of soil fertility, with (+ Fertilizer) and without N and P fertilizer (- Fertilizer) application in New Zealand

	Yield		Soil N and P fertility	
Location	**- Fertilizer**	**+ Fertilizer**	**Available N (kg/ha)**	**Olsen P (mg/l)**
Te Awamutu	10.7	14.1	168	9.6
Lochinvar	4.1	6.1	118	24.0
Lincoln	14.2	19.1	61	11.5
Te Pirita	2.8	8.1	62	10.4
Te Pirita	5.1	13.3	65	10.7
Fairlie	6.5	14.7	126	30.9
Balfour	8.2	12.6	166	9.3
Drummond	12.7	14.2	231	11.0

(Beare et al.*, 2006)*

Pasture renewal programmes in different farm systems

To maintain animal production, pasture renewal programmes have been developed for most land classes. Where possible, these usually involve a cropping phase but on land that cannot be cultivated oversowing or direct drilling of species is common. In drier South Island environments, the pasture renewal rotations differ with the provision of a summer feed supply during the rotation. Typically rotations are:

old grass pasture → Italian ryegrass for winter greenfeed → leaf turnip or rape for summer feed→autumn sown pasture.

This would ensure successful pasture establishment after autumn break rains, because spring establishment is unreliable.

South Island Finishing/Breeding properties (Farm Class 6; Section 4) employ rotations to ensure adequate feed is produced to meet livestock demand. This is because these systems experience cold winters and summer drought which limits pasture feed production (Moot *et al.*, 2007). Crop rotations provide maintenance feed in winter months and green feeds are used to meet late winter/early spring feed demand which increases during lambing/calving and lactation. Annual greenfeed crops have the added benefit of depleting soil nitrogen following lucerne stands. Old lucerne stands, which are identified for renewal when plant population declines and perennial weed species begin invasion, are cultivated in early spring and left fallow until autumn when a greenfeed Italian ryegrass or cereal is sown. This is fed to stock in late winter/early spring and then cultivated by late October. The paddock is fallowed to accumulate soil moisture, and allow appropriate chemical weed control, until late January when turnips are sown to grow aided by the conserved soil moisture. Turnips are grazed in winter (July) allowing seedbed preparation in early spring before sowing another lucerne stand. If the paddock is being sown to pasture a second summer fallow is used to conserve moisture before the pasture is autumn sown.

Intensive South Island finishing systems (Farm Class 7; Section 4) are generally in summer safe environments. Their main period of feed deficit occurs in winter when temperature limits production from conventional temperate pasture species. There are two main pasture renewal practices (Moot *et al.*, 2007). In the first, the old grass pasture is sown into swedes which are winter (June/July) grazed and then new pasture is sown in spring. Alternatively, a cereal crop is sown in October after the swedes and prior to establishment of the new pasture. These cereal crops are either used as whole crop silage or harvested for grain prior to autumn establishment of the new pasture.

6. OPPORTUNITIES FOR IMPROVEMENT OF PASTURE RESOURCES

New Zealand's pastoral resource and integrated agricultural systems rely almost entirely on improved pastures developed by human activity. Prior to settlement the country was forested (see section 1 and Figure 2) and even the high country tussock grasslands, with their low stock carrying capacity (Farm Class 1, Section 4), would not exist without the repeated burning events that occurred for hunting. Thus, most of the opportunities for the future focus entirely on improved pasture species and their management.

Because the New Zealand economy is dominated by the success or failure of its pastoral industries it is important to initially discuss physiological limitations to pasture yield within its pastoral systems. Increases in pastoral production will come from intensification of land which is currently in pasture. The land area devoted to pastoral production has declined over the last decade and, given the country's topographic constraints, it is unlikely that any new areas will be converted to pastoral agriculture. Intensification is on-going with increasing areas under irrigation, the conversion of sheep and beef farms to dairy production and the more intensive use of easier hill country.

