Improving winter feeding outcomes in South Island dairy herds

H.G. JUDSON, D.E. DALLEY[1], G.R. EDWARDS[2], D.R. STEVENS[3] and S.J. GIBBS[2]

Agricom, P.O Box 3761 Christchurch
[1]DairyNZ, PO Box 160, Lincoln University, Christchurch
[2]Faculty of Agriculture and Life Science, P.O. Box 84, Lincoln University, Christchurch
[3]AgResearch Invermay, Private Bag 50034, Mosgiel 9053, New Zealand

ABSTRACT

Winter represents an important time for South Island dairy herds. The task of improving body condition of cows during winter poses a number of challenges in this environment. Under current wintering systems, many cows fail to achieve body condition score targets and there is increased potential for nutrient leaching and the loss of soil structure and health. Improving winter feeding outcomes is not always compatible with reducing impacts on soil, reducing nutrient leaching and improving welfare of cows and staff. Strategies for improving wintering outcomes are explored.

Keywords: BCS; utilisation; welfare; sustainability; allocation.

INTRODUCTION

The South Island industry has expanded from 20% of the total New Zealand dairy herd in 1998-9 (Livestock Improvement Incorporation), to 34% in 2008-9 (NZ Dairy Statistics). South Island dairy systems are pasture-based with predominantly perennial ryegrass grazed *in situ* making up a majority of the diet for the entire lactation. Pasture is supplemented with conserved forage or cereal grain when pasture supply does not meet demand. In most South Island dairy regions climate constrains pasture production during autumn and winter at levels below the winter feed requirements of the herd. For example, herds may have a daily winter feed demand of 25-35 kg DM/ha but average pasture growth in winter is typically less than 15 kg DM/ha/day and in many dairy regions regularly drops below 5 kg DM/ha/day. As a consequence, a large proportion of South Island dairy cows are wintered outdoors and off the dairy platform on brassica crops, such as kale (*Brassica oleracaea*). Kale is viewed as a useful winter crop as it can produce high DM yield and quality for winter relative to other crops (Brown *et al.*, 2007) and is able to maintain quality for longer periods compared to other feeds such as grass.

The winter months provide the final opportunity for dairy cows to regain body condition lost in the previous lactation in preparation for the next lactation. Drying off decisions are generally made using body condition score (BCS) and average farm pasture cover targets. Achieving BCS targets at calving improves both milk production (Domecq *et al.,* 1997; Stockdale *et al.,* 2001; Roche *et al.,* 2007a; Roche *et al.,* 2009), and reproductive potential (Buckley *et al.,* 2003; Roche *et al.,* 2007b), in the following lactation. However, in many herds BCS at calving is lower than these general recommendations (Macky, 2010).

This paper outlines the importance of South Island wintering systems to subsequent herd performance, explores the potential for nutrient loss and soil degradation especially where cows are grazing kale *in situ*, and suggests approaches for improving winter outcomes.

IMPORTANCE OF ACHIEVING BODY CONDITION SCORE AND PASTURE COVER TARGETS

It is recommended that drying off decisions are made using BCS as a key indicator with a value of 4.0 at drying off being a common target (MacDonald *et al.,* 1999) where there is adequate time and opportunity for body condition improvement to desired targets prior to calving. General recommendations for BCS at calving are 5.0 for mixed age cows and 5.5 for first and second calvers (DairyNZ) which equates to 4.8 and 5.2 on the 8 point Australian scale (Roche *et al.,* 2004).

These BCS targets at calving are recommended to maximise both milk production (Domecq *et al.,* 1997; Stockdale 2001; Roche *et al.,* 2007a; Roche *et al.,* 2009) and reproductive potential (Buckley *et al.,* 2003; Roche *et al.,* 2007b) in the following lactation. Milk production is maximised by reaching peak lactation quickly and holding the peak for as long as possible (Domecq *et al.,* 1997; Roche *et al.,* 2007a). Production of spring calving mixed age cows generally increases in a linear fashion within the 3 to 5 BCS range by between 12.5 and 18 kg MS/unit BCS (Roche *et al.,* 2009).

