RESTRICTED GRAZING OF WET SOILS:
FROM CONCEPT TO SYSTEM

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Abstract
Intensive grazing by cattle on wet pasture-land can have a negative effect on soil physical quality and future pasture production. Damage generally occurs when soils are wet, due to lowered bearing capacity. Soil pugging (*vis.* soil deformation) usually causes direct damage to the pasture sward. Soil compaction affects several pedo-functions, including air diffusion as well as the transportation and storage of water and nutrients that in turn may lead to reductions in pasture production.

The Proctor compaction test has been used to identify critical soil moisture contents (CMC) beyond which soil structure will be damaged in response to a known load, such as a cow hoof. We assessed whether implementation of a grazing management approach, termed 'restricted grazing', in which dairy cattle grazing was deferred or reduced in duration when soil moisture content exceeded the CMC, would improve soil structure and increase pasture production at two sites in southern New Zealand. At the North Otago study site, experimental plots (10 m x 25 m) on a dairy farm were monitored for three years to assess the direct effect of a restricted grazing regime on soil structure and pasture production. Soil macroporosity ranged between 11.2 and 14.6 $\%_{v/v}$ and was always above the minimum guideline value of $10\%_{v/v}$ suggested for optimal pasture production. Average annual pasture production was 18.1 and 19.2 t DM/ha for Control and Restricted treatments, respectively. However, restricting cows had no apparent effect on soil macroporosity or pasture production. On a dairy farm in South Otago a similar restricted grazing management strategy was employed. This farmlet study assessed the implications of a restricted grazing management regime on the whole farm system, i.e. considering effluent management and feed supply requirements, and general practicality (including labour requirements and the extent to which cows required moving). Although the two study sites have a similar soil type, the climate and landscape are considerably different. Here we assess the benefits and challenges of such management practices using results and practical considerations obtained from both sites.

Although the soil type at both trial sites was highly vulnerable to treading pressure, the landscape and climate in North Otago encouraged ongoing wetting and drying cycles which meant cows were removed from wet paddocks on only a few occasions per year. In South Otago, soil moisture content remained high for long periods and, therefore, cow grazing restrictions were required more frequently. Grazing practices in South Otago aimed to balance benefits gained in pasture production with the sometimes competing goals of maintaining animal production and welfare, limiting costs associated with off-paddock systems and ensuring feed quality and use-efficiency.

Introduction

Animal treading damage of pastoral soils can affect productivity by directly damaging the pasture sward and/or through increasing the density of the soil, which reduces air and water diffusion and biological activity (Piwowarczyk *et al.* 2011). Under a given force, e.g. a cow standing or walking, the extent of soil damage is largely dictated by soil moisture content at the time of impact e.g. during grazing. At high soil moisture contents (SMC), the bearing capacity of soil is low and resistance to medium-term deformation or consolidation under a given force is less. Applying a load in excess of the soil's bearing strength will cause deformation that is elastic, compressive or plastic in nature. In moist soils, much of the damage that occurs during grazing may be recoverable (i.e. it is viscoelastic). However, in wet soils a similar load may result in compression of air voids (compaction) or, when soil void spaces are filled with water, permanent displacement and remoulding of the soil surface (pugging). Generally, short-term damage to the pasture sward is evident following pugging, whilst the effects of compaction are often less noticeable and can have a much longer term impact on pasture production.

Grazing strategies that prevent soil compaction can help avoid soil physical damage and, therefore, are of value from an environmental and production perspective (Kerebel *et al.* 2013). However, there is limited guidance for farm managers when making decisions that could help to decrease the likelihood of animal treading damage. A penetrometer described in Betteridge et al. (2003) can be used as a decision support tool to identify soil conditions that would result in treading damage if a soil is grazed by cattle. This particular penetrometer was developed specifically as a farmer-based tool rather than a complex and scientifically accurate instrument. It has been promoted amongst New Zealand farmers as a means to identify the risk associated with grazing pastures when soil water contents are high. Greater precision around grazing exclusion decisions can be achieved by using soil moisture monitoring equipment. Given the influence of specific soil qualities on a soil's resistance to compaction, moisture content thresholds can be determined above which grazing is not advisable for a particular soil type. The Proctor compaction test can be used to identify such threshold values (Kerebel *et al.* 2013; Vero *et al.* 2013).