Improved on-farm management

New Zealand farmers readily adopt new technology when they perceive a commercial advantage, but there will always be room for improvement in the standard of farm management. Dairy farmers are characterized as rapid adopters of new technologies in contrast to more conservative sheep and beef farmers. There is widespread acceptance of ryegrass as the principal component of dairy pastures with white clover as the only suitable legume. This widespread belief is strongly reinforced by farm advisers and seed company publicity that is difficult to challenge if circumstances require widespread adoption of pasture alternatives. For example, the adoption of tall fescue, lucerne or lucerne/grass mixed pastures for grazing in the dairy industry may be difficult to promote without significant demonstrable advantages.

In the sheep and beef sector there are moves towards more stratification within the industry. This would ensure that the pasture resource is used more efficiently with store lambs and young cattle from hill country farms (Farm Classes 1–4; Section 4) being supplied to lowland intensive finishing farms (Farm Classes 5–8; Section 4) on contract. This closer integration between farm classes results in more secure returns for the breeding farms and a guaranteed supply of quality livestock for the finishing enterprises. This would also by-pass the fickle nature of store stock auctions. These developments are being accelerated by the increasing influence of large company owned farms which have a range of properties in both wet and dry regions. They are then ideally situated to use their complementary pasture resources by trucking livestock to graze high quality pasture at their various properties. It often makes greater business sense to move animals than buy conserved forages or to grow large areas of winter feed in a self contained family farm.

Management improvements on-farm over the next decade are likely to focus on increasing production efficiencies (e.g. per ha, per mm of water, per unit of P, S or N applied, per labour unit, etc). This will occur in parallel with attempts to decrease environmental impacts of intensive pastoralism. Amongst others, mitigation or reductions are required to 1) reduce methane and nitrous oxide gas outputs from ruminants and grazed pastures and 2) reduce nitrate leaching from winter forages grazed *in situ* and from urine patches. These two areas are current subjects of intensive research where some progress is being achieved.

Management technologies which will achieve greater resource use efficiencies and which are currently being demonstrated and promoted to farmers include:

- Use of improved cultivars and pasture species,
- Faster and more precise methods for measurement of pasture mass to allow more efficient grazing management,
- Centre pivot irrigation,
- Soil moisture monitoring to ensure irrigation water is applied only when required,
- Routine use of soil and herbage testing to determine fertilizer requirements,
- More precise fertilizer and herbicide application using GPS,
- Once a day milking of dairy cows and

- Computer packages to assist in long and short term decision making (record keeping, accounting, marketing, pasture growth models, fertilizer and irrigation calculators).

The need to at least maintain production per unit area, given that there is no more land available for pastoralism, while facing the requirement that farmers must reduce the environmental impacts of intensive ruminant grazing, is the greatest challenge facing New Zealand agriculture.

The trend towards fewer larger farms, both corporate and family owned, will generate some economies of scale with bulk purchasing of inputs such as fertilizer and more importantly larger flocks and herds that will allow selection from a wider gene pool to breed animals which can more efficiently convert forage into milk and meat. However, the trend to larger paddocks on large farms may lead to less precise use of land where soils and topography may vary considerably over small areas.

Opportunities to overcome topographical limitations (also see section 5)

Over 60% of New Zealand's pastoral land is on slopes steeper than 15° and pasture production is unlikely to reach the theoretical yield limits. Some of the physical limitations for hill country pastoralists include:

- Steeper country cannot be safely worked with tractor drawn implements;
- Aerial applications of herbicide, seed and fertilizer are required but are expensive;
- Access is more difficult and soil erosion is more likely.

Interactions between topography, plant biology and climate, in most cases, cannot be altered. Hill country farmers must understand the negative effects these interactions can have on productivity and seek to minimize their potential effects. For example, nutrients will continue to be transferred from steeper slopes to high points and less steep areas of un-subdivided paddocks. More intensive subdivision of hill pastures and strategic placement of water and salt supplies (Gillespie *et al*., 2006) may moderate animal movement and grazing intensity of steep slopes. However, it seems that there is little that can be done to change the camping behaviour of free grazing livestock. Fencing dry warmer north and west slopes from cooler, later maturing east and south slopes is on-going current practice, as is the separation of higher producing rolling country from steeper mid altitude from cooler higher country, undeveloped shrub vegetation from productive pasture. As environmental imperatives become more urgent rivers, streams and steep eroding gullies will be fenced to exclude livestock.

