

## THE NEW ZEALAND ARABLE INDUSTRY

James P. Millner, Nick R. Roskrug

Institute of Agriculture and Environment, Massey University, Private Bag 11 222, Palmerston North 4442, New Zealand

**ABSTRACT:** While a variety of ecosystem services are provided by arable production systems in New Zealand, the majority (>85%) is attributed to food production. The arable industry is centred on the Canterbury Region; production of arable crops in formerly important regions including Manawatu and Southland has declined over the past 20 years. A diverse range of crops are grown including cereals, pulses, herbage seeds and vegetables. Cereals account for most of the area planted in crops each year. In 2012 the total area in cereals (wheat, barley, maize, and oats) was 145 000 hectares producing about 1.1 million tonnes of grain. However, production is not sufficient to meet domestic requirements, requiring ongoing imports of milling wheat and feed grains (wheat, barley and sorghum). More recently, forages supplied to local dairy farmers and vegetable seed produced for export, principally peas, radish and carrot, have become important sources of income; production of pulse crops has declined. Herbage seeds, dominated by perennial ryegrass and white clover, are produced to supply the requirements of New Zealand's pastoral industries and for export. Vegetable production includes both fresh and processed crops; potatoes, peas and sweetcorn are the major process crops, with significant exports. Onions and buttercup squash are the main fresh crop vegetables. Export earnings from fresh and processed vegetables generated \$614 million in 2011. Conversion of arable and mixed-arable farms to dairy is a threat to the industry through reduced economies of scale and loss of infrastructure. The development of large community irrigation schemes has facilitated dairy conversions, particularly in Canterbury. Nutrient loss limits, proposed by many regional councils, suggest that nutrient management is likely to become a challenging issue for many arable farmers, particularly those growing winter vegetables and forage crops for winter grazing of dairy cattle.

*Key words:* cereals, forage, herbage seeds, oilseeds, outdoor vegetables, pulses, vegetable seeds.

### INTRODUCTION

The three major cereal crops – wheat (*Triticum spp.*), maize (*Zea mays*), rice (*Oryza sativa*) – plus potatoes (*Solanum tuberosum*) contribute about 50% of the human daily energy intake globally (FAO 2008) but reliance on these crops varies with income. People with high incomes tend to consume more energy and protein and acquire a greater proportion of daily intake from animal products, particularly meat and dairy, compared to those with low incomes. Cereals are increasingly used as feed for livestock; about 35–40% of total global cereal production is currently utilised for this purpose (United Nations Environmental Programme 2009). Compound feeds based on cereals, produced for the pork, poultry, beef and dairy industries, account for most of the cereal use in New Zealand. Total compound feed manufactured in New Zealand in 2011 was 921 890 tonnes, of which 582 980 tonnes were cereals, principally wheat (62%), barley (20%) and maize (10%) (New Zealand Feed Manufacturers Association 2012).

The arable industry in New Zealand is primarily geared to supplying the domestic requirements for cereals used in the milling, brewing and animal feed industries, as well as outdoor vegetables and vegetable and herbage seed production. Domestic production of most arable crops is tiny by global standards; New Zealand 2012 wheat production was less than 0.07% of global wheat production (FAO 2012a). New Zealand does not produce sufficient cereal tonnages to meet its requirements, consequently significant imports of milling wheat and feed grains occur every year, mostly from Australia. Despite cereal yields being among the highest in the world (FAO 2012b) New Zealand cereal growers are not internationally competitive. The reasons for this include small-scale production and high internal transport costs. For example the average Australian grower (grain and grain-mixed-livestock farmers) plants about 500 hectares in wheat (Australian Bureau of Statistics 2012), whereas New Zealand growers typically plant <100 hectares (Ministry for Primary Industries 2012a). The cost of transporting grain from

Canterbury to mills in Auckland (\$80 t<sup>-1</sup>) is more than the cost of shipping grain from Sydney, Australia (\$50 t<sup>-1</sup>), and similar to the cost of transporting grain from the west coast of the United States to Auckland mills (\$83 t<sup>-1</sup>) (United Wheat Growers 2012). There are, however, significant exports of processed vegetables, vegetable and herbage seeds (Ministry for Primary Industries 2012a). More recently the provision of forage, including pasture, cereal and brassica forage crops and cereal silage for the dairy industry, has become an important activity.

New Zealand arable production is centred on the Canterbury Region although significant production also occurs in the Manawatu-Wanganui, Hawke's Bay, Gisborne, Bay of Plenty and Waikato regions. In 2011, 88% and 65% of the total wheat and barley areas, respectively, were planted in Canterbury, but maize grain production is largely confined to North Island regions (Statistics New Zealand 2012a). Dominance of Canterbury in the herbage and vegetable seed industry is even greater; about 90% of production is based there (Hampton et al. 2012b).

Arable crop production is dominated by properties categorised as 'arable', i.e. where the majority of income is obtained from the sale of grains and seeds; and on properties where various livestock enterprises, mostly sheep, are combined with arable crops but where most income is obtained from livestock, these properties are categorised as 'mixed livestock' (hereafter mixed arable) (Statistics New Zealand 2008a). Arable farms are generally characterised by the wide variety of crops produced. For example, the Canterbury model arable farm produces cereals, grass, clover and vegetable seeds, process vegetables and silage crops (Ministry for Primary Industries 2012a). Cereals occupy the largest area on these farms but seed production is also a major activity and an important source of income. Diversification into dairy support is another feature of recent changes in this sector (Table 1).

There has been a decline in the number of mixed arable farms in New Zealand, particularly in Southland, Otago, Canterbury and Manawatu-Wanganui, a consequence of the falling profit-

ability of sheep farming through the 1990s and the profitability of dairy relative to other land use options on arable land (Dyes et al. 2010). Consequently many arable and mixed arable farms

**TABLE 1** Production and financial profile of the Ministry for Primary Industries' Canterbury Arable Farm Model

	Year		
	2010/11	2011/12	2012/13*
<b>Area (ha)</b>			
Wheat	82	79	89
Barley	33	33	36
Grass seed	41	46	52
Clover seed	12	16	15
Vegetable/brassica seed	12	17	18
Process vegetables	16	13	17
Pulses	22	9	10
Silage crops	12	25	25
Other	15	23	14
Area in crop (%)	84	87	92
<b>Revenue and expenditure (\$/ha)</b>			
Crop revenue	3,325	4,164	4,104
Total farm revenue	3,351	4,240	4,237
Total farm working expenses	1,890	2,035	2,134

\* Budgeted

**TABLE 2** Area harvested (ha) and total production (t) for wheat, barley, maize and oat grain crops, 2003–2012

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012*
<b>Wheat</b>										
Area	42 610	39 062	39 415	37 962	40 538	42 362	53 854	54 762	52 604	54 897
Production	318 916	255 860	318 947	261 798	344 434	343 350	403 463	444 890	383 262	485 617
<b>Barley</b>										
Area	63 402	48 503	49 825	47 078	51 481	67 435	77 669	52 340	64 868	66 271
Production	371 837	226 082	302 023	277 020	335 627	408 730	435 270	308 298	367 958	435 733
<b>Maize</b>										
Area	19 500	20 300	19 200	19 700	17 000	18 300	21 600	17 500	18 500	20 200
Production	211 700	234 200	210 300	215 600	185 600	205 600	237 800	188 800	210 200	215 800
<b>Oats</b>										
Area	5900	7500	7900	6300	5800	5200	7400	8900	6100	3900
Production	29 900	30 800	28 700	28 500	27 500	25 500	33 700	47 600	28 500	18 300

\* Provisional

have converted to dairy (Beck 2012) while many of those farms that were predominantly arable (Canterbury) responded to low sheep prices by reducing sheep numbers and expanding crop production. This movement is reflected in a fall in sheep and an increase in dairy cattle numbers in these regions over this time (Statistics New Zealand 2012b). In Canterbury sheep numbers have continued to decline and dairy cattle increase (Statistics New Zealand 2012a). There was a sharp fall in the estimated number of mixed arable farms and an increase in the number of predominantly arable farms between 2000 (1017 and 250 respectively) and 2006 (190 and 300 respectively) in this region (Ministry of Agriculture and Forestry (MAF) 2000, 2006). The traditional dominance of Canterbury in the arable industry has increased as a result of these changes.

A range of different ecosystem services are provided by

arable production systems; Sandhu et al. (2008) identified 12 different services produced on Canterbury arable land. However, 87.5% of the total value of services was attributed to food production with the next most important category being the provision of shelter, contributing 5.4% of total ecosystem services value. In terms of value from human food production (both directly and via animals), Sanderson et al. (2012) estimated that the total direct gross output from grains, silage and seeds produced by New Zealand arable farms in 2011 was \$868.1 million. The inclusion of indirect impacts (farm supplies) took this value to \$2.18 billion (10<sup>9</sup>). This analysis did not include the value of vegetable crops produced on arable farms.

## CEREAL, PULSE AND OILSEED CROPS

### Wheat

Total annual wheat (*Triticum aestivum*) production over the past 10 years has ranged from 285 860 to 485 617 tonnes (averaging about 356 000 t). Variation in production is associated with variation in the area harvested (Table 2) and yield, which ranged from 6.5 t ha<sup>-1</sup> (2004) to 8.8 t ha<sup>-1</sup> (Statistics New Zealand 2012b). The area harvested has been relatively stable at over 50 000 hectares since 2009. However, the wheat area in New Zealand has declined; during the 1970s the wheat area was typically double that of the area planted in recent years but declined markedly in the late 1980s (Statistics New Zealand 2012a). The main reason for this was the deregulation of the wheat industry, particularly the disestablishment of the New Zealand Wheat Board in 1987, which had statutory control over virtually all aspects of

production, quality and pricing (Dunbier 1992). Subsequently quality standards and prices for milling wheat in New Zealand were strongly influenced by international markets resulting in a significant fall in wheat prices in New Zealand and a move away from wheat production. In the period following deregulation the quality of milling wheat destined for bread production increased greatly. This resulted from specification of good quality cultivars, assessed by means of a test bake score incorporating loaf volume and crumb texture, price premiums for high grain protein content and required standards for other quality traits, such as sprouting damage, set by mills (Lindley 1990).

