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The impacts of animal wintering on water and soil quality

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Report prepared for Environment Southland

October 2012

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1. Executive summary

Animal wintering is increasingly recognised as a critical phase of pastoral farming that has an important influence on animal performance and on contaminant losses from farms to water. Preliminary research has indicated that areas used for forage crop grazing during winter can potentially make a particularly large contribution to N, P and sediment loss from the total farm system. As part of the Water and Land 2020 project, Environment Southland has commissioned a review that documents (i) our current knowledge of the environmental effects associated with animal wintering practices, and (ii) some of the key Good Management Practices that reduce deleterious effects. The scope of the report covers the impacts of sheep and deer wintering, although most focus is placed upon the impacts of cattle wintering. Emphasis is also placed on the role of brassica forage crop wintering practices. A relative ranking of the potential environmental risks associated with wintering animals on forage crops, categorised according to soil and topography risk factors, is also provided.

Although there are relatively few datasets available, recent research has highlighted that the amounts of N lost in subsurface drainage from winter forage crops grazed by cattle are relatively high. The concentrations of nitrate-N in drainage from grazed winter forage crops are accordingly relatively high. Potentially large losses of N may occur when cattle are grazed on crops early in the winter, on light soils and during wet winters.

On-going research has also highlighted the potential for relatively large losses of sediment in overland flow from rolling landscapes that have been used for winter forage crop grazing by cattle. Evidence suggests that much of the loss originates from within the gullies where soil disturbance and overland flow generation is relatively high, and that grazing management can have a very large influence on these yields.

There are few studies reported in the literature that have measured losses of potential water pollutants derived from winter forage crops grazed by stock classes other than cattle. Although methodological and scaling issues call for caution when interpreting these datasets, they do show that the potential for N leaching losses from sheep urine deposited to pastures or crops during winter are potentially very high. The limited evidence available indicates that sediment and P losses from sheep-grazed winter forage crops are lower than from cattle-grazed winter forage crops, greater sediment and P losses can be expected from sheep-grazed winter forage crops than from sheep-

grazed pastures, and that winter forage crops grazed by deer also have a relatively high potential to adversely impact water quality and stream health.

Soil damage associated with winter grazing of forage crops can be a particular challenge for paddocks subjected to repeated use for winter forage cropping and grazing, as is sometimes the case on runoff blocks. Soils at the greatest risk of such damage are those that have a high Structural Vulnerability Index (SVI, Hewitt & Shepherd 1997), such as those found in the Pallic and Gley soil orders. As well as potentially compromising plant yield, deterioration in soil physical quality may also increase the potential for P and sediment loss in overland flow. Practical management options to minimise soil damage due to grazing of winter crops include back-fencing, reduced tillage methods for crop establishment, and ensuring paddocks are not cropped and winter-grazed for more than 2 years in a row. Whereever possible, limiting the extent of winter forage crop grazing in "vulnerable" parts of the landscape would help minimise soil damage and the associated risk of overland flow. This could be achieved by such measures as choosing paddocks with soils that have a lower SVI, or by practising on-off grazing, particularly of near-stream areas.

The role of alternative wintering approaches such as off-paddock systems is briefly reviewed. Some have the potential to avoid or mitigate a farm's impact on the wider environment, although all require good design and management to ensure that positive environmental outcomes are achieved. Capital costs incurred with some of the more expensive Herd Shelter options are also considerable and a significant issue for many farmers.

The review concludes with an assessment of the potential and relative environmental risks associated with wintering animals on forage crops, categorised according to soil and topography risk factors. These indicative estimates reflect the dichotomy of greatest risk for N loss and lesser risk for P and sediment loss for very well drained or excessively drained soils, in direct contrast to soils that are poorly drained, have lower structural resilience or are located on sloping topography where P loss risk is higher and N loss risk lower. There is thus no "ideal" soil type to choose to winter animals on.

2. Introduction

Land use change and the intensification of farming practices are recognised as important contributors to a range of environmental problems. In many parts of New Zealand economic drivers continue to encourage a shift from dry stock to dairy farming. This is particularly evident for the provinces of Otago and Southland in southern New Zealand, where dairy cow numbers have increased from 315,000 in the 1999/2000 season to more than 735,000 in 2011/2012 (LIC, 2012). This change in land use and observed declines in water quality and ecological condition (Environment Southland and Te Ao Marama Inc., 2010 & 2011) have raised concerns about the environmental impacts of a growing dairy industry. Effects on ground and surface water bodies and soil quality are issues that are of immediate concern to local regulatory agencies, whilst potential increases in the emissions of greenhouse gases such as nitrous oxide are of concern at a national level. Monitoring by Environment Southland, a local regulatory agency, indicates that N concentrations in rivers and in some of the region's aquifer monitoring sites are increasing, in some instances to levels close to or above maximum permissible concentrations for safe drinking water (Rissman, 2012). Other regional water quality issues relating to both N and P which have been documented in SOE reports and other technical papers include:

- Periphyton and macrophyte growth (Environment Southland and Te Ao Marama Inc., 2011; Matheson et al., 2012). Outbreaks of cyanobacteria can be toxic and have resulted in dog-deaths in Southland.
- Nitrate toxicity levels for fish in streams (chronic toxicity standard (Hickey & Martin, 2009) used in the SOE report showed some sites do not comply).
- Nutrient levels for in-stream ecological health and periphyton growth (N and P both important).
- Eutrophication of lakes and estuaries. Recent reports on Southland estuaries show this is a very serious concern for the upper arms of 2 Southland Estuaries (Robertson & Stevens, 2012a,b,c) and a risk for some coastal lakes and lagoons (Schallenberg & Kelly, 2012).

Unfortunately our quantitative understanding of the relative importance of different farming practices is poor, both when considering contrasting land use activities, such as sheep v. dairy, and when comparing losses from different components within a farm system. Winter grazing on forage crops is one example of a farm system component that appears to have a relatively large environmental footprint, despite usually

representing only a small part of total farm area. This animal management practice normally occurs over a 10-12 week period during winter and is seen as a cost-effective strategy for providing required amounts of winter feed and avoiding more extensive animal treading damage to soils and pastures during wet and cool winters in southern New Zealand. Preliminary research indicates that areas used for forage crop grazing during winter can make a relatively large contribution to N, P and sediment loss from the total farm system. Evidence also suggests that these impacts are magnified if animal wintering occurs on less resilient soils and landscapes. Increases in sheep and beef prices in recent years, in conjunction with the continued expansion of dairy and dairy support operations and new land development methods, have made it economically viable to introduce winter forage crops to landscapes that have traditionally been regarded as less suitable for such intensive farming practices.

The purpose of this report is to provide a scientific summary of our knowledge of the environmental effects associated with animal wintering practices. Although much of the existing information reviewed pertains to wintering of dairy cattle, it also attempts to summarise our knowledge of the environmental effects of wintering other stock classes such as sheep and deer. This report will be used to support a regional policy response to animal wintering in Southland under the Water and Land 2020 project. It is also intended to support and/or supplement other projects and responses; these include the NPS on freshwater, other Focus Activity initiatives, and improving our knowledge of the impacts of farming activities in Waituna catchment.

2.1 Definition of animal wintering

For the purposes of this report, we define animal wintering as the management approach undertaken to feed animals over the 12-week period from late May to late August. This loosely represents the period between drying off dairy cows and their subsequent calving in early spring, and includes periods at the beginning and end of winter that are required to transition animals onto and away from diets that have contrasting nutritive values. The most obvious contrast here is that between pasture and grazed forage crops such as swedes, kale and fodder beet. Because there is a wide range of potential approaches to animal wintering, the scope of this report is broadened to consider the potential impacts of alternative animal wintering methods such as off-paddock and all-grass systems.

2.2 Potential environmental effects of animal wintering systems

The primary environmental concerns associated with animal wintering can be considered in terms of four main issues:

- Water Quality - potential effects on water quality in downstream receiving environments such as aquifers, streams, rivers, lakes and estuaries. The research reviewed in this report covers contaminant losses measured in the transport pathways of surface runoff (or "overland flow") and subsurface drainage (matrix flow and/or mole-pipe drainage). The following sections will show how surface runoff is usually relatively enriched in sediment, P and faecal bacteria, whereas subsurface drainage usually accounts for the majority of N lost from farms to water;
- Soil Quality – especially long-term compaction, reduced air and water exchange, and their consequences for plant growth and contaminant runoff from farms;
- Greenhouse gas emissions – particularly nitrous oxide (N2O);
- Erosion Control – particularly on sloping land, gullies and swales.

This report focuses on the potential water and soil quality issues associated with animal wintering. In contrast to the amount of research undertaken on the impacts of grazed pastures on water quality, there are relatively few reported studies that document losses of nutrients and faecal microorganisms (FMOs) to water from forage crops grazed over winter. This is, however, being partially remedied in MSI/Pastoral21 research programmes that are currently underway. Findings from some of the key studies where losses of nitrogen (N), phosphorus (P) and sediment have been measured are reviewed in sections 3 and 4.

3. The potential impacts on water quality of wintering cattle on forage crops

3.1 N losses

Grazed winter brassica crops have a relatively high potential for N loss to water. This greater risk of loss can be attributed to the large amounts of mineral N that may remain in the soil in late autumn following pasture cultivation and forage crop establishment the preceding spring. Another contributing factor to a high potential for N loss is the

deposition of large amounts of excretal N onto bare soil when the forage crop is grazed over winter, a period when plant uptake is low and drainage likely. As a consequence of these factors, on a per hectare basis, N leaching losses from grazed winter forage crops are high relative to losses measured under pasture. This is evident from the results for the Woodlands (Southland) trial shown in Table 3.1, where the per hectare losses in the Control treatments are approximately 4 to 5 times greater than losses measured under pasture on equivalent soil types and land use (de Klein et al. 2006 and unpublished data). These losses thus make a disproportionately large contribution to total dairy system losses relative to the area occupied by winter forage crops. In the case of the Woodlands trial, losses from the area used for winter forage grazing are estimated to represent approx. 44% of whole system dairy N leaching losses but constitute only approximately 15% of the whole system area.

Studies indicate that the majority of N losses to water from grazed winter forage crops occur in a nitrate-N form and are transported via subsurface (matrix flow or mole-pipe drainage) rather than overland flow. The effectiveness of the nitrification inhibitor dicyandiamde (DCD) for reducing N leaching losses from cow urine patches deposited during grazing of the winter forage crop has been evaluated in the trial work reported in Table 3.1. A single winter application of DCD reduced nitrate leaching losses by 16, 0, 30 and 24% in the Woodlands, Five Rivers, Canterbury and Waikato studies, respectively. With the exception of the Five Rivers trial data, cost-benefit analysis suggests that the use of DCD on winter forage crops is at least as cost-effective as using DCD on grazed pastures. Winter applications of DCD do, however, carry an increased risk of the DCD product being transported in the drainage that is expected to occur during this period. Little is known about the off-site impacts of DCD lost in winter drainage. Smith & Schallenberg (2013) found measurable concentrations of DCD in many of the surface waters sampled on the Taieri Plain, Otago. Although they also observed that DCD was effective at blocking *in situ* nitrification in sediment-water mesocosms incubated in the laboratory, the effects on ammonia toxicity, eutrophication and algal community composition in aquatic ecosystems remains unclear.