Advances are being made using GPS technologies to more precisely spread fertilizer from fixed wing aircraft but helicopters, which are more expensive, would be required to achieve ideal placement over much of the finely dissected hill country of New Zealand.

Opportunities under dryland conditions

The majority of pastoral systems in New Zealand are managed under dryland conditions and thus are completely reliant on rainfall to provide adequate water for growth. In some regions water stress is uncommon as the quantity and distribution of rainfall is adequate to maintain growth. In these areas, or in irrigated systems, where N is non-limiting water use efficiencies of >30 kg DM/ha/mm water transpired are possible (Moot *et al*., 2008). However, the water use efficiency (WUE) of an average temperate pasture (e.g. perennial ryegrass with 10% white clover), which is normally N deficient and exposed to water stress during the peak growth period, may only produce ~10 kg DM/ha/mm. Clearly the scarce water resource is used inefficiently when grasses are N deficient. Annual yields from dryland pastures supplied with non limiting N can double yields and may be 50% greater than N deficient irrigated pastures (Peri *et al*., 2002b; Mills *et al*., 2006). Therefore, there is a strong case for developing pastoral farming systems where much greater emphasis is placed on legume production. Legumes grown alone or mixed with less aggressive grasses and/or herbs will not require N fertilizer and the dry matter grown will be more nutritious.

Nitrogen and legume use

Animal nutritionists tend to be critical of pure legume herbage diets because of the high crude protein content of temperate legume foliage (25–30%). They emphasize that ruminants require only 15-18% crude protein and that greater amounts supplied in pasture diets are a physiological burden which results in extravagant losses of N in urine. However, despite this, grazing animals prefer to select a diet which is 70% legume and 30% grass. Also, liveweight gains and milk production/animal are maximized at similar high proportions of legume in ruminant diets.

The maximum yield which can be achieved from perennial temperate pasture species is about 28 tonnes DM/ha/year when N and water are non-limiting (Peri *et al*., 2002a) but high rates of N (>600 kg N/ha/year) are required for C_3 grasses to reach this maximum yield (Mills *et al*., 2006) and these are unlikely to be economically viable or environmentally sustainable for ruminant production systems. This rate also exceeds the arbitrary 200 kg N/ha/year maximum N fertilizer rate set by environmental agencies. In contrast, nodulated legumes with N self sufficiency and efficient light capturing leaf canopies, such as lucerne, also have a potential yield of 28 tonnes DM/ha/year (Brown *et al*., 2005). Clovers with less efficient leaf canopies may have a yield limit of about 18 tonnes DM/ha/year as monocultures. This is at least 1.5 times the yield expected from typical perennial grass clover pastures where the clover content is normally only about 10% of total annual production. Such pastures are invariably N deficient because of low N inputs from the clover which struggles to compete with grasses.

While grass dominant pastures, which do not receive N fertilizer, may have the "optimum" crude protein levels for ruminants, such pastures generally have low grazing preference. Thus, voluntary intakes are low and animal production per head is about half that of animals on a high legume diet. Furthermore, animal production per hectare for grass dominant pasture with about 16% CP will be unsatisfactory because the pasture yield will only be about half that produced by a pasture where the grass has a CP of 25%. This is because temperate grasses require >4.0% N in their leaf DM for maximum photosynthesis (Peri *et al*., 2002b) and grass leaf with a CP of 16% contains only 2.6% N (16% CP/6.25). Such swards display obvious N deficiency with yellow/green leaves and low vigour. There is no obvious solution to this dilemma. Perennial grasses and herbs with reduced critical leaf N content (e.g. =3% N rather than >4%) may be developed in future. In the mean time high sugar grasses will not solve the problem. High energy supplements may help to balance ruminant diets but their cost is unlikely to be economically viable for unsubsidized meat production.New Zealand pastoral farming must therefore get back to basics. It must ensure the lime, superphosphate, rain (+ irrigation) and sunlight reaching the land is used with maximum efficiency for carbon fixation (photosynthesis) and nitrogen fixation by legumes. The high rate of N fertilizer required to achieve maximum productivity from grass dominant pastures is unlikely to be affordable for a sustainable, unsubsidized pastoral industry.