Much of the decline in the area planted in wheat has occurred because of a decline in wheat area in secondary regions, particularly Southland, Otago and Manawatu-Wanganui. In 2010 these regions accounted for 4.7%, 4.5% and 1.5% of the total wheat area

respectively with 88% of the total planted in Canterbury (Table 3) whereas in 1980 these regions accounted for 24.6%, 13.4% and 5.1% of the total area respectively while Canterbury contributed 53.6% (Department of Statistics 1983). The closure of the flour mill in Manawatu and the oat mill in Southland (MAF 2000) in the early 2000s contributed to the decline in wheat production and a general decline in confidence in the arable industry in those regions.

In contrast wheat yields have increased (Figure 1), partially compensating for the decline in area. For example, the mean wheat yield, calculated from the total area planted and total production from 1990 to 1996, was 5.1 t ha<sup>-1</sup> (Statistics New Zealand 1997). The increased use of high-yielding winter feed wheat cultivars has helped lift mean yields (Foundation for Arable Research 2012a, b) as has increased use of inputs including irrigation, nitrogen fertiliser, pesticides and growth regulators (Foundation for Arable Research 2011a).

Wheat production generally falls into two main categories: wheat for milling (predominantly bread baking) and feed wheat used in the livestock industries. Milling wheat used for bread generally has hard grain texture and high protein content, particularly gluten, whereas milling wheat used for biscuits and cakes has soft grain and low protein content. Prior to deregulation of the wheat industry milling wheat dominated production but is now secondary to feed wheat. In 2011 feed wheat comprised about 78% of the national harvest (Sanderson et al. 2012). Production of wheat for milling is insufficient to meet New Zealand's requirement, consequently significant amounts are imported each year to satisfy demand (e.g. 343 000 t in 2010 and 291 000 t in 2011; United Wheat Growers 2012).

Fluctuation in the area planted in wheat each year often reflects wheat prices and prices of alternative crops. The price of both feed wheat and milling wheat is influenced by several factors, principally the international price, Canterbury production and internal transport costs. For example the price for imported Australian hard milling wheat (11.5% protein) landed in Auckland for the week beginning 14 January 2013 was NZ\$543 per tonne. The cost of rail transport from Ashburton (Canterbury) to Auckland is about NZ\$80 per tonne. During the same week the value of non-contracted milling wheat (12.5% protein) delivered to Christchurch was quoted at NZ\$415 per tonne (United Wheat Growers 2012).

### Barley

The total area planted in barley (*Hordeum vulgare*) nationally

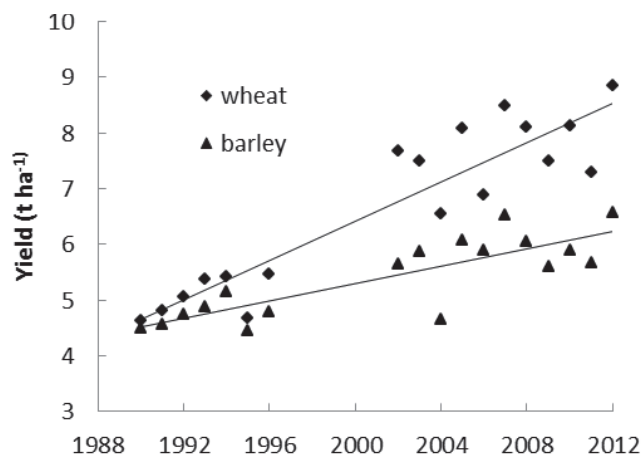


FIGURE 1 Mean national wheat and barley grain yields between 1990 and 2012. Wheat regression line:  $y = 0.18x - 350$  ( $R^2 = 0.85$ ). Barley regression line:  $y = 0.078x - 150$  ( $R^2 = 0.69$ ).

is generally greater than wheat but total production is similar, a consequence of lower yields. Production over the last 10 years has fluctuated between 226 000 (2004) and 435 733 tonnes (2012) (Table 2). The area planted in barley has declined from a peak of over 152 000 hectares in 1985 when New Zealand was exporting barley (Statistics New Zealand 2012b); exports that year peaked at 298 000 tonnes (Dunbier and Bezar 1996). The decline in area planted in barley and the annual fluctuations have both been influenced by the same factors affecting the wheat area, principally prices offered for barley relative to other crops, the decline of the sheep industry and the expansion of the dairy industry, particularly in Canterbury (Statistics New Zealand 2012a). However, a significant area of barley is still planted in the North Island, mostly in the Manawatu-Wanganui and Hawke's Bay regions (Table 3), a significant proportion of which is malting barley. Barley yields have not increased at the same rate as wheat yields (Figure 1). Reasons for this may include a higher proportion of barley being grown outside Canterbury over time compared to wheat; Canterbury generally achieves higher cereal yields than other regions (Statistics New Zealand 2012a). Barley breeding has been significantly reduced in New Zealand, in contrast to the situation with wheat. Comparison of the origin of cultivars evaluated in the spring wheat and barley 2011/12 cultivar performance trials reveals that for spring wheat 2/3rds of the cultivars evaluated (9 total) were of New Zealand origin (Plant and Food Research Ltd; PGG Wrightson) whereas none of the barley cultivars appeared to be of New Zealand origin (Foundation for Arable Research, 2012c).

TABLE 3 Wheat, barley and maize grain area harvested (ha) by region, 2009–2011

	Wheat			Barley			Maize		
	2009	2010	2011	2009	2010	2011	2009	2010	2011
Northland	0	0	0	0	0	0	-	300	400
Waikato	-	-	200	600	-	400	5400	3700	4100
Bay of Plenty	0	0	0	0	0	0	2800	3600	2600
Gisborne	200	-	-	400	-	-	3700	3000	3600
Hawke's Bay	600	-	400	-	1800	2300	3600	2700	2700
Manawatu-Wanganui	2000	700	900	7400	3800	5100	-	2300	2700
Marlborough	300	-	-	800	300	300	0	0	0
Canterbury	46 900	48 000	46 000	45 000	35 300	42 300	-	-	-
Otago	1700	2500	2100	-	4300	6100	-	-	-
Southland	-	2600	2300	4700	4600	5800	0	0	0

- = Confidential or suppressed

Barley is primarily used as a feed grain in New Zealand; in 2011, 114 282 tonnes of barley went into the manufacture of compound feed, 86% of which was produced domestically (New Zealand Feed Manufacturers Association 2012). A large amount of feed barley is also sold directly to end-users, mainly pig farms in Canterbury – which carry over 50% of the national pig herd (Statistics New Zealand 2012a).

A significant amount of barley is utilised in the malting industry, estimated to be 16% and 15% of total barley production in 2011 and 2012 respectively (Foundation for Arable Research 2012a). The only large-scale malting plant in New Zealand is located in Marton (Rangitikei District), owned and operated by Malteurop, with a capacity of 43 000 tonnes of malt annually (Malteurop 2012). While much of the barley grown in the area surrounding the plant is malting barley, most malting barley is produced in the Ashburton area (Malteurop 2012). Malting barley cultivars yield less than feed cultivars and have more stringent quality requirements (Foundation for Arable Research 2012b); consequently malting barley attracts a premium over feed barley to incentivise growers: in January 2013 the contract price per tonne for feed barley (delivered Canterbury rail) in Canterbury was \$376 whereas the malting barley price (delivered Ashburton) was \$455 (United Wheat Growers 2012). Malting barley is required to achieve specific standards that include germination (>95%), grain protein content (<2%) and maximum screenings criteria (de Ruiter and Haselmore 1996) whereas there are no limits on grain nitrogen content for feed barley and increased tolerances for screenings; grain bulk density standards ( $\text{kg hL}^{-1}$ ; 1 hectolitre = 1000 litres) are also set for feed barley.

### Maize

The maize (*Zea mays*) grain industry is almost entirely based in the North Island (Table 3); important regions include Waikato, Bay of Plenty, Gisborne, Hawke's Bay and Manawatu-Wanganui. Maize grain is a marginal crop in the South Island because of insufficient thermal time to allow crops to mature and the increased risk of frost (Wilson et al. 1994). These constraints also limit maize production in higher altitude sites in the North Island. Total area and production of maize grain has been relatively stable over the past 10 years (Table 2) averaging about 19 000 hectares and 212 000 tonnes respectively. Maize grain is used as a feed for monogastric (poultry and pigs) and ruminant animals (deer and dairy cattle). Significant end-users include compound feed manufacturers (New Zealand Feed Manufacturers Association 2012) but a significant amount (estimated at 65% of total production in 2010) of maize feed grain may be sold to other farmers (unprocessed) through more direct channels (Sanderson et al. 2012).

A significant amount of domestic maize grain is channelled through the milling industry and maize grain for milling is imported in most years (Booker 2009). Products from dry milling include maize flour, polenta and grits; products from wet milling include starch and maize oil (Chappell 1985). New Zealand production may not be sufficient to meet domestic requirements in some years, requiring imports of maize or maize substitutes. However, imports vary according to domestic production and the price of alternative grains, particularly wheat and sorghum. Sorghum imports have trended up since the early 2000s but spiked in 2008 when 166 790 tonnes were imported (Statistics New Zealand 2012c) possibly because of low domestic maize grain production in 2007 (Table 2) and high international maize prices (FAO 2012c). Sorghum is nutritionally similar to maize when fed to pigs (New Zealand Pork 2008). In 2011 there were no

maize imports for feed manufacture (New Zealand Feed Manufacturers Association 2012).

Whereas the area planted in maize for grain has remained static, the area planted for silage has increased over the last 20 years; estimates of total production suggest that the area planted for silage is almost double that for grain. In 2002 16 917 hectares were planted in maize silage (Statistics New Zealand 2003), doubling (32 459 ha) in 2007 (Statistics New Zealand 2008b) and in 2012 the estimated area was 49 457 hectares (Foundation for Arable Research 2012d). The driver for the increased area in maize silage is higher profitability for silage compared with grain (MAF 2009) with additional benefits including earlier cash flow and reduced climatic risk. In 2007 about 9% of the maize silage area was in Canterbury (Statistics New Zealand 2008b). Maize silage is grown on farm by many dairy farmers but is also grown as a cash crop and traded by arable farmers. Estimates of the proportion of maize silage produced on arable farms in different regions range from 81% in Canterbury to 36% and 37% in the Waikato and Bay of Plenty respectively (Booker 2009).

