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**The Efficacy of a Standoff Pad Wintering System to Capture Urine and
Mitigate Nitrate Leaching Whilst Maintaining Acceptable Levels of Animal
Performance**

A dissertation
submitted in partial fulfillment
of the requirement for the Degree of
Bachelor of Agricultural Science
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by

J. E.L Scahill

Lincoln University

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Abstract of a Thesis submitted in partial fulfillment of the requirement for
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**The Efficacy of a Standoff Pad Wintering System to Capture Urine and
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Wintering of dairy cows on high yielding forage crops is a key contributor towards total farm nitrate leaching losses. High stocking densities, and subsequent excretion of nitrogen-loaded urine, onto bare, saturated soils results in high nitrate leaching rates. Incorporation of standoff facilities into traditional *in situ* wintering systems has been suggested as a viable approach to mitigating nitrate leaching, but limited quantitative data exists for percentage of urine captured, and the performance of non-lactating dairy cows wintered under such systems.

Two winter systems were compared between June and July 2017 at the Ashley Dene Research and Development Station (ADRDS). Both systems fed fodderbeet (7 KgDM/cow/day fodderbeet, 4 Kg DM/cow/day silage) but in the control system, cows spent 23 hours/day grazing fodderbeet *in situ*, with a one hour supplement allocation period on a concrete feedpad while the comparison was a standoff pad system, where cows were restricted to a 6 hour fodderbeet allocation period (plus one hour on the feedpad), and spent 17 hours/day on a variety of stand of pad surfaces (stones, sand, woodchip and carpet). To quantify variation in urine deposition between the two systems, PEETER urine sensors were attached to cows and used to measure urination frequency and volume. Urination behavior from eight cows were successfully measured for a period of 24 hours. To compare the suitability of the farms systems from a production perspective, fodderbeet

and supplement utilization, cow liveweight, and body condition score were also measured throughout the trial.

Results show there was no difference in dry matter utilization ($94.2 \pm 3.4\%$), and liveweight gain (580 ± 6.7 gCow/day) between systems. Apparent energy consumption (123 MJME/cow/day) suggested that body condition score gain targets of 0.5 units would be achievable over a 60 day wintering period. Urination behavior was unaffected by wintering system, with average urination event volumes, urination event frequency's, and total daily urine volumes of (1.8 ± 1.03 l/event), (8.37 ± 4.34 events/day) and (15.12 ± 5.5 l/cow/day) were recorded. The percentage of total urine captured under the standoff pad system ($82 \pm 8.66\%$) suggest that the expected quantity captured is reflective of the duration of a stand off period. When compared to a 24 hour *in situ* system, the capture of 82% of urine reduced estimated urine coverage from 54.6% to 9.6% of total paddock area. Based on established leaching values under fodderbeet in stony, Canterbury soil types, this reduction in paddock urine coverage resulted in an estimated reduction in winter nitrate leaching of 31.4 Kg N/ha or 61.6%. It was therefore concluded that stand off pad systems can be effectively used to mitigate winter nitrate leaching whilst maintaining acceptable levels of cow performance.

Keywords: Dairy, nitrate, leaching, wintering, fodderbeet, urine, restricted grazing, utilisation, intake, body condition score, liveweight, standoff pad.

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1 INTRODUCTION

The dairy industry is a significant export earner, contributing in excess of \$13.59 billion annually to the New Zealand economy (Statistics NZ, 2014). Rapid intensification both at an on farm, and industry wide level, has resulted in an increase in the national cow herd of 1.2 million cows, with an associated increase in stocking rate of 0.1 cows/ha (DairyNZ, n.d). Whilst beneficial to farm profitability, and the New Zealand economy as a whole, the scale and intensity of New Zealand's dairy industry has significant environmental impacts (Baskaran, Cullen, & Colombo, 2009). Nitrate leaching from intensive production drives eutrophication and degradation of regional waterways; an issue that has come under considerable public scrutiny in recent times (Cameron, Di, & Moir, 2013; van Reenan, 2013). Subsequently, national policies have been released, mandating that regional councils manage land use to mitigate further environmental damage (Ministry for the Environment, 2017). In Canterbury, the country's most intensive dairying province, the 'Land & Water Regional Plan' has been implemented, ultimately functioning to enforce N leaching limits (DairyNZ, n.d). Farmers must therefore adapt their farm systems to meet regulatory standards. The traditional *in situ* approach to wintering has been identified as a key driver of whole farm/enterprise N leaching due to typically high stocking density's and excretion of N loaded urine onto bare, saturated soils (Monaghan, 2012). The "Pastoral 21" research programme has identified fodderbeet as the optimal wintering crop due to its inherently low N content (Shepherd, Shorten, Costall, & Macdonald, 2017). However, simply changing crop type does not address the impact of high stocking intensity's, and large nutrient load on wintering areas, and as such it has been suggested that stand-off pad wintering systems can achieve further reductions in winter N leaching (Shepherd *et al.*, 2017; Volger, Beukes, & Burggraaf, 2013). The efficacy of such systems is dependent on several factors; 1. the ability of cows to maintain DMI and achieve acceptable BCS/LW gains under a restricted grazing period and 2. the quantity of urine captured on the standoff pad and the subsequent reduction in paddock urine coverage achieved. Limited research exists specifically quantifying these factors. This research

project therefore aims to answer three key research questions to determine whether standoff pads represent a viable 'Next Generation Wintering System'.

1.1 Research Questions

This research project aims to answer three key research questions:

- Can non-lactating dairy cows achieve fodderbeet/silage intake rates > 10 kgDM/cow/day under a restricted grazing period?
- Can non-lactating dairy cows achieve acceptable BCS and LW gains under a standoff wintering system?
- What percentage of total urine volume will be captured under a standoff pad wintering system, and what effect does this have on paddock scale urine coverage and N leaching in Canterbury?

2 REVIEW OF THE LITERATURE

2.1 Introduction

The New Zealand Dairy industry has rapidly intensified both at an on farm, and industry wide level, driven by increased returns from milk production (Baskaran *et al.*, 2009). An increase in the national cow herd of 1.2 million cows, has been associated with a rise in average stocking rate of 0.1 cows/ha (DairyNZ, 2016). Whilst beneficial to farm profitability, and the New Zealand economy as a whole, intensification has environmental implications. High levels of nitrate leaching stimulate eutrophication and degradation of aquifers and waterways (Cameron, Di, & Condron, 2002; Colins *et al.*, 2007; Flemmer & Flemmer, 2008). Government policies have been released, mandating that regional authorities manage land use to reach targeted reductions in nitrate leaching (DairyNZ, n.d; Ministry for the Environment, 2017). Farmers are therefore looking to adapt their operational systems to the new reality of 'farming within limits' (van Reenan, 2013)

This literature review discusses the environmental impacts of intensive dairy production, identifies the traditional wintering approach as a key driver of total farm nitrate leaching, outlines recent research into 'Next Generation Wintering Systems', and discusses shortfalls in the research surrounding the use of restricted grazing and standoff pad systems to mitigate winter nitrate leaching.

2.2 Nitrate Leaching and Environmental Impacts

Nitrogen (N) is an essential element for plant growth as it is a primary constituent of amino acids, proteins, chlorophyll molecules (Hatch, Goulding, & Murphy, 2002), enzymes and co-enzymes (Mclaren & Cameron, 1996). To become available for plant uptake, N must be mineralised into (NH_4^+), or nitrified into nitrate (NO_3^-). Figure 2-1 displays this in the nitrogen cycle (Cameron *et al.*, 2013). The process of nitrification represents an environmental issue; As nitrate is negatively charged, it is not retained within the soils cation exchange matrix (Mclaren & Cameron, 1996). As such, when large drainage events occur, a portion of free moving NO_3^- will be leached from the soil solution, and distributed into local waterways and/or aquifers. Increased nitrate concentration in waterways deteriorates water quality and decrease ecosystem diversity (Cameron *et al.*, 2002; Colins

et al., 2007; Flemmer & Flemmer, 2008). This is driven by eutrophication and the subsequent shading of rivers/lakebeds. As waters shift to trophic levels, populations of plankton, cyanobacteria and blue-green algae increase, resulting in oxygen deprivation and subsequent fish death. A waterway is deemed eutrophic when total N content reaches 0.4-0.6 mg N L (Di & Cameron, 2002). Whilst the quality of waterways in New Zealand is high by international standards, significant degradation has been observed over the past five decades (Baskaran *et al.*, 2009). Thirty percent of major NZ rivers have higher NO_3^- concentrations than were measured in the 1970's, and currently, 31.8% of New Zealand's total river length does not meet acceptable guidelines for fresh and marine water quality (Ministry for the Environment, 2011). Furthermore, approximately 39% of monitored groundwater bodies contain elevated nitrate levels above natural background concentrations (Ministry for the Environment, 2011). It is therefore apparent that nitrate leaching is a significant environmental issue.