Problems associated with intensification

Increased pastoral production will result in increased livestock carrying capacities. This means the challenges to mitigate issues of pugging and soil compaction, losses of N and P from the soil profile and potential eutrophication of waterways and NH_3 volatilization will need more urgent attention.

Eutrophication of waterways has lead to nutrient application caps in some regions. The use of riparian buffers and adequate fencing to prevent animals accessing waterways is essential. There is potential for multiple species riparian vegetation buffers which allow plantings of strips of ungrazed deep rooted pastoral plants (e.g. lucerne) surrounding waterways to capture excess N at depth. This forage may then be cut, conserved and fed elsewhere. Trees closer to the waterways improve the habitat for aquatic life and create wildlife corridors. Furthermore, >30% of New Zealand's total greenhouse gas emissions are N_2O, predominately from urine patches, and recent work has shown that nitrification inhibitors can reduce total N_2O emissions from urine patches by about 70% (Di *et al*., 2007).

Most of the following mitigation strategies are currently employed but much more general adoption of these will be essential if significant progress is to be achieved. Examples of these strategies are cutting and carrying of winter forages to reduce soil compaction on sensitive land. Animals may be housed in winter and/or feeding out may occur on less fertile paddocks rather than where feed was sourced. This increases costs but provides opportunities for more efficient distribution of the nutrients in effluent across specific targeted areas of the farm.

Farm nutrient budgets

Farm nutrient budgets for individual paddocks are likely to be developed with greater precision. Maintenance fertilizer applications can then make allowances for nutrients transferred between different areas. However, if such measures are unsuccessful on some soil types stocking rates may have to be restricted. For instance, in the past, stocking rates of between 2 and 3 Jersey cows/ha on self contained, family dairy farms may have been sustainable. Such farms relied completely on legumes for their N inputs and little feed was bought in. Modern larger properties use up to 200 kg N /ha on the area adjacent to the milking shed. This area of pasture is known as the "milking platform" and all young and dry cows not in milk are grazed elsewhere. Maize silage and other supplements are also bought in to feed to the milking herd. This may result in stocking rates of 4 cows/ha on the milking platform pasture which exceeds the physical and chemical capacity of the land to absorb the increased treading and nutrient load.

Adjustment of legislation

Apart from adjustment to high country Crown lease properties by Tenure Review (see section 4) there is unlikely to be major change in land tenure law, rural subsidy policy, or biosecurity regulations in New Zealand. The current (2009) centre right government may relax some regulations relating to the Resource Management Act which may affect the individual rights of farm owners to develop their properties. They may also relax current regulations to allow foreign financiers to purchase New Zealand farmland. However such developments are still likely to be controlled by strong environmental legislation.

Legislation to protect New Zealand's "Clean green image" is likely to be strengthened and laws relating to environmental pollution issues are likely to be enforced more vigorously in the future. This is likely to result in more stringent controls on the use of nitrogen fertilizers, the spreading of effluent, and encouragement to plant riparian strips within fenced off waterways, particularly in dairying regions. Tree planting within steep erodible hill pastures may become obligatory and stocking rate limits on intensive dairy pastures may need to be introduced but as yet none of these measures have been publicly debated.

Farmers are impatiently waiting (2009) for definite legislation which will allow them to participate in the "Carbon Market". With about half of New Zealand's greenhouse gases calculated to come from livestock emissions pastoral farmers require strong market certainty regarding various mitigation measures which they may employ. Carbon sequestration by forest tree planting on less productive farmland is an obvious opportunity which is delayed pending legislative guidance. Current legislation will implement an emissions trading scheme in 2010 but agriculture is currently exempt until 2015.

Social organization

New Zealand social organization in relation to its pastoral industries is unlikely to change radically in the next few decades. There are however some rural population reduction trends which may lead to less precise pasture management. As farms become larger, labour may be substituted with increased mechanization on large scale properties and managers may prefer to use simple pasture mixtures which are most easily managed. This may result in limited uptake of new pasture technologies which require specific special management regimes.