Changes in bulk density (i.e. degree of compaction/consolidation) are measured in relation to SMC to determine a critical moisture content (CMC) beyond which soils will be compacted under an applied load. This technique was used by Houlbrooke et al. (2011) to identify a CMC of a Timaru silt loam (Typic Fragic Pallic) soil in the North Otago Rolling Downlands (NORD). This information may help farmers plan stock movements during wet periods to prevent soil structural damage.

Using Proctor test methodology we determined the CMC of Pallic soils was 35% volumetric soil moisture content (Θ_v; Houlbrooke *et al.* 2011). In North Otago this corresponds to a soil water deficit of 6 mm. Here we assess if the use of the CMC of 6 mm soil water deficit as an upper limit for stock exclusion will result in improved pasture production and soil structure. A field plot trial (25 m x 10 m) was established on an irrigated dairy farm in NORD to compare long term soil macroporosity and pasture response under standard grazing practice vs. grazing avoidance when SMC > $35\%_{v/v}$ ('restricted' grazing). This approach focused primarily on the benefits gained from restricted dairy cow grazing in relation to soil quality and pasture production.

An important implication of restricted dairy cow grazing is the need for off-paddock facilities where the animals can be accommodated during wet periods. The longer the time required off pasture, the more sophisticated the stand-off facility needs to be with regards to effluent management and animal comfort (Kennedy *et al.* 2011). Feed supply and feed quality are also important factors affecting total milk production and quality in dairy farm systems (Pérez-Ramírez *et al.* 2009). To assess the implications of a restricted grazing management regime on the whole farm system (i.e. including effluent management, feed supply and general practicality) we have recently established a farm system trial, under a similar management strategy, on a dairy farm in South Otago. Here we also report some preliminary findings from this farm system evaluation.

North Otago restricted grazing trial

Description of the study area

This trial was conducted on a dairy farm near Windsor, North Otago, throughout three lactation seasons between 2010 and 2013. Cows were removed from the farm during winter and, therefore, grazing effects during this period were not incorporated into the trial design. The research paddock comprised 8 fully fenced plots (10 m wide and 25 m long), running lengthways down a north-facing slope of c. 7-15°.

The soil type is a Mottled Fragic Pallic soil (Hewitt 1998) characterised by a fragipan or Cx horizon at approximately 500 mm depth. This region generally experiences wet winters and dry summers, with mean rainfall and potential evaporation (5 year average) during the lactation season (270 days between Aug and May) being 480 mm and 690 mm, respectively. The site is irrigated via a low application rate pod sprinkler system when soil moisture drops below approximately 0.20 m^3/m^3 (as determined by an aquaflex sensor). Fertilisers were applied throughout the three years of the trial in accordance with normal farm practice.

Grazing Management

Treatments: 1) a Control, where grazing was carried out regardless of SMC, and 2) a Restricted grazing treatment, where grazing on wet soils (with SMC >0.35 m^3/m^3) was avoided. Grazing of Restricted plots was deferred until SMC was less than CMC and was of equal duration to Control grazing events. Four replicated plots were assigned to each treatment. Generally, plots of both treatments were grazed 7-8 times during the lactation season. If SMC was above the CMC on the day of grazing, cows would be allowed to graze the Control treatment only. Grazing of the Restricted treatment was delayed until the SMC dropped below the CMC. Irrigation was timed to avoid grazing events and had no bearing on SMC on the day in which treatments were imposed. Generally, there were one or two events per year (at a stocking density of approximately 280 Friesian cows/hectare) when the Restricted grazing treatment was imposed (i.e. when high SMC coincided with a planned grazing event.

