Pasture yield and composition under different land uses in North Otago Rolling Downlands

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Abstract
A field experiment was established in 2004 in the North Otago Rolling Downlands soils near Windsor, North Otago. The aim was to determine the biophysical consequences of different land use (pasture species, grazing animal, mowing, irrigation, nitrogen) treatments on the pasture and soil resources. This paper describes the experimental set-up and the first 2 years of pasture yield and composition results. In general, pasture yield was greater under sheep grazing and mowing than cattle grazing. Irrigation and nitrogen increased pasture yield but not to the same extent across all grazing/mowing treatments. Irrigation increased yield more under sheep grazing and there was a greater nitrogen effect under mowing than grazing. White clover content was decreased by sheep grazing but increased by irrigation. Reasons for the different pasture yield and composition results under the different land uses and continuing research at the site are discussed.
Keywords: intensification, irrigation, nitrogen, sheep, dairy cattle, mowing, pasture

Introduction
Land in New Zealand available for grazing has decreased from 1994 to 2002 by 12% to 12 million ha (Pink 2003). Over the same period, agricultural production from grazing enterprises increased by 5-20% per annum. Agricultural land is likely to continue to diminish because of the retirement of high country leases and the proliferation of housing subdivisions and lifestyle blocks near urban centres. Accordingly, intensification of agriculture has, and will continue to be, how New Zealand increases its agricultural production (MacLeod & Moller 2006). Systems have not only intensified but land use has changed. Consistent profitable returns to dairy farming have driven conversion of traditional sheep/beef grazed regions into dairying. Not only have market forces driven land use change but also the adoption of technologies that allow greater land use flexibility (e.g. irrigation).

In recognition of these issues, the Foundation for Research, Science and Technology (FRST) has funded a 5-year research programme in the Canterbury and North Otago called Land Use Change and Intensification (LUCI). The LUCI programme focuses on understanding the biophysical changes to soils and plants under land use change and developing modelling tools to extrapolate to longer temporal and larger spatial scales.

Historically, agriculture in North Otago has been largely based on sheep grazing. In 1973-74, 60% of North Otago's gross revenue was derived from sheep farming and dairy farming was mostly restricted to town supply farms near Oamaru (Currie 1974). Today, however, improved returns to dairy and the completion of the 10 000 ha North Otago Irrigation Company Downlands Scheme has fuelled a large shift to dairying and other more intensive land uses such as lamb finishing. The number, area and herd size of dairy farms in the Oamaru/ Waitaki area has increased by 22, 30 and 15% over the last 7 years, respectively (Anon. 1999; Anon. 2006). This trend is likely to continue increasing irrigation in this area.

Of particular concern in the North Otago Rolling Downlands (NORD), is the ability of the soil to withstand higher stocking rates by heavier animals. The dominant soils of the region are yellow-grey earths (pallic soils) formed from wind-blown silt (loess). Their high silt but low clay and organic matter contents result in poor soil structure that is easily broken down and dispersed by water (Morton *et al.* 1996). The NORD soils are also characterised by a compacted subsoil horizon (a fragipan) that can impede drainage and plant root growth. Consequently, NORD soils can be summer dry but winter wet. The sustainability of agriculture on these potentially fragile soils has already been identified as an important issue (Ludemann *et al.* 1996).

The experiment described here is part of the LUCI programme. Its aim is to investigate land-change impacts on pastures and soils of the NORD. This paper describes the experiment and the first 2 years of pasture yield and composition.

Materials and Methods
The experiment is located on Grant and Elle Ludemann's farm near the settlement of Windsor (20 km NW of Oamaru), North Otago (45°1.2'S 170°45.9'E, 200 m a.s.l) and is adjacent to another LUCI programme experiment (Houlbrooke *et al.* 2006). This experiment is located on a flat hill top whereas the Houlbrooke *et al*. (2006) experiment is located on a hill side slope. The soil is Timaru silt loam with a dense fragipan layer from 50 to 70 cm depth. In the 2 years prior to establishing

this experiment, the paddock grew short rotation feed crops such as barley silage, annual ryegrass and turnips and was in permanent pasture for at least 7 years prior to that.