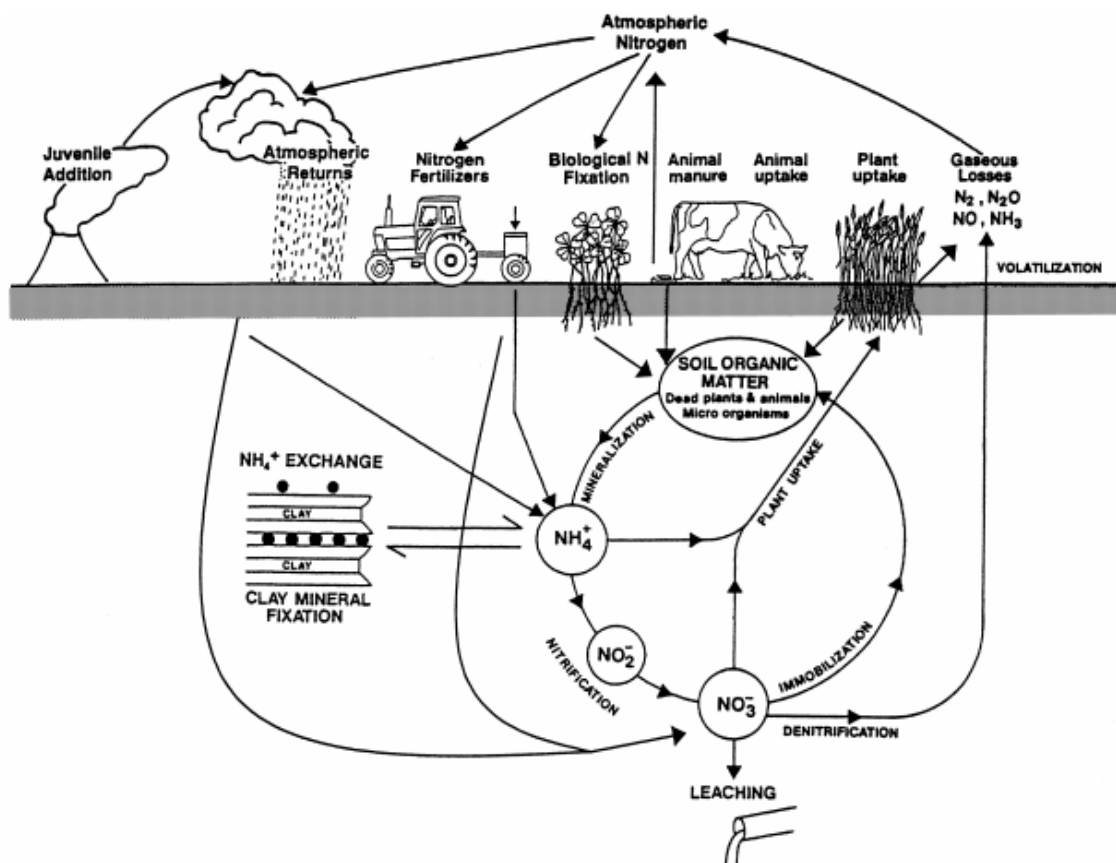


Figure 2-1 The Nitrogen Cycle.

2.3 Nitrate Leaching from Intensive Dairy Systems

It is well established that New Zealand dairy farms leach significant quantities of nitrate (Clark, Givens, & Jeannie, 2007; Parliamentary Commissioner for the Environment, 2004). The quantity of nitrate lost from the soil solution is ultimately driven by two fundamental factors; the amount accumulated in the top soil in excess of plant requirements, and drainage volume through the soil profile (Di & Cameron, 2002). Reflecting this, the greatest period of nitrate leaching typically occurs in autumn and winter, when excess rainfall exceeds evapotranspiration, soil water levels rise above field capacity and plant growth potential is low (Cameron *et al.*, 2013). Drainage volume is typically outside of the farmer's control (except for poor irrigation management). However, the quantity of nitrate in the soil, is driven to a large extent by farm system intensity (Di & Cameron, 2002). Reflecting this, dairy farms have been shown to leach significant quantities of nitrate (25-110 Kg N/ha) when compared to alternative systems such as sheep, grazing and cropping (6-58 Kg N/ha) (Cameron *et al.*, 2013). The observed difference in system nitrate leaching is driven by greater nitrogen fertiliser application (Food and Agriculture Organization of the United Nations, 2014), allowing for increased stocking rates and subsequently greater nitrate losses from grazing. The various sources of nitrate leaching are displayed in figure 2-2 (de Klein *et al.*, 2010).

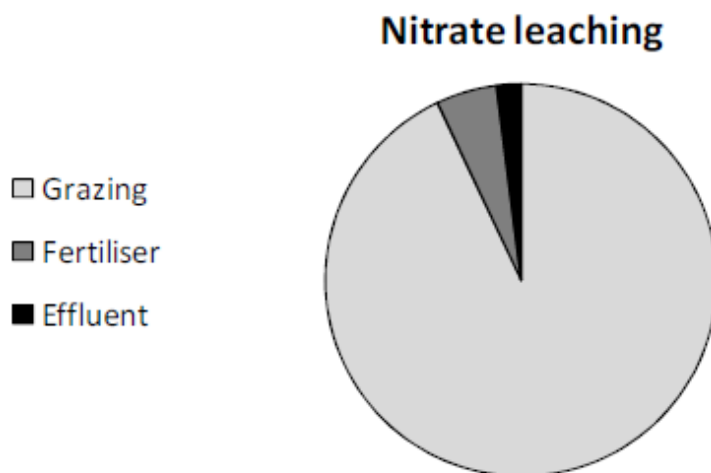


Figure 2-2 Sources of nitrate leaching in intensive dairy systems.

In Canterbury, nitrate leaching is driven by regional environmental factors; hot, dry summers facilitate topsoil accumulation of NO_3^- and subsequently, greater leaching rates in autumn and winter (Cameron *et al.*, 2002). The region's stony soil types (such as Lismore stony loam and Waimakariri sandy loam) facilitate rapid drainage, and subsequent removal of nitrate from the soil matrix (Cameron *et al.*, 2013). Furthermore, Canterbury's average stocking rate (3.25 cows/ha) is 18% higher than the national average (DairyNZ, 2016), driven by the development of efficient irrigation systems (Sage, 2008). Subsequently, it is recognised as New Zealand's most productive region on a milksolids per hectare basis, and accounts for 13.8% of the national cow herd (DairyNZ, 2016). High levels of nitrate leaching have therefore been reported in the Canterbury region (Lilburne *et al.*, 2013). It is apparent that dairy production in Canterbury and New Zealand as a whole results in significant levels of nitrate leaching, primarily driven by losses from grazing (stocking rate).

2.3.1 Nitrate Leaching from Grazing- Urinary N Excretion

A primary inefficiency of pastoral based farming systems is the discrepancy between plant and animal N requirements for optimal production; dietary N requirements of mature dairy cattle range from 1.8-2.2% of DMI (Pacheco & Waghorn, 2008), considerably lower than the potential forage N content of 3.4% (de Klein *et al.*, 2010; Ledgard, de Klein, Crush, & Thorrold, 2000). As such, it has been shown that N voided in urine is closely linked to dietary N content, with 75-95% of dietary N intake being excreted (Dijkstra *et al.*, 2013; Eckard, Grainger, & de Klein, 2010). Subsequently, in dairy cows, were N intakes can exceed 400g N/cow/day (Castillo, Kebreab, Beever, & France, 2000), mean urine N concentrations of 5.5g N L^{-1} - 8.6g N L^{-1} and total daily excretions of 80-320g N/cow/day have been reported (Betteridge *et al.*, 2013; Shepherd *et al.*, 2017; Whitehead *et al.*, 1995). Subsequent urine patch N loading rates between 200-2000 Kg N/ha have been outlined by Selbie, Buckthought, & Shepherd, (2015), with it being generally accepted that the average N loading rate is somewhere in the range of 800-1300 Kg N/ha (Cameron *et al.*, 2002; Eckard *et al.*, 2010). It has been estimated that 8%-20% of N applied as urine is leached (Cameron *et al.*, 2002) and therefore it can be concluded that urinary N excretion is a key driver of nitrate leaching, particularly under high stocking rates.

2.3.2 The Challenges of Wintering Dairy Cows in Relation to Nitrate Leaching

Wintering can be broadly defined as “the activity of feeding cows for the 12 week period from late May to late August (Monaghan, 2012). Common practice is to graze winter forages *in situ* (Chrystal, Monaghan, Dalley, & Styles, 2012) to address the typically low pasture growth rates and rapidly increasing maternal energy demands during this period (Dalley, 2013). The high yields of quality forage produced by crops such as kale and fodderbeet (Chakwizira *et al.*, 2012) allow for stocking density’s in excess of 300-3000 cows/ha (Cichota & Snow, 2009). Assuming a single annual grazing, this equates to a stocking intensity of up to 3000 cow grazing days/ha/yr, considerably greater than the 700 cow days/ha/yr reported for rotationally grazed pastoral blocks (Moir, Cameron, Di, Fertsak, 2010; Whitehead, 2000). As such, comparatively high levels of total paddock urine coverage, and N leaching can be expected under winter forages. In rotational grazing systems, 0.5-9% of the allocated area will receive a urination event within a 24 hour period (Vellinga *et al.*, 2001), accumulating to 10%-29% annually (average=23%) (Moir *et al.*, 2010; Macklusky, 1960; Williams, 1998; Whitehead, 2000; White, Sheeld, Washburn, King, & Green, 2001). In forage based wintering systems, Ravera *et al.*, (2015) reported urine coverage of 61% and 58% for fodderbeet and kale crops respectively, reflecting the conclusion of Moir *et al.*, (2010) that an increase in stocking intensity of 10000 cow grazing hours/ha/yr will result in a 7% increase in paddock urine coverage. Subsequently, winter forage blocks have been shown to leach significant quantities of N, ranging from 51-173 Kg N/ha across a variety of climate, crop and soil types (Dalley, 2011; Shepherd, Stafford, & Smeaton, 2012; McDowell & Houlbrooke, 2009; Monaghan, Smith, & de Klein, 2013; Monaghan, 2012; Smith, Orchiston, & Monaghan, 2012). As such, it has been outlined that winter forage blocks account for disproportionate quantity of whole farm N losses; 11%-60% from 4% -15% of the total farm area (Chrystal *et al.*, 2012; Monaghan, 2012). It is therefore apparent that the traditional *in situ* approach to dairy farm wintering is a significant contributor to total system N leaching. Whilst wintering often occurs on support blocks rather than the milking platform, its environmental impact is ultimately part of the dairy enterprise.

