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The impact of bale vs. crop grazing over winter on the welfare of dairy
cattle farmed in Southland, New Zealand

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Abstract

Intensive winter grazing of pregnant non-lactating dairy cattle in Southland New Zealand often leaves cows in wet, muddy and rainy conditions with minimal shelter. Management on winter crops, such as kale, involves using high stocking rates to maximise utilisation and encourage cows to eat down to the ground, leaving bare soil that easily turns into mud. This has led to welfare concerns, as these conditions leave cows unwilling to lay down and may impair thermoregulation. Lack of rest can result in frustration and stress, and prolonged thermoregulatory challenge can result in cold stress, which are negative experiences that can impair welfare. While it is less efficient due to lower yields of dry matter/hectare compared to crops, it is thought that bale grazing (management on pasture with access to hay bales) may alleviate some of these issues and improve the welfare status of cows over winter. Therefore, this study aimed to assess the impact on lying behaviours and thermoregulation when dairy cows are managed on a kale crop compared to bale grazing over winter. Eighty pregnant non-lactating dairy cows were managed on either a kale crop or using bale grazing (n = 40/group) for winter 2022. Data collection was divided into two stages. In stage one, lying behaviours were monitored for the first month of winter (27 days) in relation to weather conditions. After this, during stage two, 60 out of the 80 cows (20 bale grazing cows, 40 kale crop cows, n = 10 groups per treatment) went onto replicated experimental plots of either kale/bale grazing for in-depth, behavioural analysis of lying and thermoregulatory behaviours/parameters for two days. Hygiene scores (measure of coat cleanliness on a 3-point scale) were obtained before and after each stage. Live weight and body condition scores were obtained before and after stage one and again just before calving. Inferential statistics were only calculated during stage two due to the lack of treatment replication in stage one. During stage one, lying times were similar for both treatments (kale crop = 8.7 hours/day, bale grazing = 8.9 hours/day), whereas kale crop cows transitioned between lying and standing more often (15 vs. 19/day) and took more steps than bale grazing cows (2,327 vs. 2,045/cow/day) on average. Rain and/or cold temperatures reduced lying times, transitions and steps for both treatments, resulting in rebound lying behaviour when conditions improved. This

was more pronounced in the kale crop cows. During stage two, conditions were cold and dry. Kale crop cows lay down less than bale grazing cows ($P = 0.013$) and transitioned significantly more often between lying and standing ($P = 0.019$) on day one. However, this was likely attributed to a very low space allowance on day one. Bale grazing cows spent more time in comfortable lying postures ($P = 0.022$), were observed ruminating more ($P = <0.001$), remained cleaner ($P = 0.004$), had higher rump and thigh skin temperatures ($P = 0.007$) and higher infrared nose temperatures when lying ($P = 0.048$) than the kale crop cows. The surface for the kale crop cows became more compacted ($P = 0.008$) and got muddier (higher mud/boot score; $P = 0.051$). Overall, bale grazing cows appeared more comfortable than kale crop cows, which may be attributed to the greater thermal comfort and the provision of drier lying surfaces at a lower stocking rate.

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Chapter One: Introduction

1.1 Pasture-Based Dairy Production Systems

Unlike many overseas countries that rely on indoor housing systems, New Zealand (NZ) has a favourable climate that allows dairy cows to be managed outdoors year-round on pasture (French et al., 2020). Due to the seasonality of pasture growth, different seasons require different management practices to ensure that feed supply and demand correlate (Coveney, 2016). These management strategies will differ based on location, which is particularly prominent over winter.

During a typical South Island (SI) winter in NZ, frosts, rain, southerly winds, and low soil temperatures reduce pasture growth rates (Edwards et al., 2016). Typical temperatures over winter are between 1 and 10 degrees (French et al., 2015; Macara, 2013). These climatic conditions mean SI dairy farmers must adopt winter management strategies to combat the reduced pasture growth. Such management practices include cutting pasture silage in a feed surplus to use later in a feed deficit, planting crops more suitable for specific seasons where feed deficits are likely or purchasing additional feed (French et al., 2015).

The most common wintering strategy in the SI is to manage cattle on high-yielding crops (e.g., fodder beet or kale) using temporary fencing to control access (break feeding) with silage/baelage supplemented (Beukes et al., 2011; Dalley et al., 2021; Edwards et al., 2016; Neave et al., 2022). Although it is a lot less common, some farmers still choose to keep cows on pasture over winter, however, this will require more extra feed than is needed for a crop to meet energy requirements, as well as additional land area, as pasture has a lesser yield than a high-yielding crop. In other cases, a standoff or a feed pad may be used to feed cows silage over winter and/or keep them off pasture for certain periods to reduce environmental damage. In rare cases, wintering barns are used, but these are less common in NZ due to installation costs (Beukes et al., 2011; Edwards et al., 2016).

On most NZ farms, cows calve between July and September (from mid-winter to early spring, Southern Hemisphere) and are dried off by the end of the following June. Cows typically calve once every 365 days, ideally within an 8 – 10 week window. This is to ensure the timing of calving correlates with the greatest pasture growth rates in spring to fuel the cow's peak lactation after calving with peak pasture growth to maximise production and efficiency (O'Connor & Webster, 2023). Since cows are dried off at least eight weeks before calving, they are not in milk for most of winter and will subsequently have lower energy requirements, allowing them to regain body condition that may have been lost during the lactation period (Coveney, 2016).

Managing dry cows on a kale crop is one of the most common methods of wintering in the SI. Kale provides a large yield per hectare and large amounts of quality feed (De Wolde, 2006; Edwards et al., 2016; Rugoho, 2014). This means it is very efficient, and doesn't require much land area, allowing farmers to save as much pasture as possible for the following lactation, and minimise the number of paddocks required for wintering (and subsequently reduce the amount of environmental damage. Cattle managed on kale are break fed (using temporary fencing) and are usually given a new break/area either once or twice daily (around 10-14kgDM/ha of kale per day), where they are encouraged to graze the kale right to the ground, leaving the soil bare (De Ruiter et al., 2009; Neave et al., 2022). Silage/baelage/hay bales are usually set out in each break before the cows graze it, and these are opened each day for the cows to eat with the kale.

1.1.1 Bale Grazing

Bale grazing is a winter management practice where hay bales are placed on pasture prior to winter. Paddocks are then divided up and break fed (dividing the paddock with moveable electric fencing) to cattle over winter (Bachler, 2019; Halich, 2021). Hay bales are opened where they stand, leaving cows to eat directly from the bale. The temporary electric fence is moved when cattle have finished the hay and pasture available, which will depend on the stocking rate, bale allowance, and feed quality (Bachler, 2019). A simple bale grazing system is displayed in Figure 1.

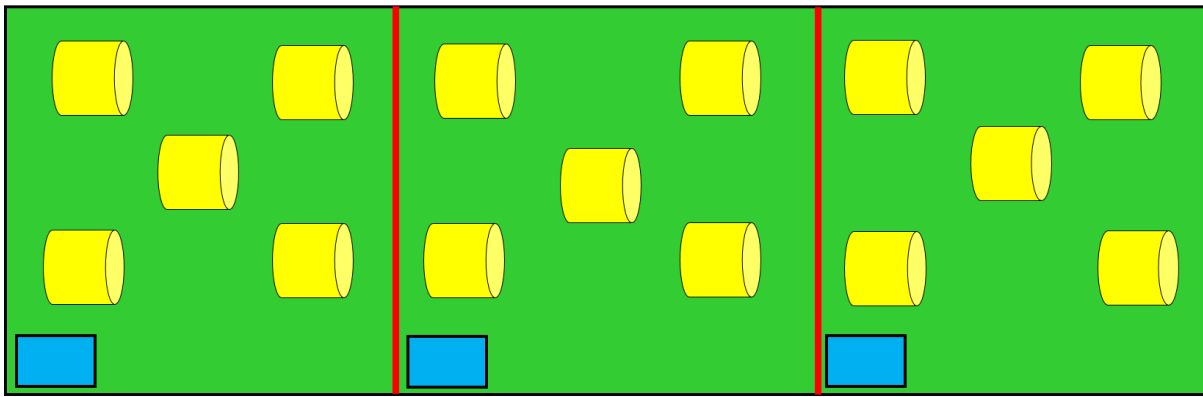




Figure 1: Example of a simple bale grazing paddock layout, divided into three breaks that the cows are allowed access to when they require more feed (inspired by Bachler, 2019).

Key:

-  = hay bale
-  = water trough

Bale grazing has primarily been researched as a management practice for beef production systems, particularly in Canada. Research conducted under these conditions has found bale grazing to have several benefits. These include more efficient nutrient cycling, better soil health, increased pasture growth and quality, lower production costs than other alternatives (e.g. barley crop), lesser nutrient waste, and lesser machine use and labour requirements (Bachler, 2019; Kelln et al., 2011).

Following these economic and environmental benefits, bale grazing has also been found to have animal health and welfare advantages. One of the reasons for this is that there is less mud and manure compared to typical conventional grazing methods (i.e. crops) because cattle are managed at a lower stocking rate, which causes less mud production as fewer hooves are stepping in the same place (Halich, 2021). Unlike crops, residual pasture is also left behind, meaning there is no bare soil, further reducing mud levels. The left-over hay bale residue also provides a drier resting surface for cattle.

The main disadvantage of this system is that a larger land area is needed compared to a typical crop wintering system. In NZ, this will likely to be the main drawback for using bale grazing, as most farmers prefer to save as much pasture as possible up over winter for the following lactation by using the least amount of wintering area possible, meaning crops will be superior in terms of maximising efficiency.

Overall, when used in beef production systems in North America/Canada, bale grazing has been shown to have greater animal performance than traditional wintering on crops. However, presently, there does not appear to be any literature on using bale grazing in dairy systems anywhere around the world, let alone in NZ.

1.1.2 Surface Conditions

One of the major differences between management on a crop vs. bale grazing is the surface conditions. To maximise utilisation, winter management on a crop typically involves allowing cows to graze the crop right down to the ground, leaving bare soil. Bare soil is then more susceptible to saturation and pugging and is generally muddier (Neave et al., 2022), resulting from the lesser soil integrity. In contrast, in bale grazing systems, cows do not graze the pasture down to the ground, meaning that the surface is less susceptible to becoming muddy as there is still plant material left holding the soil together (pasture has a thatch and root mass holding it together, which kale does not have (De Ruiter et al., 2009)). Therefore, bale grazing systems provide a less barren surface that is less susceptible to becoming muddy than a kale crop.

1.2 Animal Welfare Concerns in Wintering Systems

Animal welfare is a complex, multi-dimensional subject. At this stage, it is characterised as the animal's own perceived mental state (affective state), consisting of a sum of positive and negative experiences. It should consider all aspects of the animal's life, ranging from nutrition, environment, health, and behavioural interactions, all determining affective state (5 domains) (Mellor et al., 2020). Seeing that welfare is a subjective state within the animal, indicators are used to infer it. These are parameters we can measure that tell us about welfare. The more indicators used, the more factors that affect welfare can be considered, giving a more accurate depiction of the animal's affective state and, therefore, welfare (French et al., 2015; Tucker et al., 2021).

Several welfare issues are associated with typical winter management on crops of dairy cattle in the SI of NZ. Surface conditions are concerning for animal welfare because there are clear links to wet and muddy surfaces negatively impacting lying behaviour and thermoregulation, which is then exacerbated by the lack of shelter, and high stocking rates used to maximise utilisation (Tucker et al., 2007). These environmental conditions can lead to negative affective states, such as physiological stress, cold stress/chilling, restlessness and frustration (from inhibiting highly motivated lying/resting behaviours).

It is thought that a number of these animal welfare concerns could be solved by adopting bale grazing over winter. In conjunction with this, there is a limited understanding of how weather and surface conditions can impact the lying behaviour of dairy cattle when managed on a crop in winter grazing environments (Neave et al., 2022). Therefore, comparing bale grazing with management on a kale crop will help determine overall welfare status in winter grazing systems and may provide a feasible alternative to reduce these welfare concerns.

Chapter Two: Literature Review

Many variables within winter management systems can impact dairy cattle's lying behaviours, thermoregulation, and, thus, their welfare. A review of the published scientific literature was carried out with the following aims:

- To explore the relationships between lying behaviour, thermoregulation, and animal welfare in dairy cattle
- To identify factors that can influence lying behaviour and thermoregulation in dairy cattle managed in outdoor wintering systems
- To identify potential measures/welfare indicators that could be used to assess the welfare of dairy cattle managed in outdoor wintering systems

This will then allow a comparison between the two wintering systems, using the identified measures, allowing inferences about welfare status to be drawn.

2.1 Lying Behaviour

2.1.1 The Importance of Lying

One of the primary welfare concerns associated with winter grazing systems is the reduction in lying behaviour and its subsequent impacts (French et al., 2015). Lying is a highly motivated behaviour for cattle, as they exhibit a strong inclination to rest, and the deprivation of lying can adversely impact their affective state (Chen et al., 2017; Dalley et al., 2021; Tucker et al., 2007; Tucker et al., 2021; Webster et al., 2015). Various studies have established that cows will prioritise lying over feeding, as indicated by their willingness to forgo feeding to rest, even after as little as three hours of deprivation of both. Following this, they will put in 'work' (i.e. pushing a weighted gate) to reach suitable lying areas, and they show rebound behaviour when deprived of lying (Arends, 2016; Chen et al., 2017; Neave et al., 2022; Tucker et al., 2021; Webster et al., 2015). Rebound behaviour involves

compensating for lying behaviour lost in previous days by lying down more following the lying deprivation, further highlighting the importance of lying down for cattle.

Under optimal conditions in outdoor systems, cows generally lay for around 10-12 hours per day, distributed across approximately 10 bouts lasting between 60 and 99 minutes on average (Arends, 2016; Neave et al., 2022; O'Connor et al., 2019; Tucker et al., 2021). Failure to meet these optimal lying times has been observed to trigger behaviours that may indicate frustration in cows, even after as little as 4 hours of lying deprivation (Tucker et al., 2021). Such behaviours include weight shifting (repeated shifting of weight from one foot to the other), which is thought to alleviate muscle tiredness associated with prolonged standing (Schütz et al., 2019) and attempting to lie down by sniffing the lying surface and bending one front leg without actually lying down (Tucker et al., 2021).

Given the critical importance of lying behaviour, assessing changes and various aspects of it can provide valuable insights into affective state (Tucker et al., 2021). Multiple factors can influence lying behaviour, thereby offering a range of indicators to evaluate lying behaviour and, consequently, animal welfare.

2.1.2 Surface Quality

In terms of both moisture and substrate, surface quality can have significant impacts on lying behaviour. It is reported that cattle find wet surfaces aversive (Al-Marashdeh et al., 2019), reducing lying times by 50-75% compared to dry surfaces (Schütz et al., 2019). Furthermore, O'Connor et al. (2019) found that surface moisture levels above 75% were aversive, and surface water pooling has also been found to decrease lying times (Neave et al., 2022). Substrate impacts lying behaviour as many studies have shown that cows find lying on hard surfaces (such as concrete) aversive (Tucker et al., 2021), while others have suggested that cows find pasture a comfortable surface to rest on (Margerison et al., 2014).

Subsequently, poor lying conditions may make it energetically costly to stand up/lay down, reducing lying times and affecting lying bout frequencies and lengths (Neave et al., 2022). Bouts that last at least 30 minutes often suggest that cows find the surface more comfortable, as motivation studies have shown that cows are more willing to work for lying bouts 30 minutes or greater (Tucker et al., 2021). In the literature, lying bout frequency/number of transitions has been shown to increase or decrease in response to environmental conditions, such as inclement weather and wet/muddy/hard surfaces (Dechamps et al., 1989; Hayley et al., 2000; Munksgaard & Simonsen, 1996; Tucker et al., 2021). Such conditions are very similar to the conditions that cause lying times to change. Fewer transitions have been suggested to indicate that cows are reluctant to change position in unfavourable lying conditions, such as concrete, which is likely to cause discomfort. Hayley et al. (2000), found that cows changed position between lying and standing more when they were kept in large pens, which is thought to be because it is easier to stand up and lie down with more space. Following this, cows in tie stalls have been shown to stand up and lie down less often than cows in loose housing. These results are from indoor systems, however, we can still infer that space allowance (determined by stocking density) and surface conditions may affect lying behaviour in outdoor systems, particularly in winter crop environments with high stocking rates as mud can be challenging to move around (Dickson et al., 2022), potentially reducing transitions.

In contrast, other studies have shown that when cows are being managed on unfavourable surfaces, they increase the number of transitions between behaviours, including the transitions between standing and lying, which could possibly be because of restlessness and discomfort when lying on these surfaces (Munksgaard & Simonsen, 1996). It is thought that this happens because lying is a highly motivated behaviour, and when cattle cannot lie comfortably, they display other displacement behaviours due to restlessness (Cooper et al., 2007; Tucker et al., 2021).

We can also look at the number of steps taken across differing surfaces to quantify comfort, as cows have previously been shown to take more steps in a pasture environment when compared to

a muddy substrate, which is thought to be because mud is more difficult to move in (Dickson et al., 2022).

As a result, surface moisture and composition can be compared with lying times, lying bout lengths and frequencies and number of steps taken to assess the impacts of this on welfare, as longer lying times, more steps and bouts that last at least 30 minutes could suggest that cows find the surface more comfortable (Neave et al., 2022).

2.1.3 Weather Conditions

Rainfall and wind can impact lying behaviour by causing prolonged periods of standing (Dalley et al., 2021; Hendriks et al., 2020). Rain/wind has been shown to reduce lying times by up to 66% (Al-Marashdeh et al., 2019). As rainfall increases, lying time decreases due to increasing surface moisture (13 minutes for every 1mm of rainfall, (O'Connor et al., 2019)), again because cows find lying in wet conditions unfavourable, and cold temperatures further enhance this (Schütz et al., 2019; Tucker et al., 2007). On days with rain, lying times are found to be lesser. This effect also transfers to the following day, but on the second day after rain, Neave et al. (2022) found that cows lay down for 2 hours more, which shows rebound behaviour after not being able to comfortably rest due to the rain. Therefore, recent rainfall and surface water pooling may provide insight into whether the environment is compromising lying times, as lesser lying times can be linked to decreasing soil conditions, which are related to rainfall events (Neave et al., 2022).

2.1.4 Lameness

Lying behaviour can also be impacted by lameness and vice versa. Winter grazing environments may increase the incidence of lameness due to continuous wetness, poor hygiene and reduced lying time, which softens the hoof and weakens the protective layer that stops bacteria from entering the hoof (Coveney, 2016; De Wolde, 2006; Schütz et al., 2019; Tucker et al., 2021). This can then lead to sole and heel ulcers, digital dermatitis, laminitis and hock damage/ swelling (Coveney,

2016; Dickson et al., 2022), which are extremely painful and, thus, will impair welfare (as pain risk a negative affective state). Such conditions impact lying behaviour, making it painful for the cows to lie down and stand up. Shorter lying times can result in lameness and the inhibition of the function of the pituitary-adrenal axis, which can then result in chronic stress (Neave et al., 2022). Bout duration is also important here, as lame cattle may have longer lying bouts due to pain when standing/lying (Tucker et al., 2021). Lame cows may have longer lying times per bout but fewer lying bouts in total, which could potentially be because of the avoidance of the transition from lying to standing (Haselmann et al., 2022; Tucker et al., 2021; Zambelis et al., 2019). This again makes observing the number of transitions between lying and standing and lying bout lengths important indicators of cow comfort and welfare.

2.1.5 Stocking Rate

Stocking rates can impact lying behaviour by increasing competition for dry lying spaces and worsening surface conditions due to pugging (more hooves in less area). Since plenty of evidence shows that cattle find muddy surfaces aversive to lay on, higher stocking rates would worsen this, reducing the availability of dry/favourable lying surfaces. When suitable lying surfaces are limited, the older and/or more dominant cows will gain priority over the driest lying areas (Coveney, 2016; Neave et al., 2022; Tucker et al., 2021). Lower stocking rates are associated with increased aggressive interactions and nonaggressive lying disturbances (Schütz et al., 2015). Assessment of agonistic behaviour and stocking rate with lying behaviour is therefore essential, as they are strongly correlated (Schutz et al., 2015; Winckler et al., 2015).

2.1.6 Eating and Rumination

Foraging and grazing behaviours are innate to cattle, and in grazing systems, cattle have generally been observed to spend 6 – 13 hours per day grazing (Kilgour et al., 2012; O’Driscoll et al., 2015). Grazing time is split into several feeding bouts, the longest being early morning and late evening, as cattle are crepuscular. When cattle are break-fed and moved once per day, they have

been observed to consume >70% of their allocated feed within 4 hours, which has been attributed to hunger and competition for feed (Grant & Albright, 1995; Gregorini et al., 2009; Rugoho, 2014). This then means cows must go a long time before eating again, meaning that when they do, they consume their feed quickly due to hunger and competition. It is thought that shorter eating times, such as when cattle are grazing a crop and consume all the feed within the first 6 hours, should allow for longer lying times due to more available time (Neave et al., 2022). In contrast, high-forage diets at higher allocations (such as pasture allocated every few days) may reduce lying time, as cows must spend more time eating to meet their energy requirements (Haselmann et al., 2022). In feedlot environments, mud has been shown to increase the effort required to walk, which can decrease eating times due to it being harder to access feed (Dickson et al., 2022). It can then be presumed that increasing mud levels in outdoor systems (crop and pasture) could have a similar effect. Therefore, the quantity and type of feed cows are being managed on may impact time budget, and thus, lying time.

There is also potential for other negative connotations to arise if cows are motivated to consume their total daily allowance within such a short window. While it does not directly relate to lying behaviour, it is important to mention here that cattle have been shown to display stereotypic behaviours when unable to perform foraging behaviour, which could be a sign of frustration and hunger, as they are designed to consume large amounts of forage constantly throughout the day (Schütz et al., 2018).

One of the reasons we know why lying behaviour is of high priority to cattle is because they have been observed to forgo eating to lay down if conditions have prevented them from doing so for as little as 4 hours (Arends, 2016; Tucker et al., 2021). Therefore, lying down just after feed allocation could indicate lying deprivation. However, care must be taken when assessing this effect in outdoor systems, as much of the research displaying this information was conducted indoors on concrete flooring which is known to be extremely adverse for cows to lay on (Tucker et al., 2021). Lying down

instead of eating could lead to hunger due to not eating adequate amounts of food, particularly in systems where cattle are moved once daily and need to eat quickly to ensure they get their share. Therefore, time budget relating to management (i.e., when cattle are moved onto their new break) is an essential indicator of lying behaviour and welfare.

