MANAGING SOIL TO PROMOTE MAXIMUM PRODUCTION AND MINIMAL DAMAGE

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Summary

Intensive dairy cattle grazing on wet soil can have a negative effect on soil physical quality and pasture production. A soil in good physical health can adequately transport and store water and nutrients while physically supporting growing plants and maintaining an active biological community. Soil compaction and pugging decreases a soil's physical health, damages the pasture sward and places limitations on some of the important functions described above, therefore resulting in potential decreases in forage yield. A soil that has been compacted will also have decreased water storage and drainage capability, which often leads to greater amounts of surface runoff. Furthermore, the exchange of oxygen with the atmosphere, which is essential for soil biological functioning, becomes limited. When it comes to managing soil treading damage, prevention is better than the cure. With soil wetness being the greatest determining factor, the key grazing management options are to decrease either stocking intensity or the time on the paddock. Decreasing time spent on the paddock requires the use of off-paddock facilities and thus must be weighed up against the costs and practicalities associated with such infrastructure.

Factors influencing soil damage

The extent of soil damage under livestock pastoral grazing is dependent on five critical factors:

1. Soil susceptibility to damage
2. Soil wetness
3. Livestock loading (weight/hoof contact area)

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4. Grazing intensity (animals/ha) and duration (time on soil)
5. Vegetative cover.

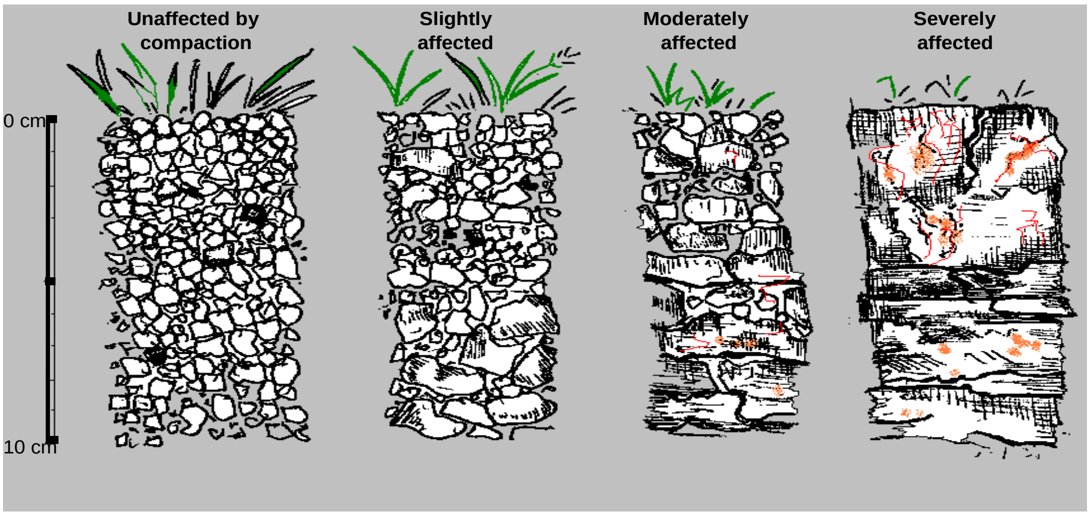
Grazing duration and intensity can have a large effect on the extent of soil pugging and damage during a single grazing event. These two factors can be controlled by applying appropriate stock management at times of soil treading risk. The treading effect of an animal is also related to its mass, hoof area and whether it is moving or stationary. One-off, severe cattle grazing events tend to result in extreme pugging that causes severe damage to the pasture sward and possible lowering of pasture production in the short term. In comparison, long term compaction damage is often a cumulative effect of livestock loading on soils during times when moisture conditions allow for soil compaction.

The properties of a soil influence its ability to resist the forces of soil compaction. Soil texture and mineralogy influence the way in which particles align with one another; fine-grained soil such as clay loams, for instance, contain smaller particles that pack tightly and leave smaller pore spaces. Clay content and clay mineralogy also influence aspects such as drainage and the cohesive strength between particles when wet. Such characteristics influence the time that soils remain wet; poorly drained soils with high clay content therefore tend to be more prone to damage from livestock grazing. The influence of vegetative cover within a typical ryegrass and white clover pasture plays a small part on minimizing the impact of soil compaction. Some protection is provided by the pasture root mass that promotes aggregate formation, and therefore improves structural stability and pore space.