Maize silage requires less thermal time to achieve harvest maturity than maize grain and the availability of early-maturing hybrids in the 1990s has allowed maize crops to be grown for silage in Canterbury, albeit mainly confined to the lower altitude areas near the coast. The risk of spring frosts killing or severely damaging early-planted maize crops if past the six-leaf stage (when the growing point is above ground) and autumn frosts killing late-planted crops means that selection of hybrid and planting date are critical to minimise climatic risk (Foundation for Arable Research 2008a). The use of plastic mulch to raise soil temperatures during the establishment period has been investigated in Canterbury. This would potentially allow maize to be grown at more southern latitudes and at higher elevations in the region and allow the use of later maturing higher yielding hybrids in areas currently able to grow maize silage (Fletcher et al. 2008).

### Oats

Oats (*Avena sativa*) are used in the milling industry for products such as breakfast cereals and snack foods and in the equine industry as feed. Most oats (about 60% of area planted) are now used in the milling industry (Greer 2010) a great increase since the 1990s when about 20% of the total area planted was milling oats (Dunbier and Bezar 1996). The proportional decline in the feed oat crop is probably associated with a marked drop in the horse population, which declined from 94 000 in 1990 to 57 000 in 2011 (Statistics New Zealand 2012b). In 2003–2012 the mean area planted annually was 6490 hectares (Table 2), less than half that of the previous decade (13 800 ha) (Statistics New Zealand 2012b). Production is almost entirely confined to the South Island and is dominated by Canterbury and Southland with 50% and 30% of the area harvested in 2007 respectively (Statistics New Zealand 2008b). Yields have increased slightly; mean yield in 2003–2012 was  $4.6 \text{ t ha}^{-1}$  whereas that in the previous decade was  $4.0 \text{ t ha}^{-1}$ . Southland has traditionally produced the highest yields in New Zealand (Dunbier and Bezar 1996). Production of forage oats for green feed and silage is an important activity on many arable properties, particularly those supplying forage to the local dairy industry (MAF 2011).

### Other cereal crops

Small-scale production of minor cereals, including ryecorn (*Secale cereale*) and Triticale ( $\times$ *Triticosecale*), occurs, mostly in Canterbury. Much is used to produce seed for forage crops of

these species but some may be milled to produce flour used in speciality loaves including mixed grain and rye breads.

#### Pulse crops

The main pulse crop in New Zealand is field peas (*Pisum sativum*); field beans (*Phaseolus vulgaris*) and lentils (*Lens culinaris*) are also produced. Lupins (*Lupinus angustifolius* and *L. albus*) and tick beans (*Vicia faba*) have been produced in the past (Claridge 1972). The area planted in peas has declined greatly from its peak (1987) when over 37 000 hectares were grown. In 2007, 80% of the total pea crop (6273 ha) was planted in Canterbury (Statistics New Zealand 2008b), but this figure also includes field peas planted for seed. A significant area is planted in the Wairarapa (529 ha in 2007), most of which was for seed multiplication and export (Statistics New Zealand 2008b). Mean yields range between 2.5 and 3.5 t ha<sup>-1</sup> in most seasons and have changed little over the last 30 years (Statistics New Zealand 2012b).

Production of field peas includes maple, white, blue and marrowfat peas. Most of the crop was exported, with domestic consumption primarily being export off-grades (Dunbier and Bezar 1996) used in the compound feed industry as a source of protein (22–24%) with high lysine content (Savage 1989), an essential amino acid for pigs and poultry. (Compound feeds based on maize are inherently low in lysine.) In 2010 and 2011, 2200 and 2400 tonnes of peas, respectively, were used in the compound feed industry (New Zealand Feed Manufacturers Association 2012), well below the quantities used historically (Dunbier and Bezar 1996). Alternative sources of plant-based proteins for the feed industry include soy beans, which are increasingly used for this purpose (Foundation for Arable Research 2007a); over 100 000 tonnes of soy meal (by-product of soy oil extraction process) was imported for the feed industry in 2010 and 2011 (New Zealand Feed Manufacturers Association 2012). For most of the last 10 years the international soybean meal (48% protein) price has been well under US\$400 t<sup>-1</sup> (FOB) (Indexmundi 2013). At these levels feed manufacturers in New Zealand have been unable to offer prices for field peas that are sufficiently profitable to encourage arable farmers to grow the crop.

The benefits of peas (and other pulse crops) in arable crop rotations include control of soil-borne cereal fungal diseases such as take-all (*Gaeumannomyces graminis*) and biological nitrogen fixation. The principal reason for the decline in field pea production is low profitability. In Canterbury, for example, the gross margins for field peas during the 1990s were generally half those of the cereals and remain uncompetitive (Canterbury Agriculture 2000). Declining interest in growing field peas resulted in the formation of the Pea Industry Development Group in 2002, which included grower, research and industry organisations (Pea Industry Development Group 2008). With funding from the Ministry of Agriculture and Forestry's Sustainable Farming fund this group has attempted to mitigate some of the constraints to increased profitability, principally low yields, and to promote the benefits of peas as a break crop.

The most important pulse crop globally is soybean (*Glycine max*) but there is currently negligible production in New Zealand. Their thermal time requirements mean that they are a marginal crop in most regions of New Zealand. Soybeans have occasionally been assessed locally, particularly when earlier maturing cultivars became available; yields in recent trials have ranged from 2.5 to over 6.0 t ha<sup>-1</sup> (Foundation for Arable Research 2006), insufficient to make soybeans an economically viable.

#### Oil seeds

Traditionally linseed (*Linum usitatissimum*) was the main oilseed crop in New Zealand with production centred in South Canterbury. The oil was extracted for use in a range of industrial processes including manufacture of paint, furniture varnish and linoleum (Claridge 1972). Today a small area of linseed is grown in Canterbury but end uses are typically culinary, for example whole linseed is often added to European style breads but some oil may still be used for industrial purposes. Unless there is a return to the use of floor coverings made from natural components it is unlikely that demand will increase greatly. The nutritional benefit of linseed in bread (and other foods) is its high alpha-linolenic acid content (a type of Omega-3 fatty acid). Oil content in the seeds is about 40% with 60% of total fatty acids being linolenic acid (Townshend and Bolyend 2008). New oilseed crops, albeit produced on a very small scale, include borage (*Borago officinalis*), which produces oil with a high gamma-linolenic acid content, used in the dietary supplement industry (Foundation for Arable Research 2007b).

Oilseed rape (*Brassica napus*) is the most important oilseed crop in New Zealand. Its uses include cooking oil, the manufacture of spreads and dressings, and biofuel (biodiesel). The oil content of the seeds is about 40% (Claridge 1972). Rapeseed oil differs in composition; oil destined for human consumption needs to be low in erucic acid and glucosinolates and preferably high in oleic acid whereas oil destined for biofuel is typically high in erucic acid. Production for the culinary industry began in the 1970s but ceased in 1999. Recent interest in oilseed rape is mostly based on its potential as biofuel and resulted from New Zealand's commitment to reduce carbon emissions under the Kyoto Protocol and the subsequent establishment of the emissions trading scheme. Estimated area planted in 2008 was about 4500 hectares, mostly in Canterbury but with limited production in Mid-Canterbury (Johnson and Gallacher 2008). The reduced area planted in Mid-Canterbury resulted from a voluntary agreement between major oilseed rape production companies and the brassica seed industry, which is largely based in Mid-Canterbury, to minimise the risk of cross pollination. Rapeseed oil destined for the food industry can be recycled and after processing used as biodiesel, but oil can be processed directly for this purpose. Estimates of the portion of New Zealand's annual diesel fuel requirement able to be replaced by current oilseed rape production together with recycled oil are 2.5–3.0% (Biodiesel New Zealand 2013). However, rapeseed oil faces headwinds as a biofuel. It has a moderate energy ratio (ratio of energy consumed during production to energy produced) of 3 and the value of carbon credits in the New Zealand Emissions Trading Scheme has dropped from over \$21 per tonne shortly after the introduction of a carbon market in 2011 to less than \$3 by early 2013 (OM Financial 2013). For biodiesel to compete with petroleum-based diesel the price of crude oil will need to rise and the value of carbon will need to be high (Foundation for Arable Research 2006).

#### SEEDS FOR SOWING

The seed industry produces seeds for both domestic use and export. Small areas of cereal and forage brassica seed crops are grown primarily for domestic use (Table 4). Some importation, multiplication and re-export of cereal seed is undertaken for Northern Hemisphere plant breeders. The domestic market is also important for forage grasses and legumes but a large proportion of total production is exported. Seed of many different vegetable crops is produced on a small scale to meet domestic requirements

**TABLE 4** Areas (ha) entered into the New Zealand Seed Certification Scheme since 2005

Seed type		2005	2008	2011
<b>Cereals</b>	Wheat	510	842	648
	Barley	997	1345	995
	Maize	25	185	293
	Oats	226	387	445
	Ryecorn	21	0	19
	Triticale	50	358	67
<b>Grasses</b>	Perennial ryegrass	10 704	14 463	7568
	Italian ryegrass	4049	5544	5140
	Hybrid ryegrass	2181	1624	1220
	Tall fescue	892	749	518
	Cocksfoot	683	958	1024
	Browntop	387	567	468
	Others	1532	1050	468
<b>Forage legumes</b>	White clover	10 160	5915	6637
	Red clover	666	380	554
	Others	281	178	134
<b>Brassicac</b>	Kale	143	411	501
	Rape	888	569	483
	Swede	41	89	26
	Turnip	197	316	201
	Other	32	73	0

Excludes: peas, linseed, cannabis, chicory, fodder radish, phacelia, plantain, white mustard, brown mustard, crambe and cabbage.

but there is a significant export industry for a small number of species.

### Herbage

Herbage seed production is dominated by perennial ryegrass (*Lolium perenne*), Italian ryegrass (*L. multiflorum*) and white clover (*Trifolium repens*) – a long-term feature of the industry (Pyke et al. 2004). The area of most herbage species entered into the New Zealand Seed Certification Scheme (Table 4) typically varies in response to prices; overseas prices dominate the pricing expectations in the industry for these species because over 50% of production is exported in most years (Statistics New Zealand 2012c), also a long-term feature of the industry (Rolston et al. 1990). The areas in Table 4 understate the total area for these species because of the production of uncertified seed. In 2011 this was estimated to be 33% and 21% of total production respectively for ryegrass and white clover (Sanderson et al. 2012). Ryegrass seed is mainly exported to Australia and South America and white clover to Europe (Pyke et al. 2004). Over 90% of the herbage seed area harvested annually is in Canterbury (Statistics New Zealand 2008b). Marlborough is also an important region, mostly producing lucerne (*Medicago sativa*) seed.