Soil and Pasture Management

Soil sampling (intact cores, 50 mm height x 100 mm diameter) was carried out in June (early winter) each year. Measurements were made of a range of soil physical parameters, of which only macroporosity (50-100 mm depth) is reported here. This depth was chosen because earlier work has shown that this is where the greatest change in macroporosity occurs in response to cow treading (Drewry *et al.* 2000). Pre- and post-grazing pasture mass was assessed using a locally calibrated rising plate meter (L'Huiller and Thompson 1988) to determine pasture growth rates from August 2010 to June 2013.

Results from the North Otago restricted grazing trial

Imposing a restricted grazing regime had little effect on macroporosity at the 50-100 mm soil depth throughout the trial, when compared to the Control grazing regime (Figure 1).

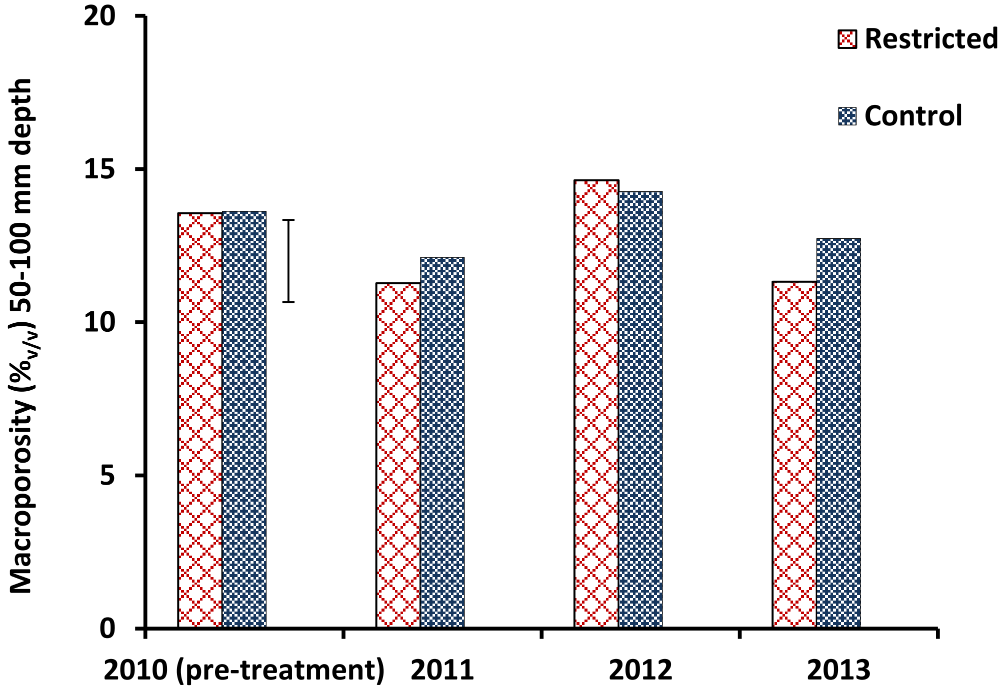

Figure 1. Soil macroporosity ($\%_{v/v}$) in the 50-100 mm soil depth layer under Restricted or non-restricted (Control) grazing management. The error bar represents $LSD_{5\%}$ between all years for each treatment.

Although pasture production was approximately 6-9% greater in the Restricted grazing treatment than the Control, this effect was not significant (*P*> 0.05; Figure 2).

