The impact of land-use intensification on soil physical quality and plant yield response in the North Otago Rolling Downlands

D.J. HOULBROOKE[1], J.D. MORTON[2], R.J. PATON[1] and R.P. LITTLEJOHN[1]
[1]*AgResearch, Invermay Agriculture Centre, PB 50034, Mosgiel*
[2]*Ballance Agri-Nutrients, PO Box 65, Rolleston*
david.houlbrooke@agresearch.co.nz

Abstract

The New Zealand agricultural industry is currently undergoing a large drive for increased productivity. Fuelling this will primarily require greater 'on-farm' land-use intensification involving increasing farm inputs to gain a large increase in farm product outputs. The North Otago Rolling Downlands (NORD) region of New Zealand has traditionally been drought-prone and limited to extensive sheep farming. The establishment of a large district irrigation scheme in spring 2006 will result in large scale intensification of land-use across the NORD region. A field trial has been established in North Otago on a common NORD Pallic soil type (Timaru silt loam) to determine the effect of land use intensification on soil quality and plant yield response. The treatments compare newly sown pasture vs. winter grazed forage crop, irrigated vs. dryland and sheep vs. cattle grazing. The application of irrigation water in 2004/2005 resulted in 17.5 kg pasture DM/mm of irrigation water and 24 kg pasture DM/mm of irrigation water for the drier 2005/2006 growing season. Results from the pasture trial suggest that both cattle grazing and irrigation (particularly in combination) are decreasing soil quality with a macroporosity of 9% v/v from pasture plots following the 2004/2005 season compared to 18% v/v for the dryland sheep treatment. In the 2005/2006 season, cattle irrigated plots had a macroporosity of 11% v/v from pasture plots c.f 19% v/v for the dryland sheep treatment To date, this measured decrease has had no significant effect on pasture or crop yield suggesting that soil quality has not yet fallen below a critical level for production under irrigated farming systems. However, further monitoring is required to assess the long term effects as strong trends are emerging that indicate soil quality decline under the cattle grazed and cropping treatments.

Keywords: land-use intensification, soil quality, irrigation, cattle grazing, sheep grazing, forage cropping, compaction, pasture yield

Introduction

The North Otago Rolling Downlands (NORD) region is one of the most drought-prone areas in New Zealand because of low annual rainfall (mean 500-550 mm/yr), high evapo-transpiration rates from excessive winds (January-February median 4.4 mm/day) and the low water holding capacity (64 mm total available water 0-300 mm) on the mainly Fragic Pallic soil types (GrowOTAGO 2006). Until now, land use in this region has been limited mainly to extensive sheep farming (6-10 SU/ha), with some cereal and winter forage crops, with yields varying greatly between years (Grant Ludemann pers.comm.). Until recently the irrigation water required to farm this area intensively has been restricted to groundwater and local stream flows, both of which are limited in supply. In May 2006 the North Otago Irrigation Company started drawing water from the Waitaki River to irrigate approximately 10000 ha over 80 farms as part of a new district scheme.

By definition, land-use intensification requires increasing farm inputs to sustain existing, or generate an increase in, farm product outputs. In North Otago, the supply of irrigation water will be inextricably associated with intensification of land-use, because of the cost of the irrigation water and the subsequent ability to increase pasture and crop production. Changes from the current land-uses may include lamb finishing, cattle grazing, growing of brassica crops to winter dairy cows, and dairy farming. The change in land use will usually reflect the proportion of the farming operation that is irrigated. Operations purchasing enough water to irrigate 100% of a property have in many cases converted to dairy farming (Grant Ludemann pers.comm.).