There has been a proliferation of cultivars for both ryegrass and white clover (AssureQuality 2012). Implications for white clover seed producers in particular include ensuring paddock isolation distances are maintained and the appropriate rotation interval if a change of cultivars is required in any paddock (Pyke et al. 2004). The driver for this change has been the introduction of proprietary cultivars and the gradual decline in importance of public cultivars (Mather et al. 1995).

There has been a decline in the herbage seed area harvested annually (White 1990) particularly white clover (Pyke et al. 2004). However, reduction in total production has been proportionately

lower especially for ryegrass (Hampton et al. 2012b), a consequence of significant increases in ryegrass seed yields resulting from improved agronomic practices including the routine use of plant growth regulators (trinexapac-ethyl) and fungicides (Pyke et al. 2004; Rolston et al. 2004). In contrast white clover seed yields are less responsive to management and have not increased to the same extent. Mean seed yields for ryegrass and white clover have increased over the past decade or so (from 585 kg ha<sup>-1</sup> and 230 kg ha<sup>-1</sup> respectively; Rolston and Clifford 1989) to 1.46 and 2.26 t ha<sup>-1</sup> for ryegrass and 363 and 564 kg ha<sup>-1</sup> for white clover respectively in 2010 and 2011 (AssureQuality 2012; Hampton et al. 2012b). The variation in seed yield in these two seasons highlights the vulnerability of herbage seed production to adverse weather (MAF 2011).

Exports of ryegrasses and white clover seeds were worth \$79.5 million in 2012, slightly higher than in previous years (Statistics New Zealand 2012c), an important source of income for arable farmers. However, the greatest contribution herbage seed producers make to the New Zealand economy is through provision of high quality, genetically improved herbage seed required by the pastoral industries. The potential value of different pasture renewal scenarios in New Zealand was estimated in 2007 (Sanderson and Webster 2009); increasing annual pasture renewal from 2% currently to 8% by the sheep and beef sector and 6.1% currently to 12% by the dairy sector, using locally produced herbage seeds, was estimated to increase total gross domestic product by \$3.2 billion annually. This figure appears to be excessive. The study assumes no failures after sowing new pasture and cites studies with limited post-establishment data. A large study evaluating the performance of 10 ryegrass cultivars in different regions found that pasture production declined from year 1 to year 3 in four out of five sites; production declines ranged from 0.8 t DM ha<sup>-1</sup> in Canterbury to 5.3 t DM ha<sup>-1</sup> in Waikato (Kerr

et al. 2012). While there is little doubt that new pasture will produce more than degraded pasture, current evidence suggests that there is no production advantage from replacing stable old pasture (Taylor et al. 2012).

The delivery of novel endophytes (*Neotyphodium lolii*) able to provide biological control of important ryegrass pests – porina (*Wiseana cervinata*), black beetle (*Heteronychus arator*) and argentine stem weevil (*Listronotus bonariensis*) (Popay and Thom 2009) – while reducing the adverse effects on livestock performance (Fletcher and Sutherland 2009) is also an important benefit of the herbage seed industry. However, the use of fungicides on ryegrass seed crops to control stem rust (*Puccinia graminis*) and blind seed (*Gloeotinia temulenta*) (reduces seed germination) has been shown to reduce the rate of endophyte transmission to seeds (Chynoweth et al. 2012) potentially reducing resistance to insects and sward persistence in new pasture. This suggests possible conflict between seed yields, seed germination and endophyte transmission in ryegrass seed crops.

### Vegetables

New Zealand produces vegetable seeds for domestic use and for export, notably field peas (*Pisum sativum*), radish (*Raphanus sativus*) and hybrid carrots (*Daucus carota*). The total value of vegetable seed exports (excluding peas) in 2012 was \$70 million, the greatest contribution coming from radish (\$26m) and hybrid carrot (\$19m) (Statistics New Zealand 2012c). These returns resulted from exports of about 3000 tonnes of radish but only 411 tonnes of hybrid carrot seed, highlighting the per unit value of the latter crop in particular. New Zealand is now one of the major producers of hybrid carrot seed. Vegetable seeds are mostly exported to the Asia-Pacific zone with some exported to Europe, particularly hybrid carrot seed (McKay 2008). The development of the export sector has occurred over about the last 20 years and is a result of New Zealand's latitude (similar to that of large Northern Hemisphere producers) and the requirement for contra

December 2011 (Statistics New Zealand 2012c). Of this \$270 million came from fresh vegetables with processed vegetables (frozen and dried) generating \$344 million. Onions (*Allium cepa*; \$110m) and buttercup squash (*Cucurbita maxima*; \$64m) dominate fresh vegetable exports; sweetcorn (*Zea mays*; \$24m), potato fries (*Solanum tuberosum*; \$81m) and peas (*Pisum sativum*; \$51m) dominate the processed vegetable sector. Onions, buttercup squash and potatoes also dominate the area of fresh vegetables grown for the local market. Additional crops produced on arable farms for the local fresh market include pumpkin and butternut (*Cucurbita maxima*), kumara (*Ipomoea batatas*), beans (*Phaseolus vulgaris*) and outdoor tomatoes (*Solanum lycopersicum*); beetroot (*Beta vulgaris*) is grown for processing and export, mostly to Australia. Exports of processed vegetables are forecast to decline in the immediate future; drivers for this include exchange rate pressures and competition for land in key regions.

The area planted in vegetable crops fluctuates from year to year (Table 5) (Statistics New Zealand 2012b). For example, sweetcorn area declined by 37% between 2009 and 2012, reflecting reduced demand experienced by processing companies, whereas the area in onions increased by 21% over this time. Production changes may be attributed to a number of reasons specific to different crops, including biological and economic factors in New Zealand and overseas. Examples of biological factors include the recent introduction of the tomato potato psyllid (TPP; *Bactericera cockerelli*) and the subsequent spread of the *Candidatus liberibacter* bacterium (Ministry for Primary Industries 2013a), which has increased potato production costs, reducing profitability, resulting in small growers exiting production, contributing to the long-term trend of fewer but larger growers producing potatoes and other vegetables (MAF 2005). The buttercup squash market is affected by competition from producers in Mexico, effectively capping growth in New Zealand production. Most squash is exported to Japan but alternative markets are being developed in countries such as South Korea (Ministry for Primary Industries 2012b).

The regional production of different crops is relatively stable

TABLE 5 Area (ha) of outdoor vegetables harvested, 2000–2012

Crop	2000	2009	2011	2012
Onions	-	4510	5140	5703
Potatoes	-	11 390	10 720	11 329
Buttercup squash	6713	6825	6467	6449
Peas	7570	5986	6232	6431
Beans	773	736	1060	-
Sweetcorn	6380	5059	3558	4024

- = Confidential or suppressed

seasonal multiplication of seed lines by many large Northern Hemisphere based seed companies. The availability of irrigation, the expertise of arable farmers and the presence of efficient seed processing and testing facilities are also key components of this industry (McKay 2008). About 75% of the total area in vegetable seed crops harvested in 2007 (7330 ha) was in Canterbury (Statistics New Zealand 2008b).

### OUTDOOR VEGETABLES

New Zealand has a considerable area of land under arable production aligned to the vegetable sector including the production of vegetable seed, processed and fresh vegetables for both the domestic and export markets. Exports of fresh and processed (mostly frozen) vegetables earned \$614 million in the year to

from year to year. The South Auckland and Waikato regions are dominated by onion and potato production (3160 ha and 3280 ha respectively in 2011). Gisborne and the Hawke's Bay are key producers of sweetcorn (2570 ha) and squash (5450 ha) as well as smaller areas in onions (850 ha), potatoes (420 ha in Hawke's Bay only) and processing peas (2310 ha). The Manawatu-Wanganui region is dominated by potato crops (1210 ha) with minor areas of squash and sweetcorn. Process peas (530 ha) and sweetcorn (c. 600 ha) are important crops in Marlborough. Otago has a small area in fresh market potato production (130 ha). Canterbury is the major vegetable-crop-growing region producing (in 2011) onions (810 ha), potatoes (5200 ha), peas (c. 3500 ha) and sweetcorn (220 ha), mostly for processing except for onions (MAF 2011; Statistics New Zealand 2012a).

Significant minor crops include kumara (variously known as sweet potato), dominated (1264 ha in 2009) by the Dargaville/Ruawai districts in Northland (Plant and Food Research 2011), beetroot and butternut, both with process markets in Hawke's Bay, and tomatoes (processing varieties only). Carrots are grown in South Auckland, Manawatu/Ohakune and Canterbury: the carrot area declining between 2002 (1831 ha) and 2007 (1320 ha). Pumpkins and green beans are produced every year in several regions, totalling about 2000 hectares (Statistics New Zealand 2012c).

The primary market for kumara and pumpkins is domestic, while beetroot, beans and butternut are primarily grown for the processed market. Carrots are grown for the fresh and processed export markets and for juice products.

### Opportunities

The process vegetable industry has considerable scope for expansion and has recently attracted significant investment. For example in 2011 Heinz Wattie's New Zealand relocated its beetroot production from Australia to Hawke's Bay, New Zealand. The move was to take advantage of the upgraded processing plant at Hastings and coincided with the investment in two new beetroot harvesters from Denmark. Production in 2012 was around 11 500 tonnes, four times the previous season, and forecasts for 2013 are for further expansion of production. This company also relocated the production of sauces and some other products to Hastings at the same time. It is expected that New Zealand can produce almost all of the volume of processing tomatoes needed for Heinz Wattie's tomato paste production.

### SHELTER

Shelter belts reduce wind speeds particularly on the lee side of the belt. Effective reductions in wind speed (up to 80% of open wind speed) are induced for distances of up to 20 times the shelter height but the greatest wind speed reductions are found three to five times the shelter height (Burke 1998). Lower wind speeds reduce evapotranspiration and increase temperature on the lee side of shelter (Sturrock 1972). Higher yields have been measured in a range of crops including cereals (Sturrock 1981) and grain legumes (Love et al. 1988). Other potential benefits include mitigation of pesticide drift; shelter can reduce drift by up to 80–90% (Ucar and Hall 2001).

Erosion of cultivated soils by wind can be a significant problem for arable farmers cultivating soil in the spring when wind runs are typically high, especially if soils are light and dry. Parts of Canterbury and central Hawke's Bay are vulnerable to wind erosion, and shelterbelts planted to minimise wind erosion have been a feature of the landscapes in these regions (Hawke's Bay Regional Council 2002). Losses of top soil have only occasionally been measured in New Zealand. Painter (1987) measured soil losses of 40 kg ha<sup>-1</sup> min<sup>-1</sup> in Canterbury during strong north-westerly winds. Soil loss in Hawke's Bay has been recorded in winds as light as 20–25 km per hour (Hawke's Bay Regional Council 2002).