Effect of soil damage

Soil macroporosity describes the percentage of air spaces within soils that are greater than 0.03 mm, while microporosity describes those less than 0.03 mm. Macroporosity reflects the degree of soil aggregation and therefore is often used as an indicator of soil physical health. The degradation of soil structure, in particular the loss of macroporosity, as a result of soil compaction, has been shown to have a negative effect on pasture production due to decreased air and water transmission and root growth development (Figure 1). Early lactation (spring time) is a critical period for soil damage on New Zealand dairy farms due to high soil moisture contents that are typically present at that time. A linear relationship has been defined between soil macroporosity and spring pasture production potential over a range of different New Zealand soil types. In summary, a unit increase in macroporosity was associated with a 1.8% increase in spring relative pasture yield. Generally, it is advisable to maintain soil macroporosity above 10% in order to maintain soil processes that are beneficial to pasture production.

The rate at which water moves through soil is commonly described as the infiltration rate. When soil structure deteriorates through the action of grazing animals that smear or indent the soil surface during wet conditions, fine textured sediments may block surface macropores thereby reducing infiltration rate considerably. An effect of decreasing soil infiltration and drainage capability is an increase in overland flow generation, resulting in greater losses of water contaminants such as phosphorus (P), sediment and faecal microorganisms.



Topsoil is loose and crumbles easily into small, granular aggregates

Abundant roots throughout topsoil

Worms are common

Upper part of topsoil is loose

Some larger, firmer aggregates between 10 to 15 cm

Roots do not commonly penetrate firmer aggregates

Larger, firmer aggregates more common. Sometimes have a horizontal platy appearance.

Roots grow around rather than through aggregates

Reddish stains along some root channels

Lumpy, irregular surface

Aggregates are coarse or absent

Few roots below 5 cm

Reddish stains along root channels. Soil often greyish in colour and may have an unpleasant smell when wet.

Few worms present.

Figure 1. Illustration of soil damage with increasing soil compaction (adapted from Betteridge et al. 2003).

As mentioned above, soils that are most prone to treading damage include those with a high clay content that drain slowly. In these soils, grazing time should be reduced when soil water content is at or near field capacity (soil moisture or water content held in the soil after

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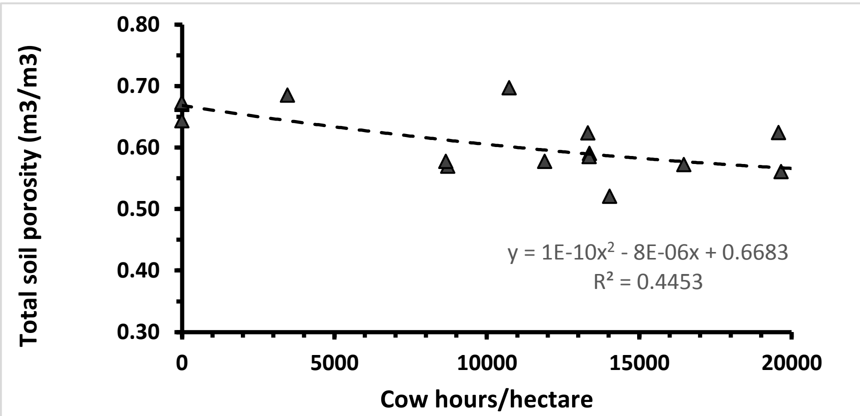
excess water has drained away). For soils with low clay contents (i.e. < 10% clay), a higher soil water content can be maintained (i.e. soil field capacity) before the effects of treading significantly affects pasture production at a farm scale.

As part of the Pastoral21 Next Generation Dairy Systems Research Programme (P21), we monitored soil physical quality on an experimental farmlet at Telford, south Otago, where no wet soil management practices were implemented. The time (in hours) that cows were allowed to graze wet soils (i.e. when the risk of treading damage was present) was quantified across the three years of the trial and is reported here on a per hectare basis. The total time cows spent on wet soils was not strongly correlated to total porosity (R^2=0.45, Fig 2a), macroporosity (R^2=0.27, Fig 2b) or microporosity (R^2=0.31) measured in 2015. While this suggests the soil physical measurements did not show a significant damage response associated with the grazing intensity imposed, a trend of declining soil physical quality with increasing grazing time on wets soils was apparent.