Table 3.1. Nitrate-N leaching results from cattle "grazed" winter forage trial sites in Southland, Canterbury and Waikato.

Experimental site	Method	Crop	Treatment	Nitrate-N loss kg N/ha/year
Woodlands, Southland[1]	Tile-drained trenches[3]	Kale	Control	52
			+DCD	46
		Dairy pasture[4]	Control	11
			+DCD	7
Five Rivers, Southland[2]	Ceramic Cups	Kale/swedes	Control	57
			+DCD	59
Lincoln, Canterbury[1]	Lysimeters	Annual Ryegrass	Control (nil urine)	1
			Urine	98
			Urine +DCD	69
Central Plateau, Waikato[5]	Ceramic Cups	Kale/swedes	Control	153
			+DCD	116

[1]from de Klein et al. 2010.
[2]from Smith et al. 2012.
[3]simulated grazing implemented by applying artificial urine to 25% of plot area.
[4]from Monaghan et al. 2009 and unpublished data.
[5]from Shepherd et al. 2012.

The relative importance of urine N versus the soil N mineralised following soil cultivation as a source of leached N seems to vary between trials. Lysimeter studies at Lincoln and the trial reported by McDowell & Houlbrooke (2008) show that very little N leaching occurred in the control (nil urine) treatments, indicating that the winter-deposited urine was by far the greatest source of leached N. In contrast, results from the Woodlands trial indicated that urine accounted for between only 10 and 20% of the N leached during Years 1 and 2 of the trial, respectively, with 80 – 90% coming from mineralised N. Similarly, inclusion of a non-grazed area at the Central Plateau (Waikato) site demonstrated that a significant proportion of leached N was derived from growing and harvesting a crop, then leaving the soil bare over winter. Forage crop sequence trials at Lincoln (Beare et al. 2010; discussed below) also showed significant amounts of N leaching from un-grazed crops. This implies that harvesting and feeding the forage off-site (e.g. by using a feedpad) would not remove the entire N leaching risk. As DCD targets mainly the urine-N (rather than mineral N derived from soil processes), DCD application in the absence of grazing is likely to be of limited benefit. Based on the findings of Thomas et al. (2004; 2008) and McDowell & Houlbrooke (2008), there is

some evidence to suggest that minimal or no tillage crop establishment techniques can substantially reduce the soil-derived N leaching load. Furthermore, there can be significant soil quality, crop performance and nitrous oxide (a greenhouse gas) emission benefits from the use of minimum and no-tillage practices to establish forage crops following grass pasture (i.e. as breakcrops in a grass renewal system) (Thomas et al., 2004) as described below.

Information from the Waikato study (Shepherd et al. 2012) indicates how the timing of forage crop grazing is an important determinant of N leaching loss. The very high losses that they measured from crops that were grazed in mid June represent a worst case scenario due to the wet winters (670-800 mm drainage) and the extended period that the grazed paddock remained bare (site cultivated and drilled in late August). The researchers estimated that losses from crops that would be grazed later in the winter would be considerably less than early winter grazings.

An important aspect of the N leaching trial datasets are the relatively high concentrations of nitrate-N measured in drainage from the grazed winter forage crops, particularly for shallow soil types such as that at the Five Rivers site. Figure 3.1 shows how these concentrations increased over the 3-year monitoring period at the Five Rivers trial site to values generally between 20 to 30 mg N/L for the period of drainage corresponding to the winter grazing activity. These concentrations are 2-3 times the guideline value of 11.3 mg N/L recommended by the NZ Ministry of Health as a maximum permissible level for nitrate in drinking water. Volume-averaged concentrations for the more poorly-drained Pukemutu soil (Woodland site) were much lower, but still averaged 11 mg N/L over the 3 year measurement period (Monaghan et al, *in press*). Much lower nitrate-N concentrations have been measured at the Five Rivers site since it was returned to pasture in late 2011 and then grazed by deer in March 2012, and sheep thereafter (Figure 3.1).

Forage crop trials at Lincoln (Beare et al. 2010) have also demonstrated that nitrate leaching losses from forage crops on shallow soil types can be substantial. This work also indicates that high nitrate leaching losses can occur during the winter period under intensively managed feed crops grown for whole crop removal, depending on the timing of sowing and crop demand for nitrogen. Nitrate leaching losses from the forage crop sequences evaluated were significantly affected by the first and second crops grown. Overall, the barley-based sequences had the lowest total nitrate-N leaching below 60 cm soil depth, in contrast to the maize-based sequences where losses exceeded 70 kg

N/ha. The differences in nitrate leaching losses were not closely linked to estimates of cumulative drainage and fertiliser inputs and therefore imply that crop demand for N and the timing of grazing (i.e. urine applications) are important determinants of the nitrate leaching losses. Forage crop husbandry techniques such as early establishment of supplementary feed crops in the autumn with minimum or no-tillage techniques, the use of crop calculators to better match fertiliser N applications with crop N uptake and delayed grazing of forage crops are most likely to assist in mitigating nitrate leaching losses from these crops.

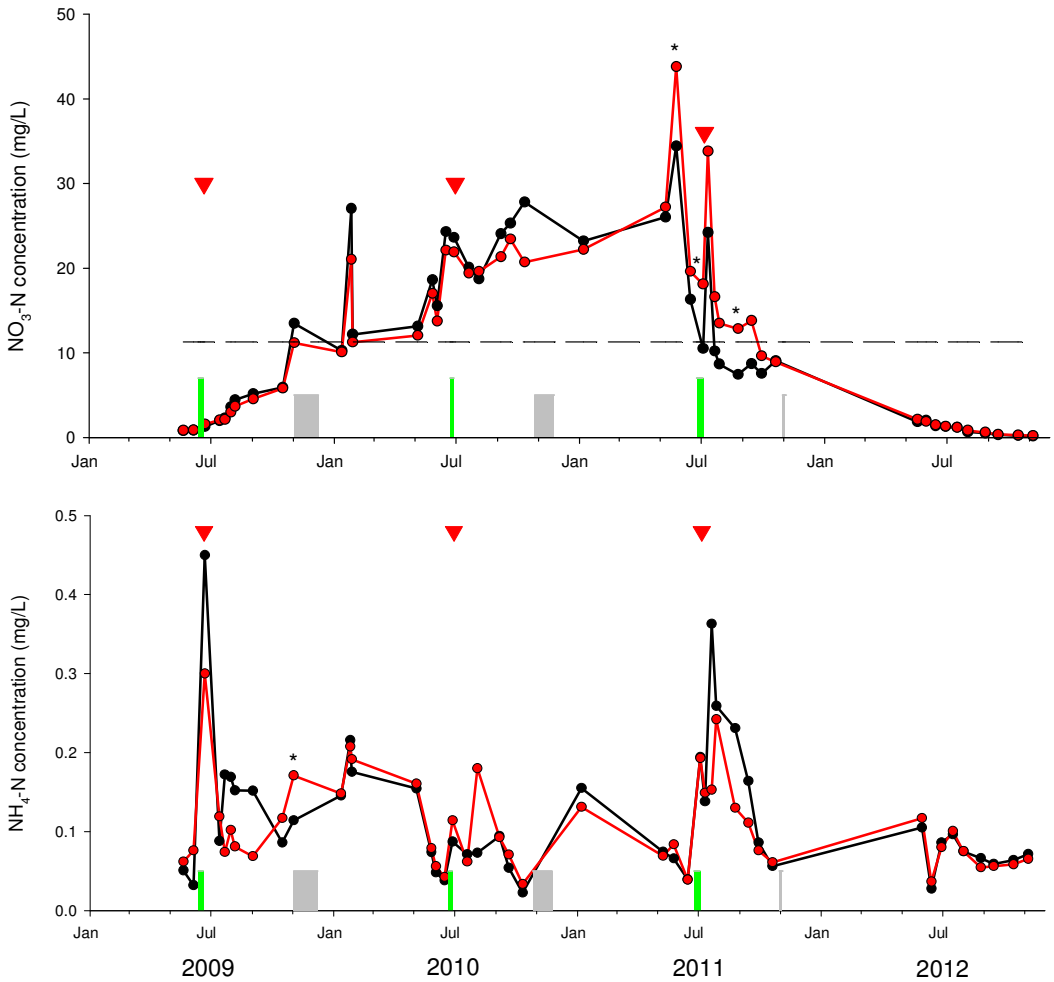

Figure 3.1. Concentrations of ammonium N (NH4-N) and nitrate N (NO3-N) in leachate collected from the control and **DCD** treatments (Smith et al. 2012). The dashed horizontal line indicates the drinking water standard of 11.3 mg N/L; green bars indicate the times of crop grazing; ▒ indicates the timing of cultivation of the trial; and red triangles indicate the timings of DCD applications. Significant (P<0.05) differences are indicated by an asterisk. The experimental site was used for winter forage grazing by dairy cows from 2009-2011, then returned to pasture in November 2011.

Nitrous oxide emissions

Recent research is showing that losses of the greenhouse gas nitrous oxide (N_2O) can be disproportionately greater from grazed forage crop paddocks than from pasture (Monaghan et al., data in press; Smith et al., 2008; van der Weerden, unpublished data). Nitrous oxide is a potent greenhouse gas (GHG) that represents about 15 to 20% of the GHG emission profile for NZ agriculture. In contrast to the findings observed for mitigating N leaching, the research trials indicate that applications of DCD can be effective in reducing these losses. Monaghan et al. (data in press) and van der Weerden et al. (data in press) estimated reductions in N_2O emissions of 25% and 57% per hectare following DCD application to winter forage crops in Southland and South Otago, respectively.

3.2 P, sediment and faecal bacteria losses

To the author's knowledge, there are only 3 NZ field studies where losses of P and sediment from winter grazed forage crops have been measured under dairy or cattle land use. These are at Hillend and Telford (South Otago), and Windsor (North Otago). All 3 sites have Pallic soils on moderately sloping terrain (5-20%).