Shelter can provide benefits for irrigation; reduced evapotranspiration reduces the need for irrigation. Savings in water consumption of 10–20% annually have been measured in Canterbury (Vries et al. 2010). Reduced wind speeds also benefit the operation of irrigation systems through improved application efficiency and uniformity.

Biodiversity on intensively farmed land is increased by the presence of shelterbelts, particularly insects and birds (Hawke's

Bay Regional Council 2006). Species choice can greatly affect the beneficial effect for different bird species, including native species. Providing tree/shrub species, both native and exotic, that produce flowers and fruit at key times can result in increased numbers of native species, which are otherwise unable to utilise arable ecosystems. Shelterbelts planted with the appropriate species, for example tagasaste (*Chamaecytisus palmensis*), can also provide pollen for bees at critical times of the year; bees are crucial pollinators of seed crops including white clover and brassica species (Foundation for Arable Research 2007c). Bees will also benefit from the shelter effect through increased temperatures allowing them to forage for a greater part of the day in cool weather. There are some negative aspects to shelter, principally a reduction in crop production in the vicinity of the belt due to shade and competition for water and nutrients (Gillingham and Hawke 1997). The presence of shelter belts can increase crop damage by birds, especially sparrows and finches (Foundation for Arable Research 2010).

### INDUSTRY ISSUES

#### Irrigation

There is an estimated 1.3 million hectares of irrigable land in Canterbury, of which 500 000 hectares are estimated to be currently irrigated (Environment Canterbury 2011), about 70% of the national total. Of the land that is potentially or currently irrigated, about 684 000 hectares are land use capability I, II or III, suitable for arable cropping (Saunders and Saunders 2012). Other estimates for currently irrigated land in Canterbury are lower than this – 385 000 hectares (Statistics New Zealand 2008b). However, access to water for additional irrigation is now very restricted because the available water, both surface and ground, is fully allocated in many areas (Aitchison-Earl et al. 2004; Tricker et al. 2012). Increasing the availability of water for irrigation is a key component of the Canterbury Water Management Strategy. The economic benefits of irrigation are well documented and include increased productivity, increased economic activity and increased employment (Saunders and Saunders 2012). Among the irrigation schemes under development in Canterbury the schemes proposed for the Central Plains (Central Plains Water 2012) and the Waitohi Irrigation and Hydro Scheme in North Canterbury (Hurunui Water Project 2012) will enable about 120 000 hectares of additional land to be irrigated in the region. Both these schemes have been controversial and have been greatly modified as they progressed through the consenting process. There are also large irrigation proposals in the North Island; both the Ruataniwha Water Storage project in central Hawke's Bay (Hawke's Bay Regional Council 2012) and the Wairarapa Water Use Project (Greater Wellington Regional Council 2012) include arable land.

Most irrigation in New Zealand is applied with sprinkler systems of various types. Traditional methods of irrigating include flood irrigation, particularly border-dyke. About 111 000 hectares were still being irrigated using this method in 2007, especially (64 000 ha) in Canterbury (Statistics New Zealand 2008b). Border-dyke irrigation is a particularly inefficient method of applying water. Its disadvantage is that the amount of water applied varies greatly with distance from the dyke; by the time water reaches the lower end of the borders the upper end will have received excess water meaning that drainage is inevitable. Apart from reducing water use efficiency the increased drainage increases the probability of nitrate leaching (Lilburne et al. 2010). Border-dyke systems are being steadily replaced with sprinkler systems (Saunders and Saunders 2012).



The expansion of the irrigable area in Canterbury, and other regions with typically dry summers such as Wairarapa and Hawke's Bay, will facilitate the further expansion of dairying. Irrigation is essential for intensive dairy systems to ensure pasture production during the summer–autumn dry period (Dynes et al. 2010; Moot et al. 2010). Experience in Canterbury has shown rapid land use change once irrigation schemes are established, principally to dairy (Dynes et al. 2010). Similarly, the proposed Ruataniwha scheme in Hawke's Bay (Hawke's Bay Regional Council 2012) and the Hurunui Scheme in North Canterbury (Hurunui Water Project 2009) are expected to result in considerable expansion of dairy production in those areas.

The growing awareness of the challenges of freshwater management and the need for consistency when addressing freshwater allocation issues and conflicts in different parts of the country has resulted in the Government's 'Fresh Start to Fresh Water' initiative. A stakeholder group, the Land and Water Forum, was established to provide advice to Government on how to manage fresh water. The forum has produced a comprehensive set of recommendations aimed at establishing a common approach to freshwater management in New Zealand (Land and Water Forum 2012). A number of recommendations have the potential to influence arable production in the long term, including proposals to introduce water charges and tradable water rights. These suggestions are widely seen as necessary to ensure efficient use of water and to ensure the greatest economic return from allocation of water. This may result in arable farmers having to compete with other producers for water rights. The ability to successfully bid for these rights will ultimately depend on the profitability of arable compared with other land use options.

#### *Land use change*

Conversion of arable and mixed-arable farms to dairy is an ongoing issue, particularly in Canterbury. In 2012 there were 974 dairy farms in the Canterbury Region (Environment Canterbury 2012b) a 22% increase from the numbers recorded in 2007 (Statistics New Zealand 2008b). Arable and mixed-arable farmers converting to dairy production are attracted by a range of benefits including improved cashflow, absence of harvest risk and increased profitability (Ministry for Primary Industries 2012a). The loss of arable farms can eventually result in loss of key infrastructure, services and economies of scale. This is regarded as a threat to the arable industry (Pyke et al. 2004; MAF 2011; Hampton et al. 2012b). Nationally, dairy cow numbers are expected to increase by 2.3% in 2013 and between 1.5 and 2.0% annually to 2016 (Ministry for Primary Industries 2012b); some of this increase will probably be at the expense of arable production. The loss of arable land neighbouring large urban areas to urban and lifestyle block development is also a concern, particularly for vegetable producers in the Pukekohe area.

Conversely, dairy conversions provide opportunities for neighbouring arable farmers –provision of grazing for dairy replacements, and winter grazing for dairy cows, albeit with nitrate leaching risks (Dalley 2012). Supplements such as grain, straw, vegetable processing by-products, maize, whole-crop cereal and pasture silages are also sold to dairy farmers (Dynes et al. 2010). Additional benefits from this activity include reduced labour requirements, better cash flow and good income potential, particularly in years with feed shortages (Ministry for Primary Industries 2012a). However, disputes between arable and dairy farmers over supply, price and quality of forage have occurred, particularly when milk prices have declined and despite contracts

being in place (MAF 2009). Determination of appropriate maize silage sampling protocols (de Fillipi et al. 2004) facilitated the development of the Maize Forage Purchase Contract and the Good Practice Guide for the trading of maize silage; both documents are available through the Foundation for Arable Research website (Foundation for Arable Research 2008b).

Another aspect of the conversion of land to dairy is the loss of shelter. Most modern irrigation systems are centre-pivot or linear-spray systems that are hindered by shelter belts, especially tall shelter, so existing shelter is usually removed during conversion (Tait and Cullen 2010). Ironically shelter can benefit sprinkler irrigation systems through reduced evaporation of falling droplets, reduced wind drift and improved uniformity of application (Goulter 2010). Evaporation can be as high as 10% and drift up to 20% in sprinkler systems during strong winds (Foundation for Arable Research 2010).

#### *Climate change*

Projected mean annual temperature change and mean annual precipitation change, based on an intermediate level of warming by 2100 (Scenario A1B) (Intergovernmental Panel on Climate Change 2000), indicates an increase in mean annual temperature of 0.9°C by 2040 and 2.1°C by 2090 for most regions in New Zealand, including Canterbury. The effect on rainfall is more variable; in many western regions rainfall is predicted to increase slightly (0–2.5%) by 2040 but in eastern regions, including Canterbury, rainfall is expected to decline (0 to –2.5%) (National Institute of Water and Atmospheric Research 2012). Higher atmospheric carbon dioxide levels and higher temperatures are predicted to increase potential yields of irrigated C<sub>3</sub> cereal crops by up to 20% whereas potential yields will decline in non-irrigated crops (Clark et al. 2012). This is because higher carbon dioxide levels will increase radiation use efficiency, and warmer temperatures, particularly in spring and autumn, will increase crop growth rates allowing more rapid canopy development, increasing radiation interception. In contrast, C<sub>4</sub> crops are not likely to benefit much from elevated carbon dioxide levels.

The negative effects of higher temperatures include increased evapotranspiration and reduce leaf area duration resulting in reduced yields when irrigation is not available. The impacts of temperature will vary with environment and crop; generally (cereals) where temperatures are currently below the optimum temperature for a particular crop, warming will be beneficial (Clark et al. 2012). Similarly, higher temperatures (and higher CO<sub>2</sub>) may increase yield potential in irrigated seed crops; but increased temperatures may reduce pollen viability, reducing seed yields, and reduce seed germination and seed vigour (Hampton et al. 2012a).

There appears to be little prospect of developing crop cultivars with different responses to temperature because there is currently very little genetic variation for this trait. There is variation for crop maturity allowing use of later maturing cultivars to compensate for reduced leaf area duration in response to increased temperatures (Parent and Tardieu 2012). The indirect effects of temperature include the response of pests and diseases to warmer temperatures but these effects are currently difficult to predict (Clark et al. 2012). Increasing temperatures will challenge the adequacy of irrigation systems because higher temperatures will result in increased potential evapotranspiration and if yield potentials are to be realised most crops will require increased irrigation (Moot et al. 2010).