The amount of time cows spend ruminating relates to eating times and patterns, as extended restrictions before feed allocation can decrease rumination times (Gregorini et al., 2012). It is also known that cattle do a lot of their rumination while lying (Gregorini et al., 2012; Kilgour et al., 2012), but there is yet to be any solid evidence that rumination times are impacted by changes in lying times, and recent literature suggests there is no impact (Munksgaard & Simonsen, 1996; Tucker et al., 2021).

Rumination is also used to indicate general health, as lesser rumination time is associated with poor health (Paudyal, 2021). Examples of this include metabolic and digestive disorders, such as acidosis and ketosis, as lower rumination times have been shown to indicate the beginning stages of the disorders (DeVries et al., 2009; Stangaferro et al., 2016).

Overall, eating, rumination times, and dietary composition are important indicators that can be linked to lying behaviours to provide a depiction of welfare status.

2.2 Thermoregulation

Along with leaving cows reluctant to lay down, bare, muddy surfaces and winter weather impairs thermoregulation. Thermoregulation is the ability to maintain a stable body temperature. The thermoneutral zone is the range of temperatures where the animal requires no additional energy to maintain body temperature. For dairy cattle, this is between 5 and 15 degrees Celsius (Aggarwal & Upadhyay et al., 2012). However, the ambient temperature over winter in the SI often drops below 5 degrees and is accompanied by wind chill (French et al., 2015).

Wind chill and rain significantly challenge a cow's thermoregulatory abilities. Rainfall exceeding 1mm/hour can reduce the insulating properties of the coat by up to 30% (Turnpenny et al.,

2000), and air speeds of 2 m/s increase the lower thermoneutral zone value. Consequently, protection from rain and wind is crucial for dairy cattle (Schütz et al., 2010), but this is often lacking in wintering systems, therefore, cattle must employ additional energy and heat conservation strategies to maintain their body temperature. Failure to carry out heat production mechanisms and the long-term display of these can indicate cold stress, where heat is lost to the environment faster than it can be replaced. Cold stress is a negative affective experience and is indicative of poor welfare (Schütz et al., 2010; Schütz et al., 2014; Webster et al., 2008). Therefore, we can assess these heat conservation strategies and link them to peripheral body temperature to determine how the environment may impact welfare status.

2.2.1 Behavioural Indicators

When cold, lying down is a strategy to conserve heat, as it reduces the surface area exposed to the air, therefore making it easier to stay warm. At present there is little evidence regarding the impacts of winter temperatures on lying behaviours, and cows have been shown to both increase and decrease lying in response to cold temperatures (Tucker et al., 2021). However, when cold temperatures are combined with rain, lying times have been shown to decrease, which is likely attributed to the fact that cows find wet surfaces aversive to lay on (Neave et al., 2022; O'Connor et al., 2019). As mentioned previously, cows are unwilling to lay down on wet/muddy surfaces, therefore a muddy surface typical of intensive winter grazing systems is likely to impair thermoregulatory ability. Cold surfaces and muddy conditions increase thermoregulatory load (Dickson et al., 2022), leading to decreased lying times, and can be further enhanced by colder air temperatures (Neave et al., 2022). This unwillingness to lay is because of the wetness of mud and likely because of the surface temperature. When cows do lay on cold, wet surfaces, they limit the surface area exposed by tucking their legs beneath their bodies and sitting more upright, which is thought to be an attempt to avoid conductive heat loss to the ground (Chen et al., 2017; Fregonesi et al., 2007; Schütz et al., 2010;

Tucker et al., 2021). Tucker et al. (2007) found that cows were three times more likely to lay with their front legs bent and their hind legs touching their body outside in cold winter conditions.

Other behavioural adaptations cattle use to maintain a stable body temperature include huddling during showers and strong wind to reduce wind chill, shivering to generate heat, seeking shelter from adverse weather and arching their backs and orienting their rear ends to the wind to reduce the surface area exposed to the environment (De Wolde, 2006; Tucker et al., 2007; Webster et al., 2008). Consequently, we can observe lying and sheltering behaviour, standing postures and whether or not cows are shivering to understand how environmental conditions are impacting their thermoregulatory ability and, thus, their welfare as cold stress is a negative affective state (De Wolde, 2006; O'Connor et al., 2019).

2.2.2 Body Fat Reserves

Body fat (triacyl-glycerides) can be mobilised to produce body heat (Cozzi et al., 2011; Zhao et al., 2019). Cows with more body fat over winter are better adapted to cold, as they have been shown to mobilise more body fat during cold exposure, allowing them to heat themselves more efficiently (Tucker et al., 2007). Tucker et al. (2007) found that thinner cows were more likely to lay down in ways that conserve heat, likely because they cannot produce as much metabolic heat via fat mobilisation. Following this, when cows are provided with shelter from wind and/or rain, they have been shown to mobilise less body fat (Tucker et al., 2007). Since most wintering systems do not provide cows with any form of shelter from wind or rain, this further highlights the importance of body fat reserves to cattle over winter. Therefore, if cows consistently fail to maintain their body temperature, they will lose body condition, meaning body condition score (BCS) is an imperative measure of both thermoregulatory ability and status (De Wolde, 2006), as it reflects how prepared the cow is for cold conditions, and can reflect how she is coping with said cold conditions.

2.2.3 Eating and Rumination

Eating and rumination produce heat, allowing cows to combat cold temperatures. Cold stress can prompt an increase in feed intake, allowing cows to elevate regulatory heat production (Christopherson, 1985; Mader, 2014; Malechek & Benton, 1976; Sjostrom et al., 2019). Cattle have also been observed to reduce their feed intake on colder days and defer grazing to a time when it is warmer, which is thought to be an attempt to conserve energy (Malechek & Benton, 1976).

Rumination also comes into play regarding thermoregulation as it is one of the cows' biggest heat production strategies, as the fermentation of roughage generates a lot of heat (Hahn, 1985). Higher consumption of feed, specifically non-detergent fibre (NDF), is positively correlated with rumination times (DeVries et al., 2009; Moon et al., 2004; Paudyal, 2021; Sjaastad et al., 2003). Therefore, eating more roughage can generate more body heat and increase rumination times, keeping the cow warmer for longer. For this reason, eating and rumination times, as well as diet, can be correlated with the thermoregulatory status of the cows, making it crucial to consider when looking at welfare status.

2.2.4 Coat Cleanliness

A cow's coat/body hair is vital in regulating body temperature, as it traps a layer of dead air for insulation. Temperature regulation can be affected by rain and surface moisture, as a wet coat has less of this insulating air, thus reducing its insulating effects. Schütz et al. (2010) found rain to decrease skin temperature by 26%. Additionally, dirtiness impacts this, as mud/manure also impairs this insulator layer on the skin, which will increase with soil moisture and more barren surfaces (Chen et al., 2017; Mader, 2014). Lying times can also be linked to cleanliness; if cows are dirty, we can infer that their lying surface is muddy or dirty (Neave et al., 2022), which is a valuable indicator when direct observations are not possible. A good measure for coat cleanliness is using a hygiene score. The Dairy Welfare Auditor Training (Professional Animal Auditor Certification Organisation (PAACO), 2020),

hygiene score is commonly used in a research setting. Two focal areas on a cow (rump/belly) are rated on a scale of 1 to 3, with 3 being the muddiest. Therefore, we can use hygiene scoring to demonstrate surface quality and cow comfort. We can then quantify these effects by hygiene scoring and looking at weather conditions to assess how mud/manure/rain could affect thermoregulation and, thus, welfare (Aggarwal & Upadhyay et al., 2012).

2.3 Conclusion

This review establishes clear links between winter management practices, lying behaviours, thermoregulation and cattle welfare. A range of indicators were identified to evaluate and compare the welfare ramifications of winter management on crop-based versus bale grazing systems. Indicators for lying behaviours encompass lying times, lying postures, the frequency of lying bouts and transitions between lying and standing, lameness incidence, stocking rates and patterns of eating and rumination. Indicators for gauging thermoregulatory impacts compromise behavioural mechanisms deployed to reduce heat loss (such as lying postures and huddling), body fat reserves (BCS), eating and rumination patterns/times and coat cleanliness. These measures can then be examined in relation to weather conditions, surface conditions, and cow time budget within the relevant wintering system, thereby providing insight into welfare status.

2.4 Research Objectives, Questions, Hypothesis and Methods

2.4.1 Research Objectives and Questions

The objective of this study is to assess the impact of management on a kale crop versus bale grazing over winter on dairy cow welfare by measuring and interpreting lying behaviours and thermoregulatory parameters. The following questions will be answered:

1. How is lying behaviour influenced when dairy cows are managed on a kale crop compared to bale grazing in a winter grazing environment?

2. Compared to using a kale crop, are cows less thermoregulatory challenged when managed using bale grazing?
3. Compared to using a kale crop, do cows have a more positive affective state when managed using bale grazing?

2.4.2 Hypothesis

It is hypothesised that the lying behaviours and thermoregulatory parameters assessed will differ between the two wintering systems. It is predicted that cows managed on a kale crop will lay less and experience greater thermoregulatory challenge than cows managed using bale grazing in a winter grazing environment. It is predicted that this lesser lying time and greater thermoregulatory challenge will be enhanced by adverse weather. It is then thought that bale grazing cows will be more comfortable in terms of achieving target lying times and thermoregulation, leaving them with a more positive affective state, and thus, better welfare.

2.4.3 Research Methods

Literature review. This literature review was conducted by searching Google Scholar, the Massey University Library database (Discover) and Web of Science in 2022 and 2023. Search terms used are displayed in table 1 below.

Table 1: Keywords and search terms used when searching the literature for articles used in the literature review/discussion

Keyword/s	Synonyms
Winter management systems	" Winter management systems " OR mud* OR wet OR damp OR moisture OR "winter grazing" OR "winter management systems" OR "winter crops" OR kale OR "soil condition" OR "pastoral dairy systems"
Cattle	cattle OR "bos taurus" OR "dairy cattle" OR cow
Animal welfare	"Animal welfare" OR comfort "welfare implications" OR thermoregulation OR lame* OR welfare OR "affective state"
And to find more specific literature about resting behaviour:	
Resting behaviour	"Resting behaviour" OR "Lying behaviour" OR lie OR lying OR rest* OR sleep OR "lying posture" OR comfort

Thermoregulation	Thermoregulation OR cold OR "body temperature" OR shiver* OR "cold weather"
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Following searching the databases, the following parameters were used to select papers:

- Focusses on cattle – prefer dairy cattle to be used, but basic principles can also be implied if the article/source uses different breeds
- Mentions animal welfare
- Prefer NZ if it is an experiment, as most other countries do not manage cows outdoors
- Mentions resting behaviour and/or thermoregulatory challenge association with wet conditions (both weather and surface at this stage)
- Studies that consider impacts of the weather will also be included, as this can then relate to surface conditions
- Articles after 2005 were preferred, but if they are still being referenced in recent literature inclusion may be considered

All articles were then uploaded to Endnote, where they were annotated and summarised before writing the literature review/discussion.

Technology. All technology used in this research was selected to align with the fact that this research was conducted on a commercial farm. We chose technology that did not require daily monitoring and was safe to use for extended periods as it was not practical to monitor cows daily for the duration of the trial.

Animal wearables used were also validated in other papers to ensure accurate data was being collected.

Chapter Three: Materials and Methods

3.1 Project Overview

This thesis uses part of the data from AgResearch's and the Ministry for Primary Industry's (MPI) "Improving wintering outcomes for winter forage systems" project. Funding was provided both from MPI's Sustainable Land Management and Climate Change fund and AgResearch's Strategic Science Investment fund (SSIF). The overarching project began in June 2021 and finished in August 2023. The welfare work was undertaken in the winter of 2022, however, cow production results were obtained from the farmer at the end of the following lactation in June 2023. The data analysed in this thesis will only include part of the data from the overarching project.

The overall project goal was to quantify the efficacy of winter management practices that aim to decrease muddy, bare soil areas for reducing nutrient leaching into waterways and improving animal welfare. It was hoped that farmer-friendly alternatives to crop management over winter would be developed that simultaneously reduce nitrogen, phosphorus, sediment and faecal organism transmission to water, as well as decrease emissions of nitrous oxide to air and provide suitable surfaces for animals to rest on that consider their welfare in muddy and wet winter conditions. These alternatives come from the idea that pasture-based wintering systems can maintain soil structure and help prevent soil degradation. To achieve these goals, traditional winter management using a kale crop was compared with winter grazing on pasture and hay (bale grazing). This was conducted by collaborating with AgResearch's Environmental South and Animal Behaviour and Welfare teams.

To summarise, the project measures included nutrient losses into waterways, the impacts on soil physical conditions, impacts on animal welfare, and greenhouse gas emissions. It was expected that reducing the amount of bare soil during winter by using bale grazing instead of a crop and reducing grazing pressures/stocking rates would improve soil structure, reduce sediment movement in surface runoff, and increase absorption of urinary nitrogen, reducing losses to water and air. Less

bare soil was also expected to provide a more comfortable resting surface for cattle, which aimed to improve animal welfare.

3.2 Experimental Design and Protocols

Table 2: Summary of key trial dates and data collection

Stage	Date	Trial Day	Milestone	Data being collected	Number of cows
1	Jun 1 st	0	Trial cows dried off. IceQubes & GPS collars attached. First hygiene score, blood sample, LWT & BCS measures taken.		80 (40 bale grazing, 40 kale crop)
	Jun 5 th	4	Bale grazing cows walked to the run-off for winter	Steps/lying times (IceQube pedometers) Location (GPS collars) Coat cleanliness (hygiene scoring)	
	Jun 5 th – Jul 3 rd	4 – 32	Cows were managed as per normal farm practice in their respective wintering system	Air temperature & rainfall (weather station) LWT, BCS & blood samples	
2	Jul 3 rd	33	Skin temperature loggers were attached to the experimental plot cows. 2 nd hygiene score, blood sample, LWT & BCS measures taken	Same as stage 1 (excluding GPS), with the addition of:	60 (20 bale grazing, 40 kale crop)
	Jul 4 th – 5 th	34 – 35	Plot stage of the trial	Instantaneous behavioural scan sampling Skin surface temperature (ibutton loggers & IRT images)	
	Jul 6 th	36	All monitoring devices were removed from the trial cattle. Final hygiene scores, LWT & BCS blood samples/measures were taken.	Surface quality measures (boot score & mud depth)	
	Aug 5 th	66	Final LWT & BCS measures taken		All 80

3.2.1 Location and Animals

Location. This experiment was carried out at Freedom Acres (latitude: -45.71153, longitude: 168.66915) and Freshford farms (latitude: -45.75612, longitude: 168.77476), which are part of a commercial dairy operation called the Ditchfield group in Wedonside/Freshford, Southland, New

Zealand. Freedom Acres is 162 hectares (155 effective hectares with a flat contour) with 53 paddocks. Freshford is a 134-hectare lease/run-off block used for wintering and harvesting supplements for the dairy operation and grazing youngstock. It is located approximately 13 km from Freedom Acres. The Ditchfield group manages 410 crossbred (Friesian x Jersey) dairy cows and 100 crossbred heifers across the two farms. The soil composition on the farms consists of Matura silt loam soil, which is moderately well drained with moderate-weak pedality (McIntosh et al., 1992). The pasture composition is 30% multi-species and 70% perennial ryegrass and white clover.

Animals. Eighty cows from the Ditchfield group's dairy herd were managed across the two farms for the trial duration. Selection was based on the expected calving date; the earliest calvers were equally divided between the two wintering systems. Cow numbers were selected based on a power analysis, and the minimum number of cattle was used in the trial. All cows were non-lactating and pregnant (mean \pm SED, 78 ± 5.5 days prepartum), with an age of 4.2 ± 2.3 years and BCS of 4.5 ± 0.4 on a 10-point scale (Roche et al., 2004) when they were enrolled in the study on the first of June 2022. The previous winter, most of the herd had been managed using bale grazing (as this is now the farm's preferred wintering method). Some were still managed using a kale crop as the environmental plot measures collected in this trial were also collected the previous year (2021), using 60 animals, however, no behavioural observations were recorded.

Before this study began, all cows were managed in a single milking herd on pasture with silage or baleage supplemented. Cows were provided with minerals via an inbuilt dosing system through the water troughs. This included Selenium (2 ml/cow from June until November, then 1 ml/cow until the subsequent June, at a rate of 5 mg selenium/1 ml), Copper sulphate (0.5 g/cow), Magnesium chloride (60 g/cow), and Iodine (1 ml/cow from the middle of October until end of December).

All procedures involving animals in this study were approved by the Ruakura Animal Ethics Committee under the New Zealand Animal Welfare Act 1999 (AE#15302).

3.2.2 Experimental Design

This study was conducted in winter 2022 (Southern Hemisphere). Most data collection occurred between the 1st of June and the 6th of July 2022, but an additional live weight and BCS measure were obtained from the end of winter. The overall project plan was to manage cows as per standard farm practice over the winter months (June–August), using bale grazing or a kale crop for the entire winter.

Data collection was divided into two stages. In stage one (June 1 to July 4), two groups (one of each management system, n = 40/group) of trial cows were monitored using various devices in the first month of winter. Data for this stage is presented descriptively due to the lack of replicated treatment groups (one group per treatment).

Upon completion of stage one (July 4), stage two began. Cattle were put onto small, replicated experimental plots (n = 10 groups per treatment, n = 4 cows/group for kale crop cows, n = 2 cows/group for bale grazing cows) that mimicked their winter management strategy to facilitate in-depth observations of behavioural and physiological parameters, along with soil observations. The experimental plots were spatially randomised in a block structure. Group sizes were based on stocking rate requirements, as because the plots were all the same size, fewer bale grazing cows went onto each one to mimic stocking rates they had been managed at in their wintering systems. Appropriate treatment replication was present in this portion of the trial, allowing inferential statistics to be calculated.

In stage one, cows subjected to the bale grazing treatment were managed at Freshford on the run-off block (except for when they were on the experimental plots) with other cows from the dairy herd in a group of 100. For stage two, they were transported via truck back to the main dairy farm, where the trial site was located. The cows subjected to the kale treatment were kept on the main dairy farm in their group of 40, specifically for this study, as the farmer no longer uses winter crops.

Stage two (experimental plots) of the trial was undertaken on the main dairy farm near the milking shed, in a large flat paddock that was relatively free-draining, and had no shelter. Paddock selection was based upon requirements for the soil measures, which required a stone-free site for ceramic cups to be inserted to assess nutrient leaching.

3.2.3 Stage One Data Collection and Procedures

In stage one, weather conditions of interest (15-minute recordings of air temperature and rainfall) were monitored using a site-specific weather station. This was located approximately 8km from the bale grazing cows (run-off block) and approximately 1 km from the main dairy farm where the kale crop cows were managed.

On the 1st of June 2022, at the end of lactation when the herd was dried off, the farm owner selected 80 cows for the trial; 40 were to be managed using bale grazing, and 40 were to be managed on kale over winter. Cows were drafted out during milking. The selection was based on the expected calving date; the earliest calvers were equally divided between the two wintering systems. Cow numbers were selected based on a power analysis, and the minimum number of cattle was used in the trial.

These cows then had GPS devices and IceQube accelerometers attached after milking. All cows were then body condition scored (BCS), weighed (LW), and hygiene scored, and two blood samples were taken via a tail bleed from each cow when these devices were attached. This was conducted in the herringbone milking shed and the veterinarian race next to the shed by the AgResearch Animal Behaviour and Welfare team technicians.

GPS devices (Oyster2, Digital Matter, Subiaco, Australia) were attached to each cow's neck via a nylon strap to investigate the lying location of cows in the paddocks (e.g. if they were lying down on the hay residue). They were set to retrieve the cows' location every 15 minutes, the optimum time to maintain



Figure 2: GPS collar on cow, showing GPS device and strap.

battery life over the month they were used. Location data was automatically uploaded to an online server, it was intended to collect drone footage of the paddocks after winter to allow comparison between GPS device data and the location of bales to determine cow location. This information is yet to be analysed, so it is hereby excluded from this thesis.

IceQube accelerometers (Icerobotics Ltd, Edinburgh, Scotland) were fitted to each cow with a Velcro strap on the lateral side of the hind leg above the metatarsophalangeal joint. This provided lying times (hours) and the number of steps for each cow daily.



Figure 3: IceQube accelerometer (yellow).

Body condition scoring was conducted by a trained observer using the 10-point scoring system described in Roche et al. (2004). Cows were weighed simultaneously as the condition scoring using portable scales.

All 80 cows were hygiene scored at dry off before they went into their respective wintering systems. Scoring was done using the method used for Dairy Welfare Auditor Training (Professional Animal Auditor Certification Organisation (PAACO), 2020), which rates cows on a scale of 1, 2 or 3. A

score of 1 indicates an area of mud/manure in the focal areas less than 10" (or A4 paper size), a score of 2 indicates an area of mud/manure >10" in one of the two focal areas, and a score of 3 indicates an area of mud/manure >10" in two of the two focal areas. Both sides of the cows were scored.

Since multiple observers did this scoring, agreement between observers was confirmed

using the PAACO training module online, a series of 30 photos pre-scored by trained observers. The Kappa score for the agreement was >0.80 for all observers, which is considered an excellent agreement.

Blood samples were taken via the coccygeal (tail) vein. Two tubes were collected – a red serum tube (10 mL) and a purple EDTA tube (4 mL). Purple EDTA samples were placed on ice immediately, and red samples were kept at ambient temperature until they were analysed (Gribbles Veterinary Pathology, Dunedin, New Zealand). Parameters tested for related to energy metabolism, immunity, and general health. Blood results will not be included in this thesis, so they will not be discussed from hereon.

The 40 bale grazing cows were then walked to the run-off block in Freshford on June 5 (approximately 13 km). They were managed in a mob of 100 with other cows from the farm. They were typically moved onto a new break (0.5 ha) every three days, depending on weather conditions. In the event of adverse weather (rainfall), cows were moved to the next break early and returned to the unfinished break once conditions improved to minimise environmental damage. The pre-grazing pasture cover averaged 3500 kg DM/ha. Bales were placed at approximately 30 bales per ha in a grid formation, with around 18 m between each bale. Cows were allocated approximately 16 m²/cow/day, or approximately 50 m²/cow per three-day break.

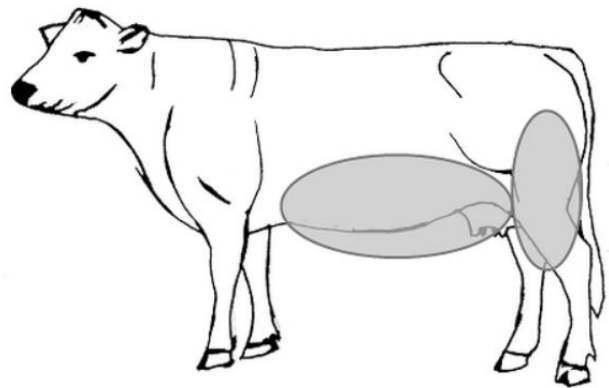


Figure 4: Focal areas assessed when hygiene scoring (PAACO, 2020).