McDowell et al. (2003a, 2005) measured relatively small volumes of overland flow and low P runoff at the Hillend site. Although the cultivated and trodden plots exhibited a greater concentration and load of sediment and P fractions lost in overland flow than in un-grazed pasture or cultivated plots, these quantities are small when compared to loads documented for intensively farmed (predominantly dairy) catchments (Wilcock et al. 2007). Total P and sediment losses in overland flow from the grazed winter forage crop treatments of McDowell et al. (2003a, 2005) were less than 0.1 and 25 kg/ha/winter, respectively. A follow-up study (McDowell 2006) to this work suggested that stock access to riparian margins was the primary source of P and sediment discharging from the sub-catchment in which the field trial of McDowell et al. (2003a) was located. The implications from these findings are that (i) overland flow losses of P and sediment from this winter-grazed forage crop were relatively low, and (ii) stock exclusion from riparian margins was an important management practice for avoiding P and sediment losses in this particular sub-catchment. Laboratory experiments reported by McDowell et al. (2003b) suggested that the treading imprints created when the forage crop was grazed led to greater surface ponding, which decreased the erosive power of raindrop impact and thus reduced sediment and P loads in the overland flow induced by simulated rainfall.

In contrast to these findings, measurements of P and sediment losses in overland flow from cattle-grazed plots at the North Otago trial site were considerably higher. Over the two years of measurement (March 2007 to October 2008), the mean Total P loss from the winter crop control treatment that was grazed by yearling cattle was approx. 1.4 kg P/ha (Figure 3.2). The implementation of a 3 hour restricted grazing system reduced these losses to approx. 0.9 kg P/ha. Corresponding figures for sediment losses in these treatments were 700 and 300 kg/ha, respectively. The greater losses reported by McDowell & Houlbrooke (2009) may at least be partially attributable to the use of irrigation in these treatments, which kept the soil close to field capacity for much of the time. Together with the relatively poor soil physical condition, these factors probably contributed to the large volumes of overland flow recorded from the crop treatments at the site (88 mm over the 20 month monitoring period) and consequently relatively large loads of P and sediment recorded.

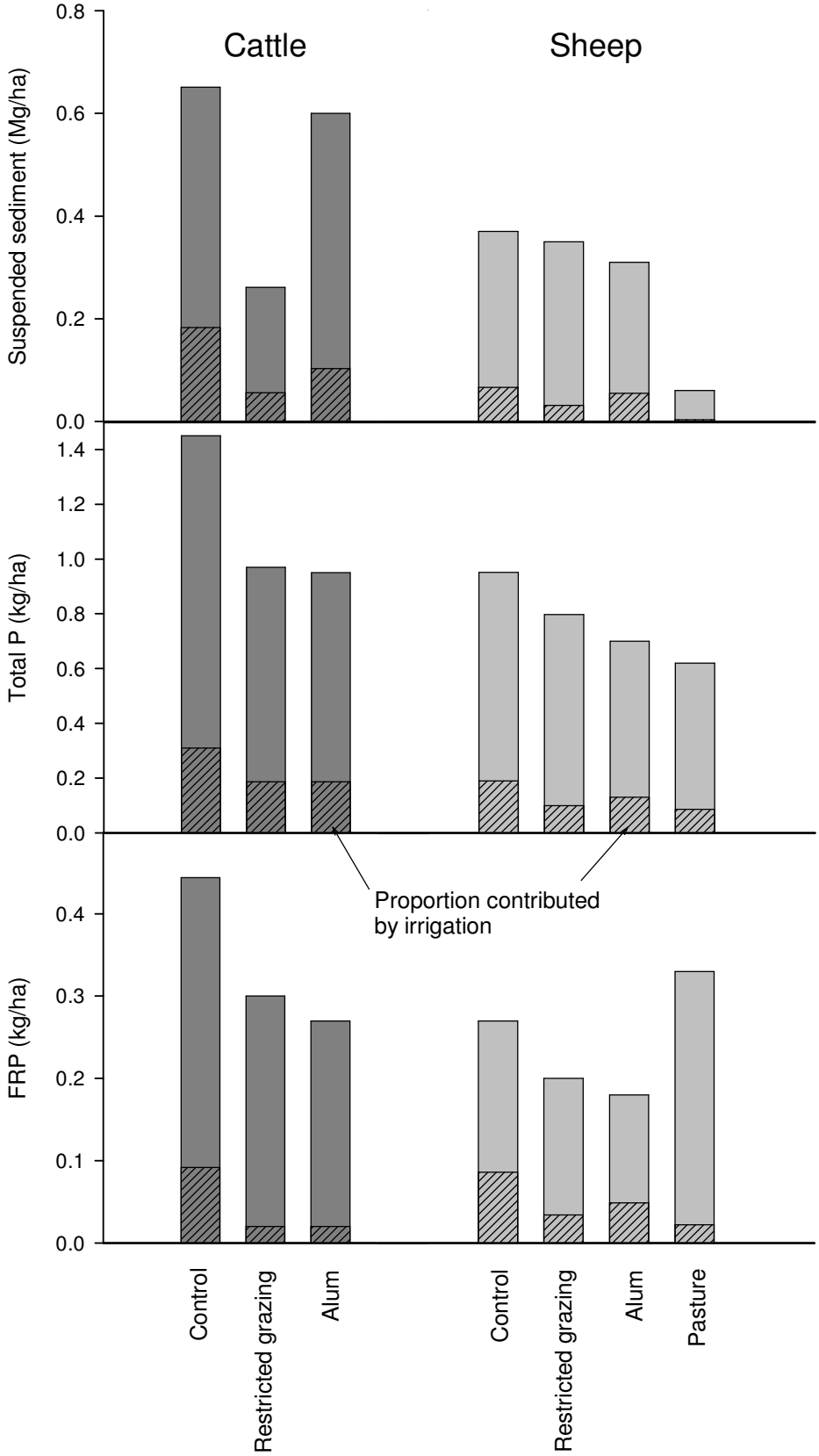

Figure 3.2. Mean loads of suspended sediment, filterable reactive P (FRP) and total P in overland flow from cattle- and sheep-grazed plots at the Windsor (North Otago) site (McDowell & Houlbrooke 2009).

A third and important study site where the impacts of forage crop cattle wintering are being monitored is at Telford Farm in South Otago. This study site has two small headwater catchments, each approx. 2 ha in area, that have been monitored since June 2011 for yields of sediment, P and *E. coli* (used as an indicator for faceal bacteria contamination) in overland flow and subsurface drainage. Both catchments were manged similarly in 2011 as a calibration step; in 2012, one catchment was grazed as per suggested Good Management Practice whereby the catchment gully (Critical Source Area, or CSA) was protected from the heavy animal treading that typically occurs during winter. This protected area represented 2% of the total paddock area. The other catchment was managed as a Control treatment where typical grazing practice (grazed from the bottom of the catchment without back-fencing) was employed and the gully was left un-protected from grazing and soil treading damage.

Some preliminary findings from this on-going experimentation are:

- The heavy treading damage caused by cows grazing in the Control treatment has reduced soil infiltration rates and caused more water to exit the paddock in overfland flow (Figure 3.3). This has resulted in relatively large yields of sediment (more than 1 Mg ha^{-1} during 2012).
- Measurements and observations suggest that much of the sediment and P loss originates from within the gully where (i) the water is flowing over the soil surface and (ii) soil aggregation is greatly reduced (see photo 1).
- Yields of water, sediment and P in overland flow have been greatly reduced in the catchment that has been grazed according to Good Management Practice. This demonstrates how management of the landscape and paddock can have a large effect on the yields of water pollutants leaving farms:
    - Back-fencing forage crop breaks will help to minimise the amount of soil damage incurred and surface runoff produced.
    - Careful grazing of the gully/CSA in the Good Management Practice treatment has reduced water and sediment yields in overland flow by 82 and 89%, respectively. “Careful” management during winter 2012 meant grazing the CSA at the end of winter (20 July) when an approx. soil water deficit of 2 mm had accumulated, grazing this area for only 3 hours, and beginning the winter by grazing the paddock towards the catchment outlet rather than away from it. This was in contrast to the Control catchment, which was grazed from the bottom of the catchment and without back-fencing.

- Ideally, it is probably safest to avoid winter cropping and grazing gullies altogether. This will obviously incur some financial penalty due to lost productive area, although, depending on the landscape, this area may be relatively small e.g. less than 2 or 3% of paddock area.

- Yields of N and P in overland flow are slightly higher than measured for pastures. These losses of N in overland flow are small relative to those typically lost in subsurface drainage and thus of lesser concern.

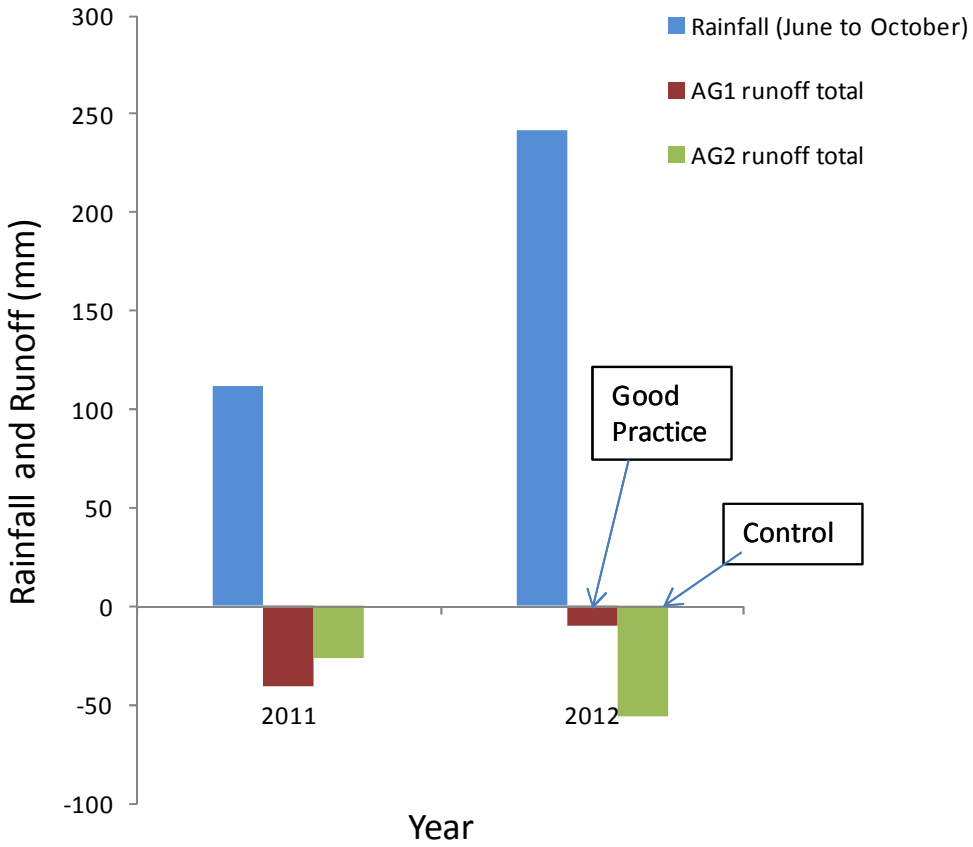

Figure 3.3. Rainfall inputs and yields of water in overland flow derived from catchments AG1 and AG2 that were used used for winter forage crop grazing by dairy cows. Note that both catchments were run as a Control treatment during 2011 as a calibration step. Catchment AG1 was then grazed according to Good Practice during 2012, whilst AG2 was grazed again as a Control treatment (treatments to be reversed during 2013).