A common concern regarding land-use intensification is the potential deterioration of soil quality. Karlen *et al*. (1997) defined 'soil quality' as the ability of soil to function, where the soil resource must be recognised as a dynamic living system that emerges through a balance of biological, chemical, and physical components. Sparling & Schipper (2002) reporting on a survey of 500 New Zealand soils, which collated soil quality data based on land-use, demonstrated a decrease in physical status of New Zealand soils under highly intensive land-uses such as dairy farming, arable cropping and horticulture. However Sparling *et al*. (2000) reported that soil type differences masked any effects of differing land-use when comparing soil quality measures of three contrasting soil types.

Pallic soils such as those in the NORD region are prone to soil compaction because poor drainage means they are wet for extended periods, and soil erosion due to their weakly structured sub soils (Hewitt 1998). Hewitt and Shepherd (1997) rated Fragic Pallic soils as having a 'high' structural vulnerability under intensive management which suggested the implementation of best land management practices should be monitored.

A number of studies have investigated the impacts of both intensive cattle grazing and traditional sheep grazing on soil physical response and subsequent pasture yield on Pallic soils such as those found in North Otago (Drewry *et al*. 1999; Drewry & Paton 2000; Drewry *et al*. 2000; Drewry *et al*. 2004). A comparison of soil physical properties on sheep and dairy farms in Southland and Otago found significant decreases in soil quality on dairy farms across a range of physical measures when compared to that of sheep farms. However, the intensive winter grazing of sheep at 1800 sheep/ha (Drewry *et al*. 1999) and spring grazing of cattle at intensities of 70-90 cows/ha (Drewry & Paton 2000) on Pallic soils also resulted in decreased soil physical quality, in particular macroporosity. The loss of macroporosity under both intensive cattle and sheep grazing resulted in decreased pasture production. Drewry *et al*. (2004) investigated dairy pasture responses to soil physical properties and found macroporosity at 0-5 and 5-10 cm depth to be strongly correlated with spring pasture yield. Drewry *et al*. (2002) determined that a 1% unit increase in macroporosity at 0-5 cm and 5-10 cm would result in a 1.8% and 2.5% increase in relative spring pasture yield. The relationship was considered linear between 5% and 22% v/v.

Monaghan *et al*. (2005) reported that increased cattle stocking rates as a result of increased nitrogen inputs had little discernible impact on physical condition of a Pallic/Brown soil mix for cattle-grazed pasture in eastern Southland. However, two studies in Nigeria and Turkey that investigated land-use intensification as a result of irrigation water inputs found deterioration in soil physical quality when compared to areas receiving only rain fed water (Urama 2005) or areas with a shorter history of irrigation inputs (Yilmaz *et al*. 2003). Despite the risks to soil compaction, it is commonly perceived that soil organic matter levels will increase under a highly productive irrigated pasture. However, Metherell (2003) found that a long-term (50 years) irrigation trial in South Canterbury decreased soil carbon levels. This was believed to be associated with increased C mineralization rates from soil with high soil moisture status.

The objective of this research is to determine the effects of irrigation and type of grazing animal on soil quality and forage production under both pasture and crop land-use in the NORD region and to use this information as a basis for developing best farm management practices for intensive land-use under irrigation.

Materials and Methods

Site details and treatments

A research site was selected on a Timaru silt loam, (Fragic Pallic soil) in a paddock with a flat terrace top area and a terrace face of about 15% slope into a gully. Timaru silt loam soils are the dominant Fragic Pallic soil type in the lower part of the Waiareka Valley catchment and the slope is representative of the Rolling Downlands. The research site was historically used for dryland sheep grazing and dairy replacement grazing. The research site was established in autumn 2004 as part of the LUCI (Land Use Change and Intensification) programme by AgResearch in collaboration with Crop and Food Research and contained two groups of 16 fully fenced plots approximately 10 m wide and 25 m long running down the slope. The groups were freshly sown in autumn 2004 as ryegrass/white clover pasture and a crop treatment (oats), respectively, and managed separately throughout the trial. The initial oats crop was grazed in early spring 2004. During the first experimental season (2004/05) a winter forage crop, kale (*Brassica oleracea*), was grown followed by swedes (*B. napus*) in 2005/06. The crop plots remained fallow during the spring period.