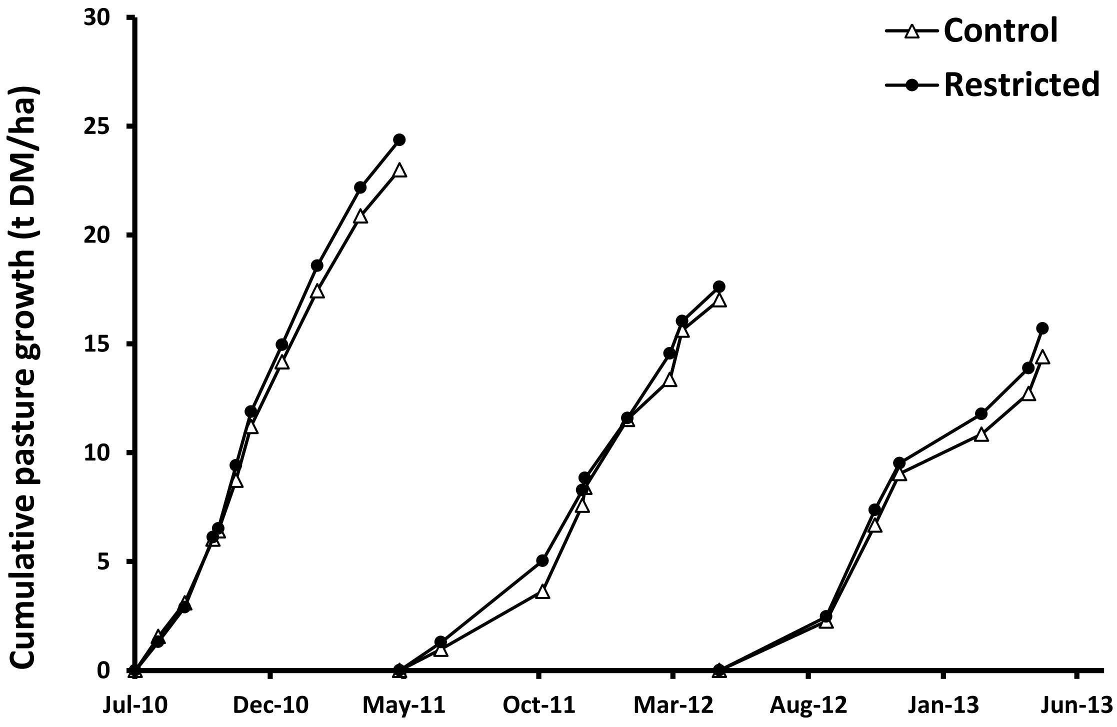

Figure 2. Pasture production for the Restricted and Control grazing treatments. Each value represents the average yield of four plots.

During the lactation season, SMC only exceeded CMC for 35 days (13% of lactation days). However, only on one or two days per year did wet days coincide with scheduled grazings of experimental plots.

Based on a stocking rate of 2.7 cows/ha, we estimate that under standard grazing practice (i.e. no restriction) one third of the farm will potentially be grazed on days when SMC exceeds CMC. However, the impact of this in relation to annual farm productivity and soil quality is predicted to be relatively minor due to the limited number of days each paddock is actually grazed when CMC is exceeded.

Logistically, implementation of a restricted grazing regime in relatively dry regions of North Otago would be easier than in wetter environments due to the fewer number of days when it is necessary. However, based on this trial, the very small benefit gained in terms of increased pasture productivity and improved soil quality are unlikely to out-weigh the costs associated with implementing such a management strategy.

Telford dairy farm –restricted grazing farm system trial

In 2012, a restricted grazing trial was established on Telford dairy farm near Balclutha in South Otago, as part of the Pastoral 21 Next Generation Dairy Systems Research Programme. This trial investigates some of the wider implications of a restricted grazing regime on the whole farm system. Soils on the farm are predominantly Pallic, similar to the North Otago trial site (Hewitt, 1998). Although this site is not irrigated, slower draining soils, lower ET and greater rainfall (890 mm during lactation) mean soil moisture contents are generally higher than in North Otago, particularly during spring (Figure 3). Consequently, on 32% of days during the 2012-13 milking season the paddocks to be grazed were above the CMC. However, in the first three months (2 Aug-6 Nov) of this season, on approximately 80% of days, the paddocks were above the CMC threshold. Grazing restrictions in this trial were implemented during spring only.