2.4 Public Concern and Government Regulation

The apparent contribution of intensive dairy production towards waterway degradation has been recognised, and as such, public pressure for improved environmental practice has increased (Scarsbrook, 2013; van Reenan, 2013). In response, a series of governmental policies have been released, outlining quantifiable targets for regional and national water quality; In 2011 the 'National Policy Statement for Freshwater Management' was released (Ministry for the Environment, 2011), whilst more recently, the "Clean Water Package" was launched, with an aim of 100% 'swimmable' water ways by 2050 (Ministry for the Environment, 2017). These policy's ultimately mandate that regional councils manage land use to maintain water quality. In Canterbury, farmers must operate under the councils 'Land & Water Regional Plan'. This involves a consent to operate, establishment of a nitrogen baseline, and development of a farm environmental plan to ensure that annual nitrate leaching remains below the established baseline level (DairyNZ, n.d). Furthermore, farm systems with comparatively high N baselines will be required to meet lower determined 'good management practice' loss rates by 2020 (DairyNZ, n.d). Wintering practices will also be regulated; from 2020 onwards, consent will be required to establish winter forage crops over more than 10% of the total farm area (DairyNZ, n.d). It is therefore apparent that intensive dairy operations in Canterbury (and nationwide) must adapt their systems to the reality of farming within limits (van Reenan, 2013).

2.5 Next Generation Wintering Systems

It is apparent that the wintering period is a key contributor to total farm nitrate leaching, due to high stocking density's and urine patch coverage (Cichota & Snow, 2009; Ravera *et al.*, 2015), negligible N plant uptake, and high drainage volume (Cameron *et al.*, 2002). Therefore, a key regional focus of the DairyNZ Pastoral 21 programme in Canterbury has been on developing 'Next Generation Wintering Systems' that allow farmers to meet baseline N leaching rates (Shepherd *et al.*, 2017). To date, a series of trials have identified fodderbeet as the ideal crop for dairy cow wintering, due to its inherently low CP (<10.9%/DM) and low forage N content (<2% DM) (Edwards *et al.*, 2014; Farrel *et al.*, 2016; Jenkinson, Edwards, & Bryant, 2014). As discussed, the quantity of N voided in urine is ultimately reflective of dietary N intake (Dijkstra *et al.*, 2013; Eckard *et al.*, 2010), with significant reductions observed at intakes below 400 g N/cow/day (Castillo *et al.*, 2000). At

moderate to high DM allowances, cows offered fodder beet, will achieve a significantly lower nitrogen intake, than those offered kale, or pasture (231 g N/cow/day vs >400 g N/cow/day)(Edwards *et al.*, 2014; Jenkinson *et al.*, 2014). As such, reduced urine N concentrations (2.1-4.02 g N/L) and urine patch N loading rates (190-300 Kg N/ha) (Edwards *et al.*, 2014; Farrel *et al.* 2016; Hogg, 1981; Jenkinson *et al.*, 2014) have been reported. It has been established that the quantity of urine N leached increases exponentially with urine patch N loading rate (de Klein *et al.*, 2010). Reflecting this, lysimeter based trials reported leaching losses of 21-32% and 43-54% of urine N deposited under fodderbeet and kale wintering systems respectively. The lower leaching rate observed under fodderbeet was attributed to reduced urine N loading, supporting the presumption that that allocation of low CP/N forages can reduce urinary N leaching on a per cow basis (Li, Betteridge, Cichota, Hoogendorn, & Jolly, 2012; Malcolm, Cameron, Edwards, & Di, 2014). Estimated paddock scale leaching rates of 64-79 Kg N/ha (Malcolm *et al.*, 2016), suggest that N losses under fodderbeet systems will be at the lower end of the 51-173 Kg N/ha range reported across a variety of winter forages (Shepherd *et al.*, 2012; McDowell & Houlbrooke, 2009; Monaghan *et al.*, 2013; Monaghan, 2012; Smith *et al.*, 2012). However, simply reducing dietary N intake does not address the effect of high stocking densities on paddock urine patch coverage. It has therefore been suggested, that incorporation of a stand-off pad into an *in situ* fodderbeet wintering system may further reduce nitrate leaching (Shepherd *et al.*, 2017). Standoff pad systems ultimately function as a hybrid between wintering barns and *in situ* systems, whereby cows spend only the time required to consume their forage allocation in the paddock, typically 4-8 hours. Under such systems, a portion of total urine, excreted will be captured on the stand-off, rather than being deposited on the soil (Volger *et al.*, 2013).

2.6 Farmer Adoption

The increasing public and regulatory pressures for agricultural production systems to meet environmental benchmarks requires farmers to invest in mitigation strategies. In a farmer survey, Dalley, (2011) reported that 45% of respondents had adapted their wintering approach away from *in situ* systems in the 5 years preceding 2013. 14% did so because of environmental concerns, suggesting that farmers are willing to invest in sustainable best practice. However, 61% of respondents suggested that capital was a key barrier to

incorporating housing/structures into their wintering systems. Simple standoff pads represent an economic alternative to traditional wintering barns. The reported capital outlay of \$125-\$400/cow (Beukes, Gregorini, Romera, & Dalley, 2011; de Klein, Monaghan, Ledgard, & Shepherd, 2010), is considerably lower than \$1500-\$3220/cow required for construction of a fully enclosed wintering barn (de Wolde, 2006; Journeaux, 2013; New Zealand Institute of Primary Industry Management, 2014). From an operational perspective, standoff pad systems are cheaper than housed systems, as cow's still harvest forage *in situ*, eliminating the requirement to cut and carry feed, and reducing the portion of supplement in the diet (de Klein *et al.*, 2010). It is therefore apparent that stand off pads represent an economical alternative system to traditional on farm structures, that does not require a significant shift away from the typically favored 'grass based' approach. However, for farmer adoption to occur, it must be proven that that standoff pad systems can effectively mitigate nitrate leaching, to meet regulatory benchmarks, whilst maintaining acceptable levels of animal performance.

2.7 Efficacy to Meet Animal Performance Targets

The effectiveness of any wintering system is measured by the capacity for cows to meet BCS/LW targets. A BCS of 5 and 5.5 is optimal at parturition for cows and heifers respectively, with a typical gain of 0.5 units required over winter (Holmes *et al.*, 2007). The maintenance/pregnancy/activity energy requirements of a non-lactating dairy cow is expressed as $10.5 \text{ MJME/Kg LW}^{0.75}$, equating to 103 MJME/day for a 510 kg animal (Nicol & Brookes, 2007). Edwards *et al.*, (2014) suggested that an additional 14-16 MJME/day is require to gain weight in the cooler Canterbury climate, accumulating to 117-119 MJME/Day to achieve a total winter BCS gain of 0.5 units over a 60 day wintering period. BCS gains ranging from 0.05-0.8 have been outlined across a range of forages at moderate-high allowances (Keogh, French, McGrath, Story, & Mulligan, 2009; Edwards *et al.*, 2014). The disparity often observed between estimated ME intake and actual BCS/LW gain is attributed to overestimation of crop yields, underestimation of energy requirements, and incorrect allocations (Judson & Edwards, 2008). However, at actual ME intakes in excess of 119 MJME/cow/day, targeted BCS gains (>0.5 units per 60 days) can be achieved (Edwards *et al.*, 2014; Judson *et al.*, 2008; Rugoho, Gibbs, & Edwards, 2014). Edwards *et al.*, (2014) reported BCS gains of 0.74-0.78 when cows achieved an energy intake of 155