The experimental design within each group consisted of the factorial interaction of an irrigation treatment (irrigated vs. dryland) and a stock treatment (sheep vs. cattle) in four randomised complete blocks. There was special interest in the comparison between the sheep-dryland and cattle-irrigated treatments as these represent the change from steady state land use to the most intensive land use. The research site received maintenance fertiliser requirements with no differentiation made between dryland and irrigated plots during the 2004/05 and 2005/06 to eliminate short-term fertility differences between treatments. A soil testing programme did not highlight any differences in fertility in the short-term as a result of the different nutrient demands of the irrigated and dryland treatments.

Management

Each pasture plot was grazed by either sheep or cattle when required, with the stocking rate dependant on the amount of feed available. Soil water content was not a driver for grazing scheduling and varied between treatments and between grazing events for the same treatment. Soil moistures at the time of grazing on the irrigated plots were typically between 25% v/v (two-thirds available water capacity) and 46% v/v (field capacity). Grazing intensities on pasture plots ranged between 100 and 180 cattle/ha and 750 and 2200 lambs/ha depending upon availability of feed associated with irrigation treatment differences. The average liveweight of cattle ranged from 500 to 580 kg/beast whilst average lamb weights ranged between 32 and 37 kg. Grazing rotations ranged from 10 to 28 days and grazing events lasted approximately 24 h. Target pasture cover at the time of grazing was 3500 kg DM/ha, grazing down to approximately 1500 kg DM/ha. Crop plots were established in early summer and grazed once during the following winter at stocking densities of 200 cattle and 2500 lambs/ha for approximately 3 days

Irrigation to both pasture and crop plots was typically made over a 24 h period using fixed K-Line pods when the soil water content fell between 50% and 66% available water capacity as determined by an *in situ* aquaflex soil moisture tape. The 2004/05 growing season (nominally taken from 15 Aug-15 May) was unseasonally wet with a well distributed total of 515 mm of rainfall. The 2005/06 season was more typical and received only 300 mm of rainfall. Median growing season rainfall for the North Otago region is approximately 370 mm (GrowOTAGO 2006). During the 2004/05 season only 200 mm of water was irrigated over three events to the pasture and only 60 mm to the crop area. During the 2005/06 season, the pasture plots received 440 mm of irrigation water over 11 events whilst the crop plots received 90 mm of water over three events. Irrigation rotations on pasture were as short as 7 days in summer of 2005/06.

Measurements

Pasture dry matter (DM) yield measurements were made throughout the growing season using a locally calibrated rising plate meter to assess pre- and post-grazing pasture mass from all plots (L'Huillier & Thompson 1988). Crop DM per plot was determined by oven drying three randomly selected 1 m row lengths of established plants (leaf and stem) at 70°C for 72 h.

Treatments were assessed for soil quality annually (pasture in autumn and crop plots post-grazing in winter). The soil quality measures reported here are macroporosity and structural condition score (SCS). Macroporosity (percentage of soil pores > 30 μm diameter) was determined at 0-5 and 5-10 cm depth and measured in a manner previously described in detail by Drewry & Paton (2000) from three paired samples per plot. In summary, cores were trimmed and the surface peeled off to provide a natural soil surface. Following the removal of earthworms using formaldehyde, all cores were equilibrated on a tension table to -10 kPa. Macroporosity data are presented per 10 cm depth by averaging the readings for 0-5 and 5-10 cm, as treatment trends for the two depths were the same with only a small depth effect. SCS was semi-quantitatively assessed on three sub-samples per plot using an intact spade square, 20 x 20 cm by 10 cm deep. Structural condition score ranged from 1-5 in half unit increments, where a high value related to a well-structured soil and a low value to a poorly structured soil. Scores were based on visual assessment of the size, shape and porosity of aggregates, and their cohesion and root development, following the break-up and spreading of each sample onto a rectangular tray. The method is described in detail by Beare & Tregurtha (2004) and was adapted from Peerlkamp (1967).