Irrespective of being a pasture-based or total mixed ration diet, some loss of BCS in the first 50 days of lactation is difficult to avoid. Pregnancy success is directly related to the lowest BCS of the cow after calving, nadir BCS (Roche *et al.,* 2007b). The likelihood of pregnancy increases as BCS recovers post calving from the nadir BCS (Roche *et al.,* 2007b). While the impact of BCS on production is observed almost immediately the impact of poor reproductive performance manifests itself 10-15 months later as either high empty rates or a prolonged calving resulting in shorter lactation. For example a decline in BCS of 0.5 at calving resulted in an increase in cows not pregnant by 12 weeks of 5%, and a greater spread of calving due to an 8% reduction in the 6-week in-calf rate (Roche *et al.,* 2007b).

In addition to body condition score, drying off decisions are often based on the average pasture cover of the milking platform. To ensure sufficient pasture is available at calving to achieve dry matter intake targets prior to balance date, average pasture cover targets at drying off must be achieved (MacDonald *et al.,* 2005). The pasture cover target for each farm will vary depending on stocking rate, calving date, calving spread and predicted winter pasture growth rates and the extent of supplementary feed or feed supply from outside the milking platform. Roche *et al.* (2007b) reported that BCS loss post-calving, nadir BCS and rate of body weight increase after planned start of mating were all associated with success or lack of success on key reproductive variables. These factors will be influenced by nutrition post-calving, although Roche *et al.* (2007a) reported a failure of nutrition in the first 50 days post calving to significantly affect the rate of BCS loss between calving and nadir. Nutrition did however impact on the days to nadir such that cows with a lower negative energy balance reached nadir sooner than those with a more severe negative energy balance. Roche *et al.* (2007b) also reported a positive association between BW gain during the 4 weeks following first service and pregnancy rates at 21, 42 and 84 days. Achieving farm average pasture cover targets at drying off and calving will enable intake targets to be met in early lactation thereby minimising the period of negative energy balance.

CHALLENGES OF CURRENT WINTERING SYSTEMS

Traditional forage wintering systems in the South Island are arguably becoming increasingly less sustainable in terms of safeguarding the environment, consistently providing sufficient feed to meet animal requirements and achieve industry targets and ensuring good animal welfare. The challenges can be classified into two major areas; Animal and Sustainability.

Animal Challenges

Inability to achieve calving BCS targets

In many herds, cow body condition does not reach recommended targets under current wintering systems (Macky, 2010). The inability of cows to achieve body condition targets on winter brassica crops may result from low DM intake or poor crop and diet quality. Potential explanations for low DM intake include poor crop utilisation or inaccurate allocation of forage. These aspects were explored in a survey of crop yield, nutritive value and grazing management of 49 kale paddocks grazed by dairy cows in winter in Canterbury (Judson & Edwards 2008).

Utilisation (the proportion of the pre-grazing yield apparently consumed) of kale averaged 80% in this survey. Free-draining soils and relatively dry conditions encountered during the survey are likely to have aided utilisation. Variable levels of utilisation were found by Keogh *et al.* (2009a) for kale (84%), swedes (69%) and grass (72%) in winter feed trials in Ireland.

The startling result from Judson and Edwards (2008) was that two thirds of the herds surveyed consumed less than the targeted kale DM intake by more than 1 kg DM/cow/day and some by more than 8 kg/DM/cow/day. Because utilisation was generally high and farmer yield assessments generally accurate, low kale DM intakes were primarily the result of poor allocation of the forage. It should not be assumed, however, that all cows were necessarily missing their total daily DM intake target as in many situations kale was not the only component of the diet, and there may have been compensation for low kale intake by consumption of more silage, hay or straw in situations where supplement allocation permitted.