Catchment AG1 Catchment AG2

Photo 1. Photographs of gullies and soil conditions for catchments used for winter forage crop grazing in 2012. Catchment AG1 was grazed according to Good Management Practice whereas AG2 was grazed irrespective of catchment layout and without back-fencing used. Photos taken 19 July 2012.

3.3 Summary of existing knowledge

- The amounts of N lost in subsurface drainage from winter forage crops grazed by cattle are relatively high. On a per hectare basis, these losses are in the order of 3 to 5 times greater than from grazed pastures. The concentrations of nitrate-N in drainage from grazed winter forage crops are accordingly relatively high. Potentially large losses of N may occur when cattle are grazed on crops early in the winter, on light soils and during wet winters.
- Single mid-winter applications of the nitrification inhibitor dicyandiamide (DCD) have had only a small or nil effect in reducing these N leaching losses in forage crop grazing trials undertaken in Southland, although more promising results have been reported for other parts of the country.
- Relatively large losses of sediment have been measured in overland flow from rolling landscapes that have been used for winter forage crop grazing by cattle.

Evidence suggests that much of the loss originates from within the gullies where soil disturbance and overland flow generation is relatively high.

- Preliminary evidence indicates that grazing management has a very large influence on soil physical condition (discussed in more detail in section 5) and thus the amounts of water and sediment yielded in overland flow from sub catchments used for winter forage crop grazing. Grazing direction, back-fencing and strategic grazing of CSAs are important management considerations that can help reduce sediment losses.

3.4 Knowledge gaps

Our knowledge of the impacts of winter forage crop grazing by cattle is rather limited. This is because there are few published studies available, yet there are a number of management, soil and climate factors that are highly likely to determine contaminant losses to water. Some particular knowledge gaps include:

- The risk of N leaching from excessively-drained soils that are often used for wintering cattle on forage crops is likely to be very high; quantification of this risk is a matter of some urgency given the widespread use of such soils and the fact that they are usually highly "connected" to rivers and aquifers.
- Current options for mitigating N leaching losses from grazed winter forage crops are not particularly cost-effective. Further R&D is required to provide affordable alternative wintering options that have a lesser impact on water quality.
- The effectiveness of DCD for reducing N leaching losses from forage crops also needs to be better understood. Some specific questions include: would repeated applications of DCD be a cost-effective strategy for its use?; how much subsequent yield does the conserved N deliver?; how does soil type affect DCD effectiveness, particularly soil attributes such as plant available water holding capacity? The potential off-site impacts of DCD, such as its effects on aquatic ecosystems, also needs to be better understood.
- Our understanding of the hydrology of rolling landscapes that are used for winter forage grazings is relatively weak. Improved understanding of these flow processes would help us to provide management decision

guides that would much reduce or avoid contaminant losses from CSAs, for minimal cost.

4. The potential impacts on nwater quality of wintering sheep or deer on forage crops

There are few studies reported in the literature that have measured losses of potential water pollutants derived from winter forage crops grazed by stock classes other than cattle. Those that are in the literature are briefly summarised below.

4.1 N losses

Sheep studies

There are two studies that document measurements of N leaching from lysimeters that were managed to simulate the effects of intensive winter sheep grazing. Both used shallow lysimeters of only 30 cm depth. Given that the measured losses from such shallow lysimeters are likely to represent a worst case scenario, results should be interpreted with caution. Scaling these results in both time and space to estimate equivalent annual paddock losses is another difficult challenge for these types of studies. The relative effects of the treatments imposed can be informative, however.

Moir et al. (2010) reported that DCD application to a ryegrass/white clover pasture treated with sheep urine (equivalent to 300 kg N applied ha^{-1}) reduced nitrate-N leaching from 147 to 44 kg N ha^{-1}. Urine and DCD applications were made in May. Three key points from this study are (i) almost 50% of the urine-N applied was lost in leachate/drainage, (ii) DCD was highly effective at reducing these losses, and (iii) N leaching losses from treatments that did not have urine applied were negligible. The high proportion of urinary N leached in this study seems unusual and may reflect the fact that shallow soil (Templeton silt loam) lysimeters were employed and inputs of rainfall (470 mm for the experimental period) were relatively high.

McDowell & Houlbrooke (2009) measured N leaching losses from a triticale crop that was treated with sheep urine (equivalent to 229 kg N ha^{-1} at each application) and DCD in May and July, in line with field operations that took place at the larger complementary

grazing trial that was located in North Otago. Nitrate-N leaching losses from the urine-treated lysimeters with and without DCD applied were 82 and 98 kg N ha^{-1}, respectively; this difference between treatments was not statistically significant, however. Nitrate leaching losses from lysimeters that did not receive urine were 31 (no DCD applied) or 22 (+DCD) kg N ha^{-1}, respectively. These higher losses from treatments without urine applied probably reflect the contribution to N leaching from un-utilised soil N that was mineralised during establishment and growth of the triticale crop. Two other key points from this study were (i) a large proportion (21%) of the urine-N applied was lost in leachate/drainage, and (ii) in contrast to Moir et al. (2012), DCD did not appear to be effective at reducing these losses.

Deer studies

To our knowledge, there is only one study that has reported measurements of N losses to water from land used for deer wintering. McDowell & Stevens (2008) document N losses in overland flow from small (2 x 2 m) plots located on adjacent pasture and swede paddocks on a deer farm in northern Southland that were monitored from 1 March to 31 October. As noted earlier, compared to transport in subsurface drainage, overland flow is usually a less important pathway of N loss from farms and so we cannot draw too many conclusions from the reported N losses. For the eight events recorded, the mean loads of total N in overland flow were equaivalent to 0.16 and 2.56 kg N ha^{-1} for the pasture and forage crop treatments, respectively. Ammonium-N accounted for 63% of these total N loads; concentrations of ammonium in overland flow were relatively high at 1 – 2 mg N L^{-1} for the pasture site, and 4 to 7 mg N L^{-1} for the crop site. High concentrations of ammoniacal-N in water can potentially pose a toxicity risk to fish if pH conditions are alkaline.

4.2 Sediment, P and faecal bacteria losses

Losses from sheep farms

The North Otago site study described by McDowell & Houlbrooke (2009; see Figure 3.2) included treatments where P and sediment losses in overland flow were measured from crop and pasture sites grazed by sheep. Some of the key findings from this study were:

- Cattle-grazing of the winter forage crop treatments led to greater volumes of surface runoff and greater losses of total P, filterable reactive P and sediment in overland flow than recorded for the sheep-grazed winter crop treatments. For

sediment and P, losses from the winter forage crop were about 40% greater for cattle than sheep (Figure 3.2).

- For the sheep-grazed treatments, losses of sediment from the winter forage crop (0.39 Mg ha^{-1}) were much greater than from pasture (0.06 Mg ha^{-1}); equivalent losses of total P were 0.9 and 0.6 kg ha^{-1}, respectively.
- The implementation of a 3 or 6 hour restricted grazing system reduced total P losses from the sheep-grazed forage crop by about 15%, and sediment losses by about 10%. Although these reductions are not particularly large, the observations support the preliminary findings from Telford (refer to section 3.2) which indicate that minimising soil treading damage through strategic grazing of cropland can help to reduce sediment and P losses in overland flow.

The large losses of water, sediment and P reported by McDowell & Houlbrooke (2009) may be at least partially attributable to the use of irrigation in their experimental treatments, which kept the soil close to field capacity for much of the time. Together with the relatively poor soil physical condition, these factors probably contributed to the large volumes of overland flow recorded from the crop treatments at the site over the 20 month monitoring period: 88 and 67 mm for cattle- and sheep-grazed crop, respectively.

Losses from deer farms

McDowell & Stevens (2008) document concentrations and estimated loads of sediment, P and *Escherichia coli* (*E. coli*) in overland flow from pasture and crop sites grazed by deer. These results (Table 4.1) show that concentrations of these analytes were greater after grazing than before, and generally greater from the winter forage crop than pasture. Of particular note was the relatively low DRP/TP ratio evident for the crop treatment. The authors suggested that there is a much greater potential for surface waterway contamination via overland flow from winter forage crops grazed by deer than pasture. Of concern was their observation that losses of dissolved analytes such as ammonium-N, DRP and E. coli were unlikely to be filtered by mitigation methods such as filter strips and riparian areas. Also of concern was the very high sediment loss esimated for the forage crop (1 Mg ha^{-1}).

Table 4.1. Mean concentrations (mg L^{-1} unless otherwise stated) and estimated loads (kg ha^{-1} unless otherwise stated) of N, P sediment and *E. coli* in overland flow from pasture and crop treatments grazed by deer (from McDowell & Stevens 2008).

	Concentrations		Estimated loads	
	Pasture	Crop	Pasture	Crop
Total N	1.8 – 6.0	4.2 – 11.5	0.16	2.56
Ammonium-N	1.1 – 2.1	3.8 – 7.2	0.10	1.62
Total P	2.5 – 6.0	1.3 – 5.6	0.19	1.60
Dissolved Reactive P	1.0 – 4.1	0.2 – 0.9	0.14	0.13
Sediment, g L^{-1} or Mg ha^{-1}	169 - 717	434 – 3126	0.03	1.01
E. coli, MPN 100 ml^{-1} or MPN ha^{-1}	29 - 363	21 – 3236	1.3×10^{8}	5.1×10^{10}

4.3 Summary of existing knowledge

- Lysimeter studies suggest that N leaching losses from sheep urine deposited to pastures or crops during winter are potentially very high.
- The reported effectiveness of the nitrification inhibitor DCD for reducing these winter losses of N is variable.
- The limited evidence available indicates that sediment and P losses from sheep-grazed winter forage crops are lower than from cattle-grazed winter forage crops.
- The limited evidence also indicates that greater sediment and P losses can be expected from sheep-grazed winter forage crops than from sheep-grazed pastures.
- Measurements of pollutant losses in overland flow indicate that winter forage crops grazed by deer also have a relatively high potential to adversely impact water quality and stream health.

