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September 1998
Soil Compaction
A direct consequence of dairy cattle treading

Diana J. Crawford

A dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Science with Honours in Geography
University of Otago, Dunedin, New Zealand

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Abstract

As New Zealand’s traditional sheep and beef farms are being increasingly converted to dairying it is important the soil does not become degraded and consequently unproductive. It is necessary to establish the effect dairy cattle treading is having on soil properties. This study set out to determine how much of an effect cattle treading is having on the soil, and to see if this effect varied locally. This was done through comparing untreaded areas under the fenceline to within paddock treaded areas.

Samples were taken from Mottled Fragic Pallic Soil underneath a dairy farm in Clydevale, South Otago to determine bulk density, gravimetric and volumetric water contents, macroporosity, total porosity and field measurements of penetration resistance.

Bulk density and gravimetric water content were the properties most affected by treading. Bulk density medians increased from 0.92 Mg m⁻³ in the untreaded areas to 1.05 Mg m⁻³ in the treaded areas (p = 0.0052) and gravimetric water content medians decreased from 56.2 % to 43.9 % (p = 0.0366). Significant changes in the level of compaction between paddocks were seen more through the comparison of the treaded and untreaded areas than by just comparing the treaded areas to each other.

These findings are in line with other research on cattle treading as they show the soil properties to be influenced by treading, thus indicating soil compaction is taking place. The level of soil compaction varies on a local scale, and thus demonstrates the importance farm management plays in controlling soil compaction.
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1.1. **Study Context**

The properties of a soil are important to farming as they can determine the level of productivity that can be gained from a piece of land. The compression of the soil by animal treading, or farm machinery can result in soil degradation if not managed properly. Degradation of the soil by treading can lead to the soil becoming compacted which occurs when the soil porosity is reduced and the density increased (Betteridge et al., 2003). This may result in root penetration, infiltration, and drainage being impeded (Hillel, 1998).

The detrimental consequences of soil compaction are widespread. When the roots of plants cannot penetrate the soil easily they can be deprived of nutrients and water found at depth (Daniel et al., 2002). A decrease in infiltration also results in plants not receiving the optimal amount of moisture, which then decreases their productivity by limiting growth. Decreased infiltration means that a high amount of runoff will take place, which ultimately ends up in local water-ways. This runoff will consist of not only water but also nutrients and effluent, thus decreasing the water quality of these water-ways.

Soil compaction can also lead to the other extreme, flooding of the soil. When the topsoil is denser, with fewer pores, excess moisture cannot drain to underlying soil layers. A decrease in drainage consequently leads to ponding of water in the topsoil which can effectively drown plants.
Introduction

The ultimate consequence of soil compaction for farmers is a loss of profits from the below optimal pasture productivity, but as these effects are indirect they are easy to overlook (Veseth, 1988). It is therefore important to study the effects of animal treading on different soil properties to ensure that compaction does not take place and lead to these unfavourable results.

Soil compaction under dairy pasture, with its related effects, is a problem that has become more prevalent in New Zealand in the last 15 years. This is because of the increased number of farm conversions from sheep and beef to dairy (Finlayson et al., 2002). Reasons for these conversions include reduced prices for meat and wool, and increased prices for dairy products. Increased irrigation schemes have also allowed for more pasture to be used for dairying (Drewry et al., 1999). In some of these conversion areas the suitability of the soils for dairy farming was not adequately assessed, and as a result treading has degraded the soil and caused compaction. For this reason an understanding of how cattle treading influences soil properties is important to possibly prevent the same mistake from occurring in another location.

1.2. Research Aim

From the above discussion it has become apparent that the issue of soil compaction is important to farming productivity. A study of the effects of dairy cattle treading is therefore warranted; to determine if soil compaction is occurring and if so by how much. Consequently the aim of this research is to determine the effects of dairy cattle treading on soil physical properties to establish if soil compaction is occurring.