The 40 kale cows went onto a kale crop (kestrel cultivar) on the main farm immediately after dry-off in their experimental group. The average crop yield was 14 t DM/ha. To transition them onto the crop, they were initially fed approximately half their DM allowance in baleage, which was gradually reduced to 5 kg DM/cow of baleage over the first four days. They were allocated a fresh break (new area) each morning (a minimum of 9.4 m²/cow/day), and baleage was provided in ring bale feeders (5 kg DM/cow/day). Cows were back-fenced every 2 -3 days. This stocking rate is standard industry practice when grazing kale to allow maximum utilisation (Edwards et al., 2016).

All cows had free access to drinking water and free access to a trace element mineral combination salt-based lick.

3.2.4 Stage Two Data Collection and Procedures

On July 3 (the day before stage two began), the 40 bale grazing cows were drafted from the mob of 100 they had been managed in until this point in the yards at the run-off block. They all had their GPS collars removed, two blood samples were collected again (same size/type) and were hygiene scored again. Only 20 of the 40 bale grazing cows went onto the plots, so those that did not go onto the plots also had their IceQube accelerometers removed and returned to the rest of the herd. The 20 bale grazing cows that were to go to the plots were transported via truck back to the main dairy platform, where the plots were located (approximately 13 km journey that took around 10 minutes).



Figure 5: Bale grazing cows in the vet race at the run-off block before being trucked back to the main dairy farm.

The 40 kale cows were yarded at the milking shed at the main dairy farm, and their GPS collars were removed. Their second set of blood samples was taken in the veterinarian race.

Once the bale grazing cows arrived at the cowshed, all cows went onto the milking platform and had two iButton (2 out of the four kale cows from each group, and both bale grazing cows) temperature data loggers (Embedded Data Systems, DS1922L, resolution: 0.0625°C, accuracy: 0.5°C, Lawrenceburg, KY) attached to the rump and thigh to record skin temperature (as pictured in Figure 6). These were attached by sticking the iButton to the centre of a piece of elastic adhesive bandage (approximately 8 by 8 cm), applying Loctite 454 adhesive glue around the edges of the tape and then sticking it to either the rump or thigh. These devices were set to record temperature every 10 minutes.

Cows were then painted with Tell Tail paint to allow for identification during behavioural observations on the plots by dipping a number brand into a container of paint. The four kale cows were marked with a 0, 1, 2 or 4, and the two pasture cows were marked with either a 0 or a 1, as pictured in Figure 7.



Figure 6: iButton placement on the rump and thigh.

A second LW and BCS measure was taken, and all cows were hygiene scored (bale grazing cows were scored again to account for any faecal contamination during the truck journey).

Pre-surface measures, mud depth and 'boot score' (sometimes referred to as mud score) were taken before and after cows went onto the plots. The 'boot score' is a 1-3 score that describes the degree of 'muddiness' and soil wetness



Figure 7: Pasture cows in cowshed after iButtons and plot ID numbers had been assigned/attached.

(O'Connor et al., 2019). The scorecard is pictured in Figure 10. To conduct this measurement, a boot

is pressed firmly into the soil at the desired site before being removed and given a score based on the appearance of the boot print. Mud depth was taken with a plastic ruler. The ruler was inserted firmly into the ground, as far as it could go, and a reading was taken. Five measurements were taken per plot for both mud depth and boot score. The positioning and order in which this was done are shown in Figure 9. Measurements one and two were in the first break for the kale cows, as they were to have half of the kale allocated each day. Photographs were also taken of each plot. These were later compared to photos taken after the cows had been on the plots for the two days.



Figure 8: Pre-plot mud-depth measurement being taken.

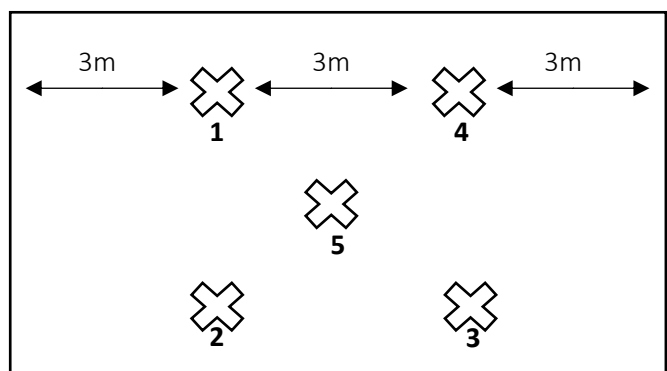


Figure 9: Diagram of where plot measures mud depth and gumboot score were taken.



GUMBOOT SCORE CARD

For each sample spot (avoid gate ways and troughs) please tick the appropriate score. Use all the descriptors to make your choice.




1. Dry	2. Wet	3. Sodden
		
Boot imprint dry and stays there No pooling	Boot imprint wet and less defined Wet but little pooling liquid	Boot imprint disappears straight away Pooling liquid obvious

Figure 10: Gumboot/boot scorecard.

To monitor the weather during the time the cows spent on the plots, a handheld device (5,000 environmental meter, Kestrel Meters, Boothwyn, USA) was attached to a post at cow-level height. Conditions recorded were ambient air temperature (°C), humidity (%), rainfall (mm), wind speed (m/s) and wind chill (°C), all in 10-minute measurements. The wind chill was calculated using

the National Weather Service Wind Chill Temperature Index. Wind speed was adjusted by a factor of 1.5 to provide wind speed results measured 10 m above ground (<https://www.weather.gov/safety/cold-wind-chill-chart>).

At approximately 10:00 am on July 4, cattle were put onto experimental plots matching their winter management strategy for in-depth analysis. There were 25 plots, 63 m² in size (9 x 7 m). The number of plots and the plot size were based on requirements for soil measures. Twenty-five plots were required to allow ten replications of two key soil treatments and five replications of a third treatment. These were spatially randomized in a block structure (Figure 11). Cows only went onto twenty of these, and the remaining five were controls for soil measurements. There were 10 kale crop plots and 10 bale grazing plots. Two cows went onto each bale grazing plot with a space allocation of 8 m² per cow/day. Four cows went onto each kale crop plot at a space allocation of 32 m²/cow/day. This allocation mimicked the stocking rate they had been managed over winter until this stage

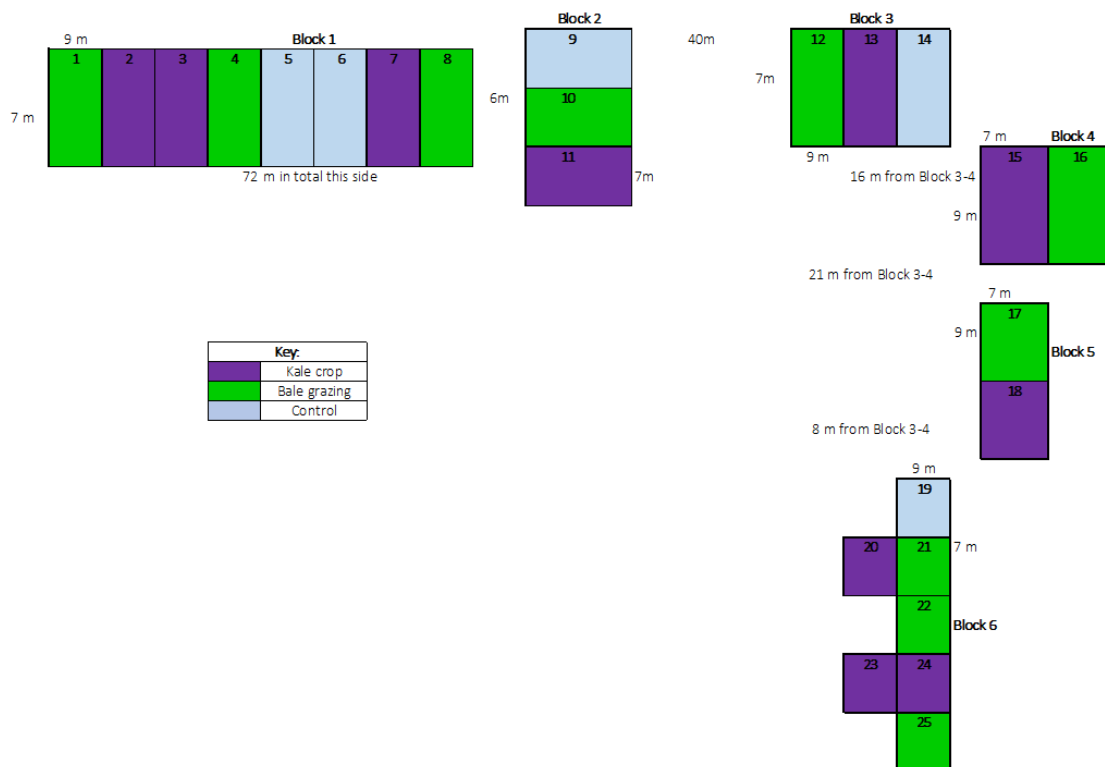


Figure 11: Plot layout map.

(normal farm stocking rate for kale crops/bale grazing). This was also a crucial determinant for urinary nitrogen returned to the soil and the risk of pugging/soil loss.



Figure 12: Cows when first introduced to kale crop (top) and bale grazing (bottom) plots (July 4).

At approximately 11:00 am, cows were fed their ration of hay (bale grazing cows) and baleage (kale crop cows). The remaining feed was weighed upon completion of stage two to estimate feed intake. Quadrant cuts were obtained, and harvested to ground level, for both pasture (0.25 m²) and kale (1 m²). Cows on the kale crops were allocated 13.4 kg DM/cow/day of kale and 4.5 kg DM/cow/day of pasture silage. Bale grazing cows were allocated 5.1 kg DM/cow/day of pasture with an additional hay allocation of 17.7 kg DM/cow/day. The hay for the bale grazing cows was put in one spot to mimic a hay bale that they



Figure 13: Hay pile to mimic bale grazing management on the plots (July 4).

are typically fed when in large mobs under this management strategy and was only provided on day one to match how they were allocated feed during stage one (a large allocation of hay/pasture every two to three days). Water troughs were filled throughout the day with a Ute and water trailer as necessary.

While on the plots, the behaviour of all cows was recorded using instantaneous scan sampling by six trained observers, beginning at 12:00 pm on July 4 and ended at 8:00 am on July 6. A behavioural ethogram was developed for scoring during observations. Refer to Table 3 for behavioural definitions. Observations were recorded using the sheet displayed in Figure 14. During the day, 20-minute scan sampling was used, and overnight, 30-minute scan sampling was conducted, as it was much easier to record observations during daylight. Night vision binoculars and a red-light headlamp were used to observe the cows overnight. In total, 106 observations were recorded per cow for plots 1-14 and 107 for plots 15-23.

To ensure inter-observer reliability, all observers underwent a practice session using photos and a live training session to ensure everyone understood the definitions before data collection. The percentage agreement between observers and a gold standard was then calculated, which resulted in an inter-observer agreement ranging between 81 and 100 % agreement. The agreement was lowest for measuring whether the cow was eating or not.

Shivering and weight shifting were not observed, so are not presented. Hind leg position (touching body or not) was excluded from the analysis, due to the incidence of missing values resulting from the fact that it was too difficult to observe, particularly at night and when bale grazing cows were lying in hay residue.

Date.....		GLENLAPPA OBSERVATIONS											Observer.....		
start time.....			STANDING			LYING					STANDING OR LYING			COMMENT	
plot	cow #	paint ID	stand	weight shift	head down	latera l lying	head resting on body	on ground	front legs underside bent	expos ed	hind leg exposed touchin	eat	ruminat e		shiver
1	12	I													W
1	152	0													J

Figure 14: Behaviour observation recording sheet.

Table 3: Behavioural ethogram (Modified from Tucker et al., 2007).

Standing/Lying/Neither	Behaviour	Definition
Standing	Standing	Weight supported by feet
	Weight shifting	Body weight is shifted between hind legs whilst being stationary.
Lying	Lying	Flank is in contact with the ground
	Lateral lying	The weight of the cow is on one side of the body, including the shoulder, barrel and hip.
	Head on body	Any part of their head is resting on any part of their body. LICKING is not scored as resting
	Head on ground	Head is in contact with the ground (<i>*if a cow is resting their head on both body (e.g. leg) and ground simultaneously, score "1" for both and make a comment to say this*</i>)
	Underside front leg bent	Underside front leg is fully bent at knee.
	Exposed front leg bent	Exposed front leg is fully bent at knee.
	Exposed hind leg touching	Exposed hind leg below the hock is touching the body of the cow.
Neither	Eating	Feed is being ingested or can be seen in mouth
	Ruminating	Regurgitation of feed (chewing movements without fresh feed being ingested or seen in the mouth)
	Shivering	Rapid twitching of muscle groups anywhere on the body



Figure 15: Bale grazing cows lying in hay bale residue.



Figure 16: Cows lying with their front legs extended. On the left is a kale crop cow and on the right is a bale grazing cow.



Figure 17: Cows lying with their heads resting against their bodies. On the right is a kale crop cow and on the left is a bale grazing cow.



Figure 18: Bale grazing cows, with one cow sitting in the hay pile.



Figure 19: Kale crop cows resting at nighttime.

Infrared thermography (IRT) images were taken between 12 am and 8 am on both nights (FLIR T650sc, Teledyne FLIR LLC). These images measure heat emitted from the cow and indicate thermoregulation and heat production. Two images were taken of each cow each night. The first was taken at around midnight, and the second was taken just before dawn. these timings were selected due to technician availability (midnight time) and dawn was chosen as this is typically the coldest time of day. Regions of interest analysed were the nose, forehead and body, as pictured in Figure 20. This was conducted using the FLIR ResearchIR Max 4 software package.

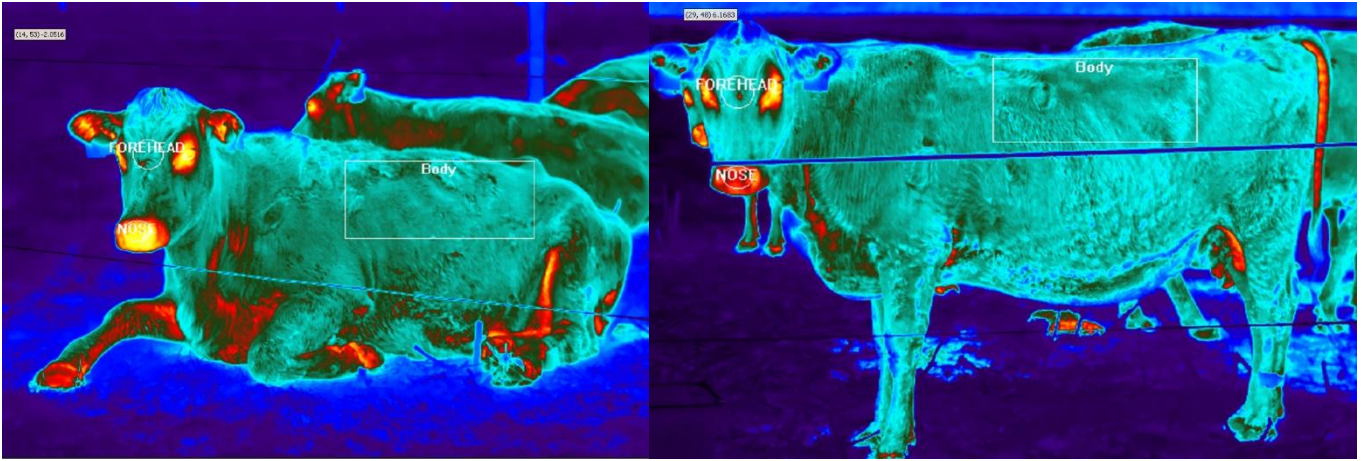


Figure 20: Infrared thermography (IRT) image examples of kale crop cows with regions of interest (nose, forehead, and body) for a standing and lying cow.

On day two (approx. 9:00 am), the kale cows were given the second half of their plot to mimic their normal daily allowance of feed, and they were also given their hay ration.



Figure 22: Conditions on two bale grazing plots in the afternoon of day two.



Figure 21: Conditions on two kale crop plots in the afternoon of day two.

On July 6, the cows were taken off the plots at 8:00 am to the cowshed. iButtons and IceQube accelerometers were removed on the milking platform, and hygiene scoring was conducted for the final time as cows left the shed. iButtons were removed by cutting a hole in the bandage used to stick them to the cow. The bandage was then allowed to detach itself on its own. The cows were then returned to kale or bale grazing for the remainder of winter. The bale grazing cows were taken back to the runoff block via truck.

The post-experiment surface measurements (boot score, mud depth and photos) were then retaken. Surface water pooling was also recorded, following the method Neave et al. (2022) described. If there was visible liquid (water or urine) pooling that was in close vicinity of the sampling site (half a boot length) and the pool of liquid was at least the size of the palm of a hand, it was scored using a binary outcome “yes”. No surface water pooling was observed.

Soil and environmental measures taken by the Environmental South Team included nitrogen leaching, pug depth, surface roughness, vegetative cover (to input into a mathematical model that describes soil erosion processes, all the feeding values (amounts and quality of feeds offered; nitrogen intake) and Soil Visual Assessment).

On August 5, cows were weighed and condition-scored again by the farmer’s veterinarian. Calf birth weights for all 80 trial cows were intended to be recorded, but only 34 weights were actually collected, so were not included in the analysis. The farmer provided herd test data from the end of lactation following the trial via MINDA®, in June 2023. This information will not be included in this thesis, so will not be discussed from hereon.

3.3 Statistical Analysis

3.3.1 Data Handling

Stage one measures. Lying times and steps were collected from June 1 to July 3 (32 days). However, results before June 5 were excluded as the bale grazing cows did not walk to the runoff block where they spent winter until this day, which also allowed habituation to the wintering systems for both groups and removed June 5, which would have had very high step counts for the bale grazing cows. Lying times, steps and number of transitions between lying and standing over the remaining 27 days were averaged per cow and day and summarised in Excel. Steps per hour were summarised for the whole period in Excel (i.e. average steps for all days taken in each hour). Average daily lying times were also summarised with daily average ambient air temperature and rainfall. Hygiene score, BCS and LW were averaged per cow and group in Excel. Air temperature and rainfall were summarised daily over stage one. Blood results were not included due to time constraints and calf birth weights and milk production parameters were also excluded, as insufficient data was collected.

Stage two measures. Mud depth (cm) and boot score (1-3) (5 measurements of each per plot) recordings were averaged per plot. Surface water pooling was not observed, so is excluded. The behaviour observations (eating, lying, ruminating) recorded during the plot stage were averaged per group per plot and expressed as a percentage of observations (out of 106 for plots 1-14 and 107 for plots 15-23 per cow). Shivering, weight shifting, hind leg position and lateral lying were rarely observed, so they were left out of the analysis. Behavioural data is presented in 3-hour blocks to explore diurnal patterns, which is an average percentage of observations per plot, per treatment in that block. Some of the iButton temperature data loggers used to measure skin temperature had errors (readings well above feasibility). For this reason, three of the kale crop plots were left out of the analysis. Skin temperature from the iButtons was averaged per cow, location (rump or thigh) and group. Lying times (hours) and number of transitions between lying and standing from the IceQube accelerometers were averaged per cow and group for each plot. Steps from the IceQube

accelerometers were not analysed due to both groups' lack of space allowance on the plots. The hygiene scores (1-3) were averaged per cow (as there was one score per side) and then per group and plot. Of the 270 IRT images taken, only 111 were suitable for analysis (57 body images, 28 forehead images, and 26 nose images). An image was excluded from the analysis for the nose temperature due to the values (average, maximum, and minimum) being much lower than the others. Weather data were summarised into average daily ambient temperature, humidity, wind speed and wind chill, and their ranges (absolute minimum and maximum values).

3.3.2 Analysis

Stage one measures. Inferential statistics were not calculated for the effect of the wintering system for stage one due to a lack of treatment replication; thus, all data relating to stage one before the plot exposure are presented descriptively. Lying behaviour (hours/day), steps and the number of transitions between lying and standing are summarised daily over 27 days, and mean values and standard errors of the mean (SEM) are presented. Diurnal stepping behaviour averages (average steps/hour for 27 days) and standard errors of the mean (SEM) are presented. Average daily air temperature, rainfall and daily range are presented. Hygiene scores, LW and BCS results are also presented descriptively at the time of dry-off, 32 days after that and then an additional LW and BCS results a further 29 days later (provided by the farmer).

Stage two measures. Inferential statistics were calculated using summaries per group/day for all behavioural and physiological parameters. Group was used as the experimental unit (n=10 groups of bale grazing and kale crop). Constant variance and approximate normality were assumed to examine residual plots for normality. Paired t-tests (19 degrees of freedom) were used to analyse the two treatments' average change in hygiene score, boot score and mud depth. An ANOVA (Analysis of variance) with a block structure and treatment as a fixed effect was used to analyse the mean skin temperature (°C) (rump and thigh from iButtons) and IRT surface temperature (°C, average, maximum, minimum) of the forehead, body and nose. Further testing of IRT image parameters

(average, maximum, and minimum °C) for the body, forehead and nose for images taken when cows were lying was conducted as a REML test (Restricted maximum likelihood). Fixed effects were treatment and side of the body (left or right, for body only) and their interaction (for body only). Random effects of plot, plot by cow, and period (1 to 4 depending on date and time (midnight and dawn, day one and two)) were also included. Behavioural observation results were analysed using ANOVA with a block structure and with day and treatment as fixed effects (day one: 12:00 pm to 9:00 am the following day, day two: 9:00 am to 8:00 am the following day). This included the percentage of observations of lying down, eating, and ruminating (out of 106/107 observations per cow) and lying times (hours/day) and the number of transitions between lying and standing recorded by the IceQube accelerometers. Day was included as a fixed effect because kale crop cows had different space allowances on the two days (8 m² then 16 m²/cow). An ANOVA with a block structure was also used to analyse the front leg and head postures when cows were lying. This was conducted as a proportion of the total observations of cows lying down, on average, over the time they were on the plots. The significance level for evidence of treatment differences was set at 5%. All statistical analyses used Excel and Genstat (statistical package), version 23 (VSN International, Hemel Hempstead, UK). Results are presented and discussed by stage.

Chapter Four: Results

4.1 Stage One

Results presented in this section come from the first month of winter (stage one of the trial), which ranged from June 1 to July 3, 2022 (32 days). Lying behaviours (lying times, number of transitions between lying and standing and steps) were only recorded for 27 days (June 6 to July 3).