Pasture plant improvement

Plant breeding programmes should focus on developing plants and animals with increased N use efficiency and increased soluble carbohydrates and lipids. This approach should focus on temperate plants that have a lower N requirement for optimal growth so that the N concentration in urine is reduced. The need for N fertilizer and pure legume pastures may then be avoided. Work is proceeding on increasing the soluble carbohydrates in grasses (see below) but results to date are ambiguous at the animal scale and there has been little publicity regarding the prospect of fixing more carbon per unit of N in C_3 grasses.

Animal breeding programmes aiming to increase the rate of conversion of pasture into saleable animal products are making progress. For example, the recent increases in New Zealand lamb production from significantly reduced ewe numbers is partly attributable to advances in animal breeding, with an emphasis on fecundity and meat production.

New Zealand farmers are familiar with current perennial ryegrass cultivars, their wild and novel endophyte options and the range of white clover cultivars available. The use of this plant material for future plant breeding of these dominant pastoral species, through either conventional and/or genetic technologies may be limited by the lack of genetic variability in highly developed lines (e.g. perennial ryegrass). Market resistance to genetic technologies (both trans- and cisgenic applications) in the food chain is strong in New Zealand and in some high value export markets. This presents a dilemma for science policy and research fund allocation. On one hand New Zealand does not wish to neglect new genetic technologies but there is a risk that these products may never be accepted for inclusion in the food chain by the end consumer. Furthermore, there may be a large opportunity cost in funding genetic technologies rather than concentrating on plant and animal improvement using traditional techniques.

The introduction of pasture species, which show improved production and persistence to the industry standard perennial ryegrass/white clover mix in some environments, can fail to be exploited by rural industry in New Zealand despite the well developed information extension structure. A current example is Caucasian clover which has shown promise for long term production and persistence in montane and lowland pastoral systems. However, it has slow establishment caused by higher thermal time requirements for leaf development in its seedlings compared with white clover (Black *et al*., 2006). This has meant the species was often suppressed by vigorous perennial ryegrass seedlings when mixtures were established. It is now recommended that Caucasian clover is established as a monoculture or with a low sowing rate of a forage cover crop such as rape. It can then establish and develop its taproot and rhizome system without competition from a companion grass. Once the Caucasian clover is established perennial grass can be oversown. However, now the establishment is understood and recommendations can be made with confidence, the seed is difficult to obtain.

The success of fast establishing perennial ryegrass/white clover pastures means farmers can be impatient with such new species that may establish more slowly. The need to manage speciality pastures with more care can make changes required from the standard ryegrass/white clover management frustrating. Also, the dominant use of pasture seeds premixed by seed companies has led to almost universal use of high seeding rates of ryegrass (>20 kg/ha) which tend to suppress most other species including weeds but do not help the promotion of alternative herbage species. A lack of explanation of the growth habits, peak production periods, management requirements for optimum production and persistence, changes in quality between vegetative and reproductive growth etc. can hinder uptake of other species which may be better adapted for specific purposes than perennial ryegrass and white clover.

Clearly, opportunities exist for new pasture species to fill specific niches but current structures in rural industries require modification before successful adoption is likely.

High sugar grasses

Several perennial ryegrass cultivars bred for high water soluble carbohydrates (WSC) overseas are currently available in New Zealand. These high sugar grasses are promoted for their ability to change the carbon and nitrogen ratio in the rumen thus increasing animal production through improved N utilization and result in reduced urinary N concentrations. However, recent reviews (e.g. Edwards *et al*., 2007) report inconsistency in water soluble carbohydrate levels when grown under New Zealand conditions. Genotype x environment interactions were proposed as the cause of variation in trait expression and plant breeders are currently selecting for lines suited to the New Zealand environment. However, the level of increases required to see a response in N utilization in New Zealand's intensive grazing systems (100–200 g WSC/kg DM), has not been seen in current material. Equally, the transfer of any benefits from plant to animal performance has been inconsistent.

Seed production in New Zealand

New Zealand is almost self sufficient in herbage seed production with ryegrass and white clover being the main species. New Zealand is the world's largest producer of white clover seed. With its suitable soils and climate, Canterbury produces more than two thirds of New Zealand's herbage seeds. Yields are high by world standards with many growers producing >2.0 tonnes/ha of white clover seed in favourable seasons. Apart from species for local consumption New Zealand also produces a wide range of herbage and vegetable seeds for niche markets overseas.