1.3. Outline

In Chapter 2 a review of the literature on soil compaction resulting from animal treading is presented. The influences on different soil properties are outlined, along with how soil structure and soil type can influence the effect of treading. In addition
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the different ways researchers have tackled this issue are examined. From this
discussion research hypotheses were formed. Chapter 3 outlines the methodology
used to collect the data for this study, including the sampling plan and field and
laboratory methods. Chapter 4 presents the results found firstly from the treaded and
untreaded areas' comparison and from the comparison between paddocks. Chapter 5
discusses the findings from the results in relation to the two research hypotheses and
compares the findings to similar research. Chapter 5 also includes the implications of
the findings for farm management. Chapter 6 summarises the conclusions from this
study and suggests possible avenues for future research.
Chapter 2

Literature Review

2.1. Introduction

Soil compaction has been described by Hillel (1998 p 365) as when: 'the total porosity is so low as to restrict aeration; as well as when the soil is so tight, and its pores so small, as to impede root penetration, infiltration and drainage.' Soil compaction occurs when the large pores in the soil are compressed (Betteridge et al., 2003) and the soil is made denser, as the air in those pores has been expelled (Greenwood and McKenzie, 2001). This dense soil has closely packed aggregates and particles, and occurs when the forces on the soil are greater than the soil's strength (Otago Regional Council, 1996). Soil compaction can occur from natural processes, such as wetting and drying cycles, or freezing and thawing of the soil, and from human induced processes such as tilling of cropping soils (Hillel, 1998). Another significant cause of soil compaction is animal treading, in particular from dairy cattle.

Noted areas that are susceptible to compaction include locations with high water tables, clayey soils or intensive stocking regimes (Environment Waikato, 2004). In addition Mapfumo et al. (1999) consider soil texture, organic matter and water content to be determinants of how much compaction occurs. Therefore compaction levels vary between areas.
2.2. Soil Compaction from Cattle Treading

Cattle exert a static loading on the soil of up to 400 kPa (Betteridge et al., 1999), much more than sheep (50-125 kPa; Finlayson et al., 2002). This loading however can be increased further through movement, particularly on hill slopes. The dynamic load of the cattle beast from walking can be up to double that of when it is stationary (Finlayson et al., 2002), as the pressure is only exerted on two or three hooves at a time (Trimble and Mendel, 1995; Greenwood and McKenzie, 2001). On hilly slopes where the weight is distributed unevenly amongst the hooves, with most of the load being transferred to the tip of the hoof as the cow moves up or down the slope (Betteridge et al., 1999). This greater loading by the cattle results in more force being exerted onto the soil which can lead to greater compaction.

The distance to water and the quality of the pasture will determine the amount of treading that occurs (Greenwood and McKenzie, 2001). Pasture availability determines the amount of treading that takes place, as most treading occurs during grazing (Greenwood and McKenzie, 2001). If there is a lot of pasture available less treading will occur, as the animal will have to move less to find satisfactory amounts of food. However, the amount of treading that occurs within a paddock is not uniform and more treading damage occurs around feeding troughs than on the outskirts of a paddock (Mulholland and Fullen, 1991; Greenwood and McKenzie, 2001).

The impact of cattle treading also depends on the stocking regime (Singleton et al., 2000). If only a few cattle are in a paddock they are able to spread out over the area, so there will be less treading on each part of the paddock. However, if there are large numbers of cattle in a paddock at one time, each part of the paddock is treaded a higher number of times as the cattle cannot spread out (Drewry et al., 2000a). More treading leads to more soil compaction, so to minimise the amount of compaction that takes place, lower stocking densities should be used (Mulholland and Fullen, 1991). The length of time cattle are left in one paddock will also directly influence the amount of soil compaction, as a longer time in an area allows more treading to take place.
On a dairy farm stock densities are generally in the region of 2-3 cows ha\(^{-1}\), but in winter months this can increase to 300-600 cows ha\(^{-1}\) (Singleton et al., 2000), with the use of block grazing. With block grazing a paddock is fenced into sections and the cattle are only allowed to graze one section at a time (Burgess et al., 2000). This is to make the most of the pasture at a time when growth is not occurring. With these high stocking rates and generally high rainfall in winter the soil is particularly susceptible to structural degradation.

Compaction or pugging can affect the soil up to 20 cm in depth as the cattle hooves can sink into the ground (Burgess et al., 2000). Generally however, compaction effects tend to be shallow, in the soil top 10 cm (Mulholland and Fullen, 1991).