4.1.1 Weather Conditions

The average air temperature from June 1 to July 3 (32 days) was 5.5 °C (range: 0 – 12.7 °C). Twenty days had rainfall, with the overall average rainfall being 1.1 mm/day (range: 0 – 5.6 mm/day). Of the days it rained, eight had less than 1 mm of rain; seven had between 1 – 3 mm, and five had more than 3 mm.

4.1.2 Lying Times and Steps

Lying times in relation to weather conditions. The average lying time for bale grazing cows in the first stage of the trial (June 6 – July 3) was 8.9 hours/day (SEM (standard error of the mean)): 2.57; range 4.6–12.5) and 8.7 hours/day (SEM: 3.06; range 5.5–13.1) for kale crop cows, with the overall difference amounting to 12 minutes. Figure 23 shows this varied with average daily rainfall (mm) and air temperature (°C). Days with higher rainfall and/or low temperatures were associated with a drop in lying times for both groups on several occasions. It appears that this reduction was more marked for the kale crop cows. On June 30 (the wettest day; 5.6 mm rain), kale crop cows lay down for 7.5 hours, and bale grazing cows lay down for 10.2 hours on average. On June 22 (coldest day; 0 °C), the kale crop cows lay down for 7.1 hours, while the bale grazing cows lay down for 10.2 hours on average. On June 11 (coldest/ wettest day; 2 °C, 5 mm rain), kale crop cows lay down for 4.6 hours, and the bale grazing cows lay down for 6.2 hours on average.

Rebound lying behaviour. On the days following reductions in lying times, an increase above average lying times was observed in some cases. This is seen at several points throughout Figure 23, particularly towards the end of June. This rebound effect is associated with lower temperatures and rainfall. An example of this is on June 27 (6.6 °C; 3.4 mm rain), when the kale crop cows lay down for 6.8 hours and the following day, lay down for 8.3 hours, and then 12.5 hours the day after on average. Similarly, for the bale grazing cows on June 14 (7 °C; 2.4 mm rain), cows lay down for 5.5 hours and then 10.1 hours on average the following day.

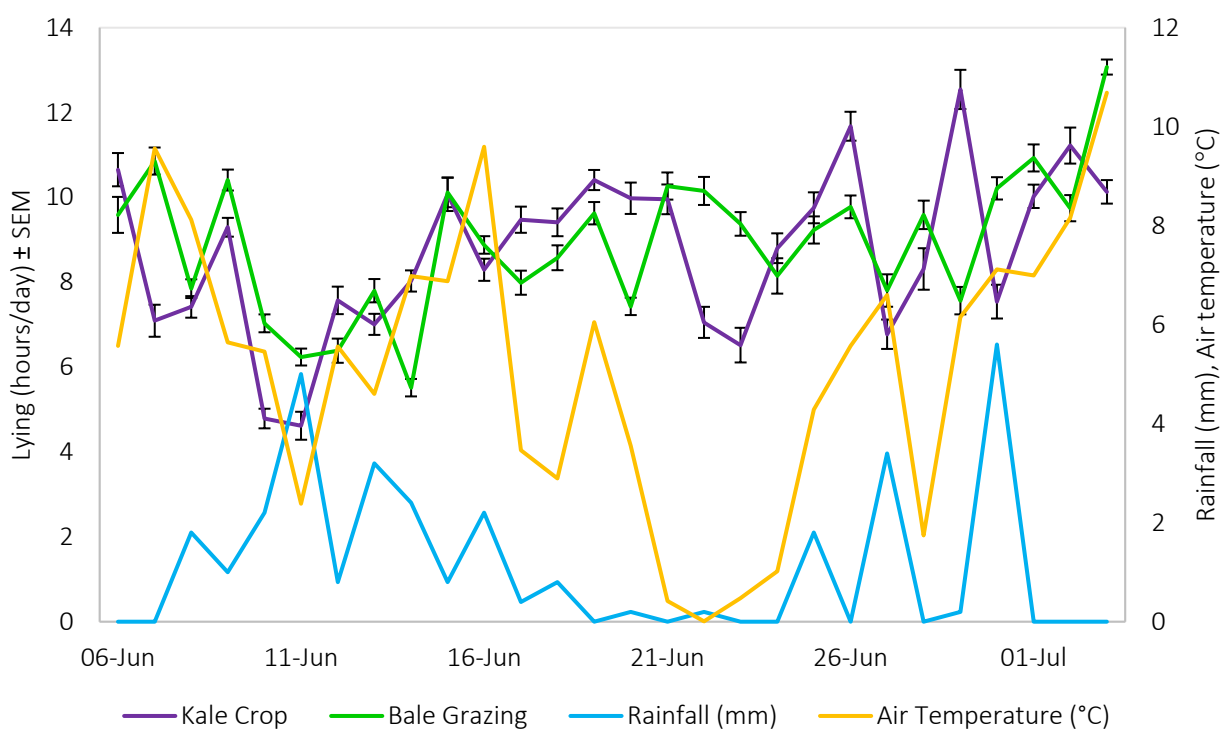


Figure 23: Raw mean \pm SEM (standard error of the mean) of daily lying times (hours/day) in the first month of winter (27 days) for the 80 pregnant non-lactating trial cows managed on either a kale crop (n=40) or bale grazing (n= 40) in relation to air temperature (°C) and rainfall (mm) daily averages.

Lying deprivation. Figure 24 shows the number of cows lying for less than 6 hours/day throughout June. An increase in rainfall and/or a decrease in ambient temperature was associated with an increase in the number of cows lying for less than 6 hours/day, and overall, fewer bale grazing cows lay for less than 6 hours/day. On June 22 (coldest day; 0 °C), 16 kale crop cows and 2 bale grazing cows lay for less than 6 hours. On June 11 (coldest/ wettest day; 2 °C, 5mm rain), 33 kale crop

cows lay down for less than 6 hours, and 21 bale grazing cows lay down for less than 6 hours. Throughout June, there were 10 days where more than 10 kale crop cows lay for less than 6 hours and only 3 days where more than 10 bale grazing cows lay for less than 6 hours.

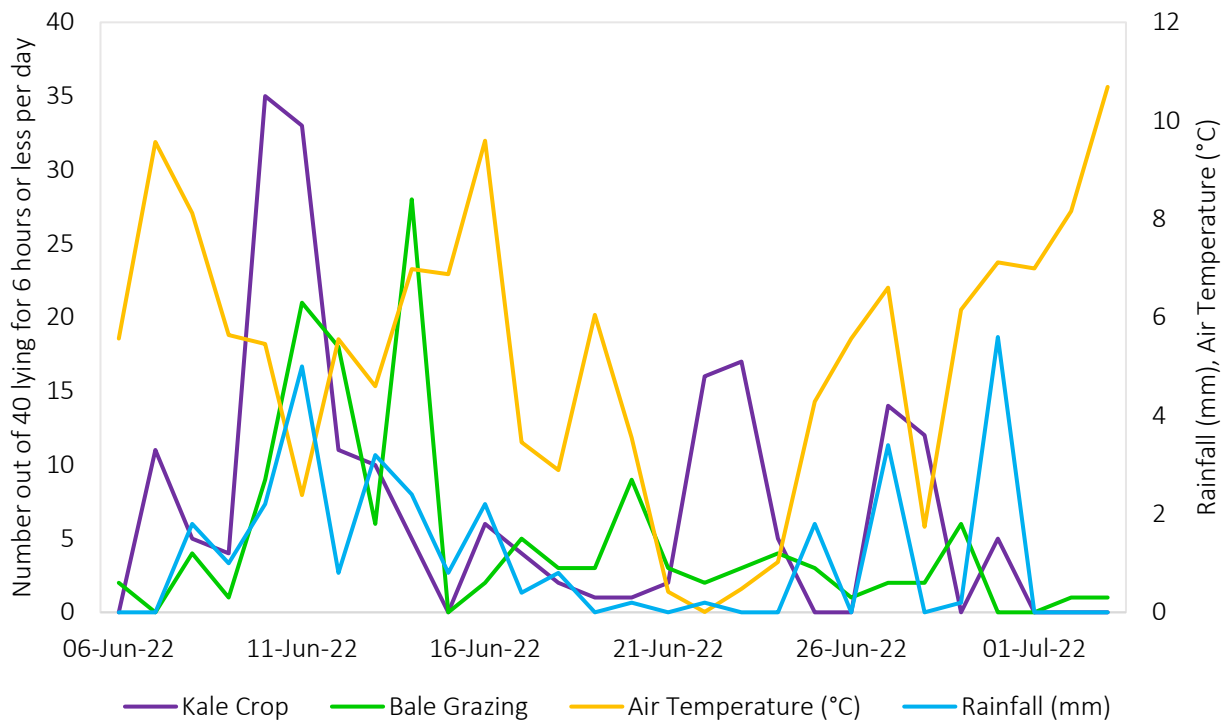


Figure 24: Number of pregnant, non-lactating cows lying for 6 hours or less per day in the first month of winter (27 days) for the 80 pregnant, non-lactating trial cows managed on either a kale crop (n=40) or bale grazing (n= 40) in relation to daily average air temperature (°C) and rainfall (mm) daily averages.

Transitions. The average number of transitions between lying and standing for bale grazing cows in the first stage of the trial (June 6 – July 3) was 15/day (SEM: 0.478; range 9-20) and 19/day (SEM: 0.935; range 10-27) for kale crop cows. In Figure 25, the number of transitions remained higher for kale crop cows, except for when there was rain, where the number of transitions dropped for both treatments. On June 30 (5.6 mm rain), kale crop cows had 13 transitions, and bale grazing cows had 15 on average. On June 12 (3.2 mm rain), kale crop cows had 10 transitions, and bale grazing cows had 13 transitions on average.

Similar to lying times, the number of transitions tended to peak straight after dropping for both groups, displaying a rebound pattern.

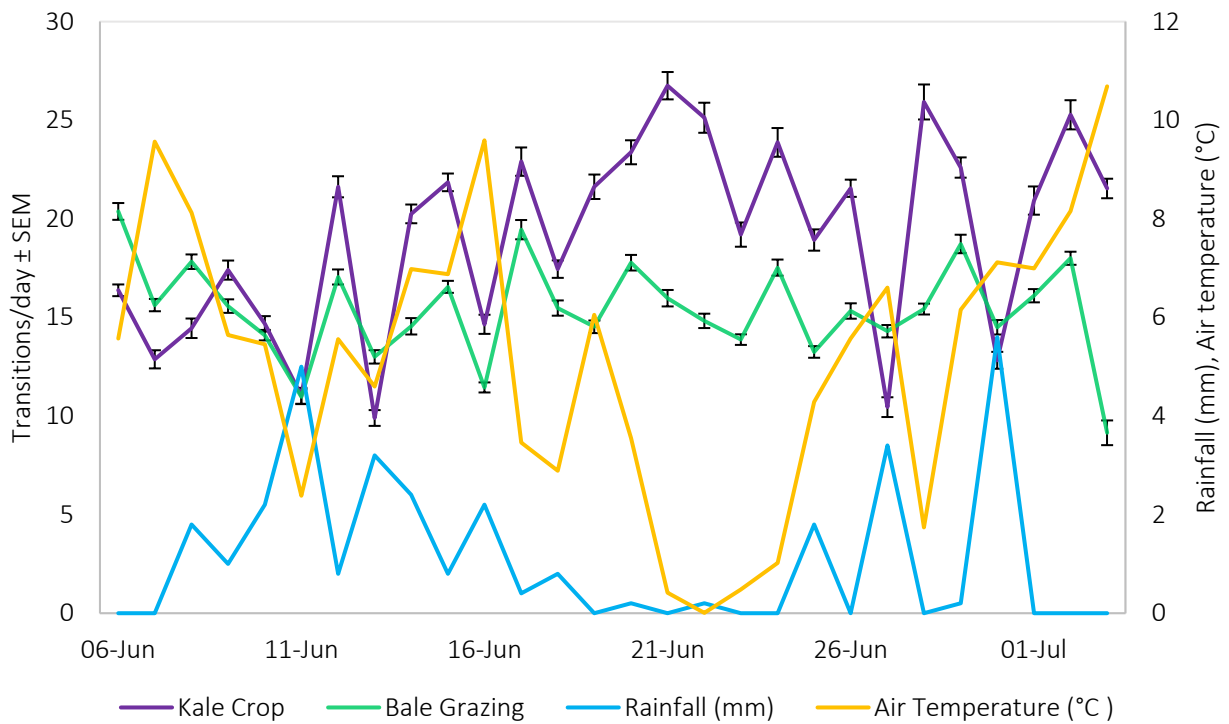


Figure 25: Raw mean \pm SEM (standard error of the mean) daily number of transitions between lying/standing in the first month of winter (27 days) for the 80 pregnant non-lactating trial cows managed on either a kale crop (n=40) or bale grazing (n= 40) in relation to air temperature ($^{\circ}$ C) and rainfall (mm) daily averages.

Steps. The average steps taken/day was 2,357 (SEM = 95) for kale crop cows and 2,045 (SEM = 130) for bale grazing cows. Steps in relation to air temperature and rainfall are displayed in Figure 26. On June 22 (coldest day; 0 $^{\circ}$ C), kale crop cows did 2,285 and bale grazing did 1,360 steps on average. On June 11 (coldest/ wettest day; 2 $^{\circ}$ C, 5mm rain), kale crop cows did 2,125, and bale grazing did 1,400 steps on average.

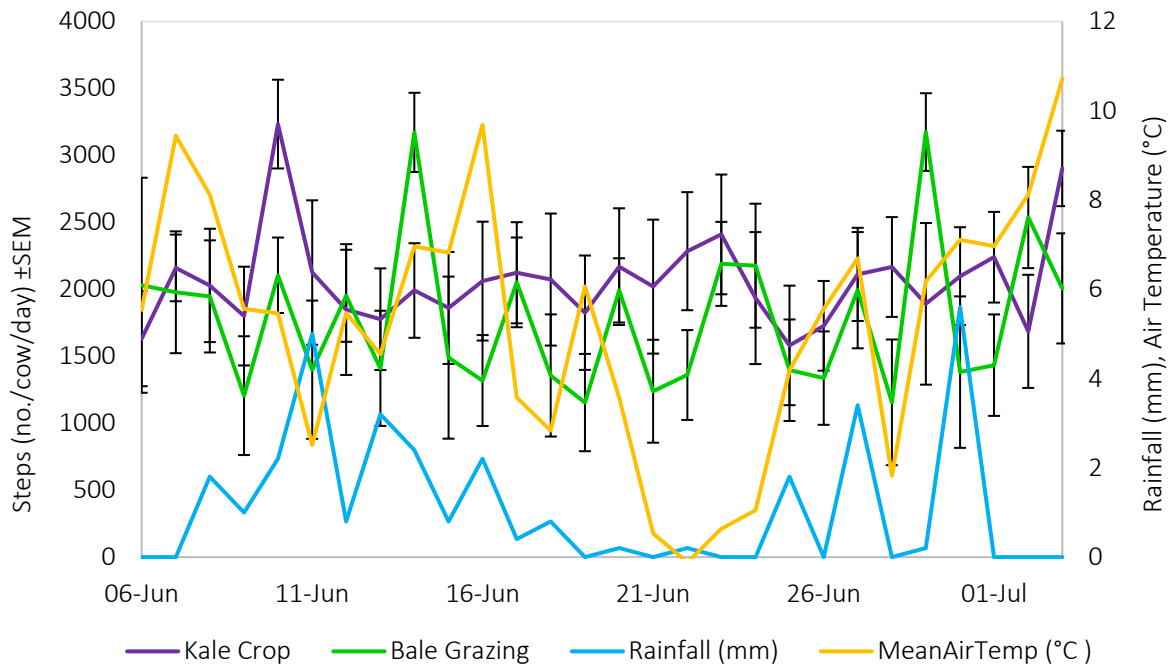


Figure 26: Raw mean \pm SEM (standard error of the mean) of daily steps taken in the first month of winter (27 days) for the 80 pregnant, non-lactating trial cows managed on either a kale crop ($n=40$) or bale grazing ($n=40$) in relation to daily average air temperature ($^{\circ}\text{C}$) and rainfall (mm) averages.

Figure 27 displays the average steps/hour across a day. Most steps were taken between approximately 7:00 am and 5:00 pm for both groups (during daylight). Kale crop cows took more steps overall than the bale grazing cows, with the main difference occurring at approximately 9:00 am, which coincided with cows being fed a new kale break.

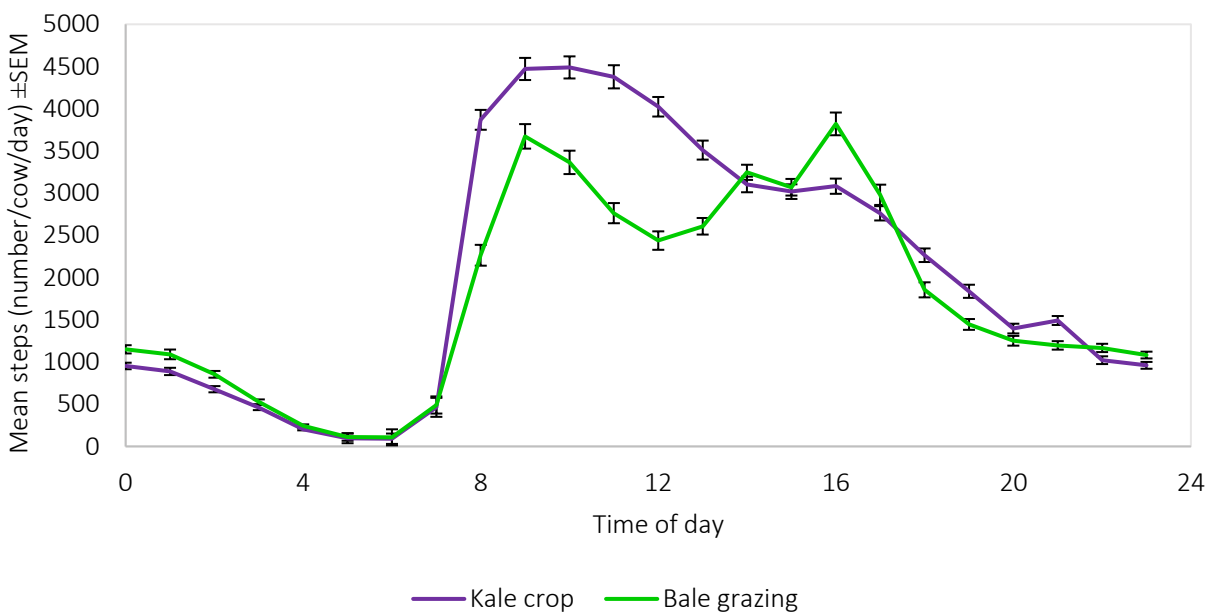


Figure 27: Raw mean \pm SEM (standard error of the mean) of diurnal stepping rate (steps/hour) of 80 pregnant, non-lactating dairy cows managed on either a kale crop ($n=40$) or bale grazing ($n=40$) for the first month of winter (27 days).

4.1.3 Hygiene Scores

After stage one, bale grazing cows had lower hygiene scores (they were cleaner) on average (on a three-point scale, looking at two focal areas; rump and belly) than kale crop cows. At dry-off (June 1), kale crop cows had a hygiene score of 1.16 (SEM = 0.04) and bale grazing cows had a hygiene score of 1.35 (SEM = 0.07) on average. Thirty-two days later (July 3), kale crop cows had a hygiene score of 1.58 (SEM = 0.08), and bale grazing cows had a hygiene score of 1.15 (SEM = 0.05) on average. Hygiene scores decreased by 0.2 (SEM = 0.08) for the bale grazing cows and increased by 0.41 (SEM = 0.10) on average for kale cows (Figure 28).

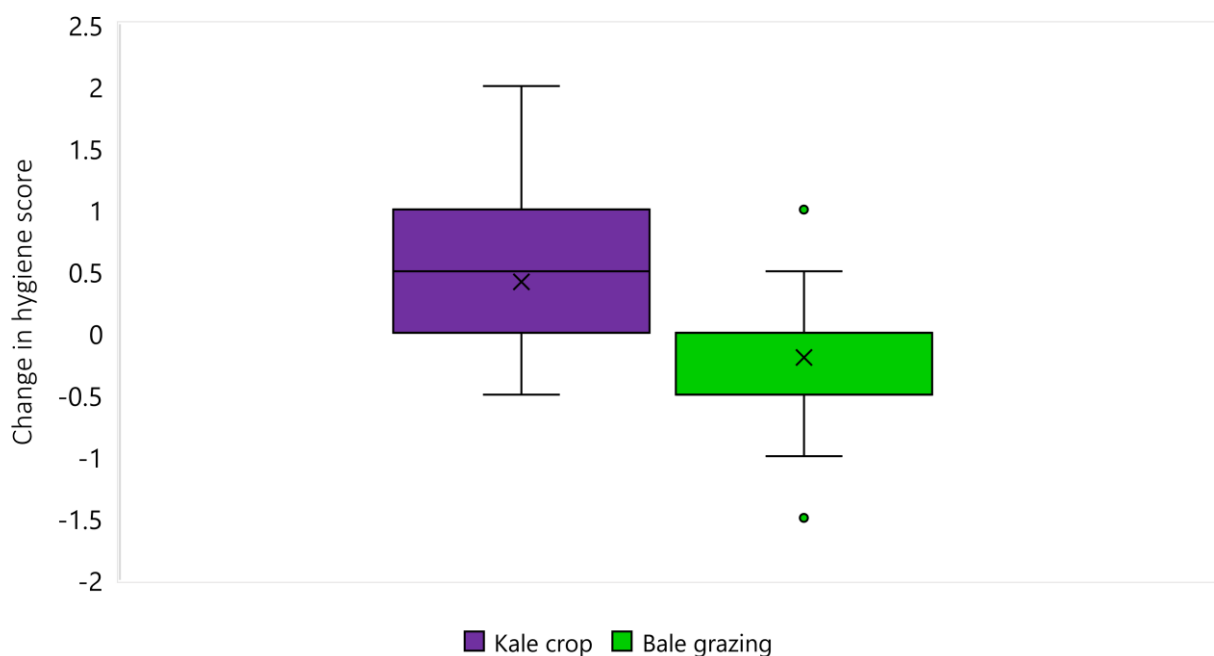


Figure 28: Raw mean hygiene score change on a three-point scale before and after stage one (32 days/first month of winter) for the 80 pregnant, non-lactating trial cows managed on either a kale crop (n=40) or bale grazing (n= 40). Higher hygiene scores indicate a dirtier coat.