A)



B)

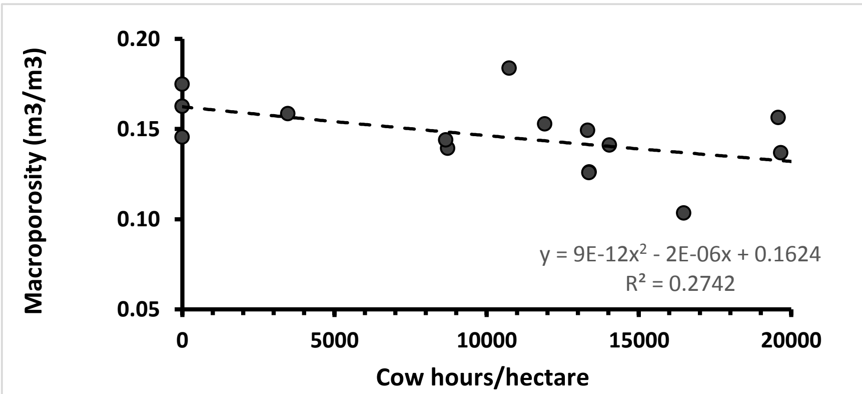


Figure 2. Relationships between soil (A) total porosity and (B) macroporosity and time cows spent on pastures when soils were wet i.e. above the wetness threshold.

Protecting against soil structural damage to ensure water infiltration rates are maintained has been shown to reduce nutrient and sediment losses that can arise following irrigation and/or rainfall events (Curran-Cournane et al., 2011; McDowell and Houlbrooke 2009; McDowell et al. 2003). Maintaining high soil infiltration rates is particularly important on sloping land and where effluent is applied.

Repairing soil damage

Once soils become compacted, structure can be restored through a process of natural recovery that is facilitated by wetting and drying cycles, freeze-thawing, pasture growth and earthworm activity. Depending on the degree of initial damage, this process may take several months, if not years, to restore soil quality and tends to be limited to the top 100 mm of soil where moisture fluctuations, pasture root growth and biological activity are typically greater than at soil depths below 100 mm. Mechanical aeration can be used to speed up the recovery process by improving drainage and air diffusion to depths of around 300 mm (typical operating depth of an aerator). This in turn promotes many of the biological processes essential for aggregate formation.

A trial located in the rolling downlands of North Otago assessed the benefit of mechanical soil aeration for improving soil structure (Laurenson and Houlbrooke, 2014). This assessment was made in soils that had been used for winter forage crop grazing immediately prior to the re-establishment of pasture (rotationally grazed by cattle). Prior to aeration, soils were in a poor physical state due to four consecutive years of cattle grazing of winter forage crops (Figure 3). Aeration was effective in increasing soil macroporosity (0-10 cm depth) by approximately 15% (from 10 to 25%) and pasture growth by approximately 2 t/ha/yr compared to the non-aerated soils. However, improvements gained from aeration generally did not persist longer than 18 months due to the subsequent grazing pressure from cows. This trial showed that mechanical aeration can provide an immediate increase in the porosity of compacted soils, leading to improved pasture growth. However, processes involved in the formation of resilient soils are curtailed if subsequent grazing events coincide with high soil water contents that cause

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re-compaction. Generally, soil carbon and nitrogen contents in the top 200 mm of soil were not affected by mechanical aeration over the 2 years of this trial.