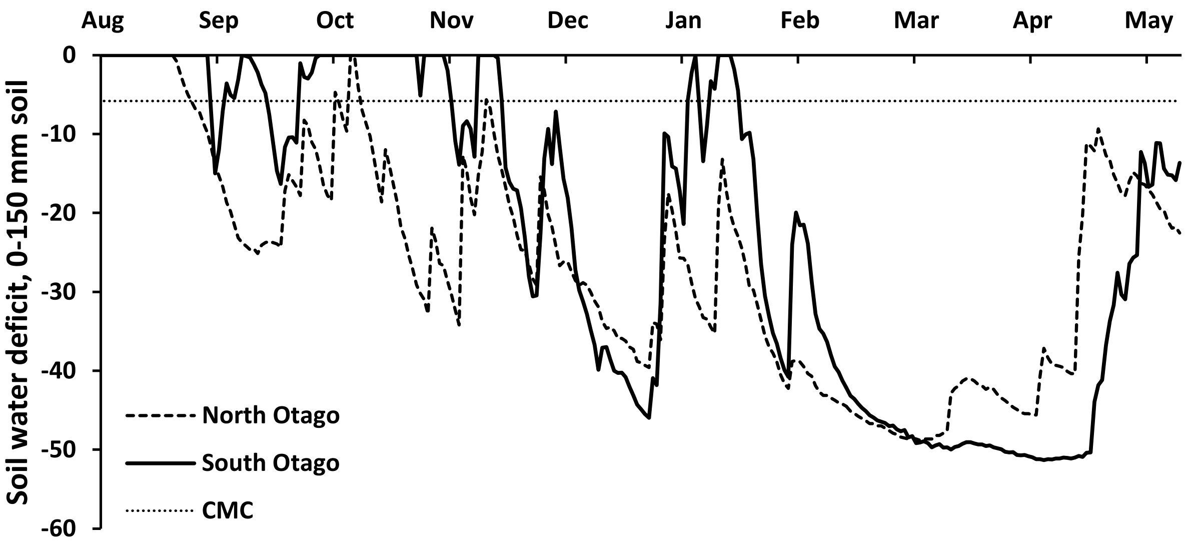

Figure 3. Measured soil moisture contents (0-150 mm depth) at the North and South Otago study sites for 2012. The critical moisture content (CMC) is shown as a dotted line.

Farmlet set-up and management

Two farmlet systems were implemented in August 2012, each with a herd size of 110 cows. Treatments included: 1) a Control where grazing was carried out regardless of SMC, and 2) a Restricted grazing treatment where grazing on wet soils was avoided. For the Control farmlet herd, the cows remained in a larger mob of 430 cows. The Restricted and control farmlets had stocking rates of 2.8 and 2.9 cows/ha respectively. Measurements of soil physical quality were carried out across all 17 paddocks assigned to the Restricted herd. An equal number (n=17) of paddocks were selected at random from the allocation of Control farmlet paddocks. For pasture production measurements, values for each treatment represent the average across all paddocks (i.e. for the Restricted farmlet n= 17 and for the Control n= 64).

Soil sampling (intact cores, 50 mm height x 100 mm diameter) was carried out in June 2013. A range of soil physical measurements were made, of which only macroporosity (5-10 cm depth) is reported here. Pre- and post-grazing pasture mass was measured as per the method detailed for the North Otago site.

The Restricted farmlet system was divided into four zones based on soil type and geographical location (Figure 4). A soil moisture sensor (AquaflexTM SI.60 soil moisture tape; Streat Instruments Ltd, Christchurch) was buried horizontally in one paddock within each zone at a depth of 100 mm. Hourly soil moisture readings for each zone were displayed on a computer screen in the farm dairy. Texts containing the SMC of each zone were sent to the farmer twice a day so farm staff could determine when the restricted grazing practices should be imposed.