### Nutrient management

Intensification of arable production systems, involving a shortened pastoral phase and increased use of irrigation and nitrogen fertiliser, has resulted in increased leaching of nitrate into groundwater (McKenzie et al. 2006) and subsequent contamination of streams, rivers and lakes. Nutrient loss from arable systems is an issue in many regions including Canterbury, Manawatu-Wanganui, Hawke's Bay and the Waikato (Ministry for the Environment 2009). Limits on the amount of nitrogen lost from production systems are being written into regional plans. These plans are typically controversial because they require substantial reductions in nitrogen losses from some farming systems, including arable, with potential constraints on productivity. For example, Horizons Regional Council's 'One Plan' has generated considerable opposition from those groups likely to be most affected, including arable farmers, particularly those producing vegetables on free-draining soils (Horticulture New Zealand 2012). The One Plan proposes limiting nitrate leaching to under 30 kg of nitrogen per hectare on land use capability classes II and III (Horizons 2012), indicating that nutrient budgeting will be a significant challenge for many arable farmers in this region. Those farmers in priority catchments (high nutrient levels in water) will require a resource consent regarding nutrient management. Environment Waikato requires farmers applying nitrogen at more than 60 kg ha<sup>-1</sup> year<sup>-1</sup> to have a nutrient management plan (Environment Waikato 2012). Environment Canterbury intends introducing a nitrogen threshold of 20 kg ha<sup>-1</sup> year<sup>-1</sup> for leached nitrate for developing, implementing and reporting a 'farm environmental plan' from 2017 (Environment Canterbury 2012a).

The leaching losses from arable crops can vary tremendously from year to year and with different crops. Webb et al. (2001) measured nitrate leaching under spring sown-wheat for 4 years in Canterbury and found that leached nitrogen ranged from 14 to 104 kg N ha<sup>-1</sup> year<sup>-1</sup> with most of the variation explained by variation in drainage. Drainage is influenced by rainfall, irrigation, irrigation method and by variation in soil depth. Shallow soils with limited water holding capacity result in more leaching (Lilburne and Webb 2002). Modelling of nitrate leaching at Hororata, Canterbury, has resulted in estimates of annual nitrogen losses ranging from 28 kg ha<sup>-1</sup> year<sup>-1</sup> on very light soils to 5.6 ha<sup>-1</sup> year<sup>-1</sup> on heavy soils. Estimates of leaching losses for other Canterbury locations (Lincoln and Darfield) were similar. Nitrate leaching can be very high when nitrogen fertiliser is applied in the autumn–winter period and crop recovery is limited by low temperatures (Cookson et al. 2001). Nitrogen losses of 114 kg (Francis et al. 2003) and 217 kg ha<sup>-1</sup> year<sup>-1</sup> (Crush et al. 1997) under winter potatoes have been measured at Pukekohe. Similar losses have been reported from winter potatoes in Oamaru after high nitrogen fertiliser application rates (Williams and Tregurtha 2003).

Irrigation may increase drainage and leaching, particularly border-dyke systems (Lilburne et al. 2010). Minimising drainage means ensuring that irrigation does not result in soil moisture reaching field capacity (McDowell and Houlbrooke 2008) and, ideally, is scheduled to ensure soil moisture does not fall below the point at which potential yield declines (trigger point) in that crop, usually about 50% of field capacity (Foundation for Arable Research 2011b). Much of the Canterbury Plains consists of shallow, stony, free-draining soils (Molloy 1993) with limited water holding capacity and, consequently, susceptible to nitrate leaching.

Nitrate leaching can also be an issue for arable farmers growing

forage crops to provide winter grazing for dairy cows. Whether on pasture or forage crops high stocking rates and wet soils can result in large nutrient losses during rainfall events, particularly if on shallow free-draining soils (Smith et al. 2012). Nitrogen losses ranged from 8.5 kg to 125 kg ha<sup>-1</sup> in different years in this study. Nitrate leaching under grazed forage crops is also primarily associated with the return of urine (McDowell and Houlbrooke 2008; Beare et al. 2010). Mitigation strategies include restricted grazing intervals with the use of standoff pads (McDowell and Houlbrooke 2008). Nitrification inhibitors (dicyandiamide (DCD)) may be used to help reduce losses when grazing forage crops over the winter with conflicting results; Smith et al. (2012) found it to be ineffective applied on free-draining soils whereas Shepherd et al. (2012) found it reduced nitrate leaching by up to 27% on free-draining soils. This difference is probably explained by the timing of application; delayed application post-grazing may reduce the effectiveness of DCD. Dicyandiamide may also reduce nitrous oxide emissions from grazed forage crops (van der Weerden and Styles 2012).

Many regional councils currently use OVERSEER<sup>®</sup> to model nitrate losses under different production and management systems (Environment Canterbury 2012a; Horizons 2012). OVERSEER<sup>®</sup> was initially developed to model nutrient loading in pastoral systems but has recently been adapted for use with arable crops (Chichota et al. 2010). Consequently there are questions about its use for arable systems, particularly if used to monitor compliance. The Foundation for Arable Research has recently published the findings of a review of the suitability of OVERSEER<sup>®</sup> version 6 for the arable industry. This review found that OVERSEER<sup>®</sup> was the best tool currently available for modelling the leaching of nitrate but that the recent addition of the capability to model nutrient movement in crops has not been fully tested under the full range of crops, crop rotations and environments in New Zealand (Dunbier et al. 2013). Estimates of nitrate leached are most dependent on the amount of mineral nitrogen in the soil profile, drainage, and a key coefficient ('a') in the prediction model. Shortcomings were identified in each of these components in the OVERSEER<sup>®</sup> crop model. The review also suggested that the limitations of the model needed to be considered by regional authorities when framing nutrient management policies.

Minimising drainage is an important strategy for reducing nitrate leaching; management to minimise leaching of nitrate over the autumn–winter period when the highest risk of drainage occurs includes ensuring nitrogen fertiliser applications are judicious and that crops are actively growing, particularly on shallow soils (Lilburne et al. 2003). If ground is to be left fallow over the winter, the use of cover crops can greatly reduce the amount of nitrate available to be leached. Soil nitrate levels are increased by cultivation, a consequence of stimulated mineralisation of soil organic nitrogen (Haynes 1999). The use of no-tillage systems has been shown to reduce leaching of nitrate compared with conventional cultivation (Pearson and Wilson 2002/2003).

Matching fertiliser demand to crop requirements is a key aspect of crop management to minimise the risk of nitrate leaching but it is also important for maximising economic returns from applying nitrogen fertiliser. Decision support systems have been developed for a range of crops including wheat (Sirius) (Jamieson et al. 1998), maize (AmaizN) (Li et al. 2006) and potatoes (Potato Calculator) (Jamieson et al. 2004). Experience with the use of these models indicates that significant savings in nitrogen fertiliser can often be made, reducing the potential for nitrate leaching, without reducing yield (Armour et al. 2002; Jamieson et al. 2006).

### Biosecurity

Biosecurity is an ongoing concern for arable farmers, and vegetable growers in particular. Each crop has its own biological threats with the potential to greatly reduce production and economic returns in both the short and long term. Biosecurity issues are constantly evident; the PSa and tomato/potato psyllid incursions of recent years are good examples of the damage a new pathogen or biological agent can have on primary production. The Ministry for Primary Industries maintains a register of unwanted organisms (Ministry for Primary Industries 2013b); it is a large list and ensuring that future incursions are kept to a minimum will require ongoing commitment from government and industry (Horticulture New Zealand 2011).