4.1.4 Body Condition Score and Liveweight

Bale grazing and kale crop cows gained similar body condition and liveweight over winter.

This is presented in Tables 4 and 5.

Table 4: Raw mean, minimum, maximum and SEM (standard error of the mean) for body condition score (BCS) before the dry period (June 1), during the dry period (July 3), and after the dry period (August 5) with the change (June 1 – August 5) over the entirety of the dry period for the 80 pregnant, non-lactating trial cows managed on either a kale crop (n=40) or using bale grazing (n= 40).

	June 1		July 3		August 5		Overall gain	
	Kale crop	Bale grazing	Kale crop	Bale grazing	Kale crop	Bale grazing	Kale crop	Bale grazing
BCS	4.5	4.5	4.7	4.8	5.0	5.3	0.5	0.7
Minimum	3.5	3.5	4.0	4.5	4.0	4.5	-0.5	0
Maximum	5.0	6.0	5.5	5.5	6.0	6.0	2.0	1.5
SEM	0.06	0.07	0.05	0.07	0.08	0.10	0.08	0.10

Table 5: Raw mean, minimum, maximum and SEM (standard error of the mean) for liveweight (LW) before the dry period (June 1), during the dry period (July 3), and after the dry period (August 5) with the change (June 1 – August 5) over the entirety of the dry period for the 80 pregnant, non-lactating trial cows managed on either a kale crop (n=40) or using bale grazing (n= 40).

	June 1		July 3		August 5		Overall gain	
	Kale crop	Bale grazing	Kale crop	Bale grazing	Kale crop	Bale grazing	Kale crop	Bale grazing
LW (kg)	468	470	466	497	492	507	29.1	30.0
Minimum	368	390	378	418	405	430	-12.0	8.0
Maximum	596	630	588	690	630	725	69.0	95.0
SEM	8.8	8.4	8.25	15.1	8.9	16.1	2.93	4.6

4.2 Stage Two

4.2.1 Weather Conditions

During the two days, cows were on the experimental plots (4 – 6 July), conditions were cold and dry. The average air temperature was 7.8 °C (range: -2.2 to 20.5 °C), with 1mm of rain on the second day. Wind chill was 7.2 °C on average (range: -3.9 to 20.4 °C).

4.2.2 Feed Intake

Kale crop cows consumed an average of 15.3 kg of DM per day of kale crop and hay combined (est. 182 MJ/cow/day). Bale grazing cows consumed 16.1 kg/DM per day on average of pasture and hay (est. 151 MJ/cow/day).

4.2.3 Lying Behaviour

Lying times. Lying times were obtained from the IceQube accelerometers. On the first day of stage two, bale grazing cows spent 13.7 hours (range: 7.7 to 16.0 hours), and kale crop cows spent 10.6 hours (range: 8.3 to 13.3 hours) lying down on average (SED = 1.01, $F_{1,9} = 9.45$, $P = 0.013$). On the second day, bale grazing cows spent 12.0 hours (range: 10.5 to 13.0 hours), and kale crop cows spent 12.1 hours (range: 10.9 to 14.7 hours) lying down on average (SED = 0.37, $F_{1,9} = 0.09$, $P = 0.767$). This is presented in Figure 29, which shows data aggregated into 3-hour blocks (averaged per plot, then per treatment then per period).

Behavioural observation data was very similar to the IceQube accelerometer data. Over the two days, 106/107 observations (106 for plots 1-13, 107 for plots 15-25) were recorded per cow. Kale crop cows were observed lying down less (57 % of observations) than bale grazing cows (44 % of

observations) on average on the first day (SED = 4.25, $F_{1,9} = 9.80$, $P = 0.012$). On the second day, both treatments were observed lying in 50 % of observations on average (SED = 1.48, $P = 0.725$).

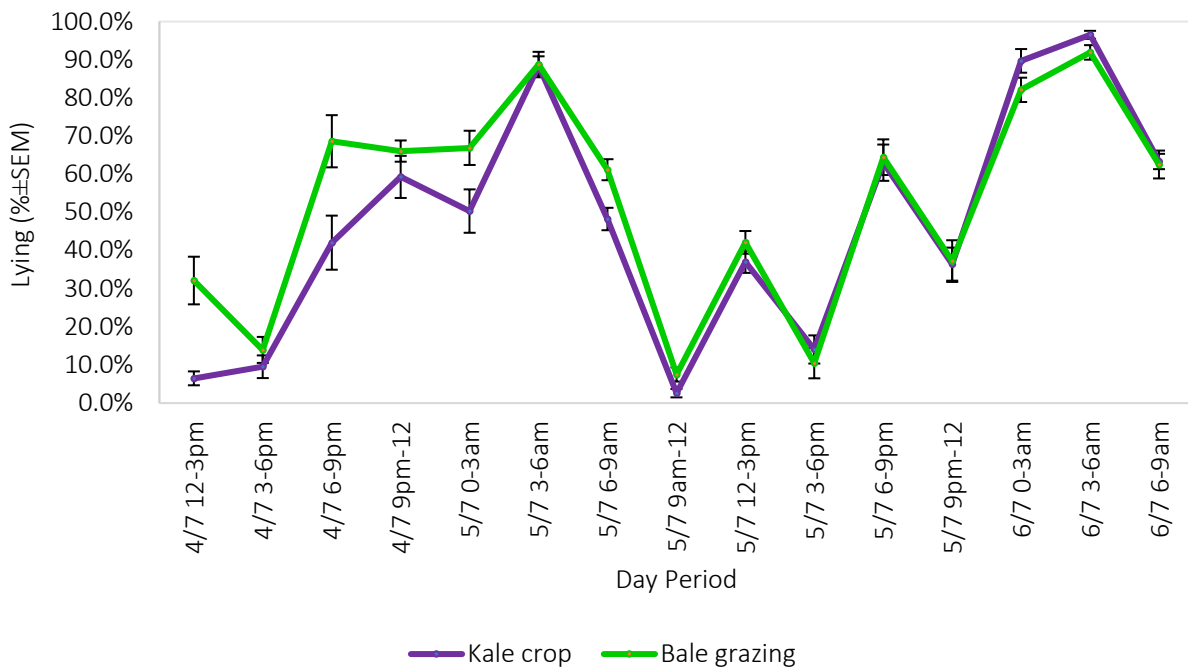


Figure 29: Diurnal lying behaviour in three-hour blocks (average % of time spent lying) \pm SEM (standard error of the mean) for pregnant, non-lactating dairy cows managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter starting at 12:00 pm on the July 4 and ending at 8:00 am on July 6 2022.

Transitions. On the first day of stage two, bale grazing cows took 16 transitions (range: 14 – 23) and kale crop cows took 20 transitions (range: 15 to 25) between lying and standing on average (SED = 3.43, $F_{1,9} = 8.12$, $P = 0.019$). On the second day, bale grazing cows took an average of 12 transitions (range: 7 – 16) and kale crop cows took an average of 13 transitions (range: 11 to 15) between lying and standing on average (SED = 2, $F_{1,9} = 0.968$, $P = 0.351$). This is presented in Figure 30, which shows data aggregated into 3-hour blocks.



Figure 30: Diurnal lying behaviour in three-hour blocks (average number of transitions to lying/standing) \pm SEM (standard error of the mean) of pregnant, non-lactating dairy cows managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter starting at 12:00 pm on the July 4 and ending at 8:00 am on July 6 2022.

Lying posture. Regarding observations of leg position when lying, cows in both treatments were observed lying with both front legs bent during most observations. Bale grazing cows were observed to spend significantly more time lying with their legs in an extended position on average (no front legs bent) (3.1% of observations when lying) compared to the kale crop cows (1.9% of observations when lying) ($SED = 0.43$, $F_{1,9} = 7.60$, $P = 0.022$, Figure 30). In terms of head position (head supported by body) when lying, kale crop cows were observed to have their head supported 4.9% of the time, and bale grazing cows were observed having their head supported 4.2% of the time on average when lying ($SED = 1.13$, $F_{1,9} = 0.37$, $P = 0.557$, Figure 31).

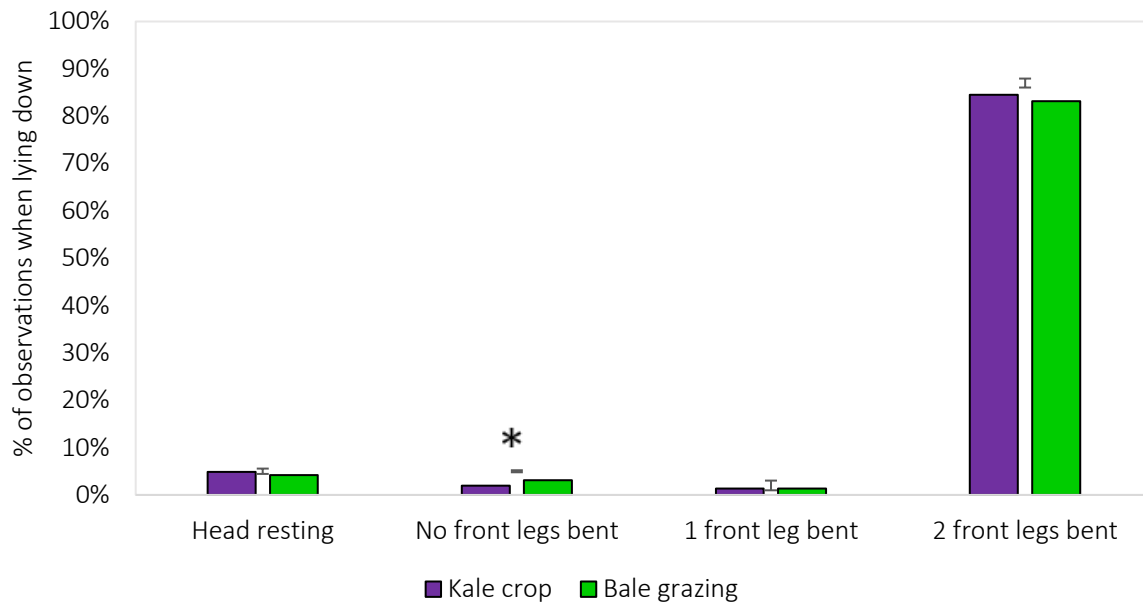


Figure 31: Mean percentage of lying observations cows were observed with their head resting, and number of legs bent (3 scans/hour to 8:00 am – 6:00 pm, 2 scans/hour 6:00 pm – 8:00 am) for pregnant, non-lactating dairy cows managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter starting at 12:00 pm on the July 4 and ending at 8:00 am on July 6 2022. Significance level is indicated by ** ($P < 0.01$) and * ($P < 0.05$).

4.2.4 Eating and Ruminating Behaviour

Rumination. Bale-grazing cows were observed ruminating more than kale crop cows while on the plots. Over the two days, 106/107 observations (106 for plots 1-13, 107 for plots 15-25) were recorded per cow. On day one, kale crop cows were observed ruminating in 30.9% of observations, and bale grazing cows were observed ruminating in 37.9% of observations on average (SED = 2.00, $F_{1,9} = 12.53$, $P = 0.006$). On day two, kale crop cows were observed ruminating in 28.7% of observations, and bale grazing cows were observed ruminating in 36.8% of observations (SED = 1.65, $F_{1,9} = 23.84$, $P = <0.001$). Rumination times peaked between 6:00 – 9:00 pm on both days for both treatments, but bale grazing cows had higher rumination times overall. This is displayed in Figure 32, where values are presented in 3-hour blocks.

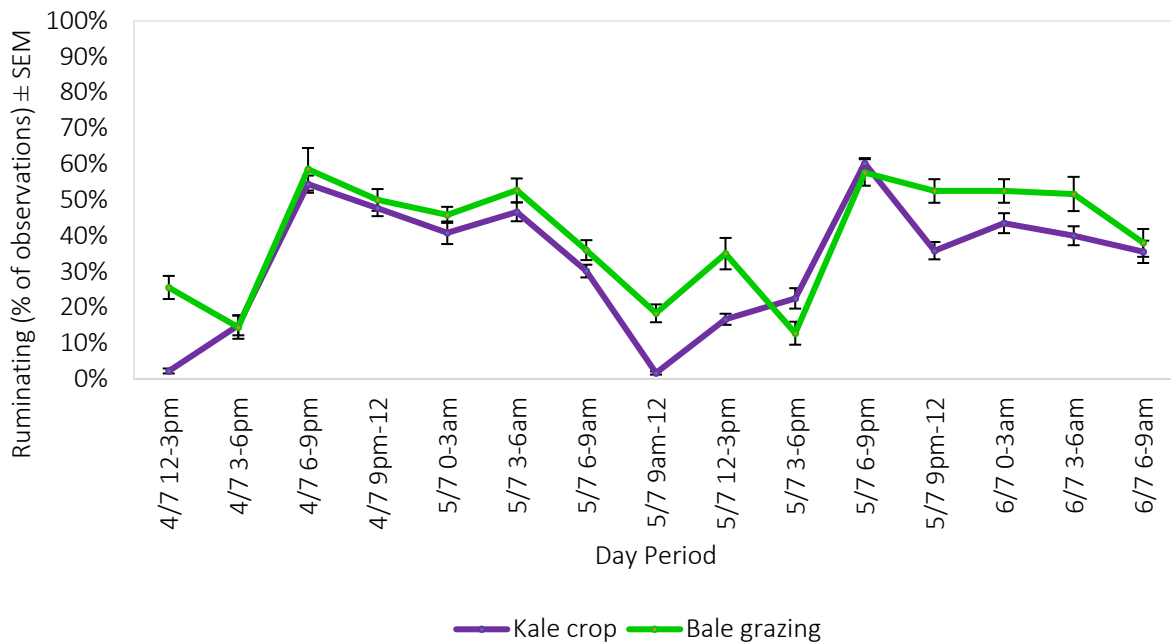


Figure 32: Mean percentage of observations in three-hour blocks \pm SEM (standard error of the mean) (3 scans/hour to 8:00 am – 6:00 pm, 2 scans/hour 6:00 pm – 8:00 am) pregnant, non-lactating dairy cows were recorded ruminating when managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter starting at 12:00 pm on July 4 and ending at 8:00 am on July 6.

Eating. Both treatments were observed eating for similar proportions of observations while on the plots. On day one, kale crop cows were observed eating in 26.6% of observations, and bale grazing cows were observed eating in 28.7% of observations on average (SED = 2.47, $F_{1,9} = 0.67$, $P = 0.433$). On day two, kale crop cows were observed eating in 32.2% of observations, and bale grazing cows were observed eating in 31.4% of observations on average (SED = 2.39, $F_{1,9} = 0.39$, $P = 0.549$). Eating times peaked earlier in the day (12:00 – 3:00 pm, day one, 9:00 am – 12:00 pm, day two) and in the evening (3:00 – 6:00 pm) for both treatments. However, the morning peak was much higher for the kale crop cows, and the only time their eating times exceeded that of the bale grazing cows was earlier both days one and two. This is displayed in Figure 33.

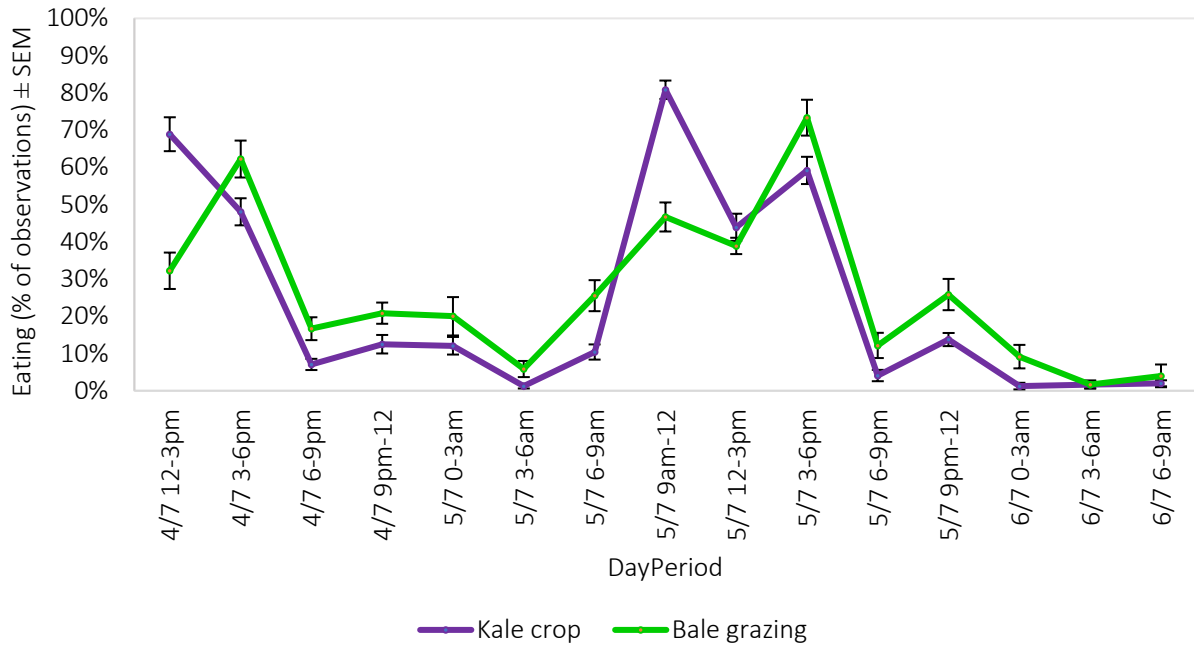


Figure 33: Mean percentage of observations in three-hour blocks \pm SEM (standard error of the mean) (3 scans/hour to 8:00 am – 6:00 pm, 2 scans/hour 6:00 pm – 8:00 am) pregnant, non-lactating dairy cows were recorded eating when managed on either a kale crop ($n = 4$ cows/group) or using bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter starting at 12:00 pm on July 4 and ending at 8:00 am on July 6.

4.2.5 Hygiene Scores

Kale crop cows, on average, had higher hygiene scores than the bale grazing cows before going on the plots (they had dirtier coats). They also had a more significant increase in hygiene scores while on the plots than the bale grazing cows, as seen in Table 6.

Table 6: Mean hygiene scores (+SED, standard error of the difference) and hygiene score change for pregnant, non-lactating dairy cows before and after stage two of the trial (experimental plots) when managed on either a kale crop (n = 4 cows/group) or bale grazing (n = 2 cows/group) treatments (n = 10 groups/treatment) for two days during winter 2022.

	Average hygiene score before plots	Average hygiene score after plots	Average change in hygiene score
Kale crop	1.58	2.45	0.88
Bale grazing	1.20	1.33	0.13
SED	0.5281	6.33	2.8125
P	<u>0.023</u>	<u><0.001</u>	<u>0.004</u>
F df	1, 9	1, 9	1, 9
F ratio	0.447	0.339	0.354

4.2.6 Skin Temperature

Bale grazing cows had significantly higher skin temperatures on average than the kale crop cows for both the rump and thigh measurements. Bale grazing cows had thigh skin temperatures of 24 °C, and kale crop cows had temperatures of 21 °C on average (SED = 0.65, $F_{1,9} = 22.3$, $P = 0.002$). For the rump, bale grazing cows had skin temperatures of 24 °C and kale crop cows had temperatures of 21 °C on average (SED = 0.44, $F_{1,9} = 11.0$, $P = 0.007$). This is displayed in Figure 34.

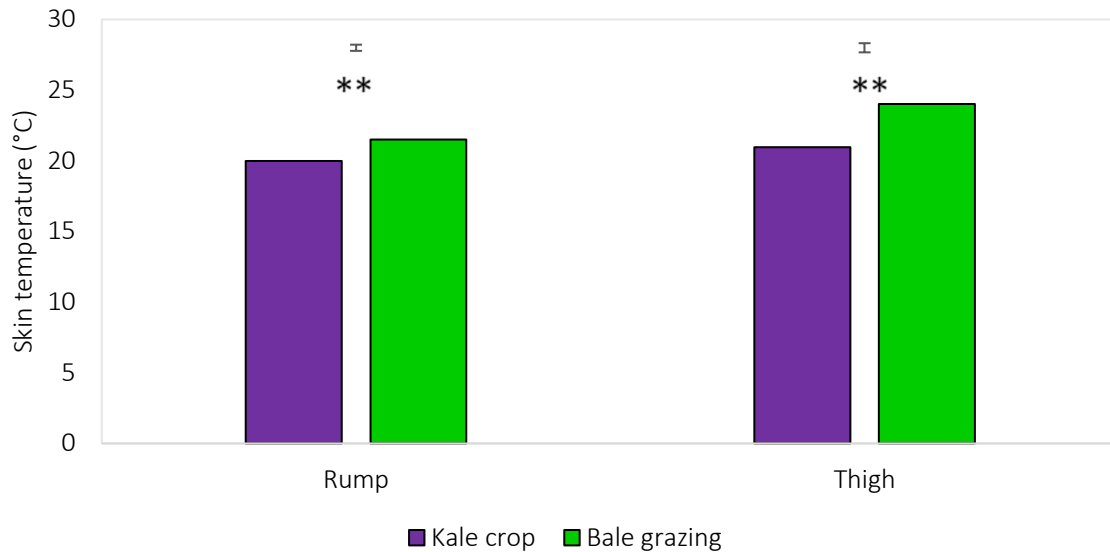


Figure 34: Mean skin temperatures (\pm standard error of the difference, SED) of the rump and thigh for pregnant, non-lactating dairy cows when managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter 2022. Significance level is indicated by ** ($P < 0.01$) and * ($P < 0.05$).

4.2.7 Infrared Thermography Images

Figure 35 shows kale crop cows had significantly colder noses (average) when lying down than bale grazing cows. While lying, kale crop cows had an average nose temperature of 23.2 °C and bale grazing cows had an average nose temperature of 27.8 °C on average (SED = 2.12, $F_{1,9} = 4.74$, $P = 0.048$). The minimum nose temperature while lying was 6.4 °C colder for kale crop cows compared to bale grazing cows on average (14.6°C vs 21.0°C, SED = 2.24, $F_{1,24.5} = 8.13$, $P = 0.009$). No other treatment differences were found for the forehead or body while lying/standing (mean, minimum, maximum $P \geq 0.176$, Figure 36). Regions of interest (nose, forehead and body) can be observed in Figure 20, located Chapter Three (Methods).