Treatments and experimental design

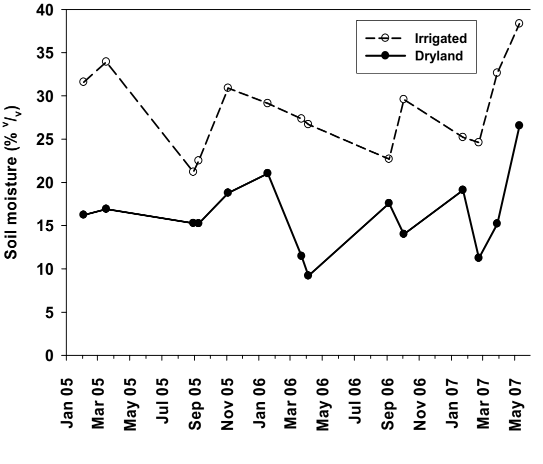
The experiment has 48 wire-netting paddocks (10 x 16.6 m) arranged in four columns of 12. Each paddock has a gate that opens onto one of two access lanes. The land use treatments include three harvest methods (cattle grazing, sheep grazing and mowing), two pasture species (perennial ryegrass and tall fescue), two levels of irrigation (with and without irrigation) and two levels of nitrogen (with and without nitrogen). Main plots are comprised of two adjacent paddocks and are randomly allocated factorial combinations of pasture species, harvest method, and irrigation. Main plots are split for nitrogen. There are two replicates of main plots.

The experiment was established by direct drilling into barley stubble in March 2004. Perennial ryegrass (*Lolium perenne* cv. Samson, AR1 endophyte) and tall fescue (*Festuca arundinacea* cv. Advance, MaxP endophyte) seed was sown at a rate of 18 and 20 kg/ha, respectively, along with 3 kg/ha of white clover (*Trifolium repens* cv. Tribute) seed and 250 kg/ha of di-ammonium phosphate. Fencing was completed during winter 2004, paddocks were lightly grazed during establishment and treatment applications began in January 2005.

Irrigation was applied by impact sprinklers attached to fence posts. Application frequency was aligned with that occurring on the Ludemann farm. Typically, 25 mm of irrigation water was applied once every 7-14 days from October to April, which resulted in average volumetric soil moisture of 27% for irrigated and 17% for dryland paddocks (Fig. 1).

The objective with the nitrogen treatment was to apply sufficient nitrogen so that nitrogen was not limiting growth without causing excessive N leaching. This meant applying different amounts to different harvest and irrigation treatments; specifically, 50, 200, 150 and 600 kg N/ha/yr to the dryland grazed, dryland mown, irrigated grazed and irrigated mown treatments, respectively. The amount applied was determined using the biophysical simulation model EcoMod (Johnson *et al.* 2008). The annual total applied was split into five even applications of urea in February, April, September, October and December.

Figure 1 Mean volumetric soil moisture through time for dryland and irrigated paddocks.



Management

The grazing/mowing was performed in accordance with the following decision rules. Sheep grazing: graze at greater than or equal to 2500 kg DM/ha down to 1 000 kg DM/ha over a 24-36 hour period. Growing lambs were typically used. Cattle grazing: graze at greater than or equal to 3000 kg DM/ha down to 1500 kg DM/ha over a 6-8 hour period. Mature dairy cows were typically used. Mowing: mow and remove herbage at greater than or equal to 4000 kg DM/ha down to 50 mm above ground level. Earlier in the experiment, mowing was achieved by a tractor-mounted rotary slasher and the cut material was raked off. From November 2006 onwards, a purpose-built sickle-bar forage harvester cut, picked-up and weighed the harvested material.