Crop yield may affect DM intake indirectly. The area of crop sown to meet the winter requirements of a herd is calculated from cows to be wintered, target feeding levels, the duration of the feeding period, and the predicted crop yield and potential utilisation. Where actual yield does not meet expectation and cows to be wintered on the crop are not reduced or additional supplement supplied intake inevitably declines below targeted levels. Consequently, improving crop yield invariably improves daily intake. Judson & Edwards (2008) reported from their survey of 49 commercial kale crops that DM yields averaged 10.9 t DM/ha and varied from 5.3 to 17.0 t DM/ha. Kale type had a significant effect on total yield with the intermediate-stem type in this survey averaging 9.9 t DM/ha and giant types averaging 13.6 t DM/ha. Cultivar, fertility, sowing date and in-crop moisture were all factors that contributed to yield variations.

While high utilisation of kale crops generally promotes lower DM intakes it may also result in reduced diet quality (Judson and Edwards 2008; Rugoho *et al.,* 2010) as the ME of kale crops declined from 12.7 MJ ME/kg DM for leaf material in the canopy to 6.6 MJ ME/kg DM for lower stem material. Cows eating 84% of an intermediate-stemmed kale cultivar (leaving just the lower stem) would have a diet quality (12 MJ ME/kg DM) greater than an equivalent cow grazing 80% (leaving just the lower stem) of a giant type cultivar (11 MJ ME/kg DM).

Crop allocation method may also affect the ability to achieve BCS targets. Forage crops such as kale are often fed as a single allocation in the morning, and even where straw is fed prior to kale, intake rates are high. Rugoho *et al.* (2010) calculated from crop yield decline measurements that 8.4 and 9.4 kg of kale DM were consumed over the first 3 hours after a 9 am allocation for cows allocated 11 and 14 kg DM/cow/day, respectively. It is proposed that these high intake rates with single meals may lead to metabolisable protein limitations later in the day. Indoor studies with cattle (Gibbs SJ, unpublished data) simulating high rates of kale intake indicated that rumen ammonia levels rose sharply to > 200 mg NH_3/L within 2 hours after the 9 am meal of 9 kg DM kale/head, stayed elevated for a period of 6 hours, before declining to levels < 100 mg NH_3/L for the remaining 16 hours of the day. As 100 mg NH_3/L is generally considered the minimum requirement for microbial protein synthesis, these results lead to the hypothesis that metabolisable protein may be limited on a diet that appears to have adequate crude protein (16-18% CP typical of kale).

Sustainability challenges

Environmental challenges largely revolve around leaching losses, in particular phosphate and nitrogen, and the impact of wintering systems on the health of soils.

Most of the nitrogen (N) losses to water from grazed winter forage crops occur in a nitrate-N form and are transported via leaching rather than overland flow (Monaghan *et al.,* 2009). Winter forage systems are only grazed once or twice a year as compared with rotationally grazed pasture systems. Also, grazing of winter forage systems traditionally takes place with very high stocking densities (10 m^2/cow vs. 35-120 m^2/cow at pasture) at a time when soil moisture is close to or at field capacity, and where leaching is likely (Houlbrooke *et al.,* 2009). As a consequence, on a per-hectare basis, N leaching losses from grazed winter forage crops are high relative to losses measured under pasture (de Klein *et al.,* 2006; R Monaghan *pers. comm.*). These nitrogen losses make a disproportionately large contribution to total dairy system losses relative to the area occupied by winter forage crops. In the case of Southland, losses from the area used for winter forage grazing were estimated to represent approximately 44% of whole system dairy N leaching losses but constituted only approximately 15% of the whole system area (Monaghan *et al.,* 2007). Nitrate leaching losses from stony shallow soils (>35% stone content in the 0 – 200 mm layer) appear to be considerably larger than from deeper soils.

The role of winter forage crops as a source of phosphorus and sediment loss to water is less clear, with some conflicting findings evident in the two published field studies. The importance of grazed winter forage crops as a source of faecal microorganisms (FMOs) is even more uncertain given the paucity of available data (Monaghan *et al.,* 2009).