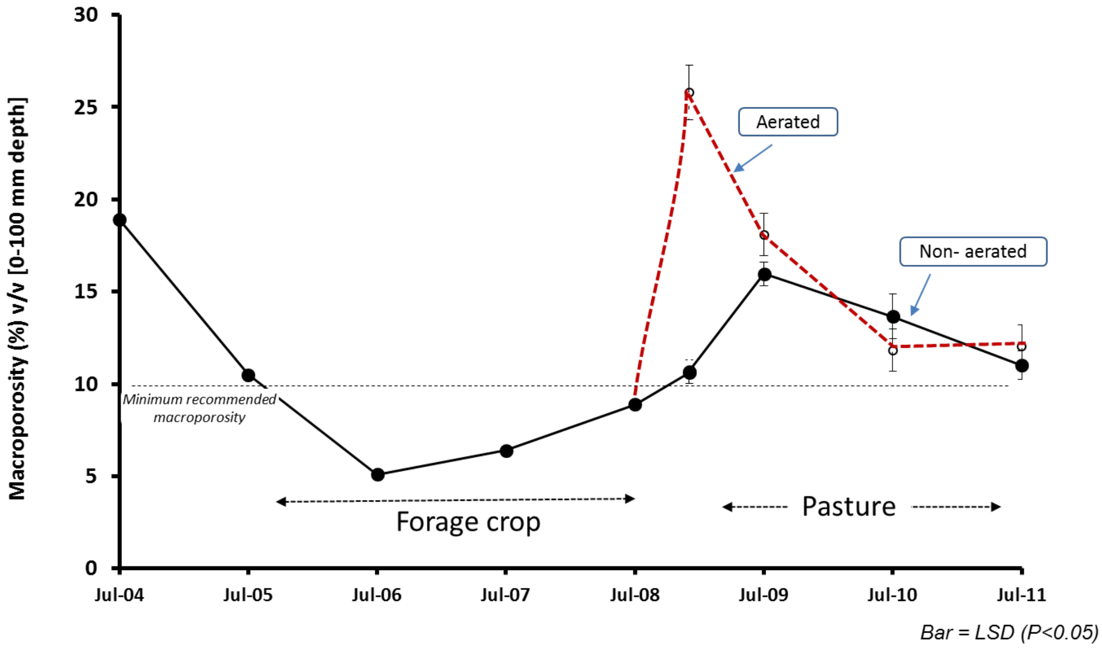

Figure 3. Soil macroporsity (0-100 mm) monitored between 2004 and 2011 at a trial site in North Otago. In December 2008, 50% of the plots were aerated prior to being sown in pasture and rotationally grazed by cows.

An investment analysis to assess the potential economic benefits of mechanical soil aeration was carried out for the North Otago Rolling Downlands dairy farm (Laurenson et al. 2015). Estimated changes in dairy farm profitability from soil aeration were calculated based on a 13% increase in annual pasture production over a 2 year period (from the area used for winter grazing). The study considered both the fixed and variable costs associated with the modelled farm enterprise. The response in farm profitability to greater pasture growth was realised through an increase in stocking rate and associated milk production. The net economic benefit from aeration (based on a milk sale price of NZ$6/kg milksolids) was $1354/year over a 12-year planning horizon, which equated to a net increase in profit of $67/ha/year of winter forage crop paddock that was aerated. Assuming the benefits of aeration are apparent for a 2 year period only and the milk sale price is $6 /kg MS, a minimum of 375 kg DM/ha/yr more pasture must be grown each year in order to gain an economic return from mechanical aeration. At a lower milk sale price of $4 /kg MS, the break-even point increases to 670 kg DM/ha/yr.

Preventing soil damage

Restricted grazing strategies have been proposed as a way to protect soils and pasture from animal treading damage. Holding cows off paddock increases a farm's required capital and operating expenditure through provision of a stand-off pad (or other holding facility) and associated effluent management system, increased labour inputs and the need for a supply of quality supplementary feed. Generally, both the capital and operating costs are similar across regions (i.e. infrastructure, feed and effluent management), yet the relative effect of cow treading on soil and pasture production is strongly influenced by specific soil and landscape characteristics. Therefore the benefit of restricted grazing management will differ across locations in response to site-specific variables. For instance, in climates such as Southland, where soils remain wet for long periods of time during winter and spring, restricted grazing strategies have been reported to improve soil structure and pasture production. However, in comparatively drier environments the impact on production that is gained through wet soil protection is less and the changes in production are often not sufficient to offset the financial costs associated with standing cows off pasture (i.e. provision of a stand-off facility and operational costs). In North Otago, for instance, soils that were not grazed when wet had significantly higher total porosity yet there was no significant improvement in annual pasture production, averaging 17.0 (standard grazing) and 17.9 (restricted grazing) t DM ha^{-1} year^{-1} (Laurenson et al., 2016). Whole farm modelling indicated that farm operating profit was reduced by NZ$1,683 ha^{-1} year^{-1} (four-year average, includes capital and operation costs, provision of feed and accounts for changes in milk production) under grazing management that avoided wet soils completely. Short duration grazing management systems that limit grazing of wet soils to several hours per day (e.g. approximately 8 h day^{-1}) allow cows sufficient time to digest a large proportion of their daily feed intake requirement as fresh pasture. This management approach resulted in a reduction in farm operating profit by NZ$74 ha^{-1} year^{-1} (four-year average).