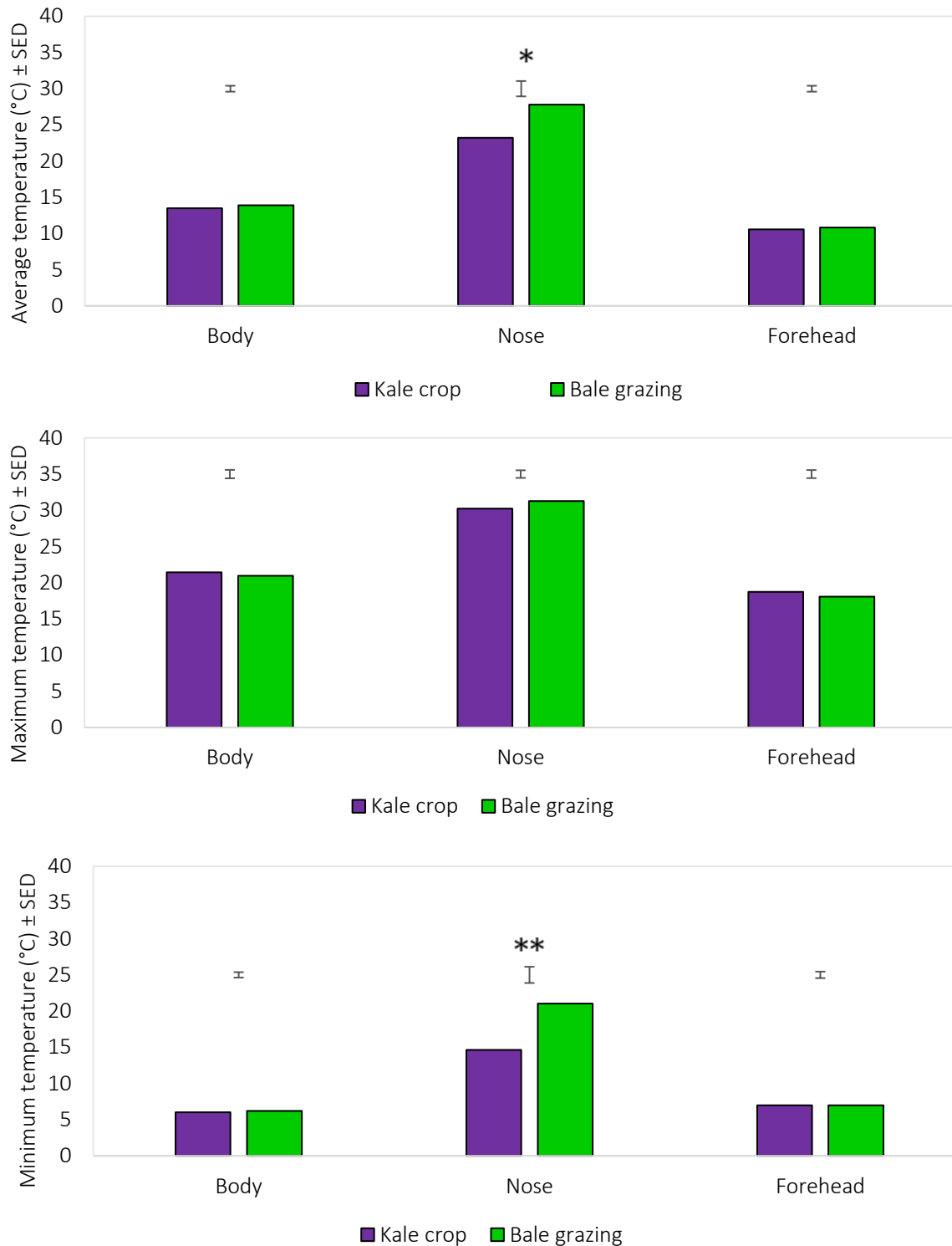


Figure 35: Average, maximum and minimum surface (\pm standard error of the difference, SED) temperature ($^{\circ}$ C) of the nose, body and forehead when lying for pregnant, non-lactating dairy cows when managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter 2022. Significance level is indicated by ** ($P < 0.01$) and * ($P < 0.05$).

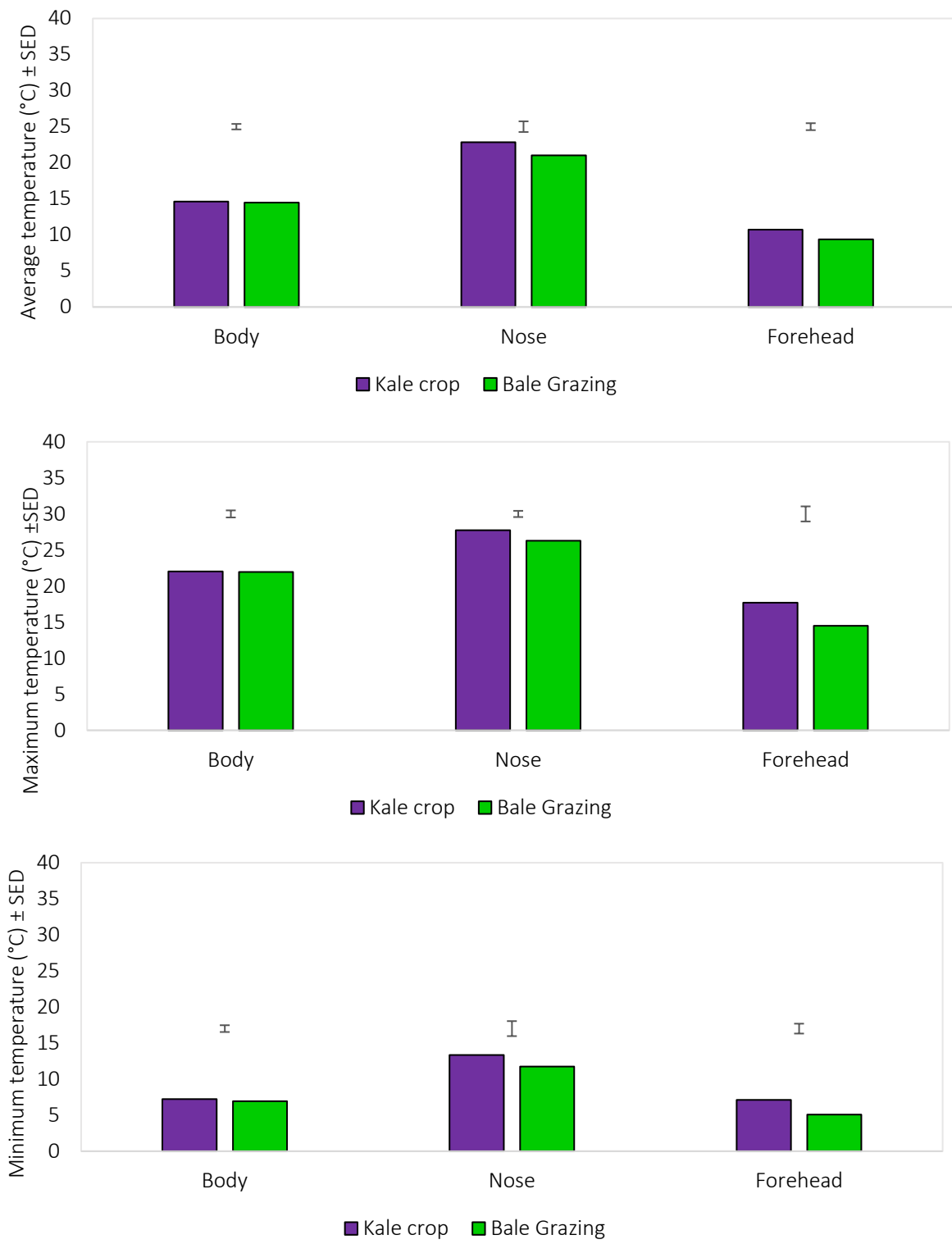


Figure 36: Average, maximum and minimum surface (\pm standard error of the difference, SED) temperature ($^{\circ}$ C) of the nose, body and forehead when standing for pregnant, non-lactating dairy cows when managed on either a kale crop ($n = 4$ cows/group) or bale grazing ($n = 2$ cows/group) treatments ($n = 10$ groups/treatment) for two days during winter 2022.

4.2.8 Surface Measurements

Boot/mud score. After the plot exposure, kale crop plots had higher average boot scores, while the bale grazing plots remained the same. The mean mud score for all plots before the cows went onto the plots was 1.0. After the cows had been on the plots, the average boot score was 1.0 for the bale grazing treatment and 1.3 for the kale crop treatment (SED = 0.28, $F_{1,9} = <0.001$, $P = 0.051$).











Mud depth. Kale crop plots became more compacted after the plot exposure. Before the cows entered the plots, bale grazing plots had an average mud depth of 0.39 cm, and kale crop plots averaged 1.38 cm deep. After the plot exposure, bale grazing plots decreased to 0.19 cm, and kale crop plots decreased to 0.46cm deep on average (SED = 0.29, $F_{1,9} = 0.17$, $P = 0.058$). The change in mud depth was significantly greater for the kale crop treatment, with depth decreasing by 0.93 cm for the kale crop treatment and 0.21 cm for the bale grazing treatment on average (SED = 0.67, $F_{1,9} = 0.27$, $P = 0.008$).











Surface water pooling. No surface water pooling was observed for either of the treatments. Any visible surface water was the result of emptying water troughs upon stage two completion.











Before and after photos. Surface conditions of the experimental plots are shown in Table 7.









Table 7: Surface conditions before (July 3) and after (July 6) non-lactating dairy cows were managed on either a kale crop (n = 4cows/group) or bale grazing (n = 2 cows/group) experimental treatments (n = 10 groups/treatment) for two days during winter 2022.

Plot	Treatment	Before	After
1	Bale grazing		

4	Bale grazing		
8	Bale grazing		
10	Bale grazing		
12	Bale grazing		
16	Bale grazing		

17	Bale grazing		
21	Bale grazing		
22	Bale grazing		
25	Bale grazing		
2	Kale crop		

3	Kale crop		
7	Kale crop		
11	Kale crop		
13	Kale crop		
15	Kale crop		

18	Kale crop		
20	Kale crop		
23	Kale crop		
24	Kale crop		

Chapter Five: Discussion

Intensive winter grazing on crops is the current standard practice for managing pregnant, non-lactating dairy cattle over winter in Southland, New Zealand. This may result in welfare issues related to inadequate lying surfaces and impaired thermoregulatory ability in cold weather. High stocking rates and cattle being encouraged to graze the crop right down to the ground result in bare surfaces that are often wet and muddy, especially in combination with rain. This then leaves cows reluctant to lay down, potentially resulting in frustration and stress, as lying is a highly motivated behaviour. Issues with thermoregulation may occur if cows must lay down on wet and muddy surfaces in cold conditions. There is little information in the literature regarding the welfare of dairy cattle when using alternatives to intensive winter grazing on crops in pasture-based systems. This study aimed to explore the welfare implications in terms of lying behaviour and thermoregulation of bale grazing (management on pasture with hay supplemented) by comparing it to traditional management on winter crops in a commercial setting.

During stage one of the trial, average lying times for both treatments were similar, and both groups of cattle showed rebound lying behaviour in cold, rainy conditions, but this was more pronounced for kale crop cows. Kale crop cows took more steps, had more transitions between lying and standing and had dirtier coats on average. During stage two (experimental plots), kale crop cows lay down less than bale grazing cows and undertook significantly more transitions between lying/standing on day one. Bale grazing cows spent more time in lying postures indicative of comfort (in terms of substrate and temperature), were observed ruminating more, remained cleaner, and had higher rump and thigh skin temperatures and higher infrared nose temperatures when lying than the kale crop cows. The surface for the kale crop cows became more compacted and got muddier. Overall, results suggested that bale grazing cows were more comfortable than kale crop cows regarding lying behaviours and thermoregulatory parameters.

5.1 Lying Behaviours During Stage One

Lying times are an essential indicator of welfare status, as lying is a highly motivated behaviour for cattle. When cattle cannot lay down enough to meet their daily requirements of lying times, affective state may be negatively impacted (Chen et al., 2017; Dalley et al., 2021; Tucker et al., 2007; Tucker et al., 2021; Webster et al., 2015). Various studies have shown that cows will forgo feeding to lay down when deprived of lying and feeding for as little as three hours, and they will put in 'work' to gain access to a comfortable lying area (Arends, 2016; Chen et al., 2017; Metz, 1985; Tucker et al., 2021; Webster et al., 2015). In optimal conditions (dry and comfortable surface), cows generally lay down for 10-12 hours daily in outdoor systems (Arends, 2016; Neave et al., 2022; O'Connor et al., 2019; Tucker et al., 2021), hence why the NZ Dairy Cattle Code of Welfare also recommends cows should lay down for 10-12 hours/day to meet their behavioural needs (MPI, 2019). Due to the high importance of lying times to cows and the fact that negative affective states result from deprivation, we can then look at the different factors that affect lying behaviours and use these to infer the affective state of the cows under the two wintering systems (Neave et al., 2022; Tucker et al., 2021).

Weather and surface conditions are two major factors influencing lying behaviours regarding lying times, transitions between lying and standing, and steps. Cows will stand for extended periods in rainy/windy conditions due to finding wet and muddy conditions unfavourable to lay in, which is then enhanced by colder temperatures (Al-Marashdeh et al., 2019; Dalley et al., 2021; Hendriks et al., 2020; Neave et al., 2022; O'Connor et al., 2019; Schütz et al., 2019; Tucker et al., 2007). There is evidence that cows find pasture a comfortable surface to rest on, as it is softer (Margerison et al., 2014). Rainfall and mud also impact stepping behaviour, as there is some evidence that cattle may reduce their energy expenditure when it is cold/wet and defer grazing to when it is warmer (Malechek & Benton, 1976). Mud is also more challenging to move in (Dickson et al., 2022) and could potentially increase this effect.

Lying bout frequency/number of transitions can fluctuate in response to environmental conditions, which are similar to the conditions that impact lying times (Dechamps et al., 1989; Hayley et al., 2000; Munksgaard & Simonsen, 1996; Tucker et al., 2021). Typically, when cows have lower lying times, they perform fewer transitions between lying and standing and have fewer lying bouts due to less overall time lying. In cases where lying times remain similar and transitions decrease, it may indicate that cows are reluctant to change position in low space allowances, where movement is difficult (Hayley et al., 2000). In contrast, cows have been found to increase the number of transitions between lying and standing in response to unfavourable conditions, possibly due to restlessness, even when lying times decrease (Munksgaard & Simonsen, 1996). This is thought to be because lying is a highly motivated behaviour, and when cows are reluctant to lay down in adverse conditions, they display more transitions between behaviours (including transitions between lying and standing) due to restlessness (Cooper et al., 2007; Tucker et al., 2021). However, most of the literature surrounding this topic comes from indoor housing systems, so care must be taken when applying this information to outdoor systems.

Stocking rates influence lying behaviour, as when suitable lying surfaces are limited, older, more dominant cows will gain priority over favourable (dry/softer) areas (Coveney, 2016; Neave et al., 2022; Tucker et al., 2021). Higher stocking rates are then associated with increased aggressive interactions and nonaggressive lying disturbances, which can result in more transitions between lying and standing (Schütz et al., 2015). Stocking rates also contribute to the surface conditions and make them more unfavourable for lying due to pugging, further confounding the effect of stocking rates on lying behaviours.

Winter grazing environments may also increase the incidence of lameness due to reduced lying times as well as the continuous wetness and poor hygiene, which softens the hoof and weakens the protective layer that stops bacteria from entering the hoof (Coveney, 2016; De Wolde, 2006; Schütz et al., 2019; Tucker et al., 2021). This further impacts lying behaviour, making it painful for the

cows to lay down and stand up. This can lead to welfare compromise due to the resultant pain and further impacts on lying behaviour. No lameness measures were taken in this study, so this will not be discussed, but it is important to acknowledge.

While no inferential statistics were calculated from stage one of the trial, we still observed several prominent patterns indicative of welfare status within the two wintering systems. Bale grazing cows were observed to lay down for 8.9 hours/day, and the kale crop cows lay down for 8.7 hours/day on average. Therefore, both treatments were getting slightly less than expected (ideally 10-12 hours/day in outdoor systems) lying times on average, but these numbers are still typical for outdoor farming systems (Tucker et al., 2021). The average number of transitions between lying and standing for bale grazing cows was 15/day and 19/day for kale crop cows. The average number of steps taken/day was 2,357 for kale crop cows and 2,045 for bale grazing cows. On average, both groups had peak average step counts at around 9:00 am, but this peak was more prominent for kale crop cows. Steps for the bale grazing cows peaked every two to three days.

On days with inclement weather (rain/cold/both), both treatments showed reductions in their lying times, which was more severe for kale crop cows. Hygiene scores (measure of coat cleanliness, on a three-point scale) demonstrated that kale crop cows were on average muddier after stage one (an increase of 0.41 vs 0.2), suggesting that their environment was muddier, as hygiene scores reflect the fact that cows were lying down in mud (Neave et al., 2022).

While surface measures were not collected during stage one, hygiene score results indicated muddier conditions for the kale crop treatment, as cows became muddier after stage one. This allows speculation of what surface conditions would have been like based on the management of the cows. The bale grazing surface would have been less susceptible to pugging and damage due to lower stocking rates and the grass residue being able to absorb some of the wetness. The kale crop surface would have been much more susceptible to pugging and surface water pooling due to higher stocking

rates and cows being encouraged to graze the kale right down to the ground, leaving bare soil (Neave et al., 2022).

When the environment became muddier (rainfall events), lying times and transitions between lying and standing decreased, which is simply because fewer lying times are correlated with fewer transitions, as cows are lying down less. However, this does not explain why kale crop cows had slightly lower lying times but slightly higher transitions on average. This aligns with previous work that has shown unfavourable lying surfaces (such as one that is wet and muddy) will cause an increase in transitions between behaviours, including that of lying and standing (Munksgaard & Simonsen, 1996). This is thought to arise because lying is a highly motivated behaviour, and when cattle cannot lay down, they display other displacement behaviours due to restlessness (Cooper et al., 2007; Tucker et al., 2021). This is possibly a reason why this trend was observed, and it potentially indicates that kale crop cows were experiencing a degree of restlessness and discomfort from the muddier surface, resulting in more transitions and potentially adverse welfare outcomes.

Another potential reason for slightly lower lying times but slightly higher transitions on average during inclement weather for kale crop cows is the stocking rate. When lying surfaces are limited, the number of lying disturbances has been shown to increase, as dominant cows will gain priority over the favourable (dry) resting surfaces (Coveney, 2016; Neave et al., 2022; Schütz et al., 2015; Tucker et al., 2021). We can presume that during rain, the amount of dry space for lying down would decrease, causing competition for these spaces, resulting in more lying disturbances and, therefore, more transitions between lying and standing. Therefore, bale grazing provided an environment more suited to lying, and due to the correlation between lying and affective state for cattle, they were likely more comfortable. It is feasible to assume bale grazing cows had more positive welfare outcomes due to the provision of a more suitable lying surface better suited to withstanding typical adverse winter weather.

Failure to meet daily lying requirements for multiple days can lead to lying deprivation. A behaviour indicative of this is rebound lying behaviour. This is where cattle will lay down more within the following days to make up for lost lying times in the days prior (Cooper et al., 2007; Hopster et al., 2002; Neave et al., 2022). This can result in cows forgoing feeding to lie down to compensate for lost lying time (Arends, 2016; Chen et al., 2017; Tucker et al., 2021; Webster et al., 2015). Continued lying deprivation can also put cattle into a state of chronic stress (Fisher et al., 2002) and cause the display of behaviours associated with discomfort and likely frustration (although links are still unclear) (Tucker et al., 2021). Such behaviours include weight shifting and leaning, which is thought to be an attempt to alleviate muscle tiredness (Schütz et al., 2019). Specifically, lying times of less than 6 hours per day have been shown to result in stress-induced fluctuations of the hypothalamic-pituitary-adrenal axis (Fisher et al., 2002; Munksgaard & Simonsen, 1996; Tucker et al., 2007). Also, other work has shown that when managed on extremely aversive surfaces (such as concrete), cows will lie down for less than 6 hours (Schütz & Cox, 2014). Therefore, we know that when cows lay down for 6 hours or less per day, they experience lying deprivation, which has further negative connotations beyond rebound behaviour the following days.

On days with inclement weather (rain/cold/both), both treatments showed reductions in lying times, the number of transitions between lying and standing, and steps. Reductions in lying times and number of transitions were more severe for kale crop cows, and the decrease in steps was more prominent for the bale grazing cows. We then saw rebound lying behaviour for both groups of cattle following inclement weather, as there are several points where lying times peak directly after they dropped. These peaks and troughs were more pronounced for the kale crop cows again, and the number of cows lying for less than 6 hours or less per day was greater for kale crop cows (there were 10 days where more than 10 kale crop cows lay for less than 6 hours and only 3 days where more than 10 bale grazing cows lay down for less than 6 hours). It is plausible to assume both groups experienced lying deprivation, but this was more pronounced for the kale crop cows. Low lying times and subsequent lying deprivation severely impact both the physiological and affective states of cattle,

meaning that kale crop cows were likely experiencing a more significant compromise to their welfare than bale grazing cows.

Time budget and management practices are also essential when discussing lying behaviours. Previous work has shown that hunger and competition for feed will motivate cows that are break-fed and only moved once daily to consume the majority of (>70%) their feed allowance within 4 hours (Grant & Albright, 1995; Gregorini et al., 2009; Rugoho, 2014). This means they have a long time before the next feed allocation. This possibly relates to lying behaviour, as shorter eating times should allow longer lying times due to more available time (Neave et al., 2022). In contrast, diets higher in forage at higher allocations (i.e. a fresh break every three days) and that require longer grazing times (such as pasture and hay) may reduce lying time, as cows will need to spend more time eating to meet their energy requirements and will be more motivated to graze due to feed availability (Haselmann et al., 2022; Tucker et al., 2021). Stepping behaviour is also related to feed availability, as cows increase their steps in relation to area and feed availability, meaning cows in crop grazing systems move less, as they do not need to search as much for food (Phillips, 2002; Shepley et al., 2020). There is also potential for other negative connotations if cows are motivated to consume all their feed within such a short window. Foraging behaviour is innate to cattle, and when allowed, they spend 6 – 13 hours/day grazing, which is broken into several grazing sessions (O’Driscoll et al., 2015; Kilgour et al., 2012). Cattle have been shown to display stereotypic behaviours when unable to perform foraging behaviour, which is potentially a sign of frustration, boredom or hunger, as they are designed to consume large amounts of forage constantly throughout the day (Schütz et al., 2018). However, more research is needed to confirm these links.