The high densities of stock that are used to graze forage crops can also result in considerable soil physical damage, because it typically coincides with a period of high soil water content (Monaghan *et al.,* 2009). Research conducted at Hillend (Otago) showed that intensive mob grazing (556 cows/ha or 18 m^2/cow) of a winter forage crop of swedes and kale severely compacted the soil (Drewry & Paton 2005). There was a large reduction in soil macro porosity, a measure commonly used to assess soil physical integrity, in both on-off and continuous grazing management treatments. Back-fencing to minimise the risk of repeated treading damage to plots did not appear to improve macro-porosity scores. Soil damage associated with winter grazing of forage crops can be viewed as short term if forage crop paddocks are used as part of a pasture renewal programme and cultivated in the spring prior to re-establishment with pasture species. However, for paddocks subjected to repeated use for winter forage cropping and grazing, as is sometimes the case on runoff blocks, this damage is likely to be cumulative and may approach thresholds where future productivity is compromised (Monaghan *et al.,* 2009).

Animal welfare

The impact of wintering systems on animal welfare has not been well documented for all wintering systems operating in the South Island. The general perception of society is that animals wintered outdoors on forage crops have a lower standard of welfare than those housed indoors. The welfare issues associated with grazing are associated with exposure to climate. Cattle are physiologically well adapted to maintain body heat even during very cold conditions, provided it is dry (Kadzere *et al.,* 2002) but conditions of wind and rain will accelerate heat loss. Cows with a lower body condition score will burn significantly more energy trying to maintain their body temperature between

36.5 and 40.7 °C. In addition cows with wet feet require additional energy to maintain body temperature and it has been shown that stock standing in mud require an additional 5 MJME/day for maintenance (Verkerk *et al.,* 2006).

The amount of time spent lying down resting by dairy cows is considered to make a significant contribution to their comfort and welfare (Fisher *et al.,* 2003). Any facility or system that decreases lying time is likely to have a negative impact on cow welfare (Fisher *et al.,* 2002). Under extremely muddy conditions Muller *et al.* (1996) reported reduced lying times in cows at pasture. Although crop paddocks can become muddy, cows are observed to lie close to the crop itself, where the surface is drier than the rest of the paddock, and may be more comfortable to lie on (Stewart *et al.,* 2002). Stewart *et al.* (2002) reported that cows wintered on crop in Southland spent 11.2 h/day lying (range 8.3-14.3 hours) and this time was not different from cows wintered on covered or uncovered sawdust pads.

People

The type of wintering system employed will dictate the knowledge and skill base required by farm staff, and it also creates a working environment which may be deemed desirable or undesirable by future employees. All grass wintering systems are generally considered 'people friendly' as they utilise similar feed and labour management skills to those that are used during the lactation period (Greig, 2004). In comparison, success with a brassica system requires that management has sufficient technical knowledge and skill to produce consistently high yielding crops and to feed these off effectively. The work associated with the feeding of brassica crops is generally perceived as hard on people and machinery.

OPTIONS TO IMPROVE WINTERING OUTCOMES

Improving allocation

A key part of improving wintering outcomes is to allocate forages more accurately. Crop allocation methods may limit cows achieving their wintering targets. The study of Judson & Edwards (2008) emphasized the importance of accurate estimation of yields, paddock sizes and break widths in ensuring cows achieve their target intake. Reducing break width by only 1 m can decrease allocation by 2 kg DM/cow/day depending on crop yield. Variation in yield across the paddock is difficult to calculate. However, with an accurate average paddock yield and corresponding estimate of the number of grazing days/break sizes, there is less daily variation in intake over the total grazing period (Dalley *et al.,* 2008).

Optimising utilisation

Increasing daily allocation of crops may be a valid way to improve DM intake and diet quality. In winter grazing trial at Lincoln (Rugoho *et al.,* 2010), intake improved from 10.6 to 12.3 kg DM/cow/day, with an increase in allowance from 11 to 14 kg DM kale/cow/day. Grazing residuals were 540 kg DM/ha and 1790 kg DM/ha for the 11 and 14 kg DM kale/cow/day allowances, respectively. Higher allowances, however, mean more kale is left behind as utilisation is generally lower. Optimising utilisation will be a balance between residuals required for target kale intakes and avoiding excessive waste of harvestable crop dry matter.

