SEASONAL CHANGES IN SOIL STRUCTURE UNDER WINTER GRAZING IN SOUTHERN NEW ZEALAND.

T. Styles[1], S. Laurenson[1], R.M. Monaghan[1], D. Dalley[2] and J.M, Chrystal[1]

[1]AgResearch, Invermay Agriculture Centre, Private Bag 50034, Mosgiel, New Zealand
[2]DairyNZ, PO Box 160, Lincoln University
**Corresponding author E-mail: Tash.Styles@agresearch.co.nz*

Abstract

Land use change and the intensification of New Zealand farming practices has occurred at a rapid rate in recent years and is recognised as an important contributor to a range of environmental issues. A decline in soil physical quality due to livestock grazing has been reported in a number of studies, particularly those relating to winter grazing. A high stock density during winter can result in considerable soil physical damage, usually because soil moisture content during this time is high. Physical properties (porosity) of poorly drained Gley and Pallic soils were assessed on two dairy farms in the southern South Island, New Zealand. On each property, forage crops were grazed by dairy cows during winter in consecutive years and cultivated between crops. Pore size distribution was determined at three soil depths in late autumn (pre grazing) and late winter (post grazing) over two years. Soil structure was significantly affected by winter forage crop grazing, with macroporosity significantly declining between grazing events to values considerably less than those previously reported as required for optimal pasture production.

Introduction

The southern South Island of New Zealand has undergone a considerable amount of land-use change and intensification over recent years. This has seen a change in stock class and increases in pasture production, animal stocking rates, and fertiliser and purchased feed inputs. During the non-lactation season it is common practice to graze cattle intensively on winter forage crops which can provide large quantities of feed in a relatively small area. Soil damage associated with winter crop grazing has been recognised as a particular challenge for the region. Soil damage generally occurs due to the coinciding of high stock densities and high soil moisture conditions (Betteridge *et al.* 1999, Drewry and Paton 2000, Ward and Greenwood 2002, Houlbrooke *et al*. 2009). Soils at the greatest risk of such damage are those that have a high Structural Vulnerability Index (Hewitt & Shepherd 1997), such as those found in the Pallic and Gley Soil Orders, which are common soils in the southern South Island. These soils are characterised as being imperfectly drained and highly vulnerable to structural compaction (Hewitt, 1998).

Soil macroporosity is a good indicator of soil physical condition (Drewry *et al*, 2004). It has been widely reported that macroporosities <10-12% indicate limiting conditions for plant health and soil aeration (Sparling and Schipper, 2002). Karlen *et al.* (1997) defined “soil quality” as the soil’s ability to function, requiring balancing between biological, chemical and physical components. The formation of macro-aggregates involves the stabilisation of micro-aggregates into larger structural macro units, a process that relies on the on-going soil biological processes involved in this soil aggregation (Wright and Upadhyaya, 1996).

However, a reduction in total porosity and macroporosity (i.e. compaction) reduces the drainage capacity of soils and increases soil bulk density. Reduced drainage means soils remain wetter for longer following rainfall events, thereby prolonging the period of ‘risk’ to soil structural damage.

Compacted soils can recover naturally under the influence of wetting and drying cycles, freeze-thawing cycles, pasture growth and earthworm activity. However, these processes tend to be most prevalent in the top 150 mm of soil where soil moisture contents fluctuate a lot more compared to the sub-soil (Drewry and Paton, 2005). Natural soil recovery can occur shortly after grazing events, although this may take months or even years (Drewry *et al,* 2004). The rate of recovery is influenced by multiple factors including soil moisture content and grazing intensity (during each event and subsequent grazings). Due to the potentially severe impact of winter grazing on soil structure, routine soil cultivation or aeration may be important to maintain a desirable macroporosity. Soil disturbance that encourages air diffusion and drainage helps to restore or enhance biological processes responsible for aggregate formation by promoting oxidative chemical and biological reactions (Celik *et al*, 2010). Cultivation or aeration may help improve soil porosity thereby moderating the overall seasonal impact of winter grazing on soil processes.

The aim of this study was to examine seasonal changes in soil structure under winter forage crop grazing of non-lactating dairy cows in South Otago and Southland. The effect of soil management techniques was assessed by comparing our study with others to help understand the practical implications of such methods on soil recovery.

Methods

Description of the study area

This trial was conducted on two dairy farms, at Wallacetown, Southland and at Balclutha, South Otago. The Southland site has a mean annual rainfall of 1100 mm and the South Otago site has a mean annual rainfall of 700-750 mm.