Statistical methods

Soil physical (macroporosity averaged over both depths and SCS) and plant production data were analysed by analysis of variance, separately for pasture and crop data. The block structure was given by sub-sample within plot within block, and the treatment structure by irrigation and stock treatments and their interaction. This was done using the statistical package GenStat 8 (2005). Statistical significance was assessed at the 5% level unless otherwise stated.

Results and Discussion

Soil quality

Percentage macroporosity between 0 – 10 cm (averaged over 0-5 and 5-10 cm cores) in 2004/05 and 2005/06 for the pasture grazed soils differed significantly with irrigation ($P<0.001$) and stock ($P<0.001$) treatments, and their interaction ($P<0.05$) (Fig. 1). Under sheep grazing in 2004/05, the mean macroporosity was 18.1% for the dryland treatment, compared to 13.2% (SED 0.92) for the irrigated treatment, with corresponding means for the cattle-grazing treatment of 13.3% and 11.3%, respectively. Under sheep grazing in 2005/06, the mean macroporosity was 18.9% for the dryland treatment, compared to 14.8% (SED 0.92) for the irrigated treatment, with corresponding means for the cattle-grazing treatment of 16.1% and 8.4%, respectively. The same relativities between treatments were observed for SCS in the pasture plots for both the 2004/05 and 2005/06 seasons (Fig. 2), with a significant main effect of stock ($P<0.05$ - 2004/05, $P<0.01$ - 2005/06) and irrigation ($P<0.05$), while the interaction was not significant. The mean SCS for the sheep-dryland treatment was 3.7 and 4.1, compared to 2.3 and 1.8 for the cattle-irrigated treatment (SED 0.43 and 0.38) for the 2004/05 and 2005/06 seasons, respectively.

The pattern of decreasing soil physical quality with increasing land-use intensity is not unexpected. On similar Pallic soil types, Drewry *et al*. (2000) found that cattle-grazed pasture suffered greater soil compaction than sheep-grazed pasture, as cattle are considerably heavier than sheep and impose more downward pressure on the soil per unit area from hoof contact. Likewise, soil compaction is more likely to occur when

Figure 1 Percentage macroporosity at 0-10 cm, (average for 0-5 and 5-10 cm cores) from pasture plot treatments for the 2004/05 and 2005/06 season. Bars represent 5% LSD for each season.