MJME/cow/day from a 13.1 Kg DM/cow/day intake of fodderbeet and silage. For a typical fodderbeet wintering diet (65% fodderbeet, 35% ryegrass silage (Al Marshadesh *et al.*, 2017; Edwards *et al.*, 2014), a DMI of 6.3 Kg DM/cow/day of fodderbeet (12.2 MJME/Kg DM. Edwards *et al.*, 2014), and 3.7 KgDM/cow/day of silage (11.1 MJME/Kg DM. de Ruiter *et al.*, 2007) would be required. It is therefore apparent that to meet typical winter BCS targets, intakes of 10Kg DM/cow/day must be achievable. Under natural ad-libitum conditions, cattle display two distinctive grazing bouts (morning and evening) (Gregorini *et al.*, 2009; Linnane, Brereton, & Giller, 2001; Rook, Huckle, & Penning, 1994). However, it has been suggested that restricted grazing drives impulsion to maximize intake rate because of behavioral adaptations (Greenwood & Demmet, 1988). As such, significant ($P < 0.05$) increases in bite rate, bite mass (0.69 g/bite vs 0.49 g/bite) and reduced handling time (690 min vs 950 min) have been reported when grazing is restricted to 6 hours/day (Kennedy *et al.* 2009). Reflecting this, it has been observed that >70% & >80% of perennial ryegrass intake can be achieved within two and four hours of allocation respectively (Dobos, Fulkerson, Sinclair, & Hinch, 2009), whilst Gregorini *et al.*, (2009) showed that cows offered pasture once a day consumed 10 kg DM/cow within three hours. It is therefore apparent that when offered pasture, the rate of DM consumption can be increased by upto 27% (Greenwood & Demmet, 1988), and the grazing period can be restricted to as low as four hours with negligible impacts on DMI and animal performance (Perez-Ramirez, Delgarde, & Delaby, 2008). However, little works exists on the restricted intake of winter forage crops. It must therefore be considered that utilization and total intake of bulb dominant crops such as fodderbeet may be reduced with restricted grazing, due to bulbs having to be removed from the soil prior to consumption. Thompson & Stevens (2012) observed a 4.8 KgDM/cow intake of swedes within 5 hours of allocation. Whilst cows offered fodderbeet have been shown to achieve a six hour DMI of 7.2 KgDM/cow (90% utilization) (Jenkinson *et al.*, 2014). Whilst indicative of high restricted intakes of winter forages, neither of these trials actually restricted grazing periods, rather intake rates were measured five to six hours' post allocation. Subsequently, the adaptive behavioral changes outlined by Greenwood & Demmet (1988) may not have been expressed. Furthermore, it has been postulated that using an 'uncomfortable' standoff surface may reduce DMI, as cows will favor lying rather than foraging when in the paddock (R. Bryant personal communication, May 2017). Reflecting this, Fisher, Stewart, Verkerk, Morrow, &

Matthews, (2003) reported lying times (6-7 hours/day) significantly lower than established optimum of >12 hours/days when cows were held in concrete yards and/or on gravel laneways. Decreased lying time results in increased energy expenditure and depression of anabolic metabolism induced by release of stress hormones. (Fisher, Verkerk, Morrow, & Matthews, 2002). As such, reduced winter BCS/LW gains have been reported under various standoff pad wintering systems (Fisher *et al.*, 2003; Webster *et al.*, 2007). It is therefore apparent that further research is required to quantify the effects of a restricted grazing, standoff pad system on forage crop DMI and BCS gain over winter.

2.8 Efficacy for Standoff Pads to Reduce Nitrate Leaching

The efficacy of a standoff pad system to mitigate N leaching will be reflective of the quantity of urine captured, and the associated reduction in paddock urine coverage. Restricting grazing from 24 to six hours daily, at a stocking density of 3000 cows/ha (over the daily crop area allocated), would reduce stocking intensity from >70,000 cow hours/ha/yr, to <18,000 cow hours/ha/yr. The findings of Moir *et al.*, (2010) suggest that this would reduce paddock urine coverage by 35% (7% reduction per 10,000 cow h/ha/yr). Based on established N leaching rates under fodderbeet in Canterbury (Malcolm *et al.*, 2016), a 35% reduction in urine patch coverage would result in an approximate decrease in N leaching of 11.9-18.9 Kg N/ha. As such, it has been suggested that reductions in N leaching of 30-65% have been can be achieved with standoff durations of 16-20 hours/day (Christensen *et al.*, 2011; Environment Waikato, 2008; Lindsay *et al.*, 2011). It is therefore apparent that standoff pad systems have potential to mitigate N losses to water. However, the extent of mitigation will be reflective of the quantity of urine captured. A strong understanding of dairy cow urination behaviour, and the temporal distribution of excretion is therefore required.

2.8.1 Urination Behavior

Previous research has outlined significant inter-cow variability in total daily urination volume (13-54.7 l/cow/day), average event volume (0.3-2.2 l/event), and event frequency (5-18 events/day) (Aland, Lidfors, & Ekesbo, 2002; Betteridge *et al.*, 1986; Castle, Foot, & Halley, 1950; Fuller, 1928; Haynes & Williams, 1993; Misselbrook *et al.*, 2016; Selbie *et al.*, 2015; Shepherd *et al.*, 2017). Average urine patch areas range from 0.03-0.7 m²,

accumulating to daily per cow urine patch coverage of 0.68-3.3m²/cow/day (Aland *et al.*, 2002; Betteridge *et al.*, 1986; Castle *et al.*, 1950; Haynes & Williams, 1993; Misselbrook *et al.*, 2016; Selbie *et al.*, 2015). Total urination volume, and thus daily urine patch coverage is ultimately reflective of the need to expel minerals and electrolytes from the body (Bannink, Valk, & Van Vuuren, 1999; 2012 Khelil-Arfa, Boudon, Maxin, & Faverdin, 2012). Subsequently, increases in DM, CP and N intake result in greater urine production. As such, it has been shown that non-lactating, fodderbeet fed cows produce comparatively lower volumes of urine (17.97 l/cow/day), when compared to kale (29.91 L/cow/day) or pasture fed cows (upto 54.7 l/cow/day) (Betteridge, Costall, Luo, & Ganesh, 2013; Ravera *et al.*, 2015). This, along with the effect of soil micro-topography (pooling of urine in depressions left by removed bulbs) (Williams & Haynes, 1994) results in typically lower daily urine patch coverage of fodderbeet wintered cows (2.04 m²/cow/day vs >3 m²/cow/day for pasture fed cows) (Ravera *et al.*, 2015). It is therefore apparent that fodderbeet fed cows will produce typically low quantities of urine, resulting in low per cow urine patch coverage. The significant inter-cow variability observed requires further quantification. However, potential diurnal variation in urination behavior is an area of greater concern; The temporal distribution of urine excretion may influence the volume, and percentage of urine captured during a standoff period. Shepherd *et al.*, (2017) observed consistent peaks and minimums in event volume at 4.30 AM and 9AM respectively, whilst time to next event was greatest at 2AM, and lowest and 10 AM. Several other authors have outlined similar temporal variation, typically concluding that event volumes peak at dawn, with a lower event frequency overnight (Betteridge *et al.*, 1986; Betteridge *et al.*, 2013). The apparent synchronization between periods of high event volume, and low event frequency suggest that the portion of total daily urine excreted within a given time, will be reflective of the duration of said time period. Supporting this, Shepherd *et al.*, (2017) suggested that an 18-hour standoff period would capture 75% of urine excreted. However, the temporal distribution of urine excretion has been linked to the well-established diurnal fluctuations in grazing activity and DMI (Gregorini *et al.*, 2009), and therefore, restricting grazing period may induce changes in urination behavior. It is therefore apparent that further research is required to quantify the percentage of urine that will be captured under a standoff pad wintering system.

2.9 Conclusions and Research Objectives

The environmental impact of intensive dairy farming in Canterbury and New Zealand cannot be disputed. Nitrate leaching drives eutrophication and degradation of regional waterways; an issue that has come under considerable scrutiny in recent times. Subsequently, national policies have been released, mandating that regional councils manage land use to mitigate further environmental damage. In Canterbury, the country's most intensive dairying province, the 'Land & Water Regional Plan' has been implemented, ultimately functioning to enforce N leaching limits. Farmers must therefore adapt their systems to meet regulatory standards. The traditional *in situ* approach to wintering has been identified as a key driver of whole farm/enterprise N leaching due to typically high stocking density's. The "Pastoral 21" research programme has identified fodderbeet as the optimal wintering crop due to its inherently low N content. However, simply changing crop type does not address the impact of high stocking intensity's, and as such it has been suggested that stand-off pad wintering systems can achieve further reductions in winter N leaching. The efficacy of such systems is dependent on several factors; 1. the ability of cows to maintain DMI and achieve acceptable BCS/LW gains under a restricted grazing period and 2. the quantity of urine captured on the standoff pad and the subsequent reduction in paddock urine coverage achieved. Limited research exists specifically quantifying these factors. This research project therefore aims to answer three key research questions to determine whether standoff pads represent a viable 'Next Generation Wintering System':

- Can non-lactating dairy cows achieve fodderbeet/silage intake rates > 10 kgDM/cow/day under a restricted grazing period?
- Can non-lactating dairy cows achieve acceptable BCS and LW gains under a stand off wintering system?
- What percentage of total urine volume will be captured under a stand off pad wintering system, and what effect does this have on paddock scale urine coverage and N leaching in Canterbury?

3 MATERIALS AND METHODS

3.1 Experimental Site and Design

The trial was conducted at the Lincoln University Ashley Dene Research and Development Station (43°39' S, 172°21' E.), Canterbury, New Zealand, between 26 June and 14 August 2017. All procedures were approved by Lincoln University Animal Ethics Committee (AEC 2017-10). The experimental site soil type was Lismore stony silt loam. Lismore stony silt loam has excessive drainage with water holding capacity (WHC) of 70- 100 mm/m of soil. It is a very light soil as stones are found at a depth of 450-750mm (McLenaghan & Webb, 2012). The site was divided into three areas: 1. Crop area, sown with fodder beet which was fed *in situ* 2. a stand-off area (0.56 ha) and 3. a feed pad area. All areas were connected by packed limestone laneways, with a maximum distance of 600 m between crop area and stand-off. The experimental design was a factorial design comparing two farm systems: 1. No stand-off facility (Control) 2. Stand-off pad (SOP) facility. Within the SOP treatment there were four stand-off pad surface treatments (stones, sand, carpet and woodchip-as described in section 3.1.2 giving a total of five groups. The control group grazed fodderbeet *in situ* for 23 hours per day, with one hour spent on a concrete feed pad for supplement feeding (0900h-1000h). The remaining 4 groups, in addition to spending one hour on the feed pad at the same time as the control group, spent 6 hours on fodder beet (1000h-1600h). One hundred and sixty crossbred in-calf dairy cows, were blocked into five groups (n= 32) based on calving date, body condition score (BCS) (4.15), liveweight (LW) (462 kg), breeding worth (95) and age (4.56 yrs), and randomly assigned to each group.