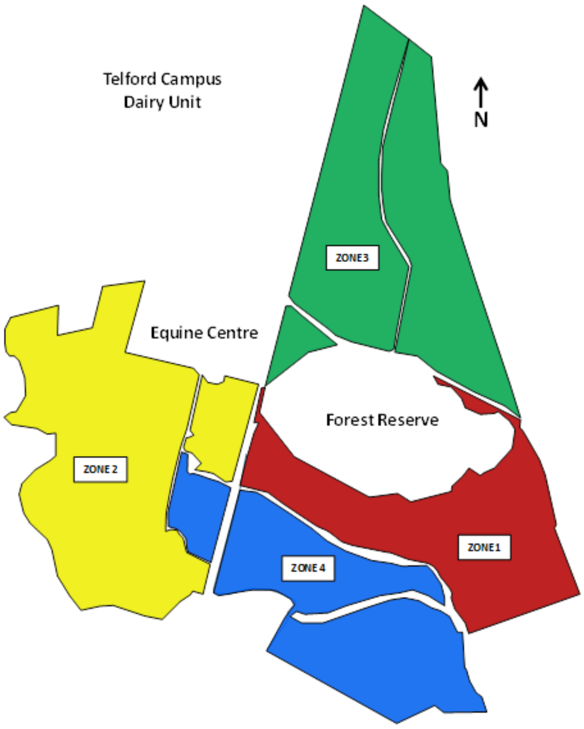

Figure 4. Management zones on Telford dairy farm. Each zone was instrumented with a soil moisture probe.

During the time cows were restricted from grazing paddocks they were kept in a loose-housed barn with bark and sawdust bedding. Grass silage was provided to cows along a concrete apron adjacent to the barn. All effluent from the barn was collected..

In the Restricted grazing treatment, a traffic light system with three criteria was devised based on soil water deficit (SWD) criteria:

GREEN	no restriction (SWD > 6 mm)
AMBER	grazing cows stood-off in the barn during the day (approx. 8 hours) but grazed on paddocks overnight (approx. 13 hours; 6 mm < SWD > 2 mm)
RED	no grazing on paddocks; cows remained in the barn (SWD <2 mm)

Animal behaviour was determined by GPS tracking (per minute) of cow location over a one month period, which enabled us to ascertain walking distances. Data suggested cow movement during night-time grazing of pasture was approximately 38% lower than during the day (time spent on laneways and in the farm dairy were excluded from this comparison). The amber SMC condition aimed to increase time at pasture by allowing grazing during the night when cows were less active and, therefore, damage to soils was expected to be less. Cows generally have two major grazing events of high intensity, at dawn and dusk. Between these times, feed consumption is relatively low i.e. accounts for less than 10% of the daily intake (Gregorini 2012). Therefore, cows restricted from late afternoon (prior to dusk) to early morning (after dawn) will consume approximately 55% of their daily feed requirements from these intensive bouts (Gregorini 2012).

Soil pasture and animal responses

Wet soil conditions at the start of lactation meant cows in the Restricted grazing treatment spent a considerable amount of time in the barn (i.e. 35% of total grazing time in September). In one two week period between 12 and 27 September, cows spent up to 50% of the time in the barn. A considerable decrease in daily milk yield occurred during this time (Figure 5) which was probably associated with the lower feed quantity and quality of the silage made on Telford Farm compared with fresh pasture offered to the Control herd.