In 2012, a restricted grazing trial was established on Telford dairy farm near Balclutha in South Otago. This Pastoral21-funded trial investigated some of the wider implications of a restricted grazing regime (Restricted) on the whole farm system compared to standard practice (Control). Soils on the farm were predominantly Pallic, similar to the North Otago trial site. However, the period that soils were wet was considerably longer in South Otago. For instance, in the first three months (2 Aug-6 Nov) of the 2012/13 season paddocks were above this critical

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wetness threshold on approximately 80% of days. Cow grazing in the Restricted farmlet was reduced to 13 hours when the soil water content was greater than 40% v/v. During this period the Restricted herd spent approximately 10% less time on pasture compared with the control herd. Fertiliser N inputs to the Control and Restricted farmlets averaged 100 and 75 kg N/ha/yr, respectively; pasture growth measured during the 2012-13 (Year 1) and 2014-15 (Year 3) seasons has been corrected for differences in these fertiliser N inputs based on an assumed N response rate of 14.8 kg DM per unit of N applied (Monaghan et al. 2005). In Year 1, pasture grown (corrected for N input) in the Restricted farmlet was approximately 18% higher compared to the Control (Figure 4). The average pasture growth rate in spring was 56 kg DM/ha/day when wet soils were protected, as opposed to 51 kg DM/ha/day. No significant difference in pasture growth was observed between the farmlets in Year 3 of the study.

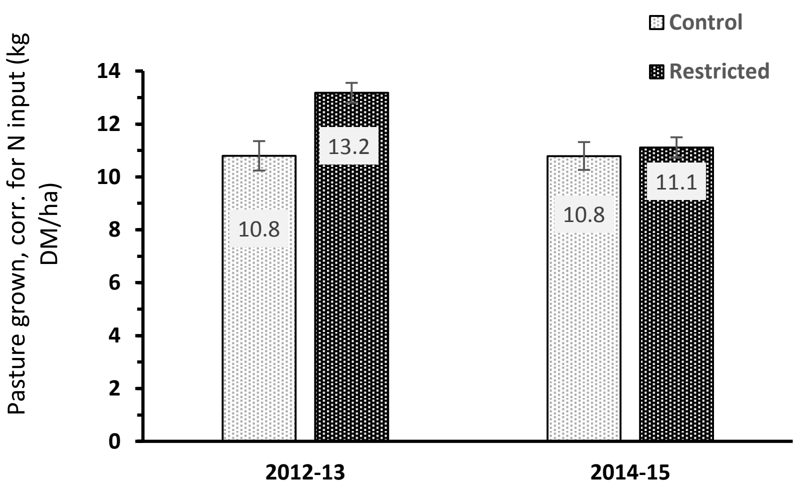

Figure 4. Average pasture grown (kg DM/ha) in the Control and Restricted farmlets in Year 1 and Year 3. Values have been corrected for differences in nitrogen (N) input assuming an N response rate of 14.8 kg DM per unit of N applied. The error bars represent the SEM (n=17 paddocks/farmlet). Paddocks used in this analysis represent a subset of the total number of paddocks within each treatment.

There is likely to be valuable environmental gains in terms of reductions in surface runoff gained from measures that protect soil structure. The relative economic advantage of removing cows from wet paddocks will vary in response to milk price, soil type and the pasture production that is lost under ‘standard’ managements where no soil protection is provided. In drier regions, the impact of treading damage across the whole farm will be low and so production and financial gains may often be less than the costs of implementing an on-off grazing strategy. Farmers will need to assess the relative impact of treading damage across their farms and estimate the potential increase in productivity likely to be achieved through wet soil protection; Figure 5 can be used as a guide.