4.4 Knowledge gaps

Our knowledge of the impacts of winter forage crop grazing by sheep is weak and limited by the scale of the experimentation that has been undertaken. Knowledge gaps include:

- A lack of data that quantifies N leaching losses from winter forage crops under grazing conditions typical of those employed on commercial farms. The methods employed to address this knowledge gap need to ensure that leaching

loss measurements are made at a soil depth that represents likely losses from the plant root zone.

- As being undertaken for dairy systems at Telford Farm, research also needs to quantify losses of water pollutants transported in surface runoff from sheep-grazed winter crops. This needs to be undertaken at a field or subcatchment scale that is more representative of flow processes than those determined using small scale plot experimentation. Confirmation that the Good Management Practice managements identified for dairy systems are equally relevant to sheep system would also be valuable.

5. The impacts of forage crop wintering systems on soil quality and subsequent plant yield

Winter forage crops can provide large quantities of standing feed on a relatively small area, at a time when there is usually a shortage of feed from pasture. The high densities of stock that are used to graze this standing crop can, however, result in considerable soil physical damage, because it typically coincides with a period of high soil water content. In spite of the high potential for soil damage, the effects of such high-risk grazing practices on soil physical quality under winter forage crops have received relatively little research attention. Studies that have been completed to date include the Hillend (South Otago) and Windsor (North Otago) trials reviewed above, on-farm assessments of winter-grazed forage crops in Southland, and field trials at Lincoln comparing the effect of different crop establishment practices. Salient findings from these studies are reviewed below.

5.1 Results from trials undertaken in Otago

Research conducted at the Hillend site showed that intensive cattle mob grazing by non lactating dairy cows (556 cows/ha) of a winter forage crop of swedes and kale lead to severe soil compaction (Drewry and Paton 2005). This was evidenced by large reductions in soil macroporosity values, a measure commonly used to assess soil physical integrity, in both on-off and continuous grazing management treatments (Figure 5.1). Research undertaken in Southland and elsewhere has shown that this measure is the most useful soil indicator of pasture yield responses (Drewry et al 2004) and the potential for losses of P and sediment in overland flow (McDowell et al. 2003b). As observed for pastures in other reported studies, the largest reductions in macroporosity

values were observed in the 0-100 mm soil depth. Back-fencing to minimise the risk of repeated treading damage to plots did not appear to result in improved scores for macroporosity. The influence of animal grazing and soil compaction on subsequent yields of brassica forage crops were not documented in this study.

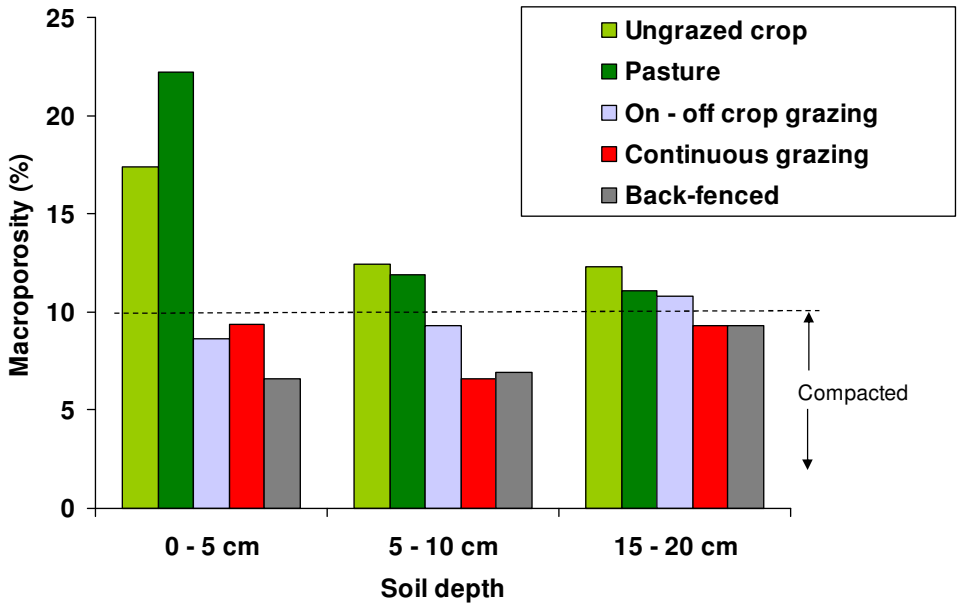

Figure 5.1. Soil macroporosity levels in contrasting grazing treatments at the Hillend (South Otago) study site (Drewry & Paton 2005).

Research conducted at the Windsor site compared the effect of cattle vs. sheep grazing management on soil quality. Due to their low carbon content, high clay content and impaired drainage characteristics, these soils have low soil strength and therefore are highly susceptible to soil structural damage when grazed. Kale, swedes and triticale were direct drilled in three consecutive years and soil physical (macroporosity, bulk density, structural condition score), chemical (total C, total N, C:N ratio) and biological (mineralisable N, mineralisable C, and earthworm mass and numbers) properties were assessed annually post-grazing in mid winter. Increased soil compaction was evident following grazing of the winter forage crops, with lower macroporosity values measured under cattle grazing relative to sheep grazing (Figure 5.2). Greater bulk density was also measured under cattle grazing for all years. However, there was no effect of stock type on crop yield for all three forage crops due to soil compaction. Furthermore, few differences in chemical or biological properties were evident between treatments following three years of continuous winter forage cropping.

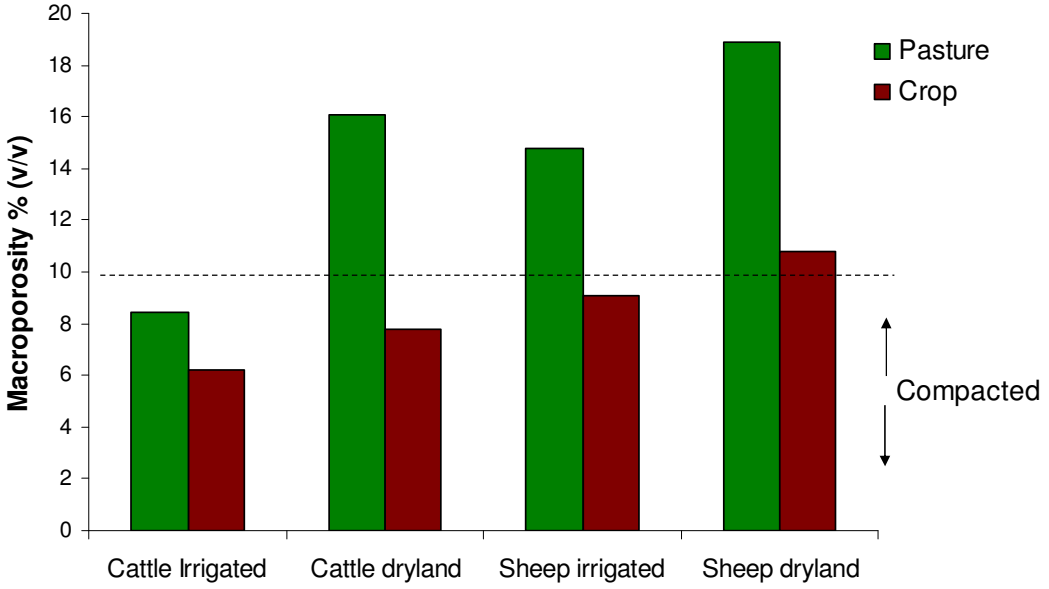

Figure 5.2. Mean soil macroporosity levels (0-100 mm depth) in pasture, forage crop, irrigation and stock type treatments at the Windsor (North Otago) study site (Houlbrooke et al. 2009 and unpublished data).

Recovery of soil structure

Compacted soils recover naturally under the influence of wetting and drying cycles, freeze-thawing cycles, pasture growth and earthworm activity. However, such processes tend to be influential in surface soils only and therefore have limited effect on soil structure at depth i.e. greater than 15 cm (Kværnø & Øygarden, 2006). Where soil compaction occurs at depths greater than this, mechanical aeration using a tractor and tine may be used to loosen soils (to depths of approximately 25 cm). This process improves soil drainage, aeration and subsequent pasture growth thereby catalysing soil structural recovery. Several studies have reported improved soil structure of Pallic soils in response to mechanical aeration whereby macroporosity increased by approximately 30%. However, re-compaction and settling following the re-introduction of cattle is likely if grazing coincides with high soil moisture content i.e. soil strength as a result of aeration remains largely unchanged. This will cause soils to revert back to their compacted state, a process that has been observed at the Windsor site (Figure 5.3).