3.1.1 Grazing Area

The crop area was sprayed out with roundup (1/10/16), cultivated (8/10/16) and roller drilled (18/10/16) with 8500 seeds/ha of fodderbeet (Cv. Rivage and Cerise). Pre-planting, 2 t Lime/ha, 250Kg Cropmaster/ha, 100 kg Muriate of potash/ha, 150 Kg NaCl/ha and 15Kg Boronate/ha was applied. Two applications of urea (85 Kg/ha) were applied in late November and January. Post planting, 2L/ha of Nortron, 25L/ha of Lorsban 50 EC and 100ml/ha of Magister was applied. The crop received approximately 360ml of water from irrigation over the growing season.

3.1.2 Stand Off Pad and Feed Pad Area

The stand-off area was subdivided into five 0.112ha sections separated by dual wire electric fences. At construction, the stand-off pad area was lined with high density polyethylene (HDPE) liner. A BIDIM® nonwoven needle-punched continuous filament polyester geotextile A24 filter fabric was installed over and under the HDPE liner. Above this, sub bedding base material was laid down. This layer consisted 5cm of compacted, angular graded gravel, approximately 40mm in diameter. Each bedding material was then applied to a depth of 40cm. Below the subsurface layer, two 110mm NEXUSFLOT™ subsoil polyethylene punched pipes were installed for drainage into the effluent holding pond. The four standoff pad surfaces used were 40mm woodchip, <0.2mm sand, 40-60mm, rounded Greywacke stones sourced from the ADRDS conversion, and CowMax geotextile carpet (designed for laneways), above a 100mm sand layer. Due to issues with drainage under one of the sections, only four standoff 'sections' were used in this trial.

3.2 Management

Each cow had access to a 10m² lying area in line with industry recommendations (DairyNZ, n.d). Electric fence reels were used to adjust each standoff area to the desired 320 m². Each group was offered 4 kg DM/cow/day on a concrete feed pad (0900h-1000h), of a silage mix containing grass and lucerne followed by 7 kg DM/cow/day of fodderbeet. Cows in the SOP groups were allowed access to fodderbeet for a restricted six hour period (1000h-1600h), and were held on the standoff area for 17 hour/day (1600h-0900h). Control group cows grazed fodderbeet *in situ* for 23 hours/day (1000h-0900h). Initially, groups were allocated to fodderbeet paddocks based on distance, with the furthest standoff pad cows grazing the closest paddock. At the initiation of the trial, cows were already transitioned to a daily fodderbeet intake of 6 kg DM/cow/day. From the 26th June- 2nd July, cows were transitioned onto the Standoff pads to reduce the risk of acidosis associated with decreased grazing length. Initially cows were moved onto the feed pads at 9pm, with this occurring two hours earlier every second day until the standard time of 4pm was achieved. Break sizes were adjusted fortnightly following

collection of fodderbeet yield data and any variation in stock number. There was no back-fencing thus the paddock area offered increased throughout the trial. Any cows with health issues, such as lameness, were removed from the trial and treated. Treated cows may then be re-introduced into their treatment group when deemed appropriate.

3.2.1 Stand Off Pad Cleaning

At the beginning of the trial the maintenance requirements of each standoff pad material was unknown, thus an 'as required' approach was taken. The wood chip was rotary hoed every second week. The carpet was cleaned fortnightly by scraping the surface to remove dung. The stone and sand based stand-off areas were not cleaned, or subjected to any maintenance activities.

3.3 Measurements

3.3.1 Crop Yield and Dry Matter Utilization

Crop yield was measured fortnightly in all fodderbeet blocks. All plants were removed from three 2 meter x 2 row plots within the following two weeks' allocation and DM yield was calculated accordingly. Utilisation was measured fortnightly using the dry matter disappearance technique. Yield cuts were used to determine the amount of fodderbeet offered. Two, 2-meter-long rows were randomly selected in the break area, and the same process as for yield testing occurred. Utilisation rate was expressed as $\frac{\text{pre-mass} - \text{post mass}}{\text{pre-mass}} \times 100$. Supplement was weighed prior to allocation and residual supplement after the 1 hour allocation period were collected (by sweeping the feed pad) and weighed. The rate of utilisation was then calculated $(100 - (\text{residual supplement} / \text{supplement offered}))$.

3.3.2 Liveweight and Body Condition Score

Liveweight and BCS was recorded at the end of the standoff transition period (4/7/2017) mid way through the wintering period (25/7/2017), and at the termination of the trial (14/8/2017). The standard 0-10 BCS scale was used with a single person (Charissa Thomas, LURDF Technician) assessing all cows. LW was recorded using a 'Gallagher W110 Digital Weigh System'. This occurred after the supplement allocation period, and was conducted as rapidly as possible to limit impacts on grazing time.

3.3.3 Urination Frequency and Volume

Urination activity was measured using modified urine sensors (PEETER sensors) to compare urine behaviour of cows on Control treatments with those on SOP. Cows from the Woodchip surface treatment were used in this part of the study as woodchip is the most commonly used surface material in commercial farming. Each urination event was measured as volume (L), with an associated time stamp to determine where urination occurred. Sensors were fitted onto a 30 cm long plastic sheath joint to a 3d printed, plastic mould. This was initially achieved using silicone glue and cable ties. A leather flap was installed around the mould to be glued over the cow's vulva. Prior to application the rear/vulva area of the cow was scrubbed clean and wiped with ethanol. The urine harness was then attached to cows using non-toxic Loctite glue applied to the leather, and the underside of the vulva mould. A measurement period of 24 hours for each attachment was targeted. If sensors fell off cows they were collected and the reason for failure was noted. This allowed for continual development of the attachment process/design throughout the trial; Cable ties were replaced with steel hose clamps, and the 3D printing of the vulva moulds was adapted (change in gluing direction) to increase strength.

3.3.3.1 Characterisation and Calibration

The urine sensors operate on the principle of pressure differentiation. The bulk of differential pressure comes from the height of fluid acting on the pressure sensor inlet orifice. Primarily this pressure is equal to gravity, however fluids entering the collection chamber display varying velocity's, reflective of volume, and subsequently force is applied to the pressure sensor. The sensors calculate outlet velocity as a proxy for event volume. Outlet velocity when liquid is draining from a vessel is described by Bernoulli's equation:

Equation 3-1 PEETER Urine Sensor Calibration: Bernoulli's Equation

$$V=C_v(2gH)^{1/2}$$

Where:

V=outlet velocity (m/s)

C_v = velocity coefficient

G= acceleration of gravity

Volume flow is expressed as

$$V=C_d A (2gH)^{1/2}$$

Where:

V=Volume flow (m^3/s)

C_d = discharge coefficient (where $C_d=C_c C_v$)

A= area aperture (m^2)

G=acceleration of gravity ($9.81 m/s^2$)

H=height (m)

A calibration apparatus that could stimulate variable flows was developed, to allow the above equations to be calibrated. This was done by passing five litres of fluid at four different velocities and recording the time for each volume to pass, which when plotted against volume, generated a flowtime relationship (Pascals). Post calibration, sensors displayed an accuracy of +/- 15% at volumes below 0.75 L, with improved accuracy of +/- 0.25% at volumes above 0.75 L. Precision was +/- 0.050 L.

3.4 Statistical Analysis

Results were analysed using Microsoft excel and Minitab 17. Excel was used to sort/filter data and calculate means, standard deviations and standard errors. Minitab 17 was then used to conduct ANOVA, and Fishers LSD tests. A significance level of 0.05 was used. Urine sensor data was filtered so that false data could be discarded. Any logs with excessive, false

events, or that did not stay attached for 24 hours were not included in the statistical analysis. Only complete, correct data sets were used for calculating average volumes, and the distributions of urine volume.

3.5 Leaching Loss Calculations

Paddock scale nitrogen (N) leaching losses were calculated using average urination values, comparing the standoff pad system outlined, and a traditional 24 hour *in situ* system:

Equation 3-2 Paddock Scale Leaching Losses.

$$N_L = (N_{L1} \times P_1) + (N_{L2} \times P_2)$$

N_L = annual average nitrate leaching losses from a grazed field.

N_{L1} = N leaching losses at the urine patch.

N_{L2} = N leaching losses at non-urine patch areas.

P_1 = Proportion of area covered by urine patches.

P_2 = Proportion of area covered by non-urine patch areas.

Estimates of leaching losses were calculated using the average leaching losses (26.5% of urine N leached, 10.5Kg N/ha leached for non-urine patch areas) from lysimetric studies at the ADRDS in Canterbury, New Zealand (Malcolm *et al.*, 2016). N leaching losses for urine patches were calculated by first determining the N load per urination, then multiplying this by the percentage of N load leached. The equation used to determine N load is as follows:

Equation 3-3 Urine Patch Nitrogen Loading.