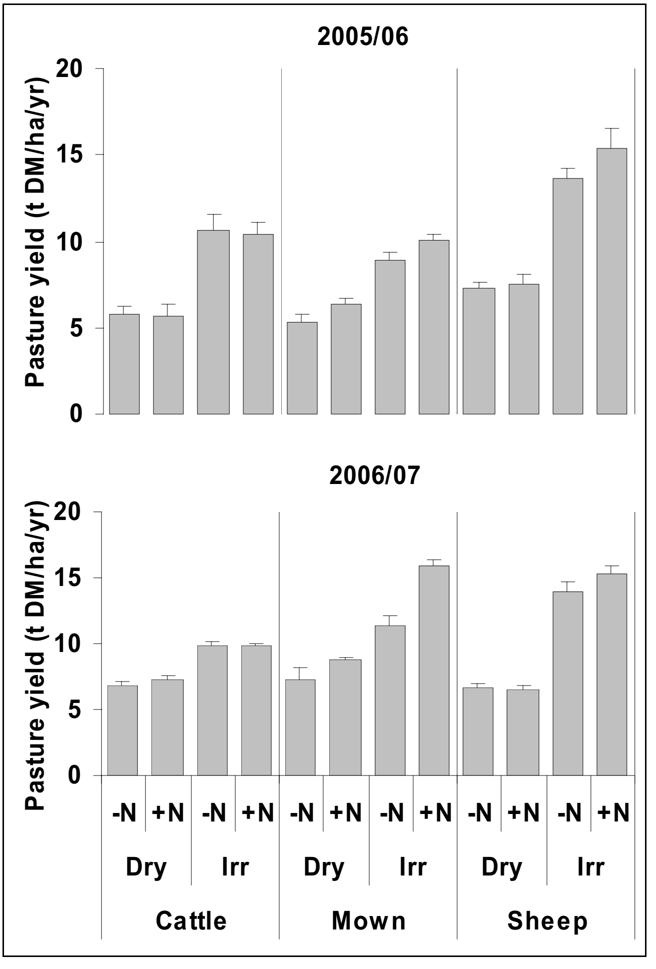
Measurements

Immediately prior to and after each grazing/mowing, pasture mass was estimated using a Tru-test GrassMaster II electronic pasture probe. Ten readings were taken per paddock and the average recorded. Small areas of pasture were cut to ground level to calibrate the pasture probe. Soil moisture was periodically measured by taking soil cores and by a Campbell Scientific Hydrosense™ soil moisture probe. Pasture composition was assessed by taking 10 random pasture clips in each paddock three to four times per year. The clipped material was subsampled, sorted into component species, dried and weighed. Pasture composition was calculated as proportion of total biomass. Total annual yield and pasture composition data were analysed using split-plot analysis of variance model specified in Genstat (version 9, Payne *et al.* 2006).

Results

There were no significant effects (either main or interaction effects) of the pasture species sown on yield. Therefore, the treatment means of pasture yield for the 2 years from July 2005 to June 2007 are presented as the average for the ryegrass and fescue paddocks (Fig. 2). Sheep grazing yielded more than cattle grazing and mowing in 2005/06 and sheep grazing and mowing

Figure 2 Mean pasture yield under different harvest methods for irrigation and nitrogen treatments in 2005/06 and 2006/07. Yields were averaged over the pasture species treatment. Error bars represent the standard error of the mean.



yielded more than cattle grazing in 2006/07 (P<0.001 harvest main effect for both years).