### REFERENCES

- Aitchison-Earl P, Scott D, Sanders R 2004. Groundwater allocation limits: Guidelines for the Canterbury Region. Environment Canterbury Report No. U04/02. <http://ecan.govt.nz/> (accessed January 2013).
- Armour T, Jamieson P, Zyskowski R 2002. Testing the Sirius wheat calculator. *Agronomy New Zealand* 32: 1–6.
- AssureQuality 2012. Seed Certification statistics 2010/2011. Lincoln, AssureQuality, Seed Certification Bureau.
- Australian Bureau of Statistics 2012. 7121.0 – Agricultural Commodities, Australia, 2010–11. <http://www.abs.gov.au/ausstats/> (accessed January 2013).
- Bearé MH, Tabley F, Gillespie R, Maley S, Harrison-Kirk T, de Ruiter J 2010. Nitrate leaching from high production forage crop sequences. *Proceedings of the New Zealand Grassland Association* 72: 23–28.
- Beck LB 2012. 2011–2012 Canterbury Region dairy report. Environment Canterbury Report No. R12/80. <http://ecan.govt.nz/> (accessed January 2013).
- Biodiesel New Zealand 2013. <http://www.biodiesel-nz.co.nz/the-biodiesel-story/> (accessed January 2013).
- Booker JW 2009. Production, distribution and utilisation of maize in New Zealand. Unpublished MAppSc dissertation, Lincoln University, Canterbury, New Zealand.
- Burke S 1998. Windbreaks. Reed Australia.
- Canterbury Agriculture 2000. Profit plan, farming for profit. Crop and livestock gross margins.
- Central Plains Water 2012. Technical elements of the scheme. <http://www.cpw.co.nz/technical/technical-elements.html> (accessed January 2013).
- Chappell PL 1985. Uses and processing of grain maize in New Zealand. *Maize: Management to market*. Agronomy Society of New Zealand Special Publication 4. Pp. 9–12.
- Chichota R, Brown H, Snow VO, Wheler DM, Hedderley D, Zyskowski R, Thomas S 2010. A nitrogen balance model for environmental accountability in cropping systems. *New Zealand Journal of Crop and Horticultural Science* 38: 189–207.
- Chynoweth RJ, Rolston MP, Kelly M, Grbavac N 2012. Control of blind seed disease (*Gloeotinia temulenta*) in perennial ryegrass (*Lolium perenne*) seed crops and implications for endophyte transmission. *Agronomy New Zealand* 42: 141–148.
- Claridge NH 1972. *Arable farm crops of New Zealand*. Lincoln, DSIR.
- Clark AJ, Nottage RAC, Wilcocks L, Lee JM, Burke C, Kalaugher E, Roche J, Beukes P, Loefflering M, Newton PCD, Li FY, Vibart R, Teixeira EI, Brown HE, Fletcher AL, Hernandez-Ramirez G, Soltani A, Viljanen-Rollinson S, Horrocks A, Johnstone P, Clothier B, Hall A, Green S, Dunningham A, Kirschbaum MUF, Meason D, Payn T, Collins DBG, Woods RA, Rouse H, Duncan M, Snelder T, Cowie B 2012. Impacts of climate change on herbicide screening.pdf (accessed January 2013).
- Foundation for Arable Research 2007c. Pollination of vegetable crops. *Arable Update* No. 70. <http://www.far.org.nz/index.php/arable-update/entry/no-70-pollination-of-vegetable-crops> (accessed January 2013).
- Foundation for Arable Research 2008a. Frost risk for maize silage grown in South Canterbury. *Arable Update*. Maize No. 60. [http://www.far.org.nz/mm\\_uploads/60Mz\\_Sth\\_Canty\\_Frosts.pdf](http://www.far.org.nz/mm_uploads/60Mz_Sth_Canty_Frosts.pdf) (accessed January 2013).
- Foundation for Arable Research 2008b. Maize Forage Purchase Contract. [http://www.far.org.nz/mm\\_uploads/FTDG\\_Mz\\_Silage\\_Contract\\_v1\\_20081.pdf](http://www.far.org.nz/mm_uploads/FTDG_Mz_Silage_Contract_v1_20081.pdf) (accessed January 2013).
- Foundation for Arable Research 2010. Bird pests in arable crops. *Arable Update* No. 91. <http://www.far.org.nz> (accessed January 2013).
- Foundation for Arable Research 2011a. FAR research and extension strategy and portfolio. <http://www.far.org.nz> (accessed January 2013).
- Foundation for Arable Research 2011b. FAR Focus. Irrigation management for cropping – a growers guide. Issue 4. <http://www.far.org.nz> (accessed January 2013).
- Foundation for Arable Research 2012a. Summary – Survey of cereal areas and volumes – July 1, 2012. <http://www.far.org.nz/index.php/arable-industry-marketing-initiative> (accessed December 2012).
- Foundation for Arable Research 2012b. FAR cultivar evaluation. Autumn sown barley and wheat. <http://www.far.org.nz> (accessed January 2013).
- Foundation for Arable Research 2012c. FAR cultivar evaluation. Spring sown barley and wheat 2011/2012. <http://www.far.org.nz> (accessed January 2013).
- Foundation for Arable Research 2012d. Summary – Survey of maize areas and volumes – May 1, 2012. <http://www.far.org.nz/index.php/arable-industry-marketing-initiative> (accessed December 2012).
- Francis GS, Trimmer LA, Tregurtha CS, Williams PH, Butler RC 2003. Winter nitrate leaching losses from three land uses in the Pukekohe area of New Zealand. *New Zealand Journal of Agricultural Research* 46: 215–224.
- Gillingham AG, Hawke MF 1997. The effects of shelterbelts on adjacent pastures and soils in a temperate climate. *Proceedings of the International Grasslands Congress*. <http://www.internationalgrasslands.org/files/igc/publications/1997/1-06-005.pdf> (accessed February 2013).
- Goulter C 2010. Dairy shelter on the Canterbury plains. [http://www.side.org.nz/IM\\_Custom/ContentStore/Assets/11/19/b26fe819de6c44f8006813d5365687b4/SIDE-Dairy-shelter-on-the-Canterbury-plains.pdf](http://www.side.org.nz/IM_Custom/ContentStore/Assets/11/19/b26fe819de6c44f8006813d5365687b4/SIDE-Dairy-shelter-on-the-Canterbury-plains.pdf) (accessed January 2013).
- Greater Wellington Regional Council 2012. Wairarapa Valley: On-Farm Demand Report, June 2012. Wairarapa Water Use Project. <http://www.wairarapawater.org.nz/assets/Wairarapa-Irrigation/On-Farm-Demand-Report-June-2012.pdf> (accessed February 2013).
- Greer G 2010. Arable industry marketing initiative quarterly survey of cereals to September 1 2010. Report to the Arable Marketing Initiative Committee. Arable Economic Research Unit, Lincoln University. <http://www.far.org.nz/index.php/arable-industry-marketing-initiative> (accessed December 2012).
- Hampton JG, Boelt B, Rolston MP, Chastain TG 2012a. Effects of elevated CO<sub>2</sub> and temperature on seed quality. *Journal of Agricultural Science* 150: 1–9.
- Hampton JG, Rolston MP, Pyke NB, Green W 2012b. Ensuring the long term viability of the New Zealand seed industry. *Agronomy New Zealand* 42: 129–139.
- Hawke's Bay Regional Council 2002. Sustainable land management: Wind erosion and control. <http://www.hbrc.govt.nz/HBRC-Documents/HBRC%20Document%20Library/Wind%20erosion.pdf>. (Downloaded January 2013).
- Hawke's Bay Regional Council 2006. Shelter species for horticulture and cropping on the plains. <http://www.hbrc.govt.nz/HBRC-Documents/HBRC%20Document%20Library/Shelter%20Design.pdf> (accessed February 2013).
- Hawke's Bay Regional Council 2012. Ruataniwha Water Storage Project feasibility report to Council. [http://www.hbrc.govt.nz/HBRCDocuments/HBRC%20Document%20Library/Feasibility%20Report%20to%20Council\\_FINAL\\_sept2012\\_web.pdf](http://www.hbrc.govt.nz/HBRCDocuments/HBRC%20Document%20Library/Feasibility%20Report%20to%20Council_FINAL_sept2012_web.pdf) (accessed February 2013).
- Haynes RJ 1999. Fate and recovery of 15N-labelled fertiliser urea applied to winter wheat in spring in the Canterbury region of New Zealand. *Journal of Agricultural Science* 133: 125–130.
- Horizons 2012. Proposed One plan as amended by decision August 2010. <http://www.horizons.govt.nz/about-us/publications/about-us-publications/one-plan-publications-and-reports/proposed-one-plan/> (accessed January 2013).
- Horticulture New Zealand 2011. Submission to: The Primary Production Select Committee on: The Biosecurity Law Reform Bill. [http://www.hortnz.co.nz/users/Image/Downloads/PDFs/Biosecurity%20Law%20Reform%20Bill%20Submission\\_copy\\_2.pdf](http://www.hortnz.co.nz/users/Image/Downloads/PDFs/Biosecurity%20Law%20Reform%20Bill%20Submission_copy_2.pdf) (accessed February 2013).
- Horticulture New Zealand 2012. Horizons One Plan appeal, final. <http://www.hortnz.co.nz/users/Image/Downloads/PDFs/Horizons.pdf> (accessed January 2013).
- Hurunui Water Project 2009. Irrigation areas and indicative demands. Christchurch, Riley Consultants. <http://www.crc.govt.nz/publications/Consent%20Notifications/AppendixBDistributionDemandIrrigatorsHurunuiDistrict.pdf> (accessed February 2013).
- Hurunui Water Project 2012. <http://www.hurunuiwater.co.nz/> (accessed December 2012).