The Southland site consists of two soil types both of which are vulnerable to structural compaction, a Gley Makarewa soil which is a predominantly silt clay loam, and a Northope soil, an imperfectly drained silt loam, classified as a Mottled Immature Pallic (Hewitt, 1998). The South Otago soil (Te Houka) is a poorly drained silt loam, classified as a Mottled Fragic Pallic soil. All sites were in winter forage crops that were strip grazed through winter (June and July). After grazing, each paddock was cultivated in late spring to 250 mm depth and re-planted with next year’s winter forage crop (two year crop rotation before returning to pasture).

Measurements

Soils were sampled in late autumn (pre crop grazing) and late winter (post crop grazing) using soil rings (100 mm dia x 50 mm length). Pore size distributions were determined at 0-50, 50-100 and 250-300 mm depth for two replicated samples per sampling point. The Southland site had six sampling points for each soil type and the South Otago site had 24 sampling points. Measurements were made as previously described by Drewry and Paton (2000). In brief, earthworms were removed using formaldehyde, and all cores were equilibrated on a tension table to -1 kPa and -10 kPa to determine the percentage of soil pores > 300 µm diameter, and the percentage of soil pores > 30 µm diameter (macropores).

Data and Statistical analysis

Differences in soil macroporosity at each depth were determined by analysis of variance (ANOVA), with pre and post grazing, year and soil type as factors of interest. Analysis was carried out using the statistical package GenStat v13. All reported differences are significant at the 5% level. While statistical analysis was conducted for all three soil depths, graphs represent the 50-100 mm depth only. This depth has been reported to indicate significant short and long term structural damage compared to other depths (Drewry *et al*, 2004).

Results and Discussion

Soil structure was significantly impacted by winter grazing whereby macroporosity values in the 50-100 mm soil layer declined from 12-17% to 6-9% v/v (Table 1 and Fig 1). These post-grazing values are considerably less than critical macroporosities required for pasture production (i.e. ≥10% v/v; Sparling and Schipper, 2002). These results are similar to findings by Drewry and Paton (2005) who reported that soil macroporosity decreased by 7% v/v following intensive grazing of a forage crop by cattle (350 cows/ha instantaneous stock density) in South Otago (Pallic Soil).

Table 1. Changes in percentage macroporosity (v/v) following grazing of winter forage crops at the Southland (Makarewa and Northope) and South Otago (Te Houka) sites. Significance is presented for comparison between pre and post grazing each year.

Year	Soil depth (mm)	Sampling occasion	Soil type		
			Makarewa	**Northope**	**Te Houka**
2011	0-50	Pre	15.2	19.6	16.4
		Post	9.7	9.5	8.2
2012		Pre	16.4	13.7	20.9
		Post	8.6	7.2	8.6
Pre vs Post			*	*	*
2011	50-100	Pre	17.3	16.7	11.7
		Post	8.4	6.8	5.8
2012		Pre	16.4	13.2	15.1
		Post	7.6	6.0	9.2
Pre vs Post			*	*	*
2011	250-300	Pre	14.5	18.9	8.0
		Post	8.1	7.1	8.0
2012		Pre	16.9	13.6	9.1
		Post	8.1	11.2	9.2
Pre vs Post			*	*	*

* = Significant difference between pre and post grazing (P value < 0.05)

Soil cultivation and crop establishment were effective in raising macroporosity values to approximately 15% v/v, thereby alleviating the potential restrictions for crop growth. However, soil structure reverted to a 'damaged' state when subsequently grazed during the following winter, when macroporosity decreased to approximately 6-9% v/v. This trend was apparent across all three soils (Fig 1) indicating a similar impact for these winter grazing practices.