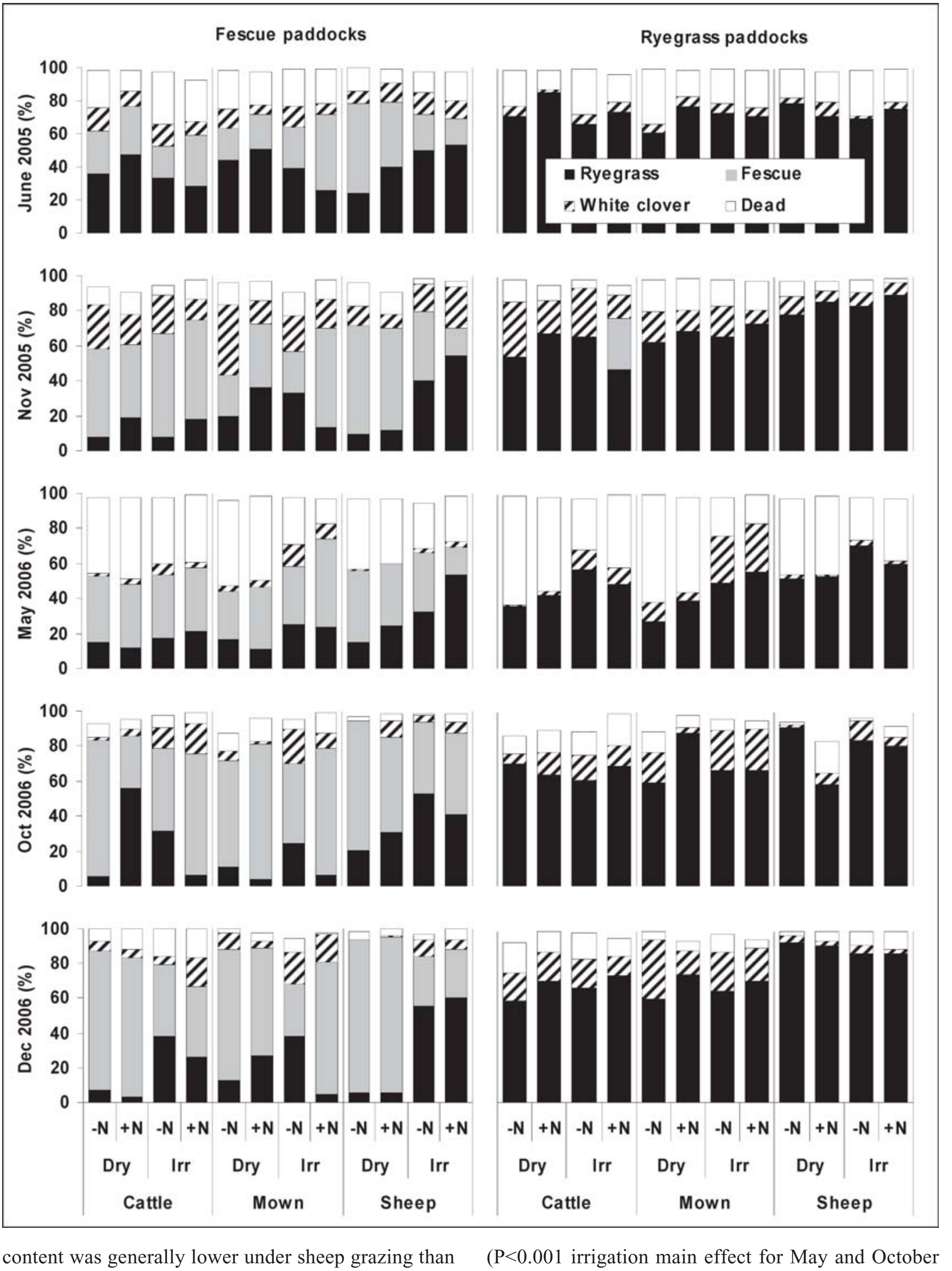
Applying irrigation significantly increased overall pasture yield by 82 and 76% in 2005/06 and 2006/07, respectively (P<0.001 irrigation main effect). The extent of the increase was, however, not the same for all harvest methods. Irrigation increased pasture yield more under sheep grazing than under cattle grazing or mowing (P<0.05 for irrigation by harvest interaction effect for both years).

Applying nitrogen also increased pasture yield but this effect differed between years and depended on the other treatments applied (Fig. 2). In 2005/06, there was only a 7% increase in pasture yield from added nitrogen compared to a 13% increase in 2006/07. In 2006/07, applying nitrogen increased pasture yield but only when combined with mowing and irrigation (P=0.01 for harvest by irrigation by nitrogen interaction effect).

Perennial ryegrass, tall fescue, white clover and dead material were the main components of the pastures and their relative contribution differed through time and between land-use treatments (Fig. 3). Perennial ryegrass was recorded in fescue paddocks. It was particularly prevalent on the first sampling occasion and in irrigated paddocks in combination with sheep grazing. There was no fescue recorded in the ryegrass paddocks except in irrigated, cattle-grazed paddocks in November 2005. Ryegrass and fescue contribution to pasture composition was not significantly influenced by the nitrogen treatment.

There were differences in the clover content of the ryegrass and fescue paddocks but they were not consistent through time. Specifically, there was more clover recorded in fescue paddocks in June 2005, no difference in November 2005 and more in ryegrass paddocks in May, October and December 2006. Clover

Figure 3 Mean pasture composition (% of biomass) for different harvest methods, irrigation and nitrogen treatments in 2005/06 and 2006/07.



content was generally lower under sheep grazing than cattle grazing or mowing. Irrigation increased clover content and this effect became more apparent with time (P<0.001 irrigation main effect for May and October 2006). This was also the case in December 2006 but only in fescue sown paddocks (Fig. 3, P=0.06 for species by irrigation interaction).