Most of the lucerne and annual clover seed (e.g. subterranean, balansa) is imported from Australia. In recent years seed supply of some annual clover seed has been compromised by Australian droughts and the reliability of seed supply for NZ farmers has been questioned. However, local production of seed from these species is problematic. For example, the technology for harvesting subterranean clover seed from burrs that mature below the soil surface needs further investigation. Strict import and biosecurity regulations mean new species introduction will only be permitted if it can be proved the species will not become invasive.

Initiating a New Zealand cultivar evaluation scheme to evaluate all new cultivars (both imported and locally bred) to test their suitability for local environments would be beneficial to the agricultural industry. Sociability of grasses with legumes and their persistence in grazed pastures should be essential for such a scheme.

Better integration of forages into farming systems

Within given farming systems, greater yields may be achieved by growing a winter active annual such as kale followed by a summer active annual (e.g. maize) but this strategy is likely to require high fertilizer inputs. Currently a collaborative project between research organizations has the objective of producing 40 tonnes DM/ha/year using this double cropping concept. However, while the 40 tonnes DM/ha objective may be theoretically achievable the nutritive value of the dry matter produced is likely to be deficient in metabolisable energy and crude protein (also see section 5).

Improvements in seedbed preparation and establishment practices used by farmers and their contractors are likely to have the biggest impact on improving integration of forage crops into pastoral systems. Farmers who experience crop failures (see section 5) whether forage crops or alternative pasture species, are unlikely to invest capital into those species again as they are then perceived to be difficult to establish and have increased likelihood of failure.

Pasture rehabilitation

Pasture rehabilitation is driven by potential economic returns. Currently, average pasture renewal intervals exceed 10 years on many farms. Degradation from overgrazing at the farm scale is monitored by individual farmers with increasing guidance and direction from regional councils. In most cases pasture rehabilitation is required after erosion events following significant rainfall. Strategic tree planting is favoured to mitigate future events.

Weed control

With pressures, both economic and environmentally driven, to reduce use of agricultural chemicals the use of goats for woody weed control may gain favour (also see section 5).

Climate change

Salinger (2003) predicted that the impacts of future climate change would result in more rain on the west coast of New Zealand, while eastern areas would be drier and warmer but with greater variability. These predictions will place further physiological limitations on pasture production. Farmers may need to learn how to manage a wider range of pasture species and farming systems will have to be modified to accommodate increased drought frequency in the east and more intense rainfall events and greater total precipitation in western regions.

Summer-moist regions

Increased mean annual temperatures would result in southerly migration of C_4 grasses which currently are limited to warmer regions such as Northland and frost free areas further south. Pest and disease prevalence would also increase. Temperature increases may also increase the number of life cycles that major pasture pests complete in a year. The combination of warmer temperatures and more rainfall in western districts will increase humidity in canopies and fungal disease prevalence could increase. The cost effectiveness of pasture pest and disease control measures will be a major limitation if commodity prices are insufficient to justify applications. Pasture growth rates will increase during winter but warmer summer temperatures will stress some temperate pasture species such as perennial ryegrass. This will require greater use of more drought tolerant species with higher optimum temperatures for growth such as tall fescue, but it will need to be infected with an effective novel endophyte to ensure persistence.

Summer-dry regions

The area of the east coast regions that is subjected to regular prolonged periods of summer/autumn soil moisture deficit are predicted to increase from the current ~3.0 M ha, through climate change. The most commonly sown pasture legume in these areas is still white clover even though it is ill adapted to summer drought. If droughts become more prolonged, and more frequent, production and persistence from white clover will be even less reliable. Leading farmers will show greater reliance on annual pasture species such as subterranean clover and deep rooted perennials such as lucerne.