Altering feeding regime

Altering the frequency of allocation of crops may mitigate problems associated with high intake rate often associated with poor rumen function. Two allocations per day, or one large allocation every three to four days, are strategies that are currently being explored (GR Edwards, unpublished data). It is proposed that cow foraging behaviour will change in response to these regimes leading to more consistent meal patterns throughout the day, so avoiding the excess and deficit patterns in rumen ammonia concentration observed with once daily feeding for kale.

This allocation strategy and associated modified foraging behaviour may also minimise the risk of intake induced toxicities of SMCO (S-methyl-L-cysteine sulphoxide), nitrates and glucosinolates. However, large allocations of crop could potentially have the opposite effect and this needs to be carefully evaluated before strategies like these are widely promoted.

More frequent allocations are likely to provide additional challenges for farm staff through the need to shift fences more often, particularly on high yielding crops. One allocation every 3-4 days, while reducing labour requirement potentially may have a negative effect on crop utilisation; although this would depend on the extent to which cow foraging behaviour changes in response to allocation patterns.

Improving crop yield

The popularity of brassicas, and more recently fodder beet, reflects the crops' ability to produce large tonnages of high quality dry matter per unit area as a standing crop that can be 'carried' forward for *in situ* grazing during the winter period (Brown *et al.,* 2007) with less deterioration in nutritive value compared with other feeds ie short-term ryegrass and green feed cereals (Chakwizira & de Ruiter, 2009).

There are a number of key drivers of brassica yields and these have been successfully combined to form brassica crop yield calculators (Wilson *et al.,* 2007).Yield is strongly driven by light interception and thermal time. Early sowing dates capturing increased thermal time improve potential yield. Estimates suggest brassicas accumulate 1.1 t/DM/ha for every 100°C days (de Ruiter, 2009). Effective control of weed and insects are also important aspects of canopy management to allow maximum light interception. Brassica yield also responds strongly to N and P fertility particularly where soil N is less than 150 kg N/ha (de Ruiter *et al.,* 2009) and P is less than 15 mg/kg soil (White *et al.,* 1999). This is primarily because high yielding brassica crops have large nutrient requirements. For example, a 12 t DM/ha kale crop contains 264 kg N/ha and 34 kg P/ha. Water availability is a major source of variation in brassica yield. Stored soil moisture to 1.0m in depth is enough to produce yields of 1.6-2.8 t DM/ha with additional yields depending on rainfall or irrigation (de Ruiter *et al.,* 2009).

Improving brassica yields through improved crop husbandry or through alternative species may invariably lead to improvements in cow intake. However, higher crop yields increase the stocking density required to consume these and provide further challenges for soil health and nutrient management within wintering systems. Further, large (>12 t DM/ha) kale crops are challenging for staff to fence for grazing owing to their tall nature. Some improved management practices such as the use of minimum and no-tillage practices to establish crops (ex grass pasture) and the use of nitrification inhibitors can help to reduce nutrient losses.

Alternative crops to kale

Alternative winter forage crops to kale for grazing in situ include swedes, forage cereals, grass, and fodder beet. All crops pose potential feed quality challenges (Nichol *et al.,* 2003). For example, compared to kale, fodder beet has higher water soluble carbohydrate concentrate (30 vs. 50+ %) but lacks the free amino acid SMCO that can cause haemolytic anaemia (Barry, 1978). However, fodder beet is lower in crude protein (7-12 vs. 20%) (Keogh *et al.,* 2009a), and may need to be fed with a higher crude protein supplement (e.g. silage or hay) rather than straw which traditionally accompanies a daily allocation of kale. In addition, there is an adaptation period for forage crops when cows are transferred from grass to forage crop and back to grass that does not exist with grass-based wintering. Barry (1978) indicated that cows grazing brassicas may take at least 5 weeks to obtain stable intakes following the transfer to pasture.