The effect of nitrogen on clover content often depended on harvest method. While adding nitrogen significantly reduced overall clover content of pastures in November 2005 ($P<0.001$ nitrogen main effect), clover content was only lower in +N paddocks when combined with mowing in October and December 2006 ($P=0.06$ for harvest by nitrogen interaction effect).

Dead material content was particularly high in May 2006 (Fig. 3). There was more dead material in dryland than irrigated pastures in November 2005 and May 2006 ($P<0.001$ irrigation main effect) but not at the other sampling dates. Sheep grazing resulted in a similar, or lower, proportion of dead material compared with mowing or cattle grazing ($P=0.08$ for June 2005 harvest method main effect; $P<0.05$ for Nov 2005, May 2006 and Dec 2006 harvest method main effect).

Discussion

The factors associated with changing land use and intensification have been well studied over the last 50 years throughout New Zealand. Irrigation, nitrogen, grazing/harvesting all have been found to impact on pasture yield and composition (Boswell 1977; Brougham 1957; Harris *et al.* 1994; Mills *et al.* 2006; Mouat *et al.* 1987; Rickard & McBride 1986; Sears 1953). The uniqueness of this experiment was that all of these effects were studied simultaneously at a location where land use change is currently occurring and the implications for the pasture and soil resources are largely unknown.

The first 2 years of this experiment indicated that average pasture production was similar to other NORD studies (McNamara 1992; Morton *et al.* 1999), but the different land use treatments significantly influenced yield. Specifically, more pasture was harvested by sheep grazing and mowing than by cattle grazing. Irrigation increased pasture yield significantly as did applying nitrogen but not to the same extent across all harvest treatments. There was a greater response to nitrogen under mowing than grazing and a greater response to irrigation under sheep grazing than mowing or cattle grazing.

The differences in pasture yield between harvest methods require further examination. The greater pasture yield under sheep grazing compared to cattle grazing agreed with the results of Boswell (1977). Boswell (1977), in an 8-year trial at Invermay, found that sheep pastures were more productive than cattle grazed pastures because of a decline in ryegrass and an increase in cocksfoot in cattle grazed pastures. In the present trial, there was no difference in yield between pasture species, either across or within harvest methods.

Differences in thresholds to graze or cut for the different harvest methods resulted in far fewer defoliations under mowing than sheep or cattle grazing, averaged over all other treatments (Table 1). It could be expected that more frequent defoliation under grazing compared to cutting would minimise losses to senescence and decay but the results were not universally consistent with this. Firstly, *sheep*-grazed pastures often contained less dead material than *mown* pastures but they both yielded the same. Secondly, *cattle*-grazed pastures often contained similar amounts of dead material to mown pastures but they yielded less. Other potential influences on pasture yield, which may differ between harvest methods such as changes in soil physical and biological properties, are currently being examined at the site. These impacts are likely to be slow to develop and will probably only be apparent after several years.

Table 1 Mean annual total (and standard error) of defoliations for each harvest method for 2005/06 and 2006/07 years.

Harvest method	2005/06	2006/07
Cattle	6.0 (±0.3)	6.5 (±0.1)
Mow	3.5 (±0.1)	3.5 (±0.1)
Sheep	7.0 (±0.3)	7.0 (±0.3)

The greater response to added nitrogen under mowing compared to grazing resulted from 1) more N being applied and 2) the greater removal of nitrogen under mowing compared to grazing (Ledgard *et al.* 1999). If a cut and carry system is adopted to provide supplementary feed for a milking platform, exogenous nitrogen will need to be applied. For example, the irrigated, no nitrogen, mown pastures lost 360-440 kg N/ha/yr (assuming 9-11 t DM/ha/yr at 4% nitrogen). At best, only a third to a half of this nitrogen would have been supplied by N-fixation (Hoglund *et al.* 1979). The remaining nitrogen, from the mineralisation of organic matter, needs to be replaced if pasture production is to be sustained over the long-term.

Soil potassium is another element that can be depleted by mowing (McLaren & Cameron 1990). MAF Quick tests performed on bulk soil samples from the different treatments indicated that soil K levels under mowing were less than grazing but levels were still adequate for non-limited pasture growth according to Morton *et al.* (1996).