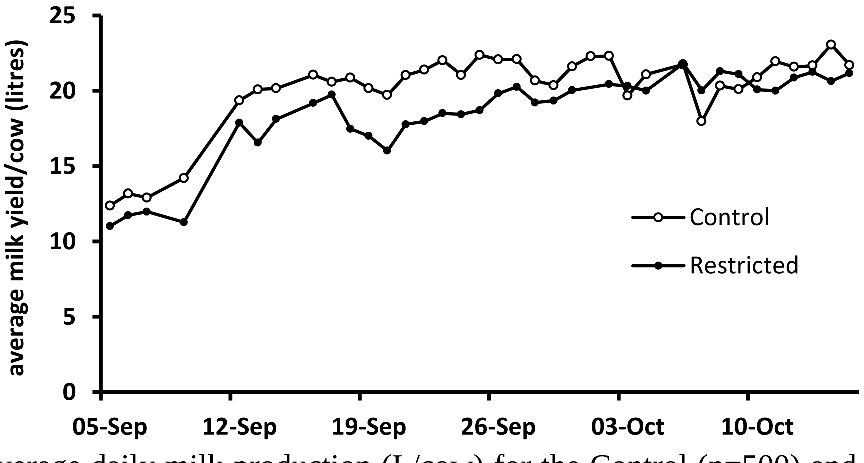

Figure 5. Average daily milk production (L/cow) for the Control (n=500) and Restricted (n= 110) herds between 5 September and 15 October 2012.

In response to the lower milk production in the Restricted herd, the decision rules were revised in early October to allow cows more time grazing. On days when soil moisture exceeded a critical level, cows were grazed for four hours in the morning then were returned to the loose-housed barn for the remaining three hours of the afternoon before evening milking. At night cows were grazed in the paddocks irrespective of soil moisture content.

This revised decision protocol for restricted grazing is listed below:

GREEN no restriction (SWD > 2 mm)

RED grazing on paddocks for 4 hours during the day; graze paddocks overnight (SWD < 2 mm)

Changes to the protocol effectively lowered the time of restriction by 95% for the remaining two months of spring. Extended use of the barn created other challenges, in particular maintaining animal performance in response to reduced feed quantity and quality and a greater financial cost for maintaining the cleanliness of the barn surface. During spring of the 2012-13 lactation season, use of the barn reduced paddock grazing by 14%. Importantly, time spent grazing wet soils during the day (i.e. between milking), when cow activity is high, was reduced by 32% compared with the Control herd (Figure 6).

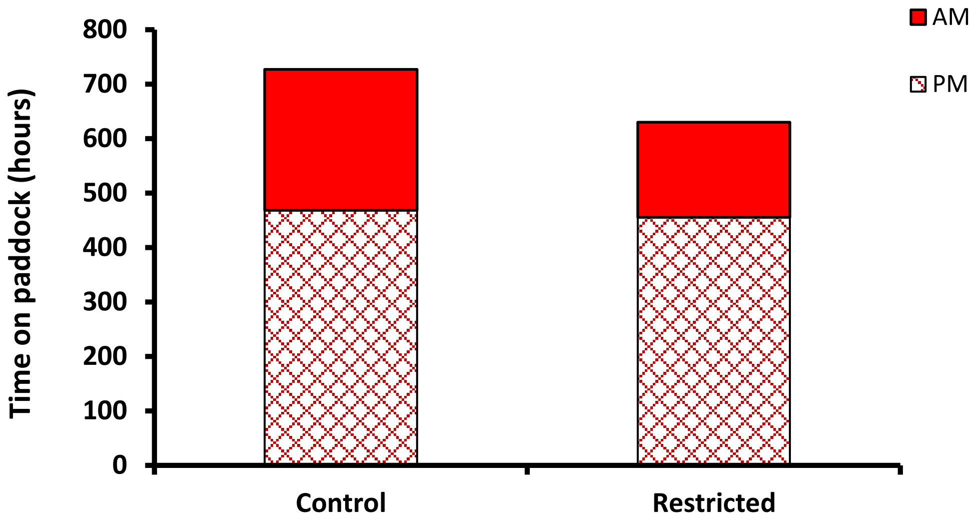

Figure 6. Time cows spent grazing wet soils when soil moisture content exceeded the critical moisture content. Time during the day (AM) is shown separately to time spent grazing during the night (PM).

Dealing with manure and effluent from the barn is important for farmers with off-paddock facilities. This management challenge is being addressed in on-going research at Telford. Despite the greater number of hours that the cows spent off-paddock in the Restricted grazing treatment (14% over the spring lactation period), soil macroporosity was similar between treatments (Figure 7). Furthermore, under the Restricted grazing regime, there was no relationship between hours spent on wet soils (i.e. when SMC>CMC) and resulting soil structural quality. It is important to note that macroporosity in both treatments was generally above the minimum guideline value of $10\%_{v/v}$ suggested for optimal pasture production (Drewry and Paton 2000).