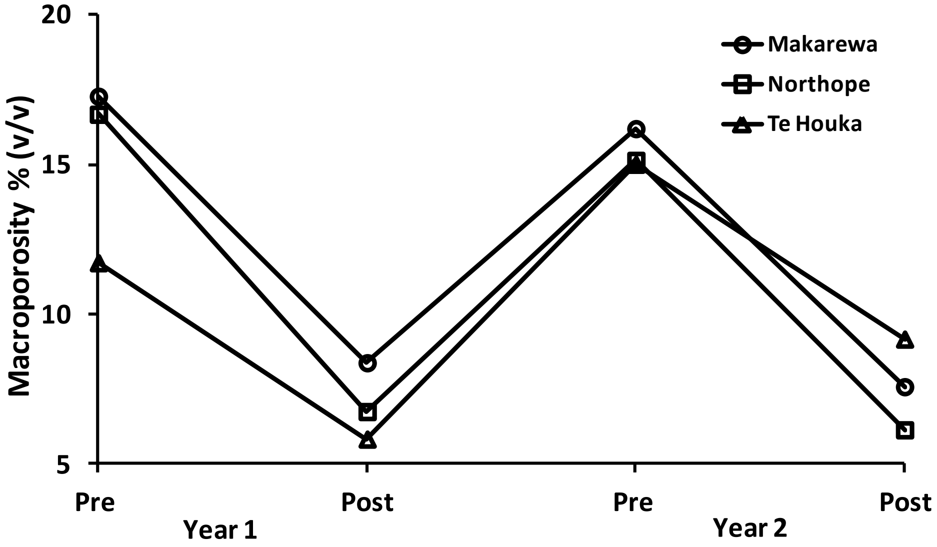

Figure 1. Changes in percentage macroporosity (v/v) in response to cultivation (pre grazing) and winter grazing (post grazing) in the 50-100 mm depth for the Makarewa, Northope and Te Houka soil types.

Results were also compared with those from similar studies using two alternative post winter grazing soil management techniques. These were:

1) Direct drill back into crop, no cultivation (Houlbrooke *et al*, 2009).
2) Aeration, then returned to seasonally-grazed pasture (Laurenson and Houlbrooke, 2012).

Both of these studies were conducted on a sheep and beef farm near Windsor, North Otago. The soil is characterised by a fragipan or Cx horizon with restricted drainage, and classified as a Mottled Fragic Pallic Soil by the New Zealand soil classification (Hewitt, 1998). Both trials were grazed during winter at similar stocking densities to those used in the study reported here.

In the first of these studies (Houlbrooke *et al*., 2009), crops were direct drilled between winter grazings (i.e. without cultivation). Irrigated and non-irrigated treatments with winter forage crops were typically grazed as a single intensive event in midwinter (approximately 3-4 days per event, animal densities averaged 350 cows/ha). This study reported a progressive decline in soil macroporosity over three consecutive years (Fig 2). In the second study, Laurenson and Houlbrooke (2012) used the irrigation plots from Houlbrooke *et al*. (2009) and mechanically loosened (aerated) one half of each plot to a depth of 200 mm using a wing-tipped aerator before direct drilling to pasture. Plots were grazed on an average 27 day rotation during the growing season for approximately 18 hours per event with a stock density of 550 cows/ha. Laurenson and Houlbrooke (2012) highlighted the effectiveness of mechanical aeration in improving macroporosity following winter grazing. However, they reported that the effect of this type of mechanical disturbance was short lived because of subsequent grazing pressure applied under pastoral land use when soil moisture content was high.

Mechanical aeration appears to play a role in improving the macroporosity of severely damaged soils. However, the duration of the aeration effect is dependent on the grazing intensity (stock numbers/ha) and the soil moisture at the time of grazing or the use. Tactical grazing management offers the opportunity to limit the damage when soils are wet by reducing the grazing intensity or duration of grazing events.

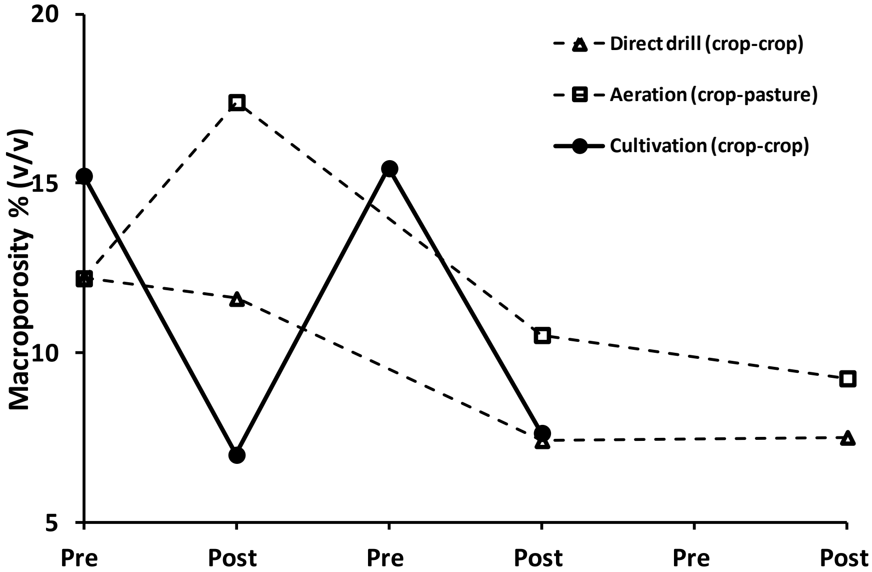

Figure 2. Changes in percentage macroporosity (v/v) in response to pre and post winter grazing at 50-100 mm for three soil management techniques. Data for direct drill (crop-crop) are from Houlbrooke *et al.* (2009) and the data for aeration (crop-pasture) are from Houlbrooke and Laurenson (2012). Cultivation (crop-crop) is from current research.