The impact of the different land use treatments on pasture composition was more varied than that on pasture yield. One consistent observation was that there was some invasion of fescue pastures by ryegrass, especially at the first measurement. This ryegrass may have originated from seed inadvertently spilling onto fescue paddocks as the raised seed drill passed over the fescue paddocks at sowing. There may also have been ryegrass seed in the soil. This invasion by ryegrass may have contributed to the lack of yield differences between ryegrass and fescue pastures. In the paddocks where there was ryegrass and fescue present, fescue content was higher under dryland than irrigated conditions. This was consistent with fescue's greater water stress tolerance than ryegrass (Rollo *et al.* 1998).

The greater amounts of dead material measured in June 2005 and May 2006 were the result of the dry summer/ autumn periods. The dead material disappeared the following spring as temperatures warmed and growth and decomposition rates increased. In 2006/07, irrigated paddocks had less dead material than dryland paddocks because the added water reduced plant stress and senescence through summer and autumn. This indicated that irrigation not only increased pasture quantity but also quality.

In general, clover content was higher under cattle grazing, mowing and irrigation. Cattle grazing and mowing are less selective toward clover than sheep grazing and therefore clover plants are able to retain more leaves in the sward and better compete for light (Brock & Hay 1993). In particular, those pastures that were mown but not fertilised with nitrogen had higher clover contents. The most likely reason for this was that repeated mowing was rapidly removing available nitrogen from the soil and creating an environment where species, like white clover, that can fix atmospheric nitrogen can compete more effectively with neighbouring grass plants (Schwinning & Parsons 1996).

White clover is a drought sensitive species so irrigation increases its survival and growth in low rainfall regions like North Otago (Brock *et al.* 2003; Knowles *et al.* 2003). The slow establishing, more erect, lower tiller density growth habit of tall fescue should make it more suitable as a companion species of white clover (Praat *et al.* 1996). The results here were not consistent with this because for four of the five occasions that composition was determined, clover content was the same or higher in the ryegrass paddocks. Stevens & Hickey (2000) found that, when tall fescue was included in pasture mixtures, the yield of white clover was reduced. It may be that fescue and clover are in direct competition for the same niche in pasture if that pasture contains a significant population of ryegrass.

This research is ongoing at this site. In addition to the impacts of land use change on pasture yield and composition, below-ground impacts on soil physical and biological properties are also being examined. This information will help formulate management strategies that can be adopted to sustain productive and profitable land use into the future on fragile soils throughout New Zealand.

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REFERENCES

Anon. 1999. Regional dairy statistics 1998-1999. Livestock Improvement Corporation Limited, Hamilton.

Anon. 2006. Regional dairy statistics 2005-2006. Livestock Improvement Corporation Limited, Hamilton.

Boswell, C.C. 1977. Comparisons of cattle grazing and sheep grazing. *Proceedings of the New Zealand Grassland Association 38*: 56-65.

Brock, J.L.; Hay, R.J.M. 1993. An ecological approach to forage management. pp. 258-263. *In*: Grasslands for our world. Eds. Baker, M. J. SIR Publishing, Wellington, New Zealand.

Brock, J.L.; Hyslop, M.G.; Widdup, K.H. 2003. A review of red and white clovers in the dryland environment. *Legumes for dryland pastures. Grassland Research and Practice Series No.11*: 101-107.

Brougham, R.W. 1957. Some factors that influence the rate of growth of pasture. *Proceedings of the New Zealand Grassland Association 19*: 109-116.

Currie, J.D. 1974. Farming in North Otago. *Proceedings of the New Zealand Grassland Association 36*: 6-16.

Harris, S.L.; Penno, J.W.; Bryant, A.M. 1994. Effects of high rates of nitrogen fertiliser on dairy pastures and production. *Proceedings of the New Zealand Grassland Association 56*: 27-31.

Hoglund, J.H.; Crush, J.R.; Brock, J.L.; Ball, R.; Carran, R.A. 1979. Nitrogen fixation in pasture. 12. General discussion. *New Zealand Journal of Experimental Agriculture 7*: 45-51.

Houlbrooke, D.J.; Morton, J.D.; Paton, R.J.; Littlejohn, R.P. 2006. The impact of land-use intensification on soil physical quality and plant yield response in North Otago Rolling Downlands. *Proceedings of the New Zealand Grassland Association 68*: 165-172.