Treading damage can decrease pasture growth (Climo and Richardson, 1984; Hillel, 1998; Drewry and Paton, 2000b; Singleton et al., 2000). This can be through decreased foliage, plant burial, excretion, localised pugging and smearing of the soil surface (Drewry et al., 2001), or from more indirect effects such as decreased macroporosity and increased bulk density and soil strength (Drewry et al., 2001; Greenwood and McKenzie, 2001). Applying increased amounts of fertiliser to gain only average pasture growth and having good soil fertility, but not seeing the pasture results, are two indicators that soil compaction may be limiting pasture growth (Betteridge et al., 2003).

The effects of compaction, as a result of treading damage usually last for months. This can happen even after a single treading event (Betteridge et al., 2003). The rebound of the soil is usually greater under shorter duration stresses as the deformation that occurs is only temporary rather than permanent (Greenwood and McKenzie, 2001). However the rebound generally depends on the soil type, the extent of the compaction, and the climatic and biological agents acting (Greenwood and McKenzie, 2001).
2.3. Soil Structure

Soil structure is the arrangement of aggregates and pores in the soil, and is the result of destructive and regenerative forces competing against each other (Greenwood and McKenzie, 2001). The structure is the “architecture” of the soil; it determines the size, shape and stability of the soil (Haynes, 1995). The type of structure a soil has will determine its ability to withstand forces acting upon it (Haynes, 1995). The process of wetting and drying and the actions of earthworms help regenerate the soil but this is acting against the pressure exerted by grazing animals (Greenwood and McKenzie, 2001). Well structured soils have a large proportion of the soil volume occupied by pores and have a number of roots present. Poorly structured soils have a small aggregate size distribution with the aggregates packed together thus limiting the pore space (Otago Regional Council, 1996). Damage to the soil structure results in the soil being more susceptible to compaction (McDowell et al., 2003). Bulk density, total porosity, macroporosity, penetration resistance, soil aggregate size, air permeability, hydraulic conductivity and infiltration rate are all measures of soil structure and so determine the amount of compaction that will occur as a result of cattle treading (Nguyen et al., 1998; Singleton and Addison, 1999; Burgess et al., 2000; Drewry and Paton, 2000a and b; Greenwood and McKenzie, 2001).

2.4. Soil Properties

A number of measurements can be used to determine the degree of soil compaction. The most common measures are those indices of soil structure mentioned above. In addition to this, soil water content has frequently been used to determine compaction levels. The relevance of these factors to soil compaction and how they can be influenced by cattle treading is detailed in the following sections.

2.4.1. Total Porosity

This is the amount of pore space within the soil that can be filled either with water or air. It is the sum of both inter-aggregate pores: pores which are important for
Literature Review

infiltration, and intra-aggregate pores: pores that determine the post infiltration retention of water (Hillel, 1998). Compaction of the soil has shown to lead to a decrease in total porosity (Climo and Richardson, 1984; Nguyen et al., 1998; Singleton and Addison, 1999), particularly from decreases in air filled porosity (Greenwood and McKenzie, 2001). The pressure exerted by cattle compresses the soil, decreasing the pore space. Nguyen et al. (1998) found that as a result of cattle treading total porosity decreased from 71.2 % to 65.3 % on steep hill land. Singleton and Addison (1999) found that for a Gley Soil total porosity changed from 73 % in a never trodden area to 65 % in a trodden area.

2.4.2. Macroporosity

Macroporosity has been investigated in nearly all research on cattle treading and compaction. It has been used for research into subsoiling, aeration, stocking pressure, degree of compaction and relative yield. This soil property has been shown numerous times to decrease with dairy cattle treading (Drewry et al., 1999; Singleton and Addison, 1999; Drewry and Paton, 2000b; Di et al., 2001). Macroporosity has even been described by Drewry et al. (2001) as the sample indicator for soil compaction because it has shown the greatest relationship between the effects of treading and relative pasture yield.