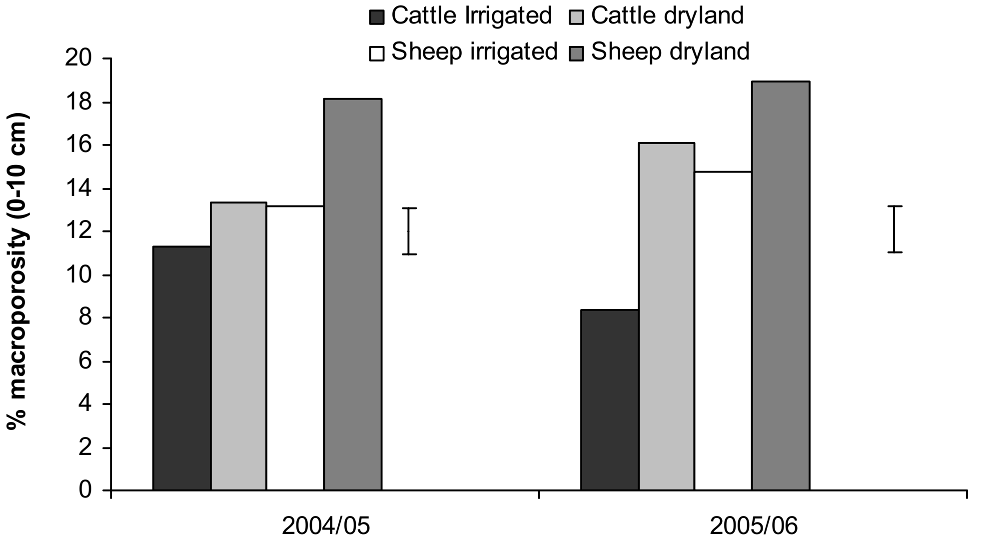
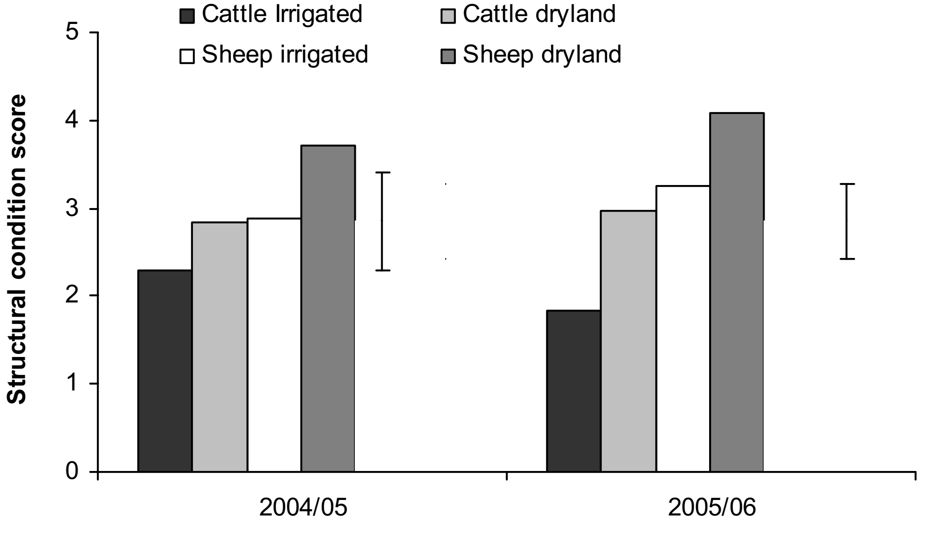


Figure 2 Structural condition score from pasture plot treatments for the 2004/05 and 2005/06 seasons. Bars represent 5% LSD for each season.



the soil is capable of plastic deformation. The irrigated treatment was kept within field capacity and 50% of available water capacity (AWC) throughout the irrigation season and was therefore at greater risk of pugging, poaching and soil compaction (Greenwood & McKenzie 2001; Drewry 2006). Such a practice is typical of many irrigated pastures, where irrigation and grazing events are scheduled as needed independently of each other; hence grazing events are likely to occur when the soil is in a plastic or easily deformed state. It is consequently not surprising that the combination of cattle grazing and irrigated land use resulted in the lowest values from the soil quality indicators measured. This combination showed further deterioration in soil physical quality between the 2004/05 and 2005/06 seasons (Figs. 1 & 2).

The crop plots showed no significant differences in soil quality measures between irrigation and stock treatments following winter grazing of the 2004/05 kale crop, although the lowest soil macroporosity (Fig. 3) and SCS (Fig. 4) means were observed for the cattle-irrigated treatment and the highest for the sheep-dryland

Figure 3 Percentage macroporosity at 0-10 cm (average of 0-5 and 5-10 cm cores) from crop treatments for the 2004/05 season. Bar represents 5% LSD.