Urine Patch N Load = (Urine N concentration x Average urination volume)/average urine patch area).

The average urine patch area was calculated from the urine volumes recorded in this trial using the regression equation (Area= 0.1092 x volume, $R^2= 0.89$) developed by Ravera *et al.*, (2015). The urine N concentration used was 2.76 g/L, the average of the concentration values reported by a range of authors for cows offered a comparative diet (Edwards *et al.*, 2014; Ravera *et al.*, 2015; Farrel *et al.*, 2016).

The proportion of area covered by urine patches was calculated as followed, assuming that no urine patch overlap occurred:

Equation 3-4 Paddock urine patch coverage

$$\text{Urine Patch Coverage (\%)} = (\text{Average number of urinations}/24\text{hrs} \times \text{average area per urination} \times \text{number of cows} \times \text{number of days in paddock}) / \text{total area grazed}$$

$$\text{Total Area Grazed} = (\text{Number of Cows} \times \text{daily allocation (kg DM/cow)}) / \text{Crop yield}$$

The proportion of area not covered by urine patches was calculated by subtracting the above value from the total area grazed. These values were then entered the initial equation described. The daily area grazed was calculated based on the trial cow's daily allocation, and actual fodderbeet yields.

4 RESULTS

4.1 Crop Yield

Average fodderbeet yield during the trial period was 22.95 ± 2.61 t DM/ha. There was no difference in yield between SOP groups fodder beet blocks, but yield for the control groups block was lower ($P=0.00$) (Table 4-1). Average herbage accumulation from the 7th July- 10th August was -0.16 ± 4.3 t DM/ha, ranging from -5.8- 5.8 T DM/ha.

Table 4-1 Average yield and growth over the trial period of each treatment groups allocated fodderbeet paddock.

Group	Crop Yield ¹ (T DM/ha)	Crop Growth ¹ (T DM/ha)
WC	25.0 ^A	-2.2
Stones	24.5 ^A	-0.1
Carpet	22.7 ^A	5.8
Sand	23.9 ^A	1.5
Control	18.5 ^B	-5.8
Grand Mean	22.95±2.61	-0.16±4.3
SEM	0.57	1.92
Significance ²	***	N.S

1. values with different supper scripts are significantly different

2. N.S= $P > 0.05$, **= $P < 0.05$, ***= $P < 0.01$.

4.2 Crop and Supplement Utilization

Mean fodderbeet utilization was 94.2%, exceeding 90% across all treatment groups. No difference between treatment groups was observed ($P > 0.05$) (Table 4-2). Supplement utilization averaged 94.95%, exceeding 90% across all treatments. Again, no difference was observed ($P > 0.05$). Apparent daily DMI was 6.65 Kg DM/FB/cow/day, and 3.8 Kg DM/cow/day of silage. Due to the lack of difference in utilization rate observed, intake rates were comparative amongst treatments.

Table 4-2 Average utilization of fodderbeet and supplement of control and SOP cows.

Group	Fodderbeet Utilization (% of DM)	Supplement Utilization (% of DM)
WC	96.3	93.4
Stones	94.1	91.8
Carpet	92.0	96.6
Sand	90.0	96.7
Control	98.6	96.2
Grand Mean	94.2±3.4	95±2.21
SEM	0.010	0.008
Significance ¹	N.S	N.S

1. N.S= P>0.05, **= P<0.05, ***=P<0.01.

4.3 Body Condition Score and liveweight

Over the course of the wintering period, all treatment groups increased average LW (P<0.05), with no difference in final LW observed (P>0.1) (Table 4-4). Average LW gain equated to 580 g/day, accumulating to 24 Kg LW/cow over the 41-day recording period. BCS was different between treatment groups at the start and end of the wintering period (P<0.05)

Table 4-3 Average start liveweight (4/7/2017), end liveweight (14/8/2017) and liveweight gain of control and SOP cows.

Group	Start LW (kg)	End LW (Kg)	LW Change (Kg)
WC	490	511	21
Stones	484	507	23
Carpet	495	520	25
Sand	497	519	22
Control	491	519	28
Grand Mean	491±5.0	515±5.84	24±2.77
SEM	4.67	5.45	5.53
Significance ¹	N.S	N.S	N.S

1. N.S= P>0.05, **= P<0.05, ***=P<0.01.

Average BCS gain was 0.425 units, however again, variability between groups was observed ($P < 0.01$). The highest gain observed was within the stones group, whilst the WC and control cows displayed the lowest gains of just over 0.25 units. The carpet group was the only one to exceed an average end BCS of five, however all groups exceeded an end BCS of 4.5 (Table 4-4). There was no relationship between initial BCS and BCS gain ($P > 0.1$). In line with the average LW gain recorded, each 0.1-unit increase in BCS was associated with a 5.64 Kg increase in LW.

Table 4-4 Average start BCS (4/7/2017), end BCS (14/8/2017) and BCS gain of control and SOP cows.

Group	Start BCS ¹	End BCS ¹	BCS Change ¹
WC	4.32 ^{AB}	4.59 ^C	0.258 ^B
Stones	4.10 ^B	4.78 ^{BC}	0.683 ^A
Carpet	4.50 ^A	5.06 ^A	0.54 ^{AB}
Sand	4.15 ^A	4.88 ^{AB}	0.367 ^{AB}
Control	4.45 ^A	4.74 ^{BC}	0.259 ^B
Grand Mean	4.39±0.17	4.81±0.17	0.425±0.186
SEM	0.043	0.037	0.051
Significance ²	*	*	***

1. values with different supper scripts are significantly different
2. N.S= $P > 0.05$, **= $P < 0.05$, ***= $P < 0.01$.

4.4 Urine Sensor Performance

A total of eight cows were successfully recorded for 24 hours, to produce valid datasets. Six of these cows were from the SOP treatment (42 events recorded), with only two from the control treatment (25 events recorded) successfully measured. Of 24 total sensor attachments (C=12, WC=12), 11 failed to reach 24 hours. The causes of this were due to failure of various harness components. The lower number of cows recorded from the control group was attributed to the extended period of time (23 hours/day) spent in the paddock. It was postulated that when cows lay down, the sensors were getting 'stuck in the mud' and dispatching when cows stood up. Three of the 24 hour datasets were not valid due to the recording of 'false' urination events of excessive value. An overall success rate of 25% was achieved. The success rate in the control cows was lower (16.67%) than the SOP cows (50%).

4.5 Urination Behavior

There was large inter-cow variability regarding total daily urine volume (9.2-26.8 l/cow/day) and frequency of events (7-18 urination events/day) (Table 4-5). However, due to large variance, no differences in average daily urination volume (15.12 ± 5.5 L/cow/day) or frequency (8.37 ± 4.34 events/cow/day) was detected between control and SOP cows ($P > 0.1$) (Table 4-6). Urine volume per event was also highly variable. The maximum value recorded was 5.29 litres, with 20.9% of events accounting for less than one litre. Average daily event volume was 1.81 ± 1.03 L, and was not different between treatments ($P > 0.1$). Event volume did not differ from 1000h-1600h, and 1600h-1000h between, or within treatment groups ($P > 0.1$). The volume of urine excreted from 1600h-1000h was not different between treatment groups ($P > 0.05$), and accounted for 82 % of total daily urine volume. With 95% confidence, it can be predicted that 65%-99% of total daily urine will be deposited during this period.

Table 4-5 Urination Behavior of eight non-lactating dairy cows wintered on fodderbeet.

Cow ID and treatment group	Total Volume (l/day)	Average event volume (l)	Frequency (events/day)
Cow 30 (SOP)	17.88	2.56 ± 0.58	7
Cow 147 (SOP)	17.93	2.98 ± 1.89	6
Cow 236 (SOP)	9.2	1.84 ± 0.83	5
Cow 105 (SOP)	14.11	1.56 ± 1.52	9
Cow 390 (SOP)	12.17	1.10 ± 0.47	11
Cow 246 (SOP)	18.55	2.98 ± 0.66	5
Cow 62 (Control)	12.1	1.72 ± 1.5	7
Cow 85 (Control)	26.88	1.49 ± 0.57	18

Table 4-6 Effect of wintering system on urination behavior. Numbers in parenthesis are the number of observations.

	Control	SOP	P value
Total Volume (l)	19.49 ± 10.5 (2)	13.66 ± 3.7 (6)	0.358
Frequency (urinations/day)	12.5±7.77 (2)	7 ± 2.28 (6)	0.126
Average event Volume (l/urination)	1.55± 0.90 (25)	1.95± 1.08 (42)	0.134
Average event volume 1000-1600h (l/ event)	1.70±0.79(4)	1.74±0.744 (15)	0.925
Average event volume 1600-1000h (l/event)	1.53±0.94(21)	2.06±1.23(27)	0.134
Volume of urine deposited 1600-1000h (l)	16.0±8.88(2)	11.4±4.26(6)	0.323
Percentage of total urine deposited 1600-1000h (l)	82±10.2(6)	82±1.58(2)	1.00

4.6 Calculated Urine Patch Coverage and Nitrogen Leaching

Paddock urine patch coverage and nitrogen leaching rate were calculated (using average urination behavior values across all cows) for a standoff pad (6 h/day in the paddock) and ‘traditional’ 24 hour *in situ* wintering system as per the method outlined in section 3.5. Actual stocking density on the daily allocated area of fodderbeet was 3278 cows/ha, equating to an annual stocking intensity of 78, 688 cow hours/ha/yr. Under an 18-hour standoff system, stocking intensity was reduced to 19,672 cow hours/ha/yr. Average urine patch area was 0.197 m² covering a total area of 1.65 m²/cow/day. Calculated paddock urine coverage was reduced by 82%, from 54.1% to 9.68% of total paddock area (Table 4-7). Calculated nitrate leaching rate was reduced by 61% under the standoff system.