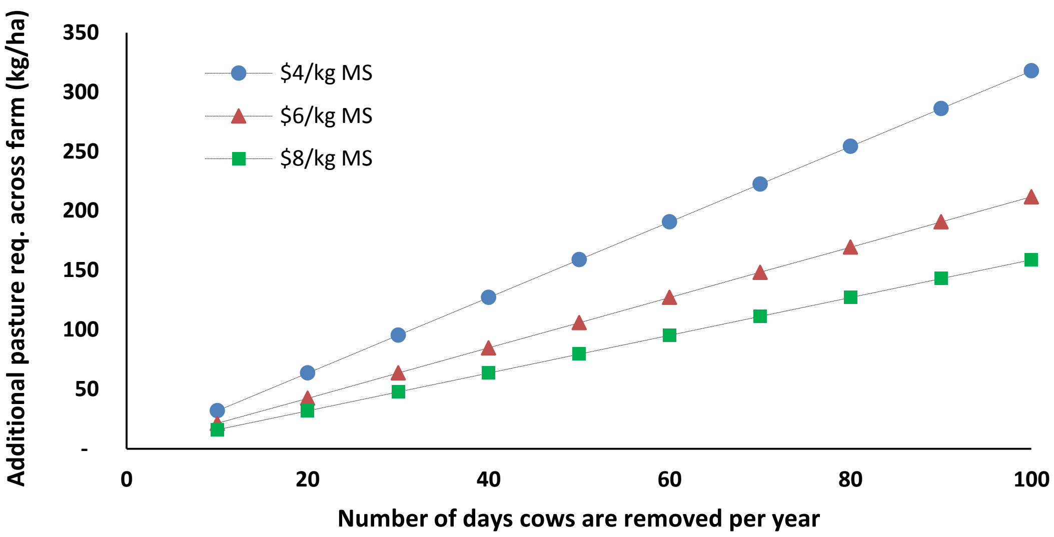

Figure 5. Estimated required increase in pasture production per hectare (all farm hectares), relative to the status quo, to off-set the operational costs associated with using a standoff facility for cows that are removed from wet pasture for 8 hours per day for a range of milksolids (MS) pay-out prices.

Calculations assume the cost to stand cows off is $0.04 cow/hr; cows are provided 2 kg DM/cow/day when stood-off in the form of silage which costs $0.12 to produce ($0.08 to ensile home-grown pasture and $0.04 to feed out); no change in milksolids production due to standing cows off; a pasture energy content of 11 MJ ME/kg DM and 7.8 kg DM is required to produce 1 kg MS (factoring in 5% wastage); Friesian cows requiring 82 MJ ME/kg MS; and a stocking density of 2.9 cows/ha. Capital cost of the facility is not included in the cost estimate.

Short duration grazing management systems that limit grazing of wet soils to several hours per day (e.g. approximately 8 h day^{-1}, as opposed to no grazing) allow cows sufficient time to digest a large proportion of their daily feed intake requirement as fresh pasture. This reduces the reliance on feeding supplements and as a result is more economical than the complete removal of cows from pasture. In wetter environments a greater benefit in pasture

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production and economic response will likely be achieved through standing cows off on wet days.

Farm management options

The period that animals remain off pasture will determine the degree of animal welfare and effluent management issues that need to be considered (DairyNZ 2005). Rudimentary options such as gravel-based laneways or concrete areas are only short term propositions as animal lameness and inappropriate containment of effluent will become issues. Animals can be stood off for short periods of time on an area of approximately 5-6 m^2 per cow. However, if animals are spending 12 hours a day or more off the paddock then they will require approximately 9-10 m^2 and a dedicated animal feeding facility to supplement their decreased pasture intake. The minimising muck, maximising money booklet (DairyNZ 2005) provides considerable management advice with regards to designing an off-grazing facility customised to farm requirements. Where it is expected that animals will spend considerable time off paddock, a system to capture and contain all excreted effluent will be necessary; this may involve a roof over the animals (and in some cases over the effluent storage pond) to prevent significant rainfall inputs.

Strategic management recommendations

- Graze more strategically by knowing the soil types and their respective vulnerability to being compacted at different times of the year. For example, utilise soils with greater resistance to compaction (free draining, sandy soils) during wet periods.
- Where heavy and poorly drained soils are prevalent, consider an investment in an off-paddock grazing facility to restrict grazing duration during expected wet periods.
- Winter animals within housing facilities or winter all stock off the milking platform to protect spring growth potential. It is acknowledged that wintering off the property can relocate the problem to a different area

Tactical management recommendations

- Monitor weather and soil moisture conditions in order to predict wet periods that are likely to encourage soil damage.
- Maintain pasture covers and feed cows well.
- Consider providing larger breaks (if break feeding) or paddock areas during wet periods to decrease stocking density, increase pasture grazing residuals and keep cows from moving around.

- Consider putting a back fence behind a fresh break during wet periods to prevent previously undamaged or partially damaged soils from being further trampled.

Key messages

The factors that influence the degree of soil treading damage are: soil moisture, livestock loading, grazing intensity, grazing duration, vegetative cover and soil susceptibility to damage.

Soil treading damage can decrease a soil's ability to transmit and store air and water, with associated increases in the potential for poor drainage and surface runoff generation.

Mechanical aeration can improve the structure of severely damaged soils. The relative advantage of soil aeration will vary in response to milk sale price, soil type, degree of initial soil damage and post-aeration grazing management when soils are wet.

The prevention of soil damage requires management intervention to decrease the influence of soil risk factors. For example, off-paddock facilities can be used during periods of high soil water content to minimise or avoid soil treading damage. Associated costs should be considered and include the requirement to provide good quality feed and ongoing operational and capital costs that are incurred when running such a facility.

Know your soil types and have strategic and tactical plans for getting through wet periods

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