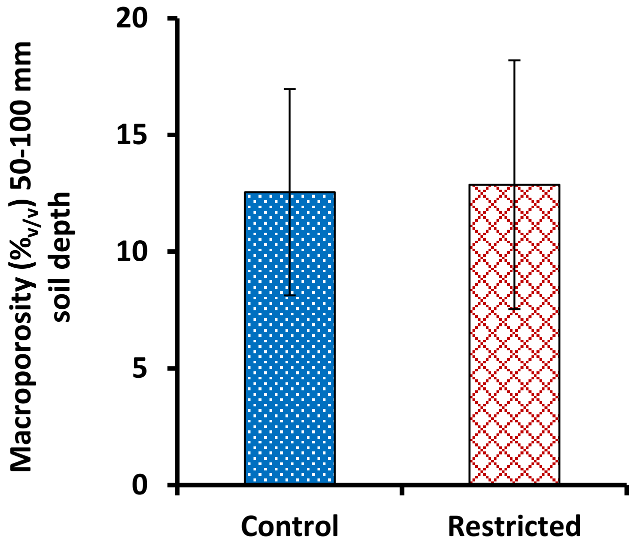

Figure 7. Soil macroporosity values ($\%_{v/v}$; 50- 100 mm) in the Restricted and Control farmlet paddocks. Error bars represent one standard deviation.

There was also no significant difference in spring pasture production between the Restricted and Control treatments. However, the trend in average pasture production for the year indicated 10% greater production in the Restricted grazing farmlet (14.2 t DM/ha) relative to the Control farmlet (13.0 t DM/ha). Pasture recovery following a compaction or pugging event has a strong influence on overall farm profitability (Beukes et al. 2013). The duration of recovery will therefore be a key determinant when assessing the benefits of restricted grazing practices. Frequently wet soils combined with the high soil structural vulnerability of the Telford soils (Hewitt and Shepard 1997) suggest long recovery periods will be required to return soil and pasture back to a pre-damaged state; even short lengths of restriction therefore have the potential to result in a treatment effect. Time off paddock must be carefully evaluated against associated costs (both capital and operational) and farm profitability. Beukes et al. (2013) concluded that zero grazing i.e. permanent stand-off from wet soils was less profitable compared with some level of grazing, due to the disadvantage of managing infrequently grazed pastures (i.e. pasture quality and ensiling costs).

Summary

The Pallic soils of both North and South Otago are vulnerable to soil compaction and pugging damage. The landscape and climate of the North Otago rolling downlands encourages rapid wetting and drying cycles that prevent prolonged periods when SMC>CMC. In this study, occasions when cows were removed from wet paddocks were few. In South Otago, SMC remained high for long periods and, therefore, cow grazing restrictions were required more frequently than at the trail site in the North of Otago. In South Otago, preventing cow grazing on wet soils during spring is predicted to have a large benefit on soil structure and pasture production in the long-term. Research to date suggests this will require cows to spend a significant amount of time off-paddock. The challenge will be to develop restricted grazing criteria that maximises time off paddock without adverse effect on farm profitability.

On-going Research

Our on-going research at Telford will continue to modify restricted grazing criteria in order to adequately balance on-farm practicality with expected benefits. We will continue to fine-tune those farm operations that are affected by restricted grazing practices such as feed allocation, effluent management and barn management so as to maintain farm productivity, profitability and animal health and welfare.

A key focus of our research will be to determine the long-term benefits of restricted grazing management in relation to soil structure, pasture growth and milk production. We aim to develop decision principles that optimise grazing restriction by balancing such benefits with the sometimes competing goals of maintaining animal production and welfare, limiting costs associated with off-paddock systems and ensuring feed quality and use-efficiency.

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