Table 4-7 Calculated paddock urine coverage and nitrogen leaching of two wintering systems.

Measure	Standoff pad system	Traditional system
Paddock urine coverage (%)	9.68	54.1
Urine N leaching (Kg N/ha)	6.48	36.35
Non urine N leaching (Kg N/ha)	4.81	9.48
Total N leaching (Kg N/ha)	15.96	41.07

5 DISCUSSION

The aim of this discussion is to interpret the above results and determine whether the incorporation of a standoff pad structure can reduce paddock urine coverage and subsequently N leaching of the traditional *in situ* wintering system, whilst maintaining acceptable levels of key production parameters, namely cow DMI, and BCS/LW gain.

5.1 Crop Yield

The average fodderbeet yield of 22.95 t DM/ha was within the range of 11 to 27 t DM/ha outlined by Goh & Maget (1989). Previous crop yields reported at the same site (ADRDS) range from 18.5-21.8 t DM/ha (Edwards *et al.* 2014; Jenkinson *et al.* 2014; Farrel *et al.* 2016). Chakwizira *et al.*, (2012) reported a comparatively higher yield of 32.8 t DM/ha, suggesting that greater production can be achieved. Total crop nitrogen application was similar to that of Chakwizira *et al.*, (2012) (116.2 Kg N/ha vs 100 Kg N/ha), and thus the production shortfall observed could be attributed, at least in part, to soil type (Lismore stony loam vs Waimakariri sandy loam), and cultivar '(Rivage/Cersie' vs 'Collessie') differences. Four fodderbeet blocks displayed comparative yields, ranging from 22.7-25 T DM/ha, however one was lower ($P < 0.05$) at 18.5 t DM/ha. Several factors may have contributed to this area of low performance; Edwards *et al.*, (2014) suggested that low yields could be attributed to poor seedling establishment ($< 8-10$ plants/m²). This presumption was supported by visual observation, as the low yielding block appeared to support a greater weed population. However, the effect of this was not quantified. It is therefore apparent that the observed crop yield is reflective of typical industry expectations.

5.2 Diet Utilization and Intake

The effectiveness of a restricted grazing system is reflective of the cow's ability to consume its forage allowance within the allocated time period. It has been suggested that restricted grazing drives impulsion to maximize intake rate as a consequence of behavioral adaptations (Greenwood & Demmet, 1988). As such, significant increases in bite rate, bite mass and reduced handling time have been reported when grazing is restricted to 6

hours/day (Kennedy, McEvoy, Murphy, & O'Donovan, 2009). Reflecting this, it has been observed that >70% of perennial ryegrass intake can be achieved within four hours of allocation (Dobos *et al.*, 2009), whilst Gregorini *et al.*, (2009) showed that cows offered pasture once a day consumed 10 kg DM/cow within three hours. Limited comparative data exist for fodderbeet, whereby bulbs must be removed from the soil prior to consumption. However, Thompson & Stevens (2012), reported a five-hour intake of 4.8 kg DM of swede, a similar bulb forming plant. Average FB utilization across the SOP treatments was 93.1%, or 6.52 KgDM. This is comparative to the 6-hour intake rate of 7.2 kgDM (90% utilization) observed by Jenkinson *et al.* (2014) in parallel work. As expected, the control group achieved the greatest utilization rate (98.6%), consistent with the unrestricted range of 96.25-99.6% previously reported (Edwards *et al.*, 2014; Farrell *et al.*, 2016). No significant difference was detected between treatment groups. This, along with the relatively high utilization rates observed suggests that 6 hours was an adequate grazing period. Whilst there is some debate around the intake potential of cows grazing winter forage crops (Greenwood *et al.* 2011), these results suggest that high DM utilization of low NDF in late pregnancy is achievable. It must however, be considered that the daily crop allocation of 7 kg FB/cow/day is relatively low by industry standards (Judson & Edwards, 2008). An increase in allocation may therefore decrease overall utilization of restricted (SOP groups). Jenkinson *et al.*, (2014) illustrated this with differing kale allocations. At an allocation of 11 kg DM/cow/day, 6-hour utilization was 82%, whilst at an allocation of 14 kg DM/cow/day, utilization declined to 72%. In fodderbeet this effect may be greater, as bulb dominate forages typically display comparatively lower intake rates (Thompson & Stevens, 2012). Supplement utilization/intake, which was fed on a concrete feed pad prior to crop allocation, was unaffected by treatment, averaging 95% or 3.8 KgDM/cow/day. This is comparatively higher than typical industry averages (Edwards *et al.*, 2014; Jenkinson *et al.*, 2014) and can be attributed to use of a concrete feedpad. Lower utilization rates of 83%-86% and 65% have been reported for grass silage and oat silage when offered *in situ* (Edwards *et al.*, 2014, Jenkinson *et al.*, 2014) which is associated with trampling of supplement. The high FB utilization rates observed, and relatively high consumption of supplement resulted in an apparent average DM intake rate of 10.4 Kg DM/cow/day. Based on the typical nutritive values (FB=12.2 MJME/KgDM; Edwards *et al.*, 2014 Silage=11.1 MJME/KgDM. de Ruiter, Dalley, Hughes, Fraser, & Dewhurst, 2007), this equates to an

estimated average daily ME intake of 122.57 MJME/cow/day. It is therefore apparent that high FB utilization rates can be achieved at an allocation of 7 KgDM/cow/day when grazing is restricted to 6 hours, whilst supplement intakes of 3.8 KgDM/cow/day can be achieved with an hour-long allocation on a feedpad. The above results suggest that unless high BCS gains, and subsequently high DMI's (>10kg DM/cow/day) are targeted, restricting of grazing is unlikely to present issues in regard to crop utilization and DMI.

5.3 Live weight and body Condition Score

Body condition score gain on winter forage crops has been shown to range from 0.05-0.8 units (Keogh *et al.*, 2009; Edwards *et al.*, 2014). Dry matter allocation, and ME intake have been outlined as primary drivers of BCS gain (Judson & Edwards, 2008). Reflecting this, Rugoho *et al.*, (2014) reported a significant reduction in BCS gain (0.2 vs 0.3 units), when kale allocation was decreased by 3 Kg DM/day. Edwards *et al.*, (2014) reported BCS gains of 0.74-0.78 units when cows achieved a total daily ME intake of 155 MJME/cow/day from fodderbeet/silage. Dry matter allocation was comparatively higher (13.1 vs 10.39 KgDM/cow/day) than in this study, however the approximate ME intake of 122.57 KgDM/cow/day observed is above the suggested 119 MJME required to meet growing foetal energy demands and achieve a 0.5 unit gain in BCS over the wintering period. It is therefore apparent that at the observed level of intake, a BCS gain of 0.5 units is achievable (over a 60-day period).

The lower average BCS gain observed (0.425 units) can be attributed to the reduced wintering period (41 days vs 60 days). Apparent BCS gain displayed significant ($P<0.05$) variability between treatment groups, with only cows on the stones and carpet SOP achieving a BCS gain of 0.5 units. Cows on the woodchip SOP, and in the control group displayed the lowest gains of 0.258 and 0.259 respectively. Contrastingly, LW gain displayed negligible variation between groups, averaging 24 Kg, equating to a daily gain of 0.58 Kg. Assuming a net energy content of 19 MJNE/kg LW gain, and a conversion efficiency of 0.53 for non-lactating cows, the calculated daily ME requirement, including that of the growing foetus, was only 2.3 MJME/cow/day, higher than the average observed intake across treatment groups. This disparity is negligible, when compared to the 14-16 MJME/cow/day shortfalls reported by Edwards *et al.*, (2014) in parallel work. It can

therefore be suggested that the LW gain observed is directly reflective of the diet offered, across all treatment groups. Holmes *et al.*, (2007) suggested the LW gain required to achieve a one unit increase in BCS ranges from 17-45Kg with typical values of 15Kg and 30Kg suggested for jersey and Friesian cows respectively.