New Zealand has well developed technologies for grazing lucerne with sheep and, to a lesser extent, cattle. The best advice for dryland farmers is that they should grow lucerne wherever conditions allow and should plant it on the best soils on their properties. Australia leads the world in annual clover research and there is opportunity for New Zealand farmers to adapt Australian technology to their local conditions. Improved management to increase the production of resident (>50 year old) cultivars of subterranean clover is currently being promoted. This in combination with the introduction of the best adapted modern cultivars and adoption of appropriate management strategies should enable dryland livestock farmers to at least maintain their current productivity if soil moisture regimes become more adverse.

The special feature of annual legumes over perennial legumes is their much faster growth rates in the cool season. Dryland farmers can exploit this annual legume productivity in late winter/spring (August to November) for ewe lactation. Twin lambs suckling from ewes grazing a pasture with 50% legume on offer can grow at 350–400 g/head/d before weaning at 90–100 days of age. Ideally all lambs should be sold from drought prone farms by the end of December. The basic technology for dryland pastoral farming is being applied by leading farmers and increasing drought experiences may hasten adoption rates of current best practice. Further advances are anticipated through the introduction of top flowering annual legumes from Australia to complement subterranean clover.

Current work in New Zealand with balansa and arrowleaf clovers suggests they may have a place in dryland pastoral systems. Gland clover (*Trifolium glanduliferum*) is an early flowering recent introduction which may also complement subterranean clover on sites with <500 mm effective rainfall (e.g. sunny north and northwest hill faces where evapotranspiration is extreme). Gland clover is one of the few annual legumes which is resistant to red legged earth mite (*Halotydeus destructor*). This major pest of annual legumes is likely to become more troublesome as conditions become warmer and drier.

Climate change predictions for a general increase in temperature will result in higher temperatures in high country regions and extend the perceived altitudinal limit to pastoral development. This limit is currently considered to be 900 m but improved pastures at higher altitudes may be viable in future. Perennial legumes such as Caucasian clover may have a role in such environments.

In conclusion, some of the issues and mitigation strategies discussed in this section are already standard practice for New Zealand's "top" farmers. Nationally, the biggest shift in future productivity is likely to be achieved by uptake of existing "best practice" strategies by other farmers. This will require the advice and support of the entire agriculture industry (including research organizations, education providers, contractors, commercial field officers and extension staff) to transfer current knowledge onto farms. These practices will then be integrated into existing systems to maintain and enhance efficiency and ecologically sustainable pastoral agriculture.

7. RESEARCH AND DEVELOPMENT ORGANIZATIONS AND PERSONNEL

There are several Government and University based pastoral research programmes in New Zealand. The dominant crown research institute is AgResearch. In addition, Massey University in the North Island and Lincoln University in the South Island provide degree-based agricultural teaching and research.

AgResearch

Website: www.agresearch.co.nz/**Summary.** AgResearch is a crown-owned research institute of approximately 1 000 staff, 650 of whom are research and development staff. Annual revenue is over NZ$ 150 M.

Their mission is focused around three complementary objectives:

1. To underpin the New Zealand pastoral sector's sustainability and profitability
2. To establish a range of biotechnologies and systems in New Zealand
3. To export AgResearch biotechnologies and systems where appropriate

Staff are mainly located on one of four campuses (Hamilton, Palmerston North, Lincoln and Invermay).

Summary of activities relevant to the dairy sector. The Dairy sector in New Zealand is served by several key research providers, including Fonterra's own research units, DairyNZ, LIC and some universities. AgResearch seeks to complement these other institutes, not compete in most cases. Almost all activity within AgResearch is relevant to the dairy sector to some extent. A brief summary by section is shown in Table 14. In addition to these R&D capabilities, AgResearch has one dairy farm in the Waikato (at Ruakura), with another under development (at Tokanui) and one dairy farm in the Manawatu (at Flock House).

Strategic intent. AgResearch has developed a comprehensive strategic plan for improving the pastoral sector of New Zealand through research and development, called 2020 Science. The Dairy sector has a significant place in the strategic direction of AgResearch. Their current plans for research for the dairy industry are encapsulated in Goal 1 of the 2020 science implementation plans. The objective of Goal 1 is:

> "by 2020, the net economic/export value of the NZ dairy sector will be doubled while halving (reducing) adverse environmental impacts (to acceptable international standards), through achieving productivity gains, sustainable intensification, reducing emissions to air and water, developing new, high-value products and enabling technologies and services (all compared to 2005 levels)".