Macropores are the largest pores in the soil and can occur from biological activity such as earthworms or decayed roots (Hillel, 1998). They are inter-aggregate pores and can act as barriers to water flow when empty, but when filled they can transmit rapid flow. In most research macropores are regarded as being greater than 30 μm (Nguyen et al., 1998; McDowell et al., 1999; Singleton et al., 2000).

Macroporosity is measured as a percentage of total volume and can be used to determine the health of a soil. The values depend on the soil type and the physical conditions, but are about 15-20 % in non-compactd, well structured soils (Drewry et al., 2001; Betteridge et al., 2003). For pasture growth to be not limited by the soil, macroporosity values should be above 10 %. Anything less than this can have detrimental effects on grass growth and relative pasture yield (Climo and Richardson, 1984; Drewry et al., 2001). For each 1 % increase in macroporosity the relative
spring pasture production in Waikato and Otago also increased by 1.8 % (Betteridge et al., 2003). Research has found that with treading macroporosity tends to decrease significantly in the top 10 cm (Drewry et al., 1999; 2001).

Both decreases in total porosity and macroporosity have been linked to impeding water movement within the soil (Nguyen et al., 1998). This is particularly relevant to macropores, as they have been described as the primary pathway for water movement within a wet soil (Beven 1980, cited in Drewry et al., 1999). The effect of treading on poorly drained soil has been shown by Greenwood and McNamara (1992) to go deeper than in well-drained soils. Since the effect goes deeper, it follows that the soil would take longer to revert back to an uncompacted state.

2.4.3. Bulk Density

Bulk density is the ratio of the mass of solids to the total volume of both soil and pores (Hillel, 1998). Bulk density can be used to quantify soil compaction, as the higher the bulk density, the smaller the available pore space, so the soil is more compact. Typical values vary for bulk density, as it depends on the packing of the soil, but for a sandy soil values range approximately between 1.85 Mg m⁻³ and 1.6 Mg m⁻³, for coarse fine silty soils the range is from 1.6 Mg m⁻³ to 1.3 Mg m⁻³, and clayey soils have even smaller values (Sumner, 2000).

Bulk density, in studies looking at treading damage, has tended to increase in areas of compaction, particularly in the 0-5 cm soil depth range. Studies have found that in treaded areas bulk density has increased from 1.18 Mg m⁻³ to 1.29 Mg m⁻³ (Di et al., 2001) and from 1.10 Mg m⁻³ to 1.25 Mg m⁻³ (Drewry et al., 2001). Bulk density has also been found to be greater with more intensive grazing regimes (Greenwood and McKenzie, 2001). Van Haveren (1983 cited in Greenwood and McKenzie, 2001) found that at high stocking densities, bulk density was higher in the fine textured soil than coarse. However, in general soils with high clay and organic matter contents have lower compacted bulk density values in comparison to other soils, so bulk density can depend on the soil properties (Mapfumo et al., 1999; Greenwood and McKenzie, 2001).
Literature Review

One study by Greenwood and McNamara (1992) goes against most other literature and suggests that bulk density is an insensitive measure of compaction. They state that bulk density measurements are insensitive to small changes in soil compactness and furthermore do not often relate well to plant or other soil physical responses to compaction.

2.4.4. Soil Aggregate Size

Aggregates form in soils with more than 15% clay content (Sumner, 2000). They consist of particles of sand, silt, clay and organic matter bound together (Otago Regional Council, 1996). Aggregates can range in size from the very tiny (< 2 mm), to medium (0.005-0.02 m), to > 0.1 m (Sumner, 2000). The distribution of aggregate sizes in a soil is a determinant of the soil's pore size, thus a measure of compaction (Hillel, 1998). Evidence of a compacted soil includes larger firmer aggregates with fewer roots and earthworm activity evident (Betteridge et al., 2003). Aggregate stability and diameter have been shown to increase with grazing (Greenwood and McKenzie, 2001).

2.4.5. Air Permeability

Air permeability is the convective path of air through the soil and is strongly dependent on pore size distribution (Hillel, 1998). If the pore size distribution decreases with compaction from treading, then the air permeability decreases also (Drewry et al., 2000a) particularly at the 0-5 cm depth. This was also found to be the case in research cited in Greenwood and McKenzie (2001). Drewry et al. (2001) noted air permeability to be very sensitive to changes not only by treading but by also earthworm movement and natural amelioration.