The disparity observed between actual LW gain, and apparent BCS gain can be attributed to several factors; It has been shown in cows of comparative liveweights, maternal adipose reserves, and subsequently BCS can vary by in excess of 40% (Andrews, Waldo, & Erdman, 1994), with only weak-moderate correlations (0.46-0.64) between LW and BCS reported (Berry, Macdonal, Penno, & Roche, 2006). Furthermore, it has been suggested that parity influences the LW/BCS interaction, with greater LW gains associated with comparative BCS gain in multiparous cows (Berry *et al.*, 2006). The differences in BCS observed may therefore be due to inherent variability in cow frame, physiology and parity between and within treatment groups (Andrew *et al.*, 1994). Lack of consistency in the body condition scoring process may also have contributed. Despite reported moderate-high classifier repeatability estimates, it has been suggested that the inherently subjective nature of BCS allows for substantial error (Bowden, 1982; Verkamp, Koenen, & De Jong, 2001). The lack of difference in LW gain between treatment groups suggests that there was no impact of the SOP treatment on production. It was postulated that decreased comfort of a given SOP surface may reduce lying time on the SOP, and as such cows might favor lying, rather than foraging in the paddock (Bryant, pers comm, 2017). This can be disregarded, as apparent DMI was unaffected by treatment ($P>0.1$). The effect of lying time, can however be two-fold; Reduced lying time increases energy expenditure and negates anabolic metabolism via excess release of stress hormones (Fisher *et al.*, 2002). Fisher *et al.*, (2003) reported lying times below 7 hours/day in cows held on various standoff surfaces, accompanied by significant reductions in LW/BCS gain. Similar observations were made by Webster *et al.*, (2007). In this scenario, any impact of the SOP treatments on lying time had a negligible impact on LW gain. It is therefore apparent that cows can be held on a variety of SOP surfaces for 18 hour/day with no significant effect on wintering performance.

5.4 Urination Behavior

The results from the present study confirm the large inter-cow variability in urination behavior previously noted (Betteridge *et al.*, 2013; Ravera *et al.*, 2015; Shepherd *et al.*, 2017). Aland *et al.*, (2002) reported an inter-cow range in urination frequency of 5-18 events/day, whilst typical averages in pastoral studies vary from 6.8-14 events/day (Castle *et al.*, 1950; Fuller, 1928; Selbie *et al.*, 2015). Farrel *et al.*, (2014) observed a comparative average urination frequency (9.4 events/day) of cows wintered on fodderbeet. It is therefore apparent that significant variability in individual cow urination frequency exists, however the urination frequency's observed (8.73+/- range) supports the conclusion of Ravera *et al.*, (2015), that the typical dairy cow urinates 7-13 times per day. Average event volume (1.8 l) and total daily volume (15.12 l/cow) were comparative to the 2.31 l/event (17.97 l/cow/day) reported by Ravera *et al.*, (2015) in fodderbeet fed cows in Canterbury. Event volumes were typically within the extreme range of 0.3-7.8 l previously outlined (Betteridge *et al.*, 2013; Haynes & Williams, 1993). Total daily urination volume (l/cow/day) was comparatively lower than the 27.2-54.7 l/cow/day reported in pasture fed cows (Betteridge *et al.*, 1986; Shepherd *et al.*, 2017). Urinary volume is ultimately reflective of the need to expel minerals and water from the body. Subsequently, total water intake and N ingested have been shown to be key drivers of urination volume (Bannink *et al.*, 1999; Khelil-Arfa *et al.*, 2012). It was therefore expected that the average urination volume observed in this trial would be lower than that reported by Betteridge *et al.*, (2013) and Shepherd *et al.*, (2017), as fodderbeet is inherently low in CP when compared to pasture (<2% vs 2-4%. de Klein *et al.*, 2010; Edwards *et al.*, 2014). The cows in this trial were also non-lactating, and as such had a lower daily water requirement (Bannink *et al.*, 199). Farrell *et al.*, (2016) observed higher average daily urination volumes (27.5 l/cow/day, 3.48 l/event) of fodderbeet fed cows. Again, this can be attributed to increased dietary N, associated with a greater DMI (13.3 vs 10.39 KgDM/cow/day). Furthermore, the osmotic influence of high K and Na relative to N in fodderbeet on urination will be increased at greater intakes (Bannink *et al.*, 1999; Farrel *et al.*, 2016). Whilst it is apparent that significant inter-cow variability exists, no difference ($P>0.1$) in any parameters of urination behavior was observed between SOP and control cows. Reflecting this, Al Marshadesh *et al.*, (2017), reported no effect of a

SOP treatment on 7-hour event frequency ($P=0.19$), whilst Shepherd *et al.*, (2017) detected no difference in urination behavior, beyond an 8% increase in event frequency when cows were subjected to an 18 hour standoff period. It is therefore apparent that holding cows on a standoff pad for 18 hours/day does not influence urination behavior. As such, the SOP and control cows displayed the same temporal distribution of urine excretion, with 82% and 18% of total urine excreted from 1600-1000h, and 1000-1600h respectively. We can therefore predict with 95% confidence that 65%-99% of total urine will be captured under the proposed standoff pad system. This indicates, regardless of diurnal variations in event volume and frequency (Betteridge *et al.* 2013; Misselbrook *et al.* 2016), that on a total volume basis, the portion of urine excreted is reflective of time. Shepherd *et al.*, (2017) supported this conclusion, stating that 75% of urine would be captured with an 18 hour standoff period. It is therefore apparent that significant reductions in the volume of urine deposited on soil can be achieved with a standoff pad system. Whilst conclusive, these results come from a small data set of 8 cows, with 67 total urination events recorded. Improvement of the urine harness system to improve durability, and an extended trial period would allow for collection of a larger, more robust data set to further validate the conclusions drawn from this trial

5.4.1 Paddock Urine Coverage and Nitrogen leaching

Paddock urine coverage, has been identified as a primary determinant of *in situ* nitrate leaching (Moir *et al.*, 2010). In rotational grazing systems, annual urine coverage ranges from 10-29%, averaging 23% (Moir *et al.*, 2010; Macklusk, 1960; Williams, 1998; White *et al.*, 2001; Whitehead, 2000; Vellinga *et al.*, 2001). Paddock urine patch coverage was 54.1% assuming a 24 hour *in situ* system. Under intensively stocked wintering systems, slightly higher urine patch coverage rates of 58% and 61% of grazed area have been estimated (Ravera *et al.* 2015). In this trial, calculated average urine patch area (0.197 m^2) and total per cow urine patch areas ($1.65 \text{ m}^2/\text{cow}/\text{day}$) were reflective of previous findings (Aland *et al.*, 2002; Betteridge *et al.*, 1986; Castle *et al.*, 1950; Haynes & Williams, 1993; Misselbrook *et al.*, 2016; Selbie *et al.*, 2015). The stocking density of 3278 cows/ha is at the upper end of the typical range (300-3000 cows/ha) reported by Cichota & Snow, (2009), and equates to >78,000 grazing hours/ha/year. When grazing was restricted to six hours/day, or 19,700

grazing h/ha/year, urine deposited in the paddock accounted for only 9.67% of total grazed area. This supports the conclusion of Moir *et al.*, (2010) that a 10,000 h/ha reduction in annual grazing time would reduce the portion of a paddock covered in urine by 7%. It must however be considered that overlap of urine patches may occur (Moir *et al.*, 2010). Pleasants, Shorten, & Wake, (2007) estimated that under a stocking density of 180 cows/ha, 1378 m² of urine patches, 60m² of 'double' urine patches, and 1.6m² of 'triple' urine patches would be produced in a 24-hour period. This supports previous work suggesting that at typical stocking density's, little urine patch overlap will occur (Richards & Wolton, 1976). However, further research quantifying the potential of urine patch overlap on paddock urine coverage of forage crops at high stocking density's is required. N leaching rates increase exponentially with the quantity of N deposited (de Klein *et al.*, 2010), and urine patch overlap would therefore influence N leaching. Calculated N leaching rate was 41 Kg N/ha for a 24 hour *in situ* system. This is at the lower end of the 51-173 Kg N/ha previously reported across a range of crop types (Shepherd *et al.*, 2012; McDowell & Houlbrooke, 2009; Monaghan *et al.*, 2013; Smith *et al.*, 2012), and reflects the range of 55-60 Kg N/ha reported by Wheeler *et al.*, (2003). Malcolm *et al.*, (2016) reported slightly higher rates of 64-79 Kg N/ha in lysimetric studies using a typical Canterbury soil type. Restricting grazing to six hours per day effectively reduced estimated N leaching by 61.1%, to 9.68 Kg N/ha. This is within the reduction range of 30-65% previously reported with various restrictions on grazing period (16-20 hours/day) (Christensen *et al.*, 2011; Environment Waikato, 2008; Lindsay *et al.*, 2011). It is therefore apparent that paddock urine coverage is ultimately reflective of stocking density and annual grazing hours. The incorporation of a standoff pad into an *in situ* wintering system can achieve significant reductions (>60%) in N leaching of fodderbeet wintering systems in Canterbury, and nationwide by effectively reducing stocking intensity, and subsequently excretion of urine onto soil.

5.5 Conclusions

It is therefore apparent that restricting grazing under a standoff pad wintering system does not reduce DMI and/or dairy cow performance when an appropriate surface is used on the stand-off. As such, BCS targets will be achievable at sufficient energy allocations. Holding cows on a standoff pad for 18 hours/day does not influence urination behavior or the

temporal distribution of urination excretion. The volume of urine captured on a standoff pad will be reflective of the standoff duration. Reduced stocking intensity results in reductions in paddock urine patch coverage of up to 45%. Based on established parameters of nitrate leaching in Canterbury, the proposed standoff pad wintering system can reduce N leaching by >60%. It can therefore be concluded, from these results that standoff pads represent a viable 'Next Generation Wintering System' that could aid farmers in reaching N leaching baseline targets. Further research to develop a more robust dataset of urination behavior, and quantification of potential urine patch overlap at high stocking densities would provide further validation of standoff pad efficacy. Systems research into the economic viability of standoff systems would aid in driving farmer adoption.

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