Despite these differences, there is a scarcity of data under New Zealand conditions on the performance of dairy cows on forage crops in winter. In an Irish study (Keogh *et al.,* 2009b), cows grazing kale and swedes (8 kg DM crop + 4 kg grass silage offered/cow/day) during winter had a greater increase in body condition score pre-partum than cows grazing grass (12 kg DM grass offered /cow/day). The poorer performance on grass may reflect restricted herbage utilisation and herbage intake of grass under wet conditions (Keogh *et al.,* 2009b). Rugoho *et al.* (2010) showed that for kale and grass both offered at 11 kg DM/cow/day, utilisation was 96% for kale and 70% for grass.

Indoor feeding

Indoor feeding systems potentially offer advantages in improving cow welfare, reducing environmental impacts, improving cow performance during winter or minimising wintering costs through greater feed utilisation. Keogh *et al.* (2009a) showed that cows grazing kale and fodder beet outdoors (6 kg DM crop + 3.5 kg grass silage offered/cow/day) had smaller increases in body condition score than cows offered grass silage (9.5 kg DM offered/cow/day) indoors. This was despite estimated ME intakes being greater on kale and fodder beet than the grass silage. This suggests that there may be constraints within the outdoor feeding treatments such as increased ME requirements for maintenance of liveweight (thermal homeostasis and activity or metabolic inhibitors) that limited the increase in body condition score that can be achieved (Tucker *et al.,* 2007; Keogh *et al.,* 2009b).

Improvements in feed utilisation may be a further benefit of indoor feeding systems. de Wolde (2006) compared cows wintered on kale with a similar group housed indoors in freestall barns. Cows wintered indoors appeared to waste less feed than those grazed outdoors based on a crude estimation of residuals.

Indoor feeding systems may also present appealing opportunities to reduce some of the environmental problems and cow comfort issues associated with high stocking densities on crops grazed in wet, cold and muddy conditions. However, standoff and housed surfaces may represent a risk to cow comfort, especially if cows do not have adequate area or the opportunity to become physically adapted to the surface. If the pad or shed is being used permanently with no on-off grazing then a minimum of 9 m^2/cow plus a 1 m^2 feeding area must be provided (Anonymous, 1998). The design of freestalls, their length, floor surface and iron work influence lying time, ease of standing and lying and comfort (O'Connell *et al.,* 1992). An inability to stand up or lie down easily and a surface which allows slipping make cows wary of lying down in cubicles. When considering standoff and indoor feeding facilities careful consideration must be given to the design as this will have a large impact on the ease of management in the long run. Existing literature suggests that housing systems such as Herd Homes and wintering barns have a low labour requirement compared to other wintering systems and that they create a favourable working environment for staff.

SUMMARY

The winter period is a critical time in a temperate seasonal calving dairy system. The success or otherwise of reaching BCS targets and pasture cover targets during this time impacts on subsequent milk production and reproductive performance.

Current wintering systems in the South Island of New Zealand are largely based on outdoor feeding of predominantly winter brassica feed crops. Challenges include accurate yield assessment of crop, crop quality, management of crop allocation, nutrient management, soil health and welfare of cows and staff. Improving the accuracy and method of allocation, increasing crop yields and moving to indoor wintering are all strategies with the potential to improve wintering outcomes. However, many of these strategies may overcome challenges in some areas but exacerbate challenges in others.

REFERENCES

Anonymous, 1998: Stand Off Pads. Livestock Improvement Advisory, Farm Facts No. 3–14. Livestock Improvement Corporation, Hamilton, New Zealand.

Barry, T.N. 1978: Some factors governing the nutritive value of brassica crops. *Proceedings of the Agronomy Society of New Zealand* **8**: 143-148.

Brown, H.E.; Maley, S.; Wilson, D.R. 2007: Investigations of alternative kale management: Production, regrowth and quality from different sowing and defoliation dates. *Proceedings of the New Zealand Grassland Association* **69**: 29-33.

Buckley, F.; O'Sullivan, K.; Mee, J.F.; Evans, R.D.; Dillon, P. 2003: Relationships among milk yield, body condition, cow weight, and reproduction in spring-calved Holstein-Friesians. *Journal of dairy science* **86**: 2308-2319.

Chakwizira, E.; de Ruiter, J. 2009: Southland winter feeding programme – evaluation of options. Report No. 2355 prepared for DairyNZ.