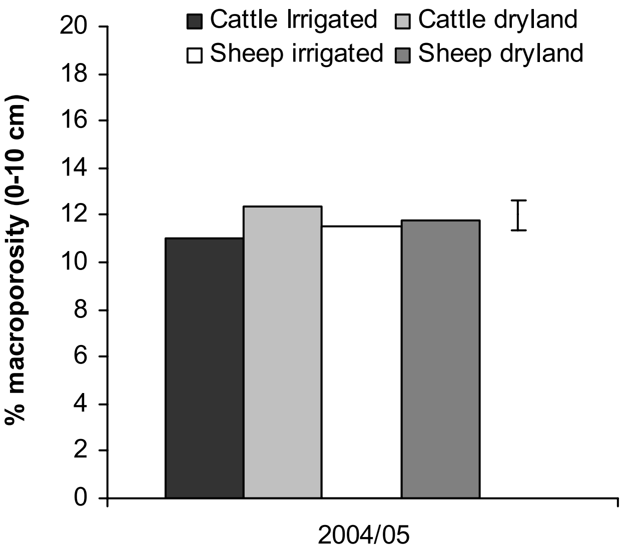
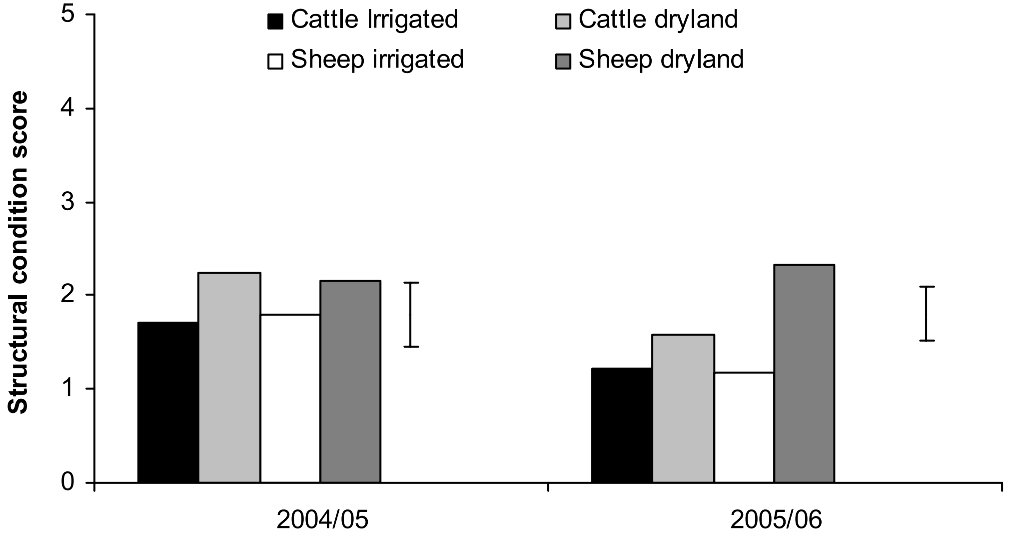


Figure 4 Structural condition score from crop plot treatments for the 2004/05 and 2005/06 seasons. Bars represents 5% LSD for each season.



treatment. The lack of discernible treatment differences may be associated with the climatic conditions during the winter of 2005 (outside the irrigation season) where only 22.2 mm of rainfall was recorded for May and June, preceding the July grazing. The resulting dry soil moisture conditions (approximately 17% v/v) within all plots essentially eliminated much of the difference between the irrigation and dryland treatments. In contrast, in 2005/06 the crop grazed soils differed significantly with irrigation ($P<0.01$) with a decreased SCS measured (dryland 1.2 cf. irrigated plots 2.0) following winter grazing of the swedes crop. The least intensive dryland sheep grazed plots had a significantly greater SCS ($P<0.05$) than all other treatments and was the only treatment that did not suggest a declining trend in SCS between the 2004/05 and 2005/06 seasons (Fig. 4).

Plant yield

For both the 2004/05 and 2005/06 season, pasture yields were significantly greater ($P<0.01$) for the irrigation treatment vs. dryland, with no significant difference between cattle vs. sheep grazing (Fig. 5). Absolute water

Table 1 Pasture yield and water use efficiency for the contrasting 2004/05 and 2005/06 growing seasons. Rainfall represents precipitation from 15 Aug-15 May.