Johnson, I.R.; Chapman, D.F.; Snow, V.O.; Eckard, R.J.; Parsons, A.J.; Lambert, M.G.; Cullen, B.R. 2008. DairyMod and EcoMod: biophysical pastoral simulation models for Australia and New Zealand. *Australian Journal of Experimental Agriculture 48*: in press.

Knowles, I.M.; Fraser, T.J.; Daly, M.J. 2003. White clover: loss in drought and subsequent recovery. *Legumes for dryland pastures. Grassland Research and Practice Series No.11*: 37-41.

Ledgard, S.F.; Penno, J.W.; Sprosen, M.S. 1999.

Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *Journal of Agricultural Science 132*: 215-225.

Ludemann, G.; Hewson, D.C.; Green, R. 1996. North Otago Sustainable Land Management Group: assisting the North Otago community to move towards the goal of sustainable land use. *Proceedings of the New Zealand Grassland Association 58*: 101-105.

MacLeod, C.J.; Moller, H. 2006. Intensification and diversification of New Zealand agriculture since 1960: an evaluation of current indicators of land use change. *Agriculture, Ecosystems and Environment 115*: 201.

McLaren, R.G.; Cameron, K.C. 1990. Soil Science: An Introduction to the Properties and Management of New Zealand Soils. Oxford University Press, Auckland.

McNamara, R.M. 1992. Seasonal distribution of pasture production in New Zealand. North and East Otago downlands. *New Zealand Journal of Agricultural Research 35*: 163-169.

Mills, A.; Moot, D.J.; McKenzie, B.A. 2006. Cocksfoot pasture production in relation to environmental variables. *Proceedings of the New Zealand Grassland Association 68*: 89-94.

Morton, J.D.; Roberts, A.H.C.; Edmeades, D.C.; Manning, M.J. 1996. North Otago soils: physical properties and nutrient requirements for economic production. *Proceedings of the New Zealand Grassland Association 58*: 17-21.

Morton, J.D.; Smith, L.C.; Metherell, A.K. 1999. Pasture yield responses to phosphorus, sulphur, and potassium applications on North Otago soils, New Zealand. *New Zealand Journal of Agricultural Research 42*: 133-146.

Mouat, M.C.H.; Hay, M.J.M.; Crush, J.R.; Nes, P.; Dunlop, J.; Hart, A.L. 1987. Effects of nitrogen and phosphorus applications on pasture growth and composition on a recent alluvial soil with low phosphorus retention. *New Zealand Journal of Experimental Agriculture 15*: 143-146.

Payne, R.W.; Harding, S.A.; Murray, D.A.; Soutar, D.M.; Baird, D.B.; Welham, S.J.; Kane, A.F.; Gilmour, A.R.; Thompson, R.; Webster, R.; Tunnicliffe Wilson, G. 2006. The Guide to GenStat Release 9, Part 2: Statistics. VSN International, Hemel Hempstead.

Pink, B. 2003. Agricultural statistics 2002. Statistics New Zealand, Wellington.

Praat, J.P.; Ritchie, W.R.; Baker, C.J.; Hodgson, J. 1996. Target populations for direct-drilled ryegrass and tall fescue. *Proceedings of the New Zealand Grassland Association 57*: 77-81.

Rickard, D.S.; McBride, S.D. 1986. Irrigated and non-irrigated pasture production at Winchmore, 1960 to 1985. Technical Report No. 21.

Rollo, M.D.; Sheath, G.W.; Slay, M.W.A.; Knight, T.L.; Judd, T.G.; Thomson, N.A. 1998. Tall fescue and chicory for increased summer forage production. *Proceedings of the New Zealand Grassland Association 60*: 249-253.

Schwinning, S.; Parsons, A.J. 1996. Analysis of the coexistence mechanisms for grasses and legumes in grazing systems. *Journal of Ecology 84*: 799-813.

Sears, P.D. 1953. Pasture growth and soil fertility. 5. The effects of nitrogenous fertilisers, and of "day" and "night" grazing. *New Zealand Journal of Science and Technology 35*: 68-77.

Stevens, D.R.; Hickey, M.J. 2000. Effects of binary seed mixtures of ryegrass, cocksfoot and tall fescue on pasture production. *Proceedings of the New Zealand Grassland Association 62*: 141-146.