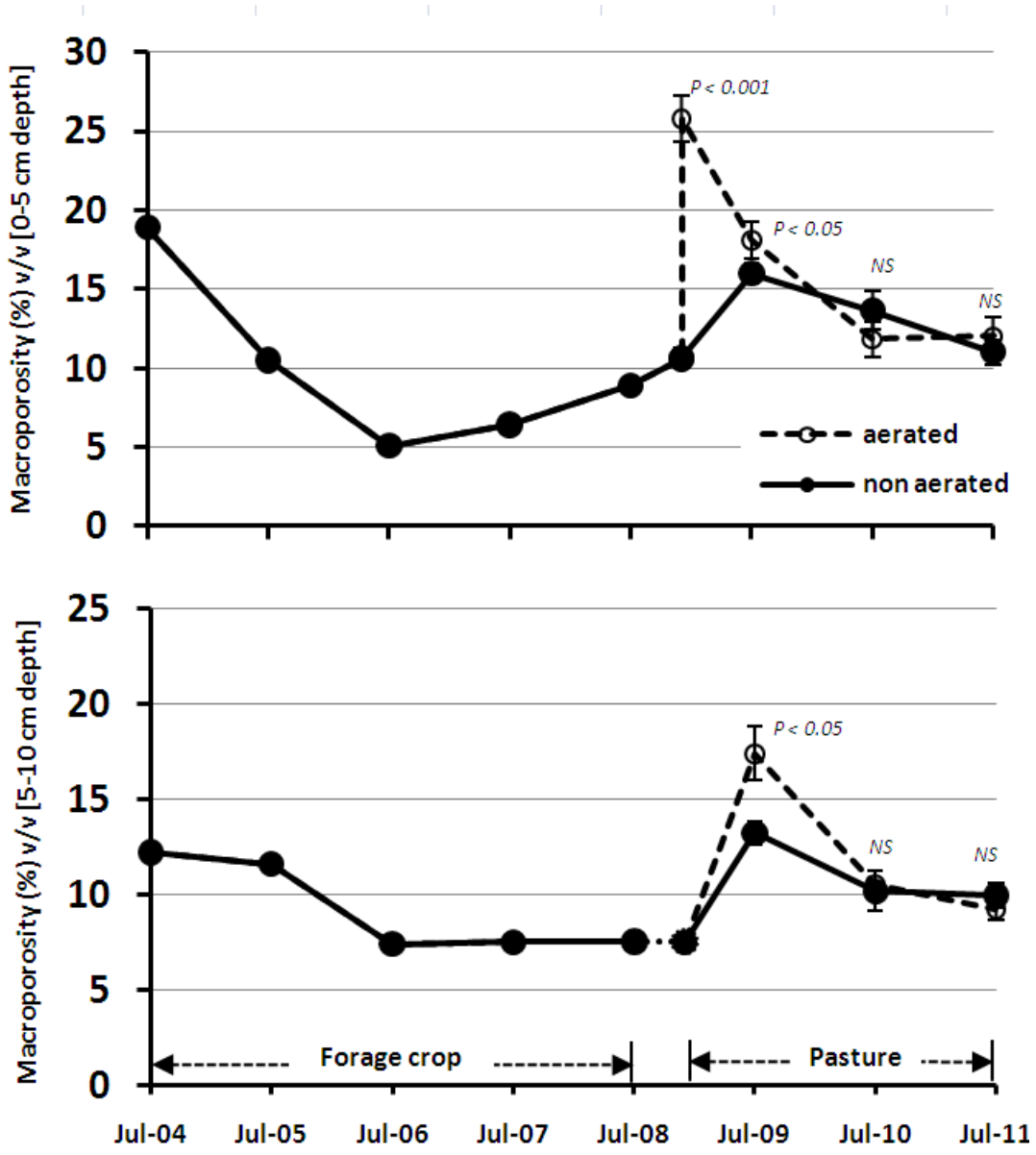

Figure 5.3 Changes in soil macroposity values due to forage crop grazing, pasture establishment and mechanical aeration of experimental plots at the Windsor (North Otago) study site (adapted from Houlbrooke et al 2009 and Laurenson & Houlbrooke 2012). For context, macroposity values less than 10% are considered to indicate a significant degree of soil compaction.

5.2 Results from monitoring undertaken in the Southern Wintering Systems project

The Southern Wintering Systems project is part of the Southern Wintering Initiative, a DairyNZ-led research project looking into how improved decisions around winter management leads to more profitable farms, good outcomes for animals and reduced environmental impacts (DairyNZ 2012). Five of the Dairy Monitor Farms that are the focus of this project are located in Southland, with a 6th located in West Otago. Part of the detailed monitoring being undertaken on these farms includes repeated measurement of soil physical quality on paddocks that have been used for winter forage crop grazing. Some summary findings from this on-going initiative are reported below.

Soil structure in winter forage crop paddocks on the Southland Dairy Demonstration Farm.

A sampling programme was initiated at the Southland Dairy Demonstration Farm (SDF) to monitor soil structural integrity in paddocks that were used for winter forage crops in 2011. The aims were to:

- determine the level of soil damage caused by cultivating and grazing the poorly-drained soils that have been used for winter forage cropping, and
- assess how quickly any soil damage incurred will recover in following years when the paddocks are eventually returned to pasture.

Soil macroporosity measurements from the 5-10 cm depth layer have been used as an indicator of soil structural integrity; research has shown that this metric is the most sensitive and reliable indicator of changes in soil structure under pastures. Results for the Makarewa (Typic Orthic Gley) and Northope (Mottled Immature Pallic) soil types, measured prior to pasture cultivation and before and after winter crop grazing, are shown in Figure 5.4.

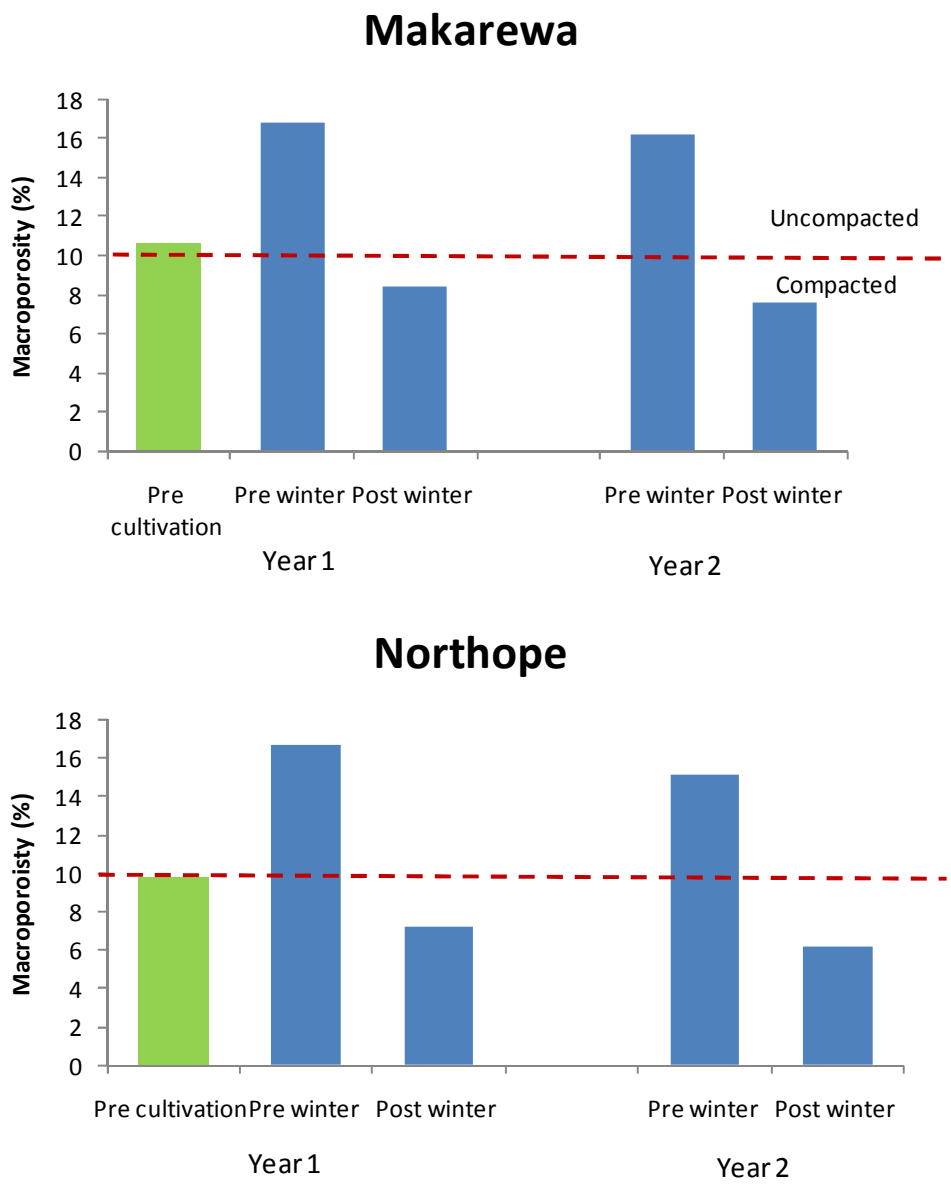

Figure 5.4. Soil macroporosity values (5-10 cm soil depth) in paddocks used for winter forage cropping.

These results show that winter grazing has considerably reduced soil macroporosity levels. Assuming values below 10% indicate a compacted soil (although because compaction occurs in a progressive manner, there is no obvious threshold to delinate good versus poor), we can see that the samples taken while the paddock was still in pasture could be classified as "OK". Although soil cultivation for crop establishment increased macroporosity values to over 15% in year 1 (2011), winter grazing caused a decrease to 8.4 and 7.2% for the Makarewa and Northope soils, respectively. These low scores will reduce water and air movement into the soil and compromise future plant growth. Cultivation at the end of year 1 appears to have ameliorated this soil damage,

although winter grazing in year 2 again reduced soil macroporosity values to levels below that measured in year 1. On-going monitoring as the paddocks are returned to pasture will determine whether this observed soil damage is a short-lived or longer-lasting effect of winter forage cropping.

Visual assessments of soil quality in paddocks used for winter forage cropping

In addition to the detailed measurements of soil macroporosity made at the Southland Demo Farm, visual assessments of soil quality were made for paddocks used for winter forage crop grazing on the other Monitor Farms. This procedure used the Visual Soil Assessment (VSA) method (Shepherd 2000) to score soil profiles located under pasture or under a forage crop before and after crop grazing. Mean scores are shown in Figure 5.5.

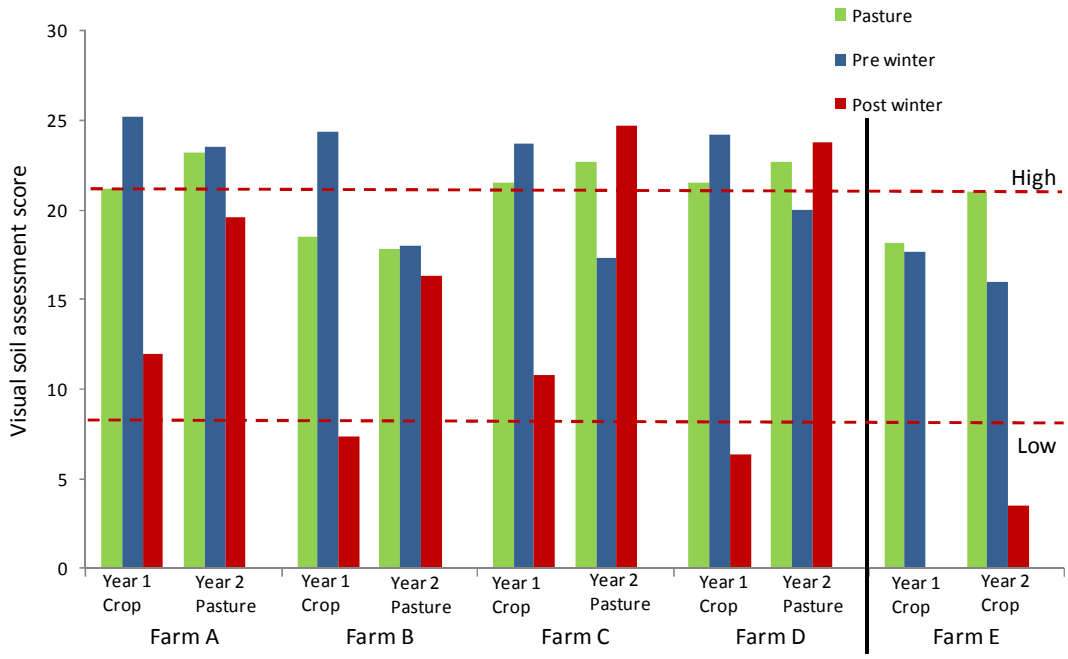

Figure 5.5. Visual Soil Assessment scores taken under pasture or under crop, before and after winter grazing.