- Indexmundi 2013. Soybean Meal monthly price. <http://www.indexmundi.com/commodities/?commodity=soybean-meal> (accessed January 2013).
- Intergovernmental Panel on Climate change 2000. Summary for Policymakers. Emissions Scenarios. A Special Report of IPCC Working Group III. <http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf> (accessed April 2013).
- Jamieson PD, Semenov MA, Brooking IR, Francis GS 1998. Sirius: A mechanistic model of wheat response to environmental variation. *European Journal of Agronomy* 8: 161-179.
- Jamieson PD, Stone PJ, Zyskowsk, RF, Sinton SM, Martin RJ 2004. Implementation and testing of the Potato Calculator, a decision support system for nitrogen and irrigation management. In: MacKerron DKL, Haverkort AJ (eds) *Decision support systems in potato production: bringing models to practice*. The Netherlands, Wageningen. Pp. 85-100.
- Jamieson PD, Zyskowski RF, Sinton SM, Brown HE, Butler RC 2006. The potato calculator: A tool for scheduling nitrogen fertiliser applications. *Agronomy New Zealand* 36: 49-53.
- Johnson N, Gallacher S 2008. Oil seed cropping risk assessment. Final report. Market Access Solutionz. Ministry of Agriculture and Forestry Policy Report 0809-12. <http://www.mpi.govt.nz/news-resources/publications.aspx> (accessed January 2013).
- Kerr GA, Chapman DF, Thom ER, Matthew C, Van Der Linden A, Baird DB, Johnston E, Corkran JR 2012. Evaluating perennial ryegrass cultivars: improving testing. *Proceedings of the New Zealand Grassland Association* 74: 127-136.
- Land and Water Forum 2012. Third report from the Land and Water Forum: Managing water quality and allocating water. Land and Water Trust. <http://landandwater.org.nz/Site/default.aspx> (accessed February 2013).
- Li FY, Jamieson PD, Pearson AJ 2006. AmaizeN: Developing a decision-support tool to optimise nitrogen management of maize. *Agronomy New Zealand* 36: 61-70.
- Lilburne LR, Webb TH 2002. Effect of soil variability, within and between soil taxonomic units, on simulated nitrate leaching under arable farming, New Zealand. *Australian Journal of Soil Research* 40: 1187-1199.
- Lilburne LR, Webb TH, Francis GS 2003. Relative effect of climate, soil and management on risk of nitrate leaching under wheat production in Canterbury, New Zealand. *Australian Journal of Soil Research* 41: 699-709.
- Lilburne L, Webb T, Ford R, Bidwell V 2010. Estimating nitrate-nitrogen leaching under rural land uses in Canterbury. *Environment Canterbury Report No. R10/127* (accessed January 2013).
- Lindley TN 1990. New Zealand's free market: The effect on domestic wheat quality. *Proceedings of the 1989 Cereal Science Conference*. Christchurch, DSIR Crop Research Division, Wheat Research Institute. Pp. 44-45.
- Love BG, Askin DC, McKenzie BA 1988. Effect of shelter, irrigation, and plant population on yield and yield components of navy beans (*Phaseolus vulgaris* L.). *New Zealand Journal of Experimental Agriculture* 16: 231-237.
- Malteurop 2012. <http://www.malteurop.com/who-we-are/our-malting-plants/new-zealand> (accessed January 2013).
- Mather RJD, Melhuish DT, Herihy M 1995. Trends in the global marketing of white clover cultivars. *Agronomy Society of New Zealand Special Publication No. 11/Grassland Research and Practice Series No. 6*. Pp. 7-14.
- McDowell RW, Houlbrooke DJ 2008. Phosphorus, nitrogen and sediment losses from irrigated cropland and pasture grazed by cattle and sheep. *Proceedings of the New Zealand Grassland Association* 70: 77-83.
- McKay J 2008. The development of the New Zealand vegetable seed industry and future opportunities. *Seed Symposium: Seeds for Futures*. Agronomy Society of New Zealand and New Zealand Grassland Association Joint Symposium. *Agronomy Society of New Zealand Special Publication No. 13 / Grassland Research and Practice Series No. 14*. Pp. 101-104.
- McKenzie BA, Edwards GR, Hill GD 2006. Are New Zealand cereal arable and pastoral rotations sustainable? *Aspects of Applied Biology* 80: 29-41.
- Ministry for Primary Industries 2012a. Farm monitoring report 2012 – Horticulture monitoring: Canterbury arable cropping. Wellington, Ministry for Primary Industries. <http://www.mpi.govt.nz/news-resources/publications> (accessed December 2012).
- Ministry for Primary Industries 2012b. Situation and outlook for primary industries. <http://www.mpi.govt.nz/news-resources/publications> (accessed January 2013).
- Ministry for Primary Industries 2013a. Pests and diseases. Potato/tomato psyllid. <http://www.biosecurity.govt.nz/pests/potato-tomato-psyllid> (accessed February 2013).
- Ministry for Primary Industries 2013b. Plant threats. <http://www.biosecurity.govt.nz/pests/plants> (accessed February 2013).
- Ministry for the Environment 2009. Our rivers: Trends in water quality. <http://www.mfe.govt.nz/publications/ser/our-rivers-information-sheets/total-nitrogen.html> (accessed January 2013).
- Ministry of Agriculture and Forestry (MAF) 2000. Farm monitoring Report 2000 – Arable monitoring report. <http://www.mpi.govt.nz/news-resources/publications> (accessed January 2013).
- Ministry of Agriculture and Forestry (MAF) 2005. Farm monitoring Report 2005 – Horticulture monitoring report. <http://www.mpi.govt.nz/news-resources/publications> (accessed January 2013).
- Ministry of Agriculture and Forestry (MAF) 2006. Farm monitoring Report 2006 – Arable monitoring report. <http://www.mpi.govt.nz/news-resources/publications> (accessed January 2013).
- Ministry of Agriculture and Forestry (MAF) 2009. Farm monitoring Report 2009 – Horticulture and arable monitoring. <http://www.mpi.govt.nz/news-resources/publications> (accessed January 2013).
- Ministry of Agriculture and Forestry (MAF) 2011. Horticulture monitoring : Canterbury arable cropping 2011. Wellington, MAF Policy.
- Molloy L 1993. Soils of the New Zealand landscape: the living mantle. *New Zealand Society of Soil Science*. 239 p.
- Moot DJ, Mills A, Pollock KM 2010. Natural resources for Canterbury agriculture. *Proceedings of the New Zealand Grassland Association* 72: 9-18.
- National Institute of Water and Atmospheric Research 2012. Climate change scenarios for New Zealand. <http://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios> (accessed January 2013).
- New Zealand Feed Manufacturers Association 2012. NZFMA compound feed production statistics: 2011. [http://www.afic.co.nz/sites/default/files/NZFMA\\_Annual\\_2011.pdf](http://www.afic.co.nz/sites/default/files/NZFMA_Annual_2011.pdf) (accessed December 2012).
- New Zealand Pork 2008. Grain sorghum – can we use it in our pig diets? *Pork R&D-Brief No. 8*. <http://www.nzpork.co.nz/> (accessed January 2013).
- OM Financial 2013. <https://www.comtrade.co.nz/> (accessed January 2013).
- Painter DJ 1978. Soil erosion rates on New Zealand farm land. Christchurch, *Proceedings of the Conference on Erosion Assessment and Control in New Zealand*, New Zealand Association of Soil Conservators. Pp. 25-42.
- Parent B, Tardieu F 2012. Temperature responses of developmental processes have not been affected by breeding in different ecological areas for 17 crop species. *New Phytologist* 194: 760-774.
- Pea Industry Development Group 2008. Making peas pay. Lincoln, Canterbury, Foundation for Arable Research 7640 08/2008. <http://maxa.maf.govt.nz/sff/about-projects/search/07-106/making-peas-pay.pdf> (accessed January 2013).
- Pearson AJ, Wilson LR 2002/2003. Impact of tillage system on sweet corn yield and some soil properties: year 2 of LandWISE Hawke's Bay. *Agronomy New Zealand* 32&33: 57-61.
- Plant and Food Research 2011. Fresh Facts. *New Zealand Horticulture* 2011.
- Popay AJ, Thom ER 2009. Endophyte effects on major insect pests in Waikato dairy pasture. *Proceedings of the New Zealand Grassland Association* 71: 121-126.
- Pyke NB, Rolston MP, Woodfield DR 2004. National and export trends in herbage seed production. *Proceedings of the New Zealand Grassland Association* 66: 95-102.
- Rolston MP, Clifford PTP 1989. Herbage seed: Production and research - a review of 50 years. *Proceedings of the New Zealand Grassland Association* 50: 47-35.
- Rolston MP, Clifford PTP, Charlton JFL, Hampton JG, White JGH, Wright AG, Knox D 1990. New Zealand's herbage seed industry: An overview. *Proceedings of the New Zealand Grassland Association* 52: 55-58.
- Rolston MP, McCloy BL, Pyke NB 2004. Grass seed yields increased with plant growth regulators and fungicides. *Proceedings of the New Zealand Grassland Association* 66: 127-132.
- Sanderson K, Webster M 2009. Economic analysis of the value of pasture to the New Zealand economy. Report to Pasture Renewal Charitable Trust. Business and Economic Research Limited, Wellington. <http://www.berl.co.nz> (accessed December 2012).
- Sanderson K, Dustow K, Dixon H 2012. Economic impact assessment of arable production. Report to the Arable Food Industry Council. Wellington, Business and Economic Research Limited. <http://www.berl.co.nz> (accessed December 2012).
- Sandhu HS, Wratten SD, Cullen R, Case B 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. *Ecological Economics* 64: 835-848.
- Saunders C, Saunders J 2012. The economic value of potential irrigation in Canterbury. *Agribusiness and Economics Research Unit, Lincoln University*. <http://www.cdc.org.nz/documents/2012/09/aeru-value-of-irrigation-report.pdf> (accessed December 2012).
- Savage GP 1989. Grain legumes: Some nutritional aspects. *Grain Legumes:*

- National Symposium and Workshop. Agronomy Society of New Zealand Special Publication No. 7. Pp. 15–19.
- Shepherd M, Stafford A, Smeaton D 2012. The use of a nitrification inhibitor (DCn™) to reduce nitrate leaching under a winter-grazed forage crop in the Central Plateau. *Proceedings of the New Zealand Grassland Association* 74: 103–108.
- Smith LC, Orchiston T, Monaghan RM 2012. The effectiveness of the nitrification inhibitor dicyandiamide (DCD) for mitigating nitrogen leaching losses from a winter grazed forage crop on a free draining soil in northern Southland. *Proceedings of the New Zealand Grassland Association* 74: 39–44.
- Statistics New Zealand 1997. Agricultural production statistics June 1996. <http://www.stats.govt.nz> (accessed December 2012).
- Statistics New Zealand 2003. Agricultural production statistics June 2002. <http://www.stats.govt.nz> (accessed December 2012).
- Statistics New Zealand 2008a. Farm types used in agricultural production statistics: A comparison between ANZSIC96 and ANZSIC06 classifications. <http://www.stats.govt.nz> (accessed December 2012).
- Statistics New Zealand 2008b. Agricultural production census 2007. [www.stats.govt.nz](http://www.stats.govt.nz) (accessed December 2012).
- Statistics New Zealand 2012a. Agricultural production statistics June 2011. <http://www.stats.govt.nz> (accessed December 2012).
- Statistics New Zealand 2012b. Agricultural production statistics June 2012. <http://www.stats.govt.nz> (accessed December 2012).
- Statistics New Zealand 2012c. Infoshare: Agriculture. <http://www.stats.govt.nz/infoshare/> (accessed December 2012).
- Sturrock JW 1972. Aerodynamic studies of shelterbelts in New Zealand – medium-height to tall shelterbelts in mid Canterbury. *New Zealand Journal of Science* 15: 113–140.
- Sturrock JW 1981. Shelter boosts crop yield by 35%: Also prevents lodging. *New Zealand Journal of Agriculture* 143: 18–19.
- Tait P, Cullen R 2010. Some external costs of dairy farming in Canterbury. Paper presented at the Australian Agricultural and Resource Economics Society Conference, 8–10 February, Sydney. [www.lincoln.ac.nz/Documents/2347\\_tait\\_s6599.pdf](http://www.lincoln.ac.nz/Documents/2347_tait_s6599.pdf) (accessed January 2013).
- Taylor AL, Fraser TJ, King WMCG 2012. Performance of new dairy pastures. *Proceedings of the New Zealand Grassland Association* 74: 159–164.
- Townshend JM, Bolyend JM 2008. Evaluation of two new linseed cultivars for oilseed production in Canterbury. *Seed Symposium: Seeds for Futures*. Agronomy Society of New Zealand and New Zealand Grassland Association Joint Symposium. Agronomy Society of New Zealand Special Publication No. 13 / Grassland Research and Practice Series No. 14. Pp. 105–112.
- Tricker J, Young J, Ettema M, Earl-Goulet J 2012. Canterbury Region water use report for the 2010/11 water year. Report No. R012/19. <http://ecan.govt.nz/publications/Reports/water-use-report.pdf> (accessed January 2013).
- Ucar T, Hall FR 2001. Windbreaks as a pesticide drift mitigation strategy: A review. *Pest Management Science* 57: 663–675.
- United Nations Environmental Programme 2009. The environmental food crisis – The environment's role in averting future food crises. <http://www.grida.no> (accessed January 2013).
- United Wheat Growers NZ Ltd 2012. Prices and trends. <http://www.uwg.co.nz/prices/index.cfm> (accessed December 2012).
- van der Weerden TJ, Styles TM 2012. Reducing nitrous oxide emissions from grazed winter forage crops. *Proceedings of the New Zealand Grassland Association* 74: 57–62.
- Vries TT, de Cochrane TA, Galtier A 2010. Saving irrigation water by accounting for windbreaks. In: Brebbia CA, Marinov AM, and Bjornlund H eds *Sustainable irrigation management technologies and policies*. Pp. 121–132.
- Webb TH, Lilburne LR, Francis GS 2001. Validation of the GLEAMS simulation model for estimating net nitrogen mineralisation and nitrate leaching under cropping in Canterbury, New Zealand. *Australian Journal of Soil Research* 39: 1015–1025.
- White JGH 1990. Herbage seed production. In: Langer RM ed. *Pastures, their ecology and management*. Oxford University Press. Pp. 370–408.
- Williams PH, Tregurtha CS 2003. Managing nitrogen during winter in organic and conventional cropping systems. *Agronomy New Zealand* 32: 61–67.
- Wilson DR, Johnstone JV, Salinger MJ 1994. Maize production potential and climatic risk in the South Island of New Zealand. *New Zealand Journal of Crop and Horticultural Science* 22: 321–334.