DairyNZ. 2008: Condition Scoring. http://www. dairynz.co.nz/ page/ pageid/ 2145836848.

Dalley, D.E.; Wilson, D.R.; Edwards, G.R.; Judson, H.G. 2008: Getting the most from your dairy support land – tips for allocating winter forage. *Proceedings of the South Island Dairy Event,* Invercargill. Pp 156-166.

de Klein, C.A.M.; Smith, L.C.: Monaghan, R.M. 2006: Restricted autumn grazing to reduce nitrous oxide emissions from dairy pastures in Southland, New Zealand. *Agriculture, ecosystems & environment* **112**: 192-199.

de Wolde, A. 2006: An alternative wintering system for Southland. A comparison of wintering cows outside, on brassica crops versus inside, in a free stall barn in Southland, New Zealand. Masters Dissertation, Lincoln University.

de Ruiter, J.; Wilson, D.; Maley, S.; Fletcher, A.; Fraser, T.; Scott, W.; Berryman, S.; Dumbleton, A.; Nichol, W. 2009: Management practises for forage brassicas. Forage Brassica Development Group.

Domecq, J.J.; Skidmore, A.L.; Lloyd, J.W.; Kaneene, J.B. 1997: Relationship between body condition scores and milk yield in a large dairy herd of high yielding Holstein cows. *Journal of dairy science* **80**: 101-112.

Drewry, J.J.; Paton, R.J.; 2005: Soil physical quality under cattle grazing of a winter-fed brassica crop. *Australian journal of soil research* **43**: 525-531.

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 dairy cows. *Livestock production science* **73**: 255-263.

Fisher, A.D.; Stewart, M.; Verkerk, G.A.; Morrow, C.J.; Matthews L.R. 2003: The effects of surface type on lying behaviour and stress responses of dairy cows during periodic weather-induced removal from pasture. *Applied animal behaviour science* **81**: 1-11.

Greig, B. 2004: The cost of wintering in Southland. *Proceedings of the South Island Dairy Event*, Lincoln University, Christchurch, New Zealand. Pp 146-152.

Houlebrook, D.J.; Paton, R.J.; Morton J.D. Littlejohn R.P. 2009: Soil quality and plant yield under dryland and irrigated winter forage crops grazed by sheep or cattle. *Australian journal of soil research* **47**: 470-477.

Judson, H.G.; Edwards, G.R. 2008: Survey of management practices of dairy cows grazing kale in Canterbury. *Proceedings of New Zealand Grassland Association* **70**: 249-257.

Kadzere, C.; Murphy, M.; Silanikove, N.; Matlz, E. 2002: Heat stress in lactating cows: a review. *Livestock production science* **77**: 59-91.

Keogh, B.; French, P.; McGrath, T.; Storey, T.; Mulligan, F.J. 2009a: Comparison of the performance of dairy cows offered kale, swedes and perennial ryegrass herbage in situ and perennial ryegrass silage fed indoors in lat pregnancy during winter in Ireland. *Grass and forage science* **64**: 49-55.

Keogh, B.; French, P.; McGrath, T.; Storey, T.; Mulligan, F.J. 2009b: Effect of three forages and two forage allowances offered to pregnant dry dairy cows in winter on peripartuient performance and milk yield in early lactation. *Grass and forage science* **64**: 292-303.

Macdonald, K.A.; Penno, J.W.; Verkerk, G.A. 1999: Validation of body condition scoring by using ultrasound measurements of subcutaneous fat. *Proceedings of the New Zealand Society of Animal Production* **59**: 177-179.

Macdonald, K.A.; Thorrold, B.S.; Glassey, C.B.; Holmes, C.W.; Pryce, J.E. 2005: Impact of farm management decision rules on the production and profit of different strains of Holstein-Friesian dairy cows. *Proceedings of the New Zealand Society of Animal Production* **65**: 40-45.

Macky, S.M. 2010: Body condition in the New Zealand dairy herd - Part one: The nature of the problem. *Vetscript 23* Issue 1, pp 13-14.