These visual scores broadly support the detailed measurements made at SDF and show how the forage crop grazing has resulted in large reductions in soil quality on all the monitored paddocks. Encouragingly, observations on paddocks that were returned to pasture during year two of the monitoring programme suggests that these soils quickly recovered to have VSA scores at least as high as neighbouring pasture paddocks that had not been used for winter forage crops (Farms C & D) or had scores that were at

least 80% of those observed for neighbouring pastures (Farms A & B). This would suggest that a single year of winter forage crop grazing has not led to any long-term soil damage. It will be interesting to see whether two consecutive years of winter forage crop grazing on Farm E results in any such long term damage.

5.3 Results from trials undertaken in Canterbury

Research at Lincoln undertaken by Plant & Food Research was briefly summarised by Dr Mike Beare in an earlier review to DairyNZ (Monaghan et al. 2009). This research has focused on developing crop establishment and winter grazing practices that minimise the adverse effects of winter grazing on soil quality and forage production. For example, Thomas et al. (2004; 2008) showed that establishment of winter forage crops with no-tillage (direct drill) practices (ex pasture) reduced soil compaction during grazing and markedly improved the re-growth of cereal silage crops. In that trial, a multi-graze triticale (cv Doubletake) crop was sown on treatments established with three different tillage practices (i.e. conventional tillage, minimum tillage and no-tillage) following continuous pasture. The triticale was grazed in mid-winter and allowed to re-grow before a green-chop silage harvest in October. Simulated grazing (cow treading) was done at three different soil moisture levels: below field capacity (moist conditions), field capacity (soil saturated and allowed to drain for 24-48 hours) and above field capacity (soil saturated, water ponding).

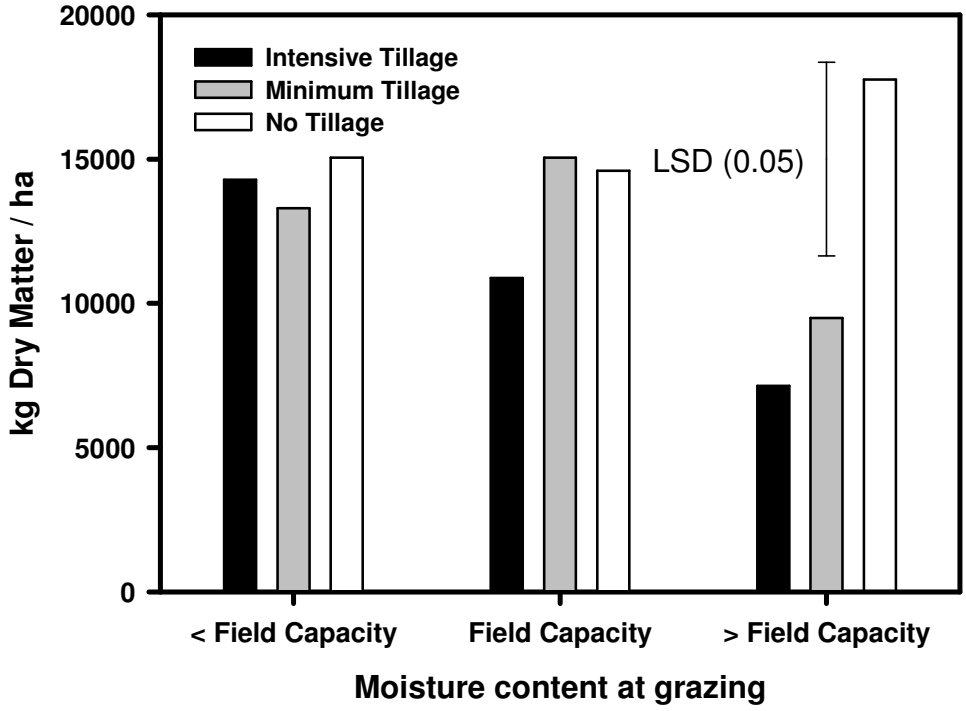

Figure 5.6: Dry matter production during the re-growth of triticale crops established with different tillage practices and grazed at three different soil moisture contents (Thomas et al. 2004).

Re-growth of the triticale was similar for crops established with all three tillage practices when grazed under moist conditions (< field capacity) (Figure 5.6). However, where the crop was established with minimum or intensive tillage practices and grazed under fully saturated conditions (> field capacity), re-growth was much less than for the crop established with no-tillage. The more stable soil surface (i.e. higher soil strength) created by direct drilling forage crops into long-term pasture appears to reduce the risk of surface compaction from heavy stock treading, even under very wet conditions. This reduction in compaction not only improved the re-growth of the forage crops but also reduced losses of nitrous oxide (a greenhouse gas)(data not shown, see Thomas et al. 2004; 2008). Further research is needed to evaluate the effects of these different establishment systems on forage crop production in the longer-term, to assess their effects on nitrate leaching and to adapt reduced tillage practices to the production of forage crop (including brassicas) in other regions.

5.4 Concluding remarks

Soil damage associated with winter grazing of forage crops can be viewed as short term if forage crop paddocks are used as part of a pasture renewal programme and cultivated in the spring prior to re-establishment with pasture species. However, for paddocks subjected to repeated use for winter forage cropping and grazing, as is sometimes the case on runoff blocks, this damage is likely to be cumulative and may approach thresholds where future productivity is compromised. Soils at the greatest risk of such damage are those that have a high Structural Vulnerability Index (Hewitt & Shepherd 1997), such as those found in the Pallic and Gley Soil Orders. The increased susceptibility to P and sediment losses in overland flow as a result of the deterioration in soil physical quality is another important consequence that needs to be considered when cropping rotations are planned. Some practical management options to minimise soil damage include:

- Although we have little quantitative data to prove the merits of back-fencing of daily breaks, visual observations would suggest that this practice will help to maintain soil infiltration rates.
- Reduced tillage methods for crop establishment.
- Ensuring paddocks are not cropped and winter-grazed for more than two years in a row.
- Where possible, locating winter forage crop paddocks on soil types that have a high degree of resilience i.e. a low Structural Vulnerability Index.

6. The role of alternative approaches to animal wintering

6.1 Herd Shelters

The use of covered housing systems for wintering cows in Southland (some examples shown in Photo 2) is becoming more common due to the myriad of difficulties sometimes experienced with forage crop wintering methods. These covered systems also offer benefits that can be captured outside of winter e.g. for tactical use as feeding platforms and/or standoff areas during wet spring periods. However, the environmental consequences of using housing systems during winter is relatively poorly understood. Based upon farmer experiences elsewhere, the tactical use of such systems is expected to provide greater flexibility for protecting soils and pastures from cow treading damage during wet periods, as commonly experienced in Southland during winter and spring. Their potential benefits for reducing nutrient and sediment losses from soil to water are less clearly defined, however. Although well-designed and managed housing systems

contain the excreta deposited by the herd during the wettest, and thus riskiest, time of the year, this containment can introduce additional system inefficiencies associated with storing and re-applying the excreta to fields when conditions permit. Increased emissions of the greenhouse gas methane is one such example of a potential introduced inefficiency; potential increases in ammonia volatilisation from stored and applied manures and slurries is another. The methods of handling and storage of collected excreta also have a large influence on such losses. Handling systems that produce large quantities of anaerobic manure are potentially likely to exacerbate methane losses, whilst systems that produce large volumes of dilute liquid effluent will require the provision of sufficient storage if runoff losses are to be avoided when this liquid effluent is applied to land. There is very little NZ-specific data available that quantifies the magnitude of some of these potential system inefficiencies. However, assuming that appropriate effluent management systems are in place, it can be assumed that housing approaches for wintering cows will result in less soil treading damage and reduced losses of nutrients and faecal microorganisms to water. These benefits accrue because the animals are prevented from treading on soils and pastures and depositing excreta during the wettest, and thus riskiest, time of the year for soil damage and nutrient loss.

An important programme of research that seeks to better define some of the consequences of using Herd Shelters as an alternative wintering option is the research being undertaken at Telford Dairy Farm as part of the Pastoral21 (P21) programme. Some of the relevant questions being addressed in this programme are (i) what are the characteristics (volumes and nutrient loads) of effluents generated from a Herd Shelter during winter, and (ii) what are the appropriate management practices that are required to ensure that use of the Herd Shelter does not create an additional set of environmental risks. Experimentation during winter 2012 has sought to identify whether it is safe to apply liquid effluent to soils during winter using low rate-low depth (LRLD) application methods. Preliminary assessments suggest that LRLD effluent application methods result in very high nutrient and bacterial attenuation by soil which, if confirmed for winter applications of effluent, will much reduce the costs associated with storing effluents generated from Herd Shelters during winter use. Another relevant programme of research that addresses concerns regarding potential emissions of greenhouse gases from contrasting winter system options is the SFF-funded project “Greenhouse gas footprints associated with housed (dairy) wintering systems” led by Dr Tony van der Weerden.

A desktop evaluation of the environmental and economic implications of using a covered wintering system on dairy farms in the Bog Burn catchment was documented by Monaghan et al. (2007). This suggested that dairy farm and catchment N losses could be significantly reduced by about 30% without incurring losses in farm profits. However, this evaluation assumed that a low-cost wintering shelter costing $470 per cow was used, a figure which is probably too low for the types of shelters often considered by farmers today; cost estimates for these currently range between $500 and $3000 per cow and are hence major farm investments.

6.2 Uncovered pads and feedlots

Uncovered pads and feedlots (some examples shown in Photo 3) are usually cheaper off-paddock wintering alternatives to many of the Herd Shelter options decribed above. If these systems are well-designed and managed they can prevent the escape of contaminants deposited in animal excreta and instead direct them to a collection area. The resulting effluents and sludges can then be stored until such time as soil conditions and grass pasture growth rates allow the nutrients to be either taken up by the plants or retained in the soil. As with animal housing structures, these facilities are also very useful for avoiding treading damage to soil during wet periods. There are however a number of design and management issues that need to be carefully considered to ensure these benefits are achieved.

Photo 2. Examples of some of the Herd Shelter systems that are used for cow wintering in southern New Zealand. (A) Herd Homes®, (B) Wintering Barn, and (C) Litter Barn.