Season	Treatment	Rainfall (mm)	Irrigation (mm)	Pasture yield (t DM/ha)	Water use efficiency (kg DM/mm water)	Irrigation water efficiency (kg DM/mm irrigation)
2004/05	Dryland	515	-	10.4	20.0	-
2004/05	Irrigated	515	200	13.9	19.5	17.5
2005/06	Dryland	364	-	8.4	23.1	-
2005/06	Irrigated	364	480	19.9	23.5	23.8

Figure 5 Total pasture yield from all treatments for the 2004/05 and 2005/06 seasons. Bars represent 5% LSD for each season.

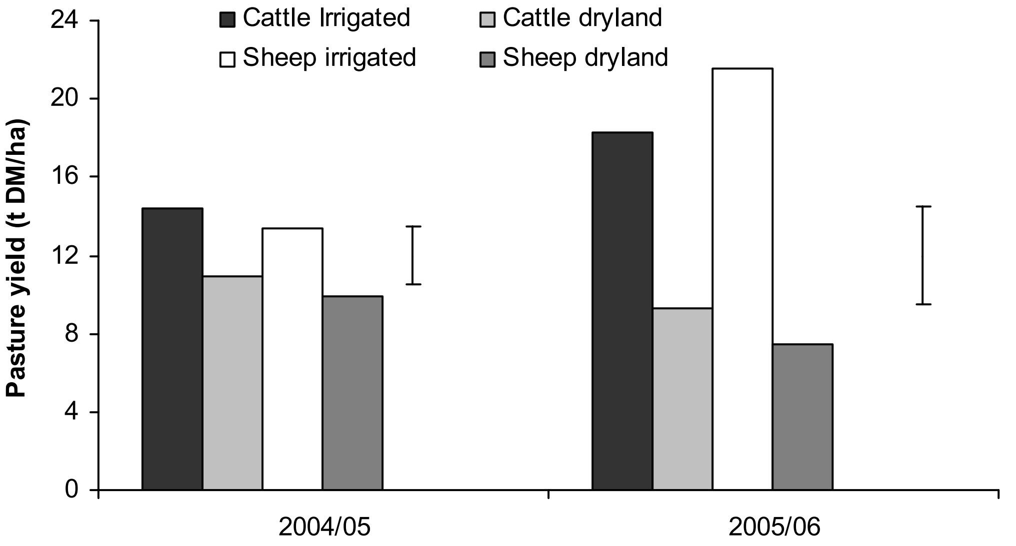
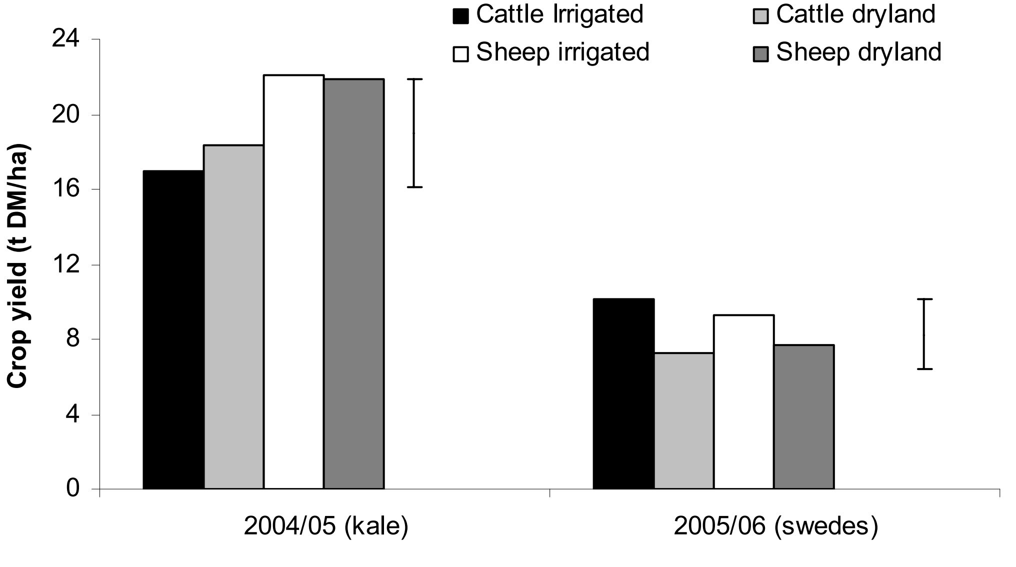