Differences in management and diet then likely influenced lying times and stepping behaviour. Despite expectations, bale grazing cows had similar lying times and took slightly fewer steps on average than kale crop cows. Daily feed allocation (new break) for kale crop cows presumably encouraged quicker feed consumption and should theoretically have allowed optimal (at

least 10-12 hours/day) lying times due to cows having more 'free time'. Furthermore, given their lesser space allowance and reduced need to search for feed compared to bale grazing cows, kale crop cows were expected to perform less activity (Phillips, 2002; Shepley et al., 2020b). It would be more acceptable for bale grazing cows to have lower lying times and to take more steps, as previous work has shown cows in grazing systems increase their steps in relation to the area and feed availability and need to spend more time eating (because of the high forage content of the diet), thus leaving less time for lying. This is potentially why we did not observe longer lying times within the bale grazing treatment during stage one; cows were spending more time grazing.

Steps for the bale grazing cows peaked every two to three days, which coincided with them being shifted to a new break, thus exploring their new grazing area and supporting this relationship between feed availability and activity seen in the literature. In adverse weather conditions, kale crop cows maintained a similar average number of steps to days with favourable weather, unlike bale grazing cows, who reduced their steps. We would have expected reductions in activity for both groups, as there is some evidence that cattle will reduce their activity in inclement weather to conserve energy (Malechek & Benton, 1976). A potential reason for kale crop cows maintaining their usual eating and stepping patterns is hunger and competition for feed. In contrast, bale grazing cows, who had near constant access to feed, were allowed more flexibility in managing energy conservation strategies and eating patterns, thus reducing their activity in inclement weather. The unsuitability of the kale crop surface for lying was further verified by kale crop cows not lying down for longer, even with more 'free time'. They would be expected to lay down for 10-12 hours/day, which is typically observed in outdoor systems (Tucker et al., 2021). This provides further evidence that bale grazing cows were possibly more comfortable, as they had the flexibility to manage their hunger and energy conservation strategies (by limiting activity and/or eating more), unlike the kale crop cows that were compelled to eat their feed allowance as quickly as possible each day, regardless of weather conditions. Further research is needed to confirm the link between foraging behavioural needs and hunger, as the mental consequences of limiting grazing in a hungry cow are unclear. However, it is

speculated to cause some degree of discomfort or frustration (Gregory, 2004). Therefore, it is plausible that bale grazing cows may have experienced less frustration and, overall, were more satiated than kale crop cows.

Overall, patterns in lying times, steps and the number of transitions between treatments displayed that bale grazing cows were more comfortable despite only lying down for 12 minutes more each day throughout stage one. This was presumably due to the provision of a softer, slightly drier and warmer place to lay (hay residue) that allowed bale grazing cows to evade muddy conditions. In contrast, the surface for kale crop cows was more barren and likely more prone to surface water pooling and becoming muddy. Differences in surfaces, stocking rates and dietary management likely caused kale crop cows to have greater reductions in lying times, more transitions and more prominent rebound lying behaviour responses than bale grazing cows in adverse weather conditions. Consequently, bale grazing may alleviate some of the challenges relating to lying behaviours in wintering environments. However, even with improved surface conditions, lower stocking rates and more available feed, bale grazing cows still experienced some degree of lying deprivation in adverse weather.

5.2 Lying Behaviours During Stage Two

Similar patterns were observed in stage two of the trial. While on the plots, bale grazing cows spent significantly more time lying down than the kale crop cows on the first day, but times did not differ significantly on the second day. Both treatments lay down for more than 10 hours on average for both days on the plots, which is what is expected in outdoor systems (Tucker et al., 2021). Kale crop cows took significantly more transitions between lying and standing on day one than kale crop cows, but there was no significant difference on day two. Step data from stage two was not used, as cows were constrained to the experimental areas.

While on the plots, weather conditions were cold but dry, so weather is unlikely to be why we saw the significant difference on day one of the plot exposure. The surface never had the chance to

get severely muddy and wet, as there was minimal rain, and cows only spent two days on the plots. Despite this, kale crop plots became muddier and more compact than bale grazing plots after the two days. When looking at before and after photos, kale crop plots became almost bare soil, compared to bale grazing plots, which had residual pasture cover and hay left behind. Although conditions were dry, the kale crop treatment still ended up pugged, and if it had rained, it would have quickly become saturated due to the lack of plant matter left after grazing. The lying surface was also stalky kale for kale crop cows, which cows may have found uncomfortable. Surface conditions are likely a contributing reason why kale crop cows had significantly lower lying times on day one of the plot exposure, as cows find colder, muddy surfaces aversive to lay on (Chen et al., 2017; Tucker et al., 2021). However, since lying times did not differ on day two, we cannot be sure that the surface conditions were the main cause of the difference on day one.

A further indicator that can infer cow comfort regarding the substrate of a lying surface is lying posture. When cows lay down on cold and/or wet surfaces, they limit the surface area exposed to the ground by tucking their legs beneath their bodies and sitting more upright, which is thought to be an attempt to avoid conductive heat loss to the ground (Chen et al., 2017; Fregonesi et al., 2007; Schütz et al., 2010; Tucker et al., 2021).

While lying, bale grazing cows were observed to spend significantly more time lying with both legs in the extended position than the kale crop cows. Since we know cows lay in more tucked positions when lying on surfaces they find aversive, we can presume they will be less likely to lay with their front legs extended. We can then infer that the bale grazing cows found their lying surface more comfortable, as they spent more time in comfortable postures. This is supported by literature that suggests cows find lying on pasture more comfortable (Margerison et al., 2014). This again highlights that bale grazing may provide cattle with a more comfortable lying surface than the kale crop environment.

It was expected that the number of transitions would be lower to correlate with lesser lying times on day one for kale crop cows, but this was not the case, as cows undertook significantly more transitions on day one. This again supports the idea that an unfavourable lying surface increases transitions due to cows finding the surface uncomfortable to lay on, meaning they perform more transitions due to restlessness and potential frustration (Munksgaard & Simonsen, 1996; Tucker et al., 2021).

A critical reason for the difference in lying times and transitions between days is the stocking rates and space allowance. Due to management constraints, requirements for the soil measures and various other factors, plot sizes were small (63 m²), and on day one, kale crop cows were only allocated half of the plot (8 m²/cow) (see Figure 37). The restriction of suitable lying surfaces, as well as lower stocking rates, is associated with an increased



Figure 37: Kale crop cows on the first day of stage two (plot exposure) in their first break.

occurrence of aggressive interactions and nonaggressive lying disturbances (Coveney, 2016; Neave et al., 2022; Schütz et al., 2015; Tucker et al., 2021). This means it can be presumed that the lower space allowance on day one resulted in more disruptions to lying behaviour, causing lesser lying times and more transitions, as cows would have been unable to avoid each other as they typically would in larger areas (Tucker et al., 2021; Winckler et al., 2015).

Regarding 8 m²/cow being an adequate stocking rate for cows to meet lying times, there is little evidence in the literature relating lying times to stocking densities in outdoor systems. The European recommendation (EFSA AHAW Panel) for minimum space allowance is 9 m²/cow for indoor conditions (EFSA Panel on Animal Health and Animal Welfare, 2023). In terms of work done in outdoor systems, Schütz et al. 2015 found that 4.5 – 6 m² was sufficient for cows (in groups of five) to

achieve daily lying times on a stand-off pad without feed; however, cows were managed in their experimental groups for five days before the study began, allowing social habituation, which theoretically would have reduced the incidence of agonistic behaviour. Prior to stage two in this trial, cows had no time to habituate to their social/experimental groups, meaning they likely had to re-establish a dominance order once entering the plots, as it is known that aggressive acts are highest after regrouping and in smaller space allowances (Schirmann et al., 2011; Soonberg, 2021). Therefore, this provides further evidence of space allowance being a primary contributing reason to lesser lying times and greater transitions on day one; the lack of space meant cows could not avoid each other during regrouping, further enhancing aggressive behaviours.

Bale grazing cows had the same total space available, but only two were on each plot. This means there would be less regrouping impact on behaviour due to fewer cows in more space. Additionally, more dry/suitable lying areas were provided in the form of hay bale residue, reducing competition as more space to lay down was available. Aggressive behaviour is another welfare concern, as it can lead to stress for the subordinate animals (Soonberg, 2021), allowing the presumption that some of the kale crop cows may have experienced stress during the first day on the plots as they could not avoid dominant cows. Aggressive interactions were not recorded, but they may have proved helpful in justifying the differences in lying times and transitions, making it important to consider in future studies. However, even though they were not recorded, agonistic interactions are still a feasible reason for these results occurring, and we can still speculate that bale grazing cows had a more favourable lying surface and environment due to lower stocking rates and more suitable lying areas, resulting from less aggressive behaviour.

Lying behaviours from the first day on the plots indicate that bale grazing cows found the lying surface more comfortable due to taking fewer transitions and having greater lying times than kale crop cows; however, space allowance likely influenced the results. Due to the high importance of lying behaviour, we can conclude that bale grazing cows experienced more positive welfare outcomes

than the kale crop cows on day one. Once kale crop cows had more space and a less stalky surface, lying behaviours improved, highlighting the importance of space allowance and surface type on cow comfort and welfare.

5.3 Thermoregulatory Parameters

Winter temperatures in Southland often fall below a cow's thermoneutral zone, meaning additional energy is required to keep them warm (Aggarwal & Upadhyay et al., 2012; French et al., 2015). The thermoneutral zone is the range of temperatures where the animal requires no additional energy to maintain body temperature, and for dairy cattle, this is generally between -0.5 and 20 °C (Aggarwal & Upadhyay et al. 2012; Godyń et al., 2019). When conditions are below the thermoneutral zone, particularly in the presence of wind and rain, cows display behaviours such as shivering, huddling, seeking shelter, arching their backs and orienting their rear ends to the wind to reduce the surface area exposed to the environment (De Wolde, 2006; Tucker et al., 2007; Webster et al., 2008). Continued cold exposure can lead to cold stress, which is a negative affective experience and is indicative of poor welfare (Schütz et al., 2010; Schütz et al., 2014; Webster et al., 2008). Therefore, we can assess these heat conservation strategies and other factors that may affect thermoregulation and link them to peripheral body temperature to assess how the environment may impact welfare status.

The weather during stage two was cold and dry. The average air temperature was 7.8 °C, with a minimum of -2.2 °C and a minimum calculated wind chill of -3.9 °C, meaning cows were likely experiencing some degree of cold challenge, as this is below the thermoneutral zone for dairy cattle. In saying that, conditions do often become colder and wetter than this in Southland, so the effects observed in stage two would likely be enhanced in a typical Southland winter (Macara, 2013).

5.3.1 Skin Temperature

Body temperature can reflect how cows are coping with environmental conditions and their health and physiological status (Cai et al., 2023). In a research setting, two non-invasive ways to

measure temperature are via skin temperature loggers and infrared thermography images (IRT). Invasive methods, such as vaginal loggers can be used, but because the trial cows were heavily pregnant, only non-invasive methods were used. Data from skin temperature loggers can be used to infer cow comfort. Specifically, sensor nodes (such as the iButtons used in this research) have been found to correlate with rectal temperatures and reflect variations in ambient temperature (Godyń et al., 2019; Nogami et al., 2013). Specifically, IRT nose and forehead temperatures have been demonstrated to be closely associated with rectal temperatures, thus making them a reliable reflection of a cow's internal body temperature (Cai et al., 2023; Salles et al., 2016). IRT images also reflect heat loss/gain relevant to environmental conditions (Godyń et al., 2019). These measures can then be used to infer welfare status, as it is expected that feeling cold and being cold stressed results in a negative affective status (O'Connor & Webster, 2023).

Skin temperature measures were obtained via temperature loggers and IRT images during stage two of the trial. For both skin temperature readings (rump and thigh), kale crop cows had significantly colder average temperatures than bale grazing cows. The same trend was seen for nose temperature when the kale crop cows were lying down, but none of the other IRT image regions of interest (side of body and forehead) or nose when standing differed. Due to the relationship between IRT nose temperatures and sensor nodes with rectal temperatures (Cai et al., 2023; Nogami et al., 2013), we can presume that the environmental conditions on the kale crop plots lead to the cows being colder. This is further supported by the fact that none of the IRT measures differed when standing, potentially making the surface temperature the major contributing factor to lower temperatures observed in the kale crop cows. This is noteworthy as weather conditions were not wet or overly cold during stage two when the measures were recorded, and overall, June was warmer than average in 2022 (Macara, 2013). Treatment differences would likely be exacerbated in colder temperatures and rain.

5.3.2 Lying Postures

Thermoregulation is heavily linked with lying behaviour, as a lack of a dry lying space exacerbates the stressful effects of cold and wet conditions (De Wolde, 2006). In the literature, there is little evidence regarding the impacts of winter temperatures on lying behaviours, and cows have been shown to both increase and decrease lying in response to cold temperatures (Tucker et al., 2021). When cold, lying down is a strategy to conserve heat, as it reduces the surface area exposed to the air, therefore making it easier to stay warm. However, when cold temperatures are combined with rain, lying times have been shown to decrease, which is likely attributed to the fact that cows find wet surfaces aversive to lay on (Neave et al., 2022; O'Connor et al., 2019). Following this, bare/wet/muddy surfaces increase conductive heat loss to the ground, meaning cows will be colder when they lay on a colder surface. Therefore, surface temperature and moisture levels are highly important in this relationship. Lying postures are an important indicator of cow comfort in general, they can also reflect how the animal is coping with the surface temperature. When cows lay down on cold and/or wet surfaces, they limit the surface area exposed to the ground by tucking their legs beneath their bodies and sitting more upright, which is thought to be an attempt to avoid conductive heat loss to the ground (Chen et al., 2017; Fregonesi et al., 2007; Schütz et al., 2010; Tucker et al., 2021). Therefore, lying posture can be observed to assess cow comfort levels in terms of temperature.

As mentioned previously, while lying, bale grazing cows were observed to spend significantly more time with both of their front legs in the extended position than the kale crop cows. Since skin and IRT temperature results revealed that kale crop cows were colder during the plot exposure, mainly when lying, this is likely a contributing reason why these postures were observed, especially considering surface conditions were dry during stage two. Additionally, finding the surface uncomfortable is another possible reason these results were observed. This is more likely than if it was because the surface was wet, as conditions were dry during stage two of the trial.

As previously stated, the surface for the kale crop cows was bare dirt once they had finished grazing the kale, while bale grazing cows had pasture and hay left over due to less grazing pressure. When lying, the bare dirt surface would have resulted in greater heat loss to the environment due to the lesser insulation, thus leaving kale crop cows colder when lying. Lying on hay residue or pasture would reduce heat loss to the ground when lying, making it much more pleasant for cows to lay on. Nevertheless, this underlines that bale grazing cows had a more favourable surface for lying, leaving them warmer and likely with better welfare outcomes.

5.3.3 Eating and Rumination

In grazing systems, cattle are generally observed to graze for 6 – 13 hours in 24 hours (Kilgour et al., 2012). This is split into several feeding bouts throughout the day, but because cattle are crepuscular, they have their largest meals early in the morning and late in the evening. Rumination is one of the cows' most extensive heat production strategies, as much heat is generated from the fermentation of roughage (Hahn, 1985). When allowed, cows consume more feed to maintain body heat in the wintertime, which may contribute to higher rumination times (Sjostrom et al., 2019). Therefore, providing cows with ad libitum feed is a way to ensure they can adequately heat themselves during times of inclement weather. Rumination is also used to indicate general health, as low rumination time is associated with poor health (Paudyal, 2021). Examples of this include metabolic and digestive disorders, such as acidosis and ketosis, as lower rumination times have been shown to indicate the beginning stages of the disorders (DeVries et al., 2009; Stangaferro et al., 2016).

While there was no significant difference between the percentage of observations cows were observed eating on the experimental plots, the diurnal pattern of eating behaviour differed between treatments. A crepuscular eating pattern was observed, as eating times peaked earlier in the day (12:00 – 3:00 pm, day one, 9:00 am – 12:00 pm, day two) and in the evening (3:00 – 6:00 pm) for both treatments. However, the morning peak was much higher for the kale crop cows, and the only time their eating times exceeded that of the bale grazing cows was earlier in the day when they were

allocated their fresh break of kale. As explained in 5.1, bale grazing cows were allocated hay nearly *ad libitum* and had plenty of pasture, while kale crop cows were allocated their kale/baelage once daily. This means bale grazing cows had nearly constant access to feed and the freedom to choose when they ate. This is important because cows sometimes consume more feed when cold (Mader, 2014; Malechek & Benton, 1976). This contrasts with the kale crop cows, who were only allocated feed once per day, which would have encouraged them to consume their feed as quickly as possible, therefore meaning they ended up finishing it long before the next break was allocated, thus leaving them without the ability to consume more feed when the temperature drops.

While on the plots, bale grazing cows were observed to spend significantly more time (percentage of observations) ruminating than the kale crop cows. Rumination times opposed eating patterns in that they peaked overnight and dropped off in the morning when cows were fed (peaked 6:00 – 9:00 pm on both days for both treatments, but bale grazing cows were observed ruminating more overall). A possible reason for bale grazing cows ruminating more is the differences in roughage contents (specifically non-detergent fibre (NDF)) of the diets, as rumination time is positively correlated with roughage content (DeVries et al., 2009; Moon et al., 2004; Paudyal, 2021; Sjaastad et al., 2003). Hay and pasture have a higher NDF content than kale and baelage, hence why these results were observed. Since kale crop cows consumed most of the daily feed allowance relatively quickly, they were left without or with very little feed until the next day. This is potentially another contributing factor to the lesser rumination times observed in the kale crop cows (Gregorini et al. 2012). Since rumination times were recorded as observations and specific rumination times (such as in minutes) were not obtained, it is difficult to use this information to specifically assess rumination in relation to metabolic conditions. However, since rumination times are correlated with general health and heat production, we can presume the bale grazing cows were more comfortable, as they had the choice of consuming more feed when necessary to stay warm, and their diet would result in higher rumination times anyway, leaving them warmer and likely with a more positive affective state.

5.3.4 Cleanliness

Thermoregulation can be affected by coat cleanliness, as a cow's coat/body hair plays a vital role in regulating body temperature because it traps a layer of dead air for insulation against the skin (Chen et al., 2017; Mader, 2014). This insulation is compromised with soiling from manure, mud, water, etc., which reduces the coat's insulative value (Aggarwal & Upadhyay et al. 2012). Therefore, based on how dirty the cow is, we can begin to gauge the level of thermoregulatory impairment, as excess mud can reduce piloerection, a mechanism cows use to stay warm (Chen et al., 2017; Mader, 2014). Regarding health, dirtier udders are more prone to infection with mastitis, even in the dry period (Chen et al., 2017). Consequently, a dirtier animal would be more at risk of compromised welfare due to potential impairment in thermoregulation and increased likelihood of infection, which can lead to pain.

After stage two, kale crop cows were significantly dirtier than the bale grazing cows, even in the mild conditions they endured. We can then use these results to infer both surface quality and cow comfort (Aggarwal & Upadhyay et al., 2012; Neave et al., 2022), as cleanliness is a multi-faceted welfare concern, both in terms of health and welfare due to the impact on thermoregulation and hygiene (O'Connor et al., 2019). As with stage one, these hygiene score results once again highlight the unsuitability of the kale crop environment as a lying surface, as we can infer that the environment would have been muddy due to the hygiene scores of the cows.

Coat cleanliness could also be one of the contributing reasons why kale crop cows were colder due to the impedance mud places on the coat's ability to thermoregulate. Therefore, the environment for the kale crop cows resulted in dirtier cows, and potentially negative impacts on affective state, as cows were unable to thermoregulate as well as they could have if they were clean, possibly causing them to feel colder.

5.3.5 Body Condition and Liveweight

Body condition and liveweight are important indicators of general health. This is especially true over winter, as cows need to meet target condition scores before calving to ensure they can meet the energy demands of lactation, as they will be in a negative energy balance for a time and require adequate energy reserves to fuel this (Coveney, 2016). Body condition can also be linked to thermoregulation. When heat conservation strategies fail, the animal must produce additional heat on top of normal metabolic heat. Triacyl-glycerides (fat) can be metabolised to produce glycerol and non-esterified fatty acids (NEFA), which are then oxidised to produce heat when the animal is cold (Cozzi et al., 2011; Zhao et al., 2019). Therefore, body condition score, which indicates body fat levels, can indicate whether the cow is equipped to cope with colder temperatures (Tucker et al., 2007). Tucker et al. (2007) found that sheltered cows mobilised less body fat, as the shelter meant they were not required to produce as much body heat to maintain their body temperature. This highlights the importance of fat reserves (De Wolde, 2006). Further evidence of the importance of body fat reserves was found in Tucker et al. (2007) where thinner cows were found to be more likely to lay down in ways that conserve heat. This is because they need to spend more time behaviourally attempting to increase their body temperature, as they cannot produce as much metabolic heat.

On average, both treatment groups met the target body condition score for calving (5.0, (Dairy NZ, 2023)). This, therefore, means that bale grazing is a feasible alternative to winter grazing. It allows cows to meet condition score targets and meet the energy demands of early lactation. Cows would have also been prepared to cope with the lack of shelter provision in both wintering systems. This is very important regarding welfare, as negative energy balance and cold stress result in a negative affective state. Because both groups gained body condition and weight over winter, it is unlikely they were experiencing metabolic stress due to a lack of body fat reserves for thermoregulation, but this does not mean they did not experience any thermoregulatory discomfort.

Overall, thermoregulatory parameters recorded in stage two demonstrated that bale grazing cows were likely more comfortable due to the provision of a softer, more insulating lying surface and a greater space allowance.

5.4 Limitations

A major limitation of this study is that it was conducted on a working, commercial farm. While this allowed us to gather data in a 'real' environment, it made controlling variables very difficult, and limited our ability to conduct replication in stage one, and thus, inferential statistics. Another major limitation was that this study was done in conjunction with a horticulture team that had different research aims and requirements, leading to compromises regarding certain aspects of the animal behaviour and welfare work. Therefore, these factors lead to many limitations that potentially impacted the results of this study.

Stage one. During stage one, treatment replicas were not possible. Therefore, no inferential statistics were calculated, which reduces the strength of conclusions able to be drawn from this data.

Stage two. Stage two was associated with several limitations. Ideally, group sizes and space allowances would have been the same. This would account for aggression during regrouping, as with the present design, a pair of bale grazing cows would establish hierarchy much more quickly than the four-cow kale crop group. This was not possible with the current design due to requirements for soil measures and to replicate the typical stocking rates used in these systems within the allocated spaces. Another way to account for regrouping aggressive behaviour would be to allow time for habituation to their new social groups before data collection or keep the cows on the plots longer. The longer duration on the plots would also allow observations of potential rebound lying behaviour, which was not possible over the two days. Plot size could also have been bigger to mimic the fact that cows are managed at a much larger scale in actual management systems. These limitations then potentially meant that the behaviour of the cows in their small groups was not fully representative of that of a large herd, and time budgets were also likely influenced by the lack of space, particularly for kale crop

cows. Therefore, results may not accurately represent a commercial setting. To reduce these limitations, the experiment would need to be repeated with the same measures and replication but with larger groups of animals in larger areas for a longer duration/with a social habituation period. However, extensive resources, time and funding would be required. Despite limitations, these results are still significant as they highlight the potential impact of stocking rates and space allowance on lying behaviour in outdoor systems, which is still a subject of limited knowledge in the literature (Tucker et al., 2021).