Partner organizations. AgResearch sections work with DairyNZ (in the areas of farm systems, forage and the environment), Fonterra (environment, forage development through its subsidiary Vialactia Biosciences), Massey University, LIC and many dairy processors (including Fonterra) in the development of processed dairy products. Investors include Pastoral21, FRST, DairyNZ and dairy companies.

Table 14. Description of activities in AgResearch sections.

Section	Section manager	Summary of activities relevant to the pastoral sector
Dairy Science & Technology	Dr Kerst Stelwagen	R&D in dairy genetics, epigenetics (in collaboration with LIC), milk composition, milk-based bioactives and dairy product processing.
Agricultural Systems	Dr Greg Lambert	Improved agricultural systems, through modelling, increasing rates of technology adoption and links between nutrients, feed, animals and the value chain.
Climate, Land & Environment	Dr Harry Clark	Research to reduce ruminant methane emissions, environmental damage emission of nitrogen compounds into the air and water and damage to soil.
Biocontrol, Biosecurity & Bioprocessing	Dr Glyn Francis	Research on biological control mechanisms and ways to prevent invading animal, plant and insect pest species from entering NZ, thereby protecting all our pastoral industries.
Forage Biotechnology	Dr Chris Jones	This section develops improved plant cultivars and endophytes for pastoral production, including dairy, sheep, beef and deer.
Forage Improvement	Dr Syd Easton	This section develops improved plant cultivars and endophytes for pastoral production, including dairy, sheep, beef and deer.
Reproductive Biology	Dr Jenny Juengel	Some research relating to cattle reproduction, but most of their work is on sheep.
Animal Health	Dr Wayne Hein	Research to reduce the impact and treatment of disease in all pastoral animals, including mastitis, TB and some parasite work relevant to dairy cattle.

DairyNZ Ltd, Hamilton

Website: www.dairynz.co.nz/

DairyNZ is the single dairy industry-good body owned by and operated on behalf of all of New Zealand's dairy farmers. The organization is based at Newstead with two adjacent research farms. Other research staff are based in Northland, Taranaki and Canterbury, also with access to major research farm facilities.

The Science Programme is managed by;

Chief Scientist – Eric Hillerton (Email: Eric.hillerton@dairynz.co.nz)

Leader of Animals Research - John Roche

Leader of Feed/Farm Systems Research - Dave Clark

The whole research team comprises 25 post-doctoral scientists and 75 technical, support and farm staff. More than 55 research projects are commissioned but the major effort is in 6 key areas. These are in;

- Feed Conversion Efficiency (Garry Waghorn and Kevin Macdonald)
- Lactation Management Strategies (John Roche)
- Novel tools to prevent mastitis in dairy cows (Jane Lacy-Hulbert)
- Improved cow fertility by novel nutritional strategies and epigenetics (Susanne Meier)
- Animal welfare (Gwyn Verkerk)
- Dairy systems for environmental protection (Dave Clark).

Lincoln University

Website: http://www.lincoln.ac.nz/

Name	Area of expertise	Email
Cameron, Keith	Soil and environmental quality, nitrification inhibitors, nitrate and phosphate leaching, lysimetry, land application of wastes	Keith.Cameron@lincoln.ac.nz
Edwards, Grant	Annual and perennial forage legume improvement, ecology & management of annual grass weeds, high country grazing manipulation	Grant.Edwards@lincoln.ac.nz
Greer, Andy	Balancing parasite immunity with production in sheep	Andy.Greer@lincoln.ac.nz
Hill, George	Agronomy and use of forage legumes	George.Hill@lincoln.ac.nz
Hofmann, Rainer	Plant biology and environmental plant physiology, plant responses to environmental stress	Rainer.Hofmann@lincoln.ac.nz
Moir, Jim	Nitrification inhibitors, nutrient cycling and plant nutrition, sustainability of high production systems	Jim.Moir@lincoln.ac.nz
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Nicol, Alastair	Grazing behaviour and intake with special emphasis on mixed grazing, animal behaviour and animal production systems	Alastair.Nicol@lincoln.ac.nz
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