Figure 6 Total crop yield from all treatments for the 2004/05 and 2005/06 seasons. Bars represent 5% LSD for each season.



use efficiencies between treatments during the 2004/05 and 2005/06 growing seasons (15 Aug-15 May) ranged from 19.5 to 23.5 kg DM/mm water received as either precipitation or irrigation (Table 1). The greatest efficiency came from the irrigated plots in 2005/06 that grew 19.9 t DM/ha from the combination of 364 mm of rainfall and 480 mm of irrigation water. The additional irrigation water (over and above rainfall) netted a further 23.8 kg DM for every mm of irrigation water applied (Table 1). Similarly in 2004/05, the addition of 200 mm of water provided an extra 17.5 kg DM/mm of water, thus demonstrating the potential increase in production from the NORD region when applying irrigation water in an effective manner. The application of irrigation water, whilst showing some evidence of decreasing soil physical quality, has been able to compensate for any adverse effects on plant yield. This, suggests that in the short-term, soil physical quality, as it affects productive capacity under an irrigated system, has not fallen below a critical level for production. This assumption will need to be monitored, as evidence of decreasing soil physical quality between the first and second season, along with a trend (although not considered significant) emerging in the 2005/06 season of decreased pasture yield in the cattle-irrigated compared to the sheep-dryland treatment, could be important for determining long-term sustainability (Fig. 5).

The crop yield from the winter forage crop (kale) in 2004/05 was higher for sheep than for cattle (22.0 t/ha cf.17.6 t/ha (SED 1.36) t/ha; $P<0.05$). Considering this was the first season that treatments were imposed, the reasons for this are unknown. Crop yield was not significantly different between irrigation and dryland treatments (Fig. 6), a likely result of climatic conditions for that season where only one irrigation event of 60 mm was required from the time of crop establishment in late December. In comparison the crop yield from the winter forage crop (swedes) in 2005/06 showed no significant differences between treatments (Fig. 6). The yield from the 2005/06 swedes crop was smaller than would otherwise be expected and may relate to the late sowing date and higher density seed placement than what was planned for. As would be expected, no relationship between 2004/05 or 2005/06 crop yield and soil physical quality was evident. However differences in crop yield between irrigated and dryland treatments were smaller than would have been anticipated and may be related to the general poor physical quality of the soil measured under the cropped treatment.

Economics

The economic value gained from irrigating water to the NORD region is highly dependant upon the climate on a per season basis. Irrigation water acts as an insurance policy to grow pasture when rainfall supply is not sufficient. In North Otago, with an average annual rainfall of only 550 mm and high evapo-transpiration rates, irrigation water is required in most seasons to prevent large soil water deficits. Based on the estimated cost of $1000/ha/yr to supply irrigation water via the North Otago irrigation scheme, the return on investment for the unseasonally wet 2004/05 season of 3.7 t DM/ha of pasture would provide feed at a cost of 27 cents/kg DM grown. However the more typical 2005/06 season provided an additional 11.5 t DM/ha of pasture which represents a more cost effective 9 cents/kg DM grown. This compares favourably with an estimated end cost of providing pasture silage at 20 cents/kg DM. With regards to crop value in 2004/05, an extra 4.6 t DM/ha of kale provided winter feed at a cost of 21 cents/kg DM grown. In 2005/06, the increase 2.2 t DM/ha of swedes provided winter feed at a cost of 45 cents/kg DM grown.

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