Monaghan, R.; Rutherford, A.; McDowell, R.; Smith, C. 2007: Linkages between land management practices and potential impacts on soil and water quality within the Inchbonnie catchment. Summary Report prepared for the Inchbonnie Catchment Group. http://www.maf.govt.nz/sff/about-projects/search/05-047/linkages.pdf

Monaghan, R.; Beare, M.; Boyes, M. 2009: The environmental impacts of dairy cow wintering in Southland. Report prepared for DairyNZ.

Muller, C.J.C.; Botha, J.A.; Smith W.A. 1996: Effect of confinement area on production, physiological parameters and behaviour of Friesian cows during winter in a temperate climate. *South African journal of animal science* **26**: 1-5.

Nichol, W.W. 2003: Brassica wintering for dairy cows: overcoming challenges. *Proceedings of the South Island*

Dairy Event, Lincoln University, Christchurch, New Zealand. Pp.154-172.

O'Connell, J.M.; Giller P.S.; Meaney W.J. 1992: Factors affecting cubicle utilisation by dairy cattle using stall frame and bedding manipulation experiments. *Applied animal behaviour science* **35**: 11-21.

Roche, J.R.; Dillon, P.; Stockdale, C.R.; Baumgard, L.H.; VanBalle, M.J. 2004: Relationships among international body condition scoring systems. *Journal of dairy science* **87**: 3076–3079

Roche, J.R.; Friggens, N.C.; Kay, J.K.; Fisher, M.W.; Stafford, K.J.; Berry, D.P. 2009: Invited review: Body condition score and its association with dairy cow productivity, health and welfare. *Journal of dairy science* **92**: 5769-5801.

Roche, J.R.; Lee, J.M.; Macdonald, K.A.; Berry, D.P. 2007a: Relationships among body condition score, body weight, and milk production variables in pasture-based dairy cows. *Journal of dairy science* **90**: 3802-3815.

Roche, J.R.; Macdonald, K.A.; Burke, C.R.; Lee, J.M.; Berry, D.P. 2007b: Associations among body condition score, body weight, and reproductive performance in seasonal-calving dairy cattle. *Journal of dairy science* **90**: 376-391.

Rugoho, I.; Gibbs, S.J.; Bryant, R.H.; Edwards, G.R. 2010. Intake and feeding behaviour of dairy cows grazing kale and grass at low and high allowances during winter. *In:* G.R. Edwards and R.H. Bryant eds. 'Meeting the challenges for pasture-based dairying.' *Proceedings of the 4th Australasian Dairy Science Symposium* Lincoln University, New Zealand. Pp 317-320.

Stewart, M.; Fisher, A.D.; Verkerk, G.A.; Matthews, L.R. 2002: Winter dairy grazing systems: management practices and cow comfort. *Proceedings of the New Zealand Society of Animal Production* **62**: 44-48.

Stockdale, C.R. 2001: Body condition at calving and the performance of dairy cows in early lactation under Australian conditions: a review. *Australian journal of experimental agriculture* **41**: 823-839.

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**: 1-13.

Verkerk, G.A.; Tucker, C.; Kendall, P.; Webster, J.; Bloomberg, M.; Rogers, A.; Stewart, M.; Davison, D.; Matthews, L. 2006: Physical environments and dairy cow welfare – lessons from New Zealand Research. *Proceedings of the 23rd Annual Seminar of the Society of Dairy Cattle Veterinarians of the New Zealand Veterinary Association*. Pp 35-46.

White, J.G.H.; Mathews, C.; Kemp, P.D. 1999: Supplementary feeding systems. pp. 175-198. *In*: J. White and J. Hodgson eds. New Zealand Pasture and Crop Science. Oxford University Press, Auckland.

Wilson, D. R.; Reid, J. B.; Zyskowski, R. F.; Maley, S.; Pearson, A. J.; Armstrong, S. D.; Catto, W. D.; Stafford, A. D. 2007: Forecasting fertiliser requirements of forage brassica crops. *Proceedings of the New Zealand Grassland Association Conference* **68**: 205-210.