Another limitation present in stage two was the fact that the IRT images were taken in field conditions, and since it was difficult to ensure each image was taken of the same view and distance from the cow, it is possible to record incorrect temperatures (Racewicz et al., 2018). Photos may have been too far away to observe a difference in forehead temperature, as studies using this body region of analysis have used images much closer to the cow (Salles et al., 2016). For the lack of difference in the side of the body region, factors such as gut fill (/feed digestion) and coat dirtiness can impact the measurement (Salles et al., 2016). Therefore, conditions would need to be replicated to ensure accurate results. Cameras and cows would need to be set up in a fixed position, and cows may need to be fasted and cleaned before the photos are taken to ensure conditions are controlled (Salles et al., 2016). However, the impact of diet and gut fill on thermoregulation is a substantial contributing variable within the two wintering systems being compared, so this would need to be further thought out before these measures are used again in this environment/type of research. Additionally, IRT measures are not as accurate as temperature recording devices (Cai et al., 2023). Care must be taken when concluding IRT temperature data, but results are still important.

In general, the practicality of farmers using bale grazing in NZ is limited as stocking rate is a major limiting factor due to land availability. One of the reasons why crops are used so widely is because they provide such high yields on a small amount of land, which allows farmers to save feed for lactation when grass growth picks up again after winter.

5.5 Future Research

This study strengthens the knowledge of the impacts of wintering systems on the welfare of dairy cattle in NZ. It also highlights several key areas where further research is required. Ideally, a similar experiment to stage two of this trial should be repeated in more adverse weather as the conditions in this study were relatively mild for Southland. Specific impacts of surface temperature/substrate on lying times, postures and skin temperature would also be interesting to explore, as there is currently limited literature surrounding this topic in outdoor systems. Following this, it would be interesting to explore whether bale grazing cows choose to lay down in the hay bale residue as intended, as this would provide further validation of the comfort this management system may provide. Links between limiting grazing behaviour, hunger, frustration and stress is another area with limited knowledge, specifically in outdoor wintering systems where break feeding is used. This is important, as the current standard practice of intensive winter grazing typically encourages cows to consume their feed within 6 hours of allocation (Grant & Albright, 1995; Gregorini et al., 2009), and the welfare implications of this are currently unclear.

5.6 Conclusions

Although no inferential statistics were calculated from stage one data, results were still used to interpret welfare status, as stage two data backed up clear trends. In stage one, both treatments experienced a reduction in lying times and transitions between lying and standing in relation to weather and surface conditions, but this was more severe for the kale crop cows. Bale grazing cows had more agency to choose to conserve energy and change their eating patterns during inclement weather, and they remained cleaner than kale crop cows. During stage two, kale crop cows were significantly colder and dirtier. They spent significantly less time lying with both front legs outstretched and significantly less time lying on day one on the plots. They also spent significantly less time ruminating, potentially resulting in them being more thermoregulatory challenged than bale grazing cows. The bale grazing cows appeared to cope better with winter conditions, which was

attributed to lower stocking rates, pasture underfoot, and the provision of almost ad libitum hay. Despite these advantages, the requirement for greater land area that bale grazing entails may mean this management strategy may be unfeasible for some farmers. Additionally, further research is needed to assess the long-term impacts of wintering systems on animal health and welfare outcomes. Overall, this trial found that bale grazing has the potential to reduce some of the major welfare concerns associated with winter grazing on crops as bale grazing cows appeared more comfortable than kale crop cows, which may be attributed to the greater thermal comfort and the provision of drier lying surfaces at a lower stocking rate.

References

- Aggarwal, A., & Upadhyay, R. (2013). Thermoregulation. In *Heat stress and animal productivity* (pp. 1-25). Springer.
- Al-Marashdeh, O., Cameron, K. C., Bryant, R. H., Chen, A., McGowan, B., Gille-Perrier, C., Carey, P., Chrystal, J., Hodge, S., & Edwards, G. R. (2019). Effects of surface type in an uncovered stand-off pad system on comfort and welfare of non-lactating dairy cows during winter. *Applied Animal Behaviour Science*, 211, 17-24. <https://doi.org/10.1016/j.applanim.2018.11.001>
- Arends, A. N. (2016). *The effects of stand-off pad surface materials on the welfare and behaviour of dairy cows over the winter dry period in Canterbury, New Zealand* [Lincoln University].
- Barry, T. (2013). The feeding value of forage brassica plants for grazing ruminant livestock. *Animal Feed Science and Technology*, 181(1-4), 15-25.
- Beukes, P., Gregorini, P., Romera, A., & Dalley, D. (2011). The profitability and risk of dairy cow wintering strategies in the Southland region of New Zealand. *Agricultural Systems*, 104(7), 541-550.
- Burke, C., & Roche, J. (2007). Effects of pasture feeding during the periparturient period on postpartum anovulation in grazed dairy cows. *Journal of Dairy Science*, 90(9), 4304-4312.
- Cai, Z., Cui, J., Yuan, H., & Cheng, M. (2023). Application and research progress of infrared thermography in temperature measurement of livestock and poultry animals: A review. *Computers and Electronics in Agriculture*, 205, 107586.
- Chen, J. M., Stull, C. L., Ledgerwood, D. N., & Tucker, C. B. (2017). Muddy conditions reduce hygiene and lying time in dairy cattle and increase time spent on concrete. *Journal of Dairy Science*, 100(3), 2090-2103.
- Christopherson, R. (1985). Management and housing of animals in cold environments. *Stress physiology in livestock. Volume II. Ungulates.*, 175-194.

- Cooper, M., Arney, D., & Phillips, C. (2007). Two-or four-hour lying deprivation on the behavior of lactating dairy cows. *Journal of Dairy Science*, *90*(3), 1149-1158.
- Coveney, A. (2016). *Stand-off pad wintering system: effect of surface type on cow welfare and behaviour* [Dissertation, Lincoln University]. Research Archive Lincoln.
<https://researcharchive.lincoln.ac.nz/items/5c5ca365-c2ee-4ff8-aa46-bd7fb9566628>
- DairyNZ. (2023). *BCS Strategies*. Retrieved 10/01/2024 from <https://www.dairynz.co.nz/animal/body-condition-scoring/bcs-strategies/#:~:text=Range%20in%20body%20condition%20score,well%20as%20a%20herd%20target.>
- Dalley, D., Edwards, J., Masterson, E., & Woods, R. (2021). The effect of winter fodder beet or kale allocation on behaviour and blood metabolite status of non-lactating dairy cows. *Journal of New Zealand Grasslands*, 153-162.
- Dechamps, P., Nicks, B., Canart, B., Gielen, M., & Istasse, L. (1989). A note on resting behaviour of cows before and after calving in two different housing systems. *Applied Animal Behaviour Science*, *23*(1-2), 99-105.
- DeVries, T., Beauchemin, K., Dohme, F., & Schwartzkopf-Genswein, K. (2009). Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feeding, ruminating, and lying behavior. *Journal of Dairy Science*, *92*(10), 5067-5078.
- Dickson, E., Campbell, D. L., Monk, J. E., Lea, J. M., Colditz, I. G., & Lee, C. (2022). Increasing mud levels in a feedlot influences beef cattle behaviours but not preference for feedlot or pasture environments. *Applied Animal Behaviour Science*, 105718.
- Dillon, P., Crosse, S., Stakelum, G., & Flynn, F. (1995). The effect of calving date and stocking rate on the performance of spring-calving dairy cows. *Grass and Forage Science*, *50*(3), 286–299.
- Edwards, J., Mashlan, K., Dalley, D., & Pinxterhuis, J. (2016). A survey of dairy cow wintering practices in Canterbury, New Zealand. *Animal Production Science*, *57*(7), 1323-1329.

- EFSA Panel on Animal Health and Animal Welfare (AHAW), Nielsen, S. S., J. Alvarez, D. J. Bicot, P. Calistri, E. Canali, J. A. Drewe, B. Garin-Bastuji, J. L. Gonzales Rojas, C. G. Schmidt, M. Herskin, V. Michel, M. A. Miranda Chueca, B. Padalino, H. C. Roberts, H. Spoolder, K. Stahl, A. Velarde, A. Viltrop, A. De Boyer des Roches, M. B. Jensen, J. Mee, M. Green, H.- H. Thulke, E. Bailly-Caumette, D. Candiani, E. Lima, Y. Van der Stede, & Winckler, C. (2023). Welfare of dairy cows. *EFSA Journal*, 21(5), e07993.
- Fisher, A. D., Verkerk, G. A., Morrow, C. J., & Matthews, L. R. (2002). The effects of feed restriction and lying deprivation on pituitary–adrenal axis regulation in lactating cows. *Livestock Production Science*, 73(2-3), 255-263.
- Fregonesi, J. A., Veira, D. M., von Keyserlingk, M. A. G., & Weary, D. M. (2007). Effects of bedding quality on lying behavior of dairy cows. *Journal of Dairy Science*, 90(12), 5468-5472.
<https://doi.org/10.3168/jds.2007-0494>
- French, P., Driscoll, K., Horan, B., & Shalloo, L. (2015). The economic, environmental and welfare implications of alternative systems of accommodating dairy cows during the winter months. *Animal Production Science*, 55(7), 838-842.
- Godyń, D., Herbut, P., & Angrecka, S. (2019). Measurements of peripheral and deep body temperature in cattle—A review. *Journal of Thermal Biology*, 79, 42-49.
- Grant, R., & Albright, J. (1995). Feeding behavior and management factors during the transition period in dairy cattle. *Journal of Animal Science*, 73(9), 2791–2803.
- Gregorini, P., Clark, C., Jago, J., Glassey, C., McLeod, K., & Romera, A. (2009). Restricting time at pasture: Effects on dairy cow herbage intake, foraging behavior, hunger-related hormones, and metabolite concentration during the first grazing session. *Journal of Dairy Science*, 92(9), 4572-4580.
- Gregorini, P., DelaRue, B., McLeod, K., Clark, C., Glassey, C., & Jago, J. (2012). Rumination behavior of grazing dairy cows in response to restricted time at pasture. *Livestock Science*, 146(1), 95-98.

- Gregory, N. G. (2004). Sickness and disease. *Physiology and behaviour of animal suffering*. Oxford (UK): Blackwell, 183–192.
- Hahn, G. (1985). Management and housing of farm animals in hot environments. *Stress physiology in livestock. Volume II. Ungulates.*, 151-174.
- Haselmann, A., Wenter, M., Knaus, W. F., Fuerst-Waltl, B., Zebeli, Q., & Winckler, C. (2022). Forage particle size and forage preservation method modulate lying behaviour in dairy cows. *Applied Animal Behaviour Science*, 254, 105711.
- Hendriks, S. J., Phyn, C. V. C., Turner, S. A., Mueller, K. R., Kuhn-Sherlock, B., Donaghy, D. J., Huzzey, J. M., & Roche, J. R. (2020). Effect of weather on activity and lying behaviour in clinically healthy grazing dairy cows during the transition period [Article]. *Animal Production Science*, 60(1), 148-153. <https://doi.org/10.1071/AN18569>
- Industries, M. f. P. (2019). *Code of Welfare: Dairy Cattle*.
<https://www.mpi.govt.nz/dmSEDocument/46024-Code-of-Welfare-Dairy-cattle>
- Keim, J. P., Rodriguez, J. R., Balocchi, O. A., Pulido, R. G., Sepúlveda-Varas, P., Pacheco, D., Berthiaume, R., & Vargas-Bello-Pérez, E. (2021). Effect of dietary inclusion of winter brassica crops on milk production, feeding behavior, rumen fermentation, and plasma fatty acid profile in dairy cows. *Journal of Dairy Science*, 104(10), 10699-10713.
- Keogh, B., French, P., Murphy, J., Mee, J., McGrath, T., Storey, T., Grant, J., & Mulligan, F. (2009). A note on the effect of dietary proportions of kale (*Brassica oleracea*) and grass silage on rumen pH and volatile fatty acid concentrations in dry dairy cows. *Livestock Science*, 126(1-3), 302-305.
- Kilgour, R. J., Uetake, K., Ishiwata, T., & Melville, G. J. (2012). The behaviour of beef cattle at pasture. *Applied Animal Behaviour Science*, 138(1-2), 12-17.
- Macara, G. R. (2013). *THE CLIMATE AND WEATHER OF SOUTHLAND 1173-0382*. NIWA.

- Mader, T. L. (2014). BILL E. KUNKLE INTERDISCIPLINARY BEEF SYMPOSIUM: Animal welfare concerns for cattle exposed to adverse environmental conditions. *Journal of Animal Science*, *92*(12), 5319-5324. <https://doi.org/10.2527/jas.2014-7950>
- Malechek, J. C., & Smith, B. M. (1976). Behavior of range cows in response to winter weather. *Rangeland Ecology & Management/Journal of Range Management Archives*, *29*(1), 9-12.
- Mann, S., Yepes, F. L., Overton, T., Wakshlag, J., Lock, A., Ryan, C., & Nydam, D. (2015). Dry period plane of energy: Effects on feed intake, energy balance, milk production, and composition in transition dairy cows. *Journal of Dairy Science*, *98*(5), 3366-3382.
- Margerison, J., Lau, J., Hedley, M., Horne, D., Hanly, J., Powell, N., & Shilton, A. (2014). Lying and feeding behaviour of dairy cows at pasture and housed in free stalls fitted with sand and water filled mats. *Nutrient management for the farm, catchment and community*. Currie LD, Christensen CL editors. *Occasional Report*, 27.
- McIntosh, P., Allen, R., Porter, N., & Lammerink, J. (1992). Garlic production in North Otago and Southland, New Zealand. *New Zealand journal of crop and horticultural science*, *20*(1), 11-16.
- Mellor, D. J., Beausoleil, N. J., Littlewood, K. E., McLean, A. N., McGreevy, P. D., Jones, B., & Wilkins, C. (2020). The 2020 five domains model: Including human–animal interactions in assessments of animal welfare. *Animals*, *10*(10), 1870.
- Metz, J. (1985). The reaction of cows to a short-term deprivation of lying. *Applied Animal Behaviour Science*, *13*(4), 301–307.
- Moon, Y., Lee, S., & Lee, S. S. (2004). Effects of neutral detergent fiber concentration and particle size of the diet on chewing activities of dairy cows. *Asian-Australasian Journal of Animal Sciences*, *17*(11), 1535-1540.
- Munksgaard, L., & Simonsen, H. B. (1996). Behavioral and pituitary adrenal-axis responses of dairy cows to social isolation and deprivation of lying down. *Journal of Animal Science*, *74*(4), 769-778.

- Neave, H. W., Schütz, K. E., & Dalley, D. E. (2022). Behavior of dairy cows managed outdoors in winter: Effects of weather and paddock soil conditions. *Journal of Dairy Science*, *105*(10), 8298-8315.
- Nogami, H., Okada, H., Miyamoto, T., Maeda, R., & Itoh, T. (2013). Wearable and compact wireless sensor nodes for measuring the temperature of the base of a Calf's Tail. *Sens. Mater*, *25*(9), 577-582.
- O'Connor, C., Dowling, S., Cave, V., & Webster, J. (2019). Cow lying behaviour and bedding quality changes during five weeks on a stand-off pad. *Animals*, *9*(5), 257.
- O'Connor, C., & Webster, J. (2023). Welfare of Dairy Cows in Pasture-Based Systems. In *Cattle Welfare in Dairy and Beef Systems: A New Approach to Global Issues* (pp. 105-124). Springer.
- O'Driscoll, K., Lewis, E., & Kennedy, E. (2015). Effect of feed allowance at pasture on lying behaviour and locomotory ability of dairy cows. *Applied Animal Behaviour Science*, *166*, 25-34.
- Paudyal, S. (2021). Using rumination time to manage health and reproduction in dairy cattle: A review. *Veterinary quarterly*, *41*(1), 292-300.
- Phillips, C. (2002). Locomotion and movement. *Cattle Behaviour and Welfare*, 180-297.
- Racewicz, P., Sobek, J., Majewski, M., & Różańska-Zawieja, J. (2018). The use of thermal imaging measurements in dairy cow herds. *Animal Science and Genetics*, *14*(1), 55-69.
- Roche, J., Dillon, P., Stockdale, C., Baumgard, L., & VanBaale, M. (2004). Relationships among international body condition scoring systems. *Journal of Dairy Science*, *87*(9), 3076-3079.
- Rugoho, I., Gibbs, S. J., & Edwards, G. (2014). Dry matter intake and body condition score gain of dairy cows offered kale and grass. *New Zealand Journal of Agricultural Research*, *57*(2), 110-121.
- Salles, M. S. V., da Silva, S. C., Salles, F. A., Roma Jr, L. C., El Faro, L., Mac Lean, P. A. B., de Oliveira, C. E. L., & Martello, L. S. (2016). Mapping the body surface temperature of cattle by infrared thermography. *Journal of Thermal Biology*, *62*, 63-69.
- Schirmann, K., Chapinal, N., Weary, D., Heuwieser, W., & Von Keyserlingk, M. (2011). Short-term effects of regrouping on behavior of prepartum dairy cows. *Journal of Dairy Science*, *94*(5), 2312-2319.

- Schutz, K. E., Cave, V. M., Cox, N. R., Huddart, F. J., & Tucker, C. B. (2019). Effects of 3 surface types on dairy cattle behavior, preference, and hygiene. *Journal of Dairy Science*, *102*(2), 1530-1541. <https://doi.org/10.3168/jds.2018-14792>
- Schutz, K. E., Clark, K. V., Cox, N. R., Matthews, L. R., & Tucker, C. B. (2010). Responses to short-term exposure to simulated rain and wind by dairy cattle: time budgets, shelter use, body temperature and feed intake. *Animal Welfare*, *19*(4), 375-383.
- Schütz, K. E., & Cox, N. R. (2014). Effects of short-term repeated exposure to different flooring surfaces on the behavior and physiology of dairy cattle. *Journal of Dairy Science*, *97*(5), 2753-2762. <https://doi.org/10.3168/jds.2013-7310>
- Schütz, K. E., Huddart, F. J., & Cave, V. M. (2020). Do dairy cattle use a woodchip bedded area to rest on when managed on pasture in summer? *Applied Animal Behaviour Science*, *223*, 104922.
- Schütz, K. E., Huddart, F. J., Sutherland, M. A., Stewart, M., & Cox, N. R. (2015). Effects of space allowance on the behavior and physiology of cattle temporarily managed on rubber mats [Article]. *Journal of Dairy Science*, *98*(9), 6226-6235. <https://doi.org/10.3168/jds.2015-9593>
- Schütz, K. E., Lee, C., & DeVries, T. J. (2018). Cattle priorities: Feed and water selection, ability to move freely and to access pasture. In *Advances in Cattle Welfare* (pp. 93-122). Elsevier.
- Shepley, E., Lensink, J., Leruste, H., & Vasseur, E. (2020). The effect of free-stall versus strawyard housing and access to pasture on dairy cow locomotor activity and time budget. *Applied Animal Behaviour Science*, *224*, 104928.
- Shepley, E., Lensink, J., & Vasseur, E. (2020). Cow in Motion: A review of the impact of housing systems on movement opportunity of dairy cows and implications on locomotor activity. *Applied Animal Behaviour Science*, *230*, 105026.
- Sjostrom, L., Heins, B., Endres, M., Moon, R., & Sorge, U. (2019). Effects of winter housing system on hygiene, udder health, frostbite, and rumination of dairy cows. *Journal of Dairy Science*, *102*(11), 10606-10615.

- Soonberg, M. (2021). *Regrouping effects on behaviour and welfare of dairy cows* [Doctoral Dissertation, Estonian University of Life Sciences]. EMU DSpace.
<https://doi.org/10.15159/emu.68>
- Stangaferro, M., Wijma, R., Caixeta, L., Al-Abri, M., & Giordano, J. (2016). Use of rumination and activity monitoring for the identification of dairy cows with health disorders: Part I. Metabolic and digestive disorders. *Journal of Dairy Science*, *99*(9), 7395-7410.
- Sundrum, A. (2015). Metabolic disorders in the transition period indicate that the dairy cows' ability to adapt is overstressed. *Animals*, *5*(4), 978-1020.
- Tucker, C. B., Jensen, M. B., de Passille, A. M., Hanninen, L., & Rushen, J. (2021). Lying time and the welfare of dairy cows. *Journal of Dairy Science*, *104*(1), 20-46.
<https://doi.org/10.3168/jds.2019-18074>
- Tucker, C. B., Rogers, A. R., Verkerk, G. A., Kendall, P. E., Webster, J. R., & Matthews, L. R. (2007). Effects of shelter and body condition on the behaviour and physiology of dairy cattle in winter. *Applied Animal Behaviour Science*, *105*(1-3), 1-13.
- Turnpenny, J., McArthur, A., Clark, J., & Wathes, C. (2000). Thermal balance of livestock: 1. A parsimonious model. *Agricultural and forest meteorology*, *101*(1), 15-27.
- Webster, J., Schütz, K., Sutherland, M., Stewart, M., & Mellor, D. (2015). Different animal welfare orientations towards some key research areas of current relevance to pastoral dairy farming in New Zealand. *New Zealand veterinary journal*, *63*(1), 31-36.
- Webster, J. R., Stewart, M., Rogers, A. R., & Verkerk, G. A. (2008). Assessment of welfare from physiological and behavioural responses of New Zealand dairy cows exposed to cold and wet conditions. *Animal Welfare*, *17*(1), 19-26.
- Winckler, C., Tucker, C. B., & Weary, D. M. (2015). Effects of under-and overstocking freestalls on dairy cattle behaviour. *Applied Animal Behaviour Science*, *170*, 14-19.

Zambelis, A., Gagnon-Barbin, M., St John, J., & Vasseur, E. (2019). Development of scoring systems for abnormal rising and lying down by dairy cattle, and their relationship with other welfare outcome measures. *Applied Animal Behaviour Science*, 220, 104858.

Zhao, W., Chen, X., Xiao, J., Chen, X. H., Zhang, X. F., Wang, T., Zhen, Y. G., & Qin, G. X. (2019). Prepartum body condition score affects milk yield, lipid metabolism, and oxidation status of Holstein cows. *Asian-Australasian Journal of Animal Sciences*, 32(12), 1889.