Unsealed pads or feedlots have a high potential for leakage of faecal nutrients (N and P particularly) and micro-organisms into water-ways. In the case of P losses, calculations would suggest that the escape of as little as 5% of the excretal P deposited on an unsealed pad would represent an overall loss greater than that estimated for the excretal P deposited onto a grazed winter forage crop. In the case of N, the same calculation process would suggest that the escape of as little as 15% of the excretal N deposited on an unsealed pad would represent an overall loss greater than that estimated for the excretal N deposited onto a grazed winter forage crop. A design and management objective should therefore be to ensure that the capture of excretal nutrients and microbes is as close to 100% as practically possible. Achieving this goal will require that pad structures are engineered to (i) capture all of the surplus rainfall landing on the pad via the use of appropriate under-drainage, (ii) store this liquid material until such time as soil and growing conditions are favourable (often late spring in Southland), and (iii) apply the stored liquid and residual solid manure (e.g. spent sawdust/bark mix used on loafing areas) to land at the appropriate rates and hydraulic loadings to ensure that the material stays in the root zone.

The merit of storing winter-generated liquid effluent derived from uncovered pads and feedlots is the subject of on-going research, as noted in section 6.1. Farm surveys have noted that many farmers have limited effluent pond storage attached to uncovered pads and therefore apply liquid effluent to pasture during winter. Although this practice would normally be discouraged due to the lower potential for nutrient uptake by pastures during cooler winter months, and consequently higher leaching risk, the low rate and low depth application methods used for applying the effluent greatly help to minimise risks to water quality. This risk will be lower for soils that are well-drained and have little preferential flow. Completion of field research at Telford Dairy Farm will help to quantify this risk for poorly-drained soil types. An important aspect of this risk assessment will be comparing risks associated with off-paddock systems that apply effluent during winter to risks associated with wintering systems that use a grazed brassica forage crop. Although the latter wintering approach does not have the challenge of ensuring that the hydraulic loadings of effluent liquids are appropriate to soil type and soil wetness, it does have an increased risk of N loss from the concentrated cow urine patches that remain following crop grazing (section 3.1), and the potentially high losses of pollutants in surface runoff from CSAs (section 3.2).

Photo 3. Some examples of uncovered pads and feedlots.

The use of shallow and/or stony, very free-draining soils as standoff or feedlot areas is a high environmental risk activity. Although these surfaces will provide excellent drainage, and thus minimise overland flow transfers of P, sediment and faecal micro-organisms, this characteristic will also result in relatively high losses of soluble nutrients such as nitrate-N. There are unfortunately very few studies that have documented such losses within a context relevant to Southland. Studies in the US have documented extremely high concentrations of ammonium-N in soil profiles below feedlots. Lysimeter studies in Canterbury show that large quantities of nitrate-N can be leached from urine applied to stony shallow free-draining pastoral soils in late autumn (Di and Cameron, 2002a,b, 2007; Di et al. 2002) . Although these studies were not conducted to mimic conditions such as those found in winter feedlots, this set of data is probably the most relevant available for New Zealand systems where cows are wintered on shallow and very free-draining soils. There is some evidence to suggest that there is a higher nitrate leaching potential per unit of N applied at higher urine-N loading rates (Di and Cameron, 2007).

This suggests that the operation of unsealed feedlots can be expected to have a cumulative effect as the underlying soil becomes saturated, is less able to bind nitrogen, and proportionately more nitrate is lost from the soil profile. On feedlots, these effects will be exacerbated by the lack of pasture cover, which in a paddock situation would act as a sink for recovering urine-N.

6.3 All grass methods

To the author's knowledge, there are no reported studies which document the environmental impacts of all grass cow wintering systems under conditions relevant to Southland. This approach to dairy cow wintering is relatively uncommon within the province given the low winter pasture growth rates; past experience has actually led most farmers to actively preserve soils and pasture from hoof treading damage over the wet Southland winter. The most common strategies for achieving this were to send the animals away from the milking platform, often onto a forage crop on a dry stock farm, or to confine the area of damage to a forage crop paddock on the milking platform. The latter option would often fit within a farm re-grassing programme.

For some well-drained soil types, however, it will be possible to winter cows on pasture providing careful grazing management practices are considered. These would ensure that stocking densities/grazing pressures were reduced during periods when soils are particularly wet, either by spreading the animals out onto larger breaks or by sending the animals back to a stand-off pad. The latter system is successfully used by many dairy farmers under the high rainfall conditions of the West Coast. Losses of water pollutants in surface runoff from such management systems and soil types would be expected to be low relative to losses expected from grazed winter forage crops on heavier/more poorly drained soil types. We would thus expect lower yields of P, sediment and faecal bacteria from all grass wintering methods, assuming of course that the paddocks are located on the well-drained soil types that are required to make this type of wintering option feasible. It is difficult to determine whether we would expect lower N leaching losses from all grass wintering methods, however. On one hand, N leaching losses from all grass wintering paddocks will potentially be higher due to the more freely-draining nature of the soil type that is typically chosen for this wintering method. Conversely, the urine N deposited to the winter-grazed pasture has a greater potential for plant uptake when soil temperatures are more favourable in late winter/early spring. The potential for plant uptake of this urinary N is obviously much lower in paddocks that have been used for brassica forage crop grazing, which often lie bare until pasture or crop re-estbalishment late in the following spring.

6.4 Broader system considerations

Introducing infrastructure such as herd shelters or off-paddock feeding systems often acts as a catalyst for change in other aspects of the farming business. This is particularly evident for some dairy systems where the introduction of a herd shelter as an improved option for cow wintering has provided opportunity for greater farm productivity through intensification; indeed this is often an essential element of the business case to help cover the cost of the new infrastructure. Hence, increased per cow production through better feeding (often from imported supplement) and increased stocking rate may follow the shift to an indoor wintering system (e.g. Laurenson et al 2012). Although this intensification may potentially increase N leaching losses on a per hectare basis, the use of the herd shelter during the shoulders of the milking season may also confer some significant environmental benefits. Examples here would include:

- extending the use of the herd shelter into autumn to allow animals to spend more time off paddock, thus reducing their return of urinary N to pasture during this relatively high risk time of year (autumn-deposited urine has a much higher potential for loss via leaching than spring-deposited urine).
- also using the herd shelter during wet periods in autumn and spring to avoid/minimise soil and pasture damage as a result of animal treading. This would help maintain soil infiltration rates (and pasture growth) and thus reduce losses of water pollutants transported in surface runoff.

Another important consideration when exploring the role of a herd shelter or off-paddock wintering system is how the farming business will integrate with the cropping systems that often provide a significant source of high energy feeds to the dairy industry. This has important implications for nutrient balances and flows and accordingly for how effluents and manures are handled. Transfers of N and K in harvested crops that are fed back at the herd shelter can be particularly large and need to be replaced either via the manures and effluents captured in the herd shelter, or via artificial fertiliser. If the latter, care needs to be taken to ensure that the large amounts of K and N accumulated in the captured effluent are appropriately returned to the other pastoral blocks on the farm so as to maintain nutrient balance at farm, block and paddock scales.

The key points to make here are that (i) the introduction of additional farm infrastructure such as herd shelters may lead to positive or negative environmental outcomes, and (ii) it is important that tools such as the Overseer® Nutrient Budgets model are used to evaluate the full systems impact of the proposed changes in farm management on

nutrient flows and balances. Such tools such can also be used to explore the full potential of the new farm infrastructure to mitigate the farm's impact on the wider environment.

7. Environmental Risk Matrix

7.1 Matrix/ranking of environmental effects & activities: forage crop wintering

Based on our review of the literature and our knowledge of the influence that flow pathways have on contaminant losses, Table 7.1 below provides a relative ranking of the potential environmental risks associated with wintering animals on forage crops in the Southland region. These indicative estimates are categorised according to soil and topography risk factors and reflect how very well drained or excessively drained soils pose greater risk for N loss. Conversely, these soils pose less risk for P and sediment loss than soils that are poorly drained, have lower structural resilience or are located on sloping topography. There is thus no "ideal" soil type to choose to winter animals on. Due to the limited information available, the risk rankings between stock classes are best guesses based upon animal behaviour chartacteristics and nutrient excretion attributes.

Table 7.1. Ranking of relative environmental risks (potential) associated with wintering animals on forage crops in Southland.

Land use	Topography	Soil type	N loss	P loss	*E. coli* loss	Sediment loss
Dairy	Flat	Shallow, excessively drained	XXXXXX	?	?	Low
		Moderately deep soils	XXXXX	X	X	XX
		Poorly/artificially drained	XXXX	XX	XX	XXX
	Rolling	Moderately deep soils	XXXX	XXX	XX	XXXX
		Poorly-drained or low structural resilience	XXX	XXXX	XXX	XXXXX
Sheep	Flat	Shallow, excessively drained	XXXX	?	?	Low
		Moderately deep soils	XXX	X	?	XX
		Poorly/artificially drained	XX	XX	?	XXX
	Rolling	Moderately deep soils	XX	XX	?	XXX
		Poorly-drained or low structural resilience	XX	XXX	?	XXXX
Deer	Flat	Shallow, excessively drained	XXXX	?	?	Low
		Moderately deep soils	XXX	XX	XX	XXX
		Poorly/artificially drained	XX	XXX	XXX	XXXX
	Rolling	Moderately deep soils	XX	XXX	?	XXXXX
		Poorly-drained or low structural resilience	XX	XXXX	?	XXXXXX

7.2 Key management considerations to minimise the environmental impacts of animal wintering systems

7.2.1 Crop wintering systems

Based on the scientific information available to date, we can recommend some management practices that will help to minimise the risk of contaminant losses from grazed brassica forage crop paddocks to water:

- Choose the "right" paddock i.e. the paddock with least environmental risk posed by landscape factors such as structural vulnerability of soil type, poor drainage, steepness, proximity to waterways, etc.
- Use fertiliser calculators to determine appropriate nutrient requirements for crops
- Judicious timing of paddock cultivation; decreased tillage intensity
- Graze gullies and wet parts of the paddock as late in winter as possible to minimise their contribution to runoff. Ideally, leave buffer areas through swales; leave a minimum of a 3 m buffer along waterways. If you have to graze gullies and swales, use on-off grazing to minimise soil damage in these wet areas.
- Back-fence breaks to minimise soil structural damage.

7.2.2 Off-paddock wintering systems

Some important management practices that will help to minimise the risk of contaminant losses to water from off-paddock wintering systems include:

- Using nutrient budgeting tools to ensure farm blocks receive the appropriate amounts of effluent and fertiliser nutrients according to crop or pasture requirements.
- Ensure all drains are linked to effluent system; bund edges of pad and feeding areas.
- Increase storage capacity to remove the need to apply effluent to pasture over winter. Apply at correct rates when soil moisture and temperature conditions allow.
- Have a large enough contained sealed area to store solids until they can be applied when conditions allow.
- Store silage on concrete pad with bunded sides. Direct any silage leachate to effluent system; divert stormwater away from silage stack.

- If practicable and allowable, consider looking outside the farm boundary to apply effluent e.g. to a neighbouring farm that may have a more suitable soil type and topography.

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