Soil macroporosity is expected to increase with time between mechanical disturbance and stock grazing because soil biological processes continue to improve soil aggregation (Celik *et al*, 2010). Soil conditions achieved through mechanical disturbance are likely to increase crop or pasture yields in the short term. However, loss of soil structure and poorer growing conditions are likely to occur with subsequent winter grazing. Therefore, it seems apparent that two key factors are important for alleviating the effects of soil compaction following winter grazing:

1. Alleviation of poor aeration and drainage
2. Restricting stock grazing on newly sown pastures, particularly when soil moisture contents are high.

Although mechanical disturbance (aeration or cultivation) can be effective in improving the macroporosity of soils that are severely damaged, it is unlikely to improve soil resistance to compaction from on-going treading damage caused during winter grazing. If grazed soon after mechanical disturbance, periods of high soil moisture should be avoided.

Summary

Mechanical loosening of soil via cultivation or aeration will aid biological processes that are important for helping to rejuvenate structurally damaged soils. Subsequent stock management, however, plays an important role in the longevity of these soil ameliorative measures. The results suggest there is no cumulative effect of the compaction and cultivation cycle in winter forage crops grazed by cows. On-going research aims to identify how long this cycle could continue before soil aggregation fails to recover from the pressures of winter grazing that result in prolonged periods of sub-optimal soil condition.

Acknowledgements

The authors would like to thank the technical staff involved. This project is part of the Southern Wintering Systems project co-funded by New Zealand dairy farmers through Dairy NZ Inc & MPI's Sustainable Farming Fund.

References

Betteridge, K., Mackay, A.D., Shephard, T.G., Barker, D.J., Budding, P.J., Devantier, B.P and Costall, D.A (1999) Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. *Australian Journal of Soil Research* 37: 743-760.

Celik, I., Gunal, H., Budak, M and Akpinar, C (2010) Effects of long-term organic and mineral fertilisers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions. *Geoderma* 160: 236-243

Drewry, J.J. and Paton, R.J (2000) Effects of cattle treading and natural amelioration on soil physical properties and pasture under dairy farming in Southland, New Zealand. *New Zealand Journal of Agricultural Research* 43: 337-386

Drewry, J.J and Paton, R.J (2005) Soil physical quality under cattle grazing of a winter fed brassica crop. *Australian Journal of Soil Research* 43: 525-531.

Drewry, J. J., Paton, R. J., Monaghan, R. M. (2004) Soil compaction and recovery cycle on a Southland dairy farm: implications for environmental monitoring. *Australian Journal of Soil Research 42*: 851–856.

Hewitt, A.E (1998) ‘New Zealand Soil Classification’ (Manaaki Whenua Press: Lincoln, New Zealand).

Hewitt, A.E and Shepherd, T.G (1997) Structural vulnerability of New Zealand soils *Australian Journal of Soil Research* 35: 461-474.

Houlbrooke, D.J., Paton, R.J., Morton, J.D, and 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

Karlen, D.L., Mausbach, M.J., Doran, J.W, Cline, R.J, Harris, R.F, Schuman, G.E (1997) Soil quality: a concept, definition, and framework for evaluation. *Soil Science Society of America Journal* 61: 4-10.

Laurenson, S. and Houlbrooke, D.J. (2012) The effect of soil aeration on the recovery of soil structure in the North Otago Rolling Downlands following winter grazing of sheep and cattle. Fertiliser and Lime Research Centre.

Sparling, G.P and Schipper, L.A (2002) Soil quality at a national scale in New Zealand. *Journal of Environmental Quality* 31: 1848-1857

Ward, G and Greenward, K (2002) Research and experiments in treading and wet soil management in Victoria. In 'Dairy farm soil management' (Eds LD Currie, P Loganathan) pp 47-59. (Fertiliser and Lime Research Centre: Massey University, Palmerston North, NZ)

Wright, S.F and Upadhyaya, A (1996) Extraction of An Abundant and Usual Protein From Soil and Comparison with Hyphal Protein of Arbuscular Mycorrhizal Fungi. *Soil Science* 161, 575-586