2.4.6. Penetration Resistance

Penetration resistance is the soil resistance to deformation and is correlated to root growth. It can be used to measure the strength of the soil. Penetration resistance can exceed 2 MPa with root growth only being limited by half, however if resistance is
more that 3 MPa then root growth will often be prevented (Sumner, 2000). Thus high penetration resistance values indicate soil compaction.

Animal treading has been shown to increase the penetration resistance of a soil, particularly at the 0-5 cm depth (Daniel et al., 2002). Mulholland and Fullen (1991) used penetration resistance to measure the amount of compaction taking place on loamy sands as a result of cattle treading. Their cone penetrometer readings showed a progressive increase with treading suggesting soil compaction.

2.4.7. Hydraulic Conductivity

Hydraulic conductivity has been used in many types of research relating to treading and compaction, in particular saturated hydraulic conductivity. McLaren and Cameron (1996) note that saturated hydraulic conductivity is an important measure of the drainage capacity of the soil. Research findings show that when the soil becomes compacted, as a result of treading, the hydraulic conductivity is decreased and the soil cannot conduct water so well (Willatt and Pullar, 1983; Drewry et al., 1999; 2001).

2.4.8. Soil Water Content

Soil water content can vary between soils as a result of changes in infiltration rates, runoff, pasture composition and growth (Greenwood and McKenzie, 2001). The amount of water within a soil is important not only for plant growth, but also because it can determine the amount of compaction that will occur in a soil. In dry soils, treading damage to the plants or the soil is unlikely to occur (Betteridge et al., 2003) as the particles are interlocked and there is frictional resistance to deformation (Hillel, 1998). However, small or medium amounts of soil moisture will allow compaction to occur (Burgess et al., 2000; Betteridge et al., 2003). When a soil is moist a small indentation of the hoof can take place, thus allowing compaction to occur (Betteridge et al., 2003). At high soil moisture levels, i.e. saturated or nearly saturated soil, plastic deformation (poaching or pugging) rather than compaction will occur (Climo and Richardson, 1984; Mulholland and Fullen, 1991; Burgess et al., 2000). This is because at high water contents the soil has lower soil strength (Greenwood and McKenzie, 2001).
Compaction has detrimental effects but plastic deformation can ruin the structure of the soil, so the risk of damage from treading is particularly high when the soil moisture is high (Di et al., 2001). With pugging and plastic deformation, the soil is not actually being compacted; rather it is being turned into slurry (Betteridge et al., 2003), and soil particles flow around the hoof (Greenwood and McKenzie, 2001). Repeated treading in wet soil increases the depth to which the soil is pugged (Mullins and Fraser, 1980 cited in Greenwood and McKenzie, 2001). However compaction can occur below this, in the area where the hoof penetration ends (> 5 cm; Betteridge et al., 2003).

2.4.9. Infiltration Rate

The infiltration rate of a soil has been shown to decrease in compacted soils (Trimble and Mendel, 1995; Drewry et al., 2001; Daniel et al., 2002). Infiltration rates in compacted soils can be decreased by 75-98.5 % in comparison to ungrazed soil (Greenwood and McKenzie, 2001; Mulholland and Fullen, 1991). Most of this reduction occurs after the initial compaction (Mulholland and Fullen, 1991). A consequence of this decrease is an increase in runoff which can lead to erosion of the topsoil (Daniel et al., 2002), thus resulting in a loss of nutrients. Heathwaite et al. (1990 cited in Mulholland and Fullen, 1991) found runoff was almost twelve times greater off heavily grazed pasture than off non grazed pasture. Decreased infiltration rates mean less water is available in the soil for plant uptake; therefore another consequence of reduced infiltration is below optimal pasture growth.

2.5. Approaches to Animal Treading

Two main approaches have been taken to investigate animal treading on soils. The most common approach is to physically measure in the field the amount of damage done to the soil as a result of treading. The second approach is to simulate the effects of treading in some way, and use this to estimate the actual damage done in the field by cattle. Within these two approaches various methods have been used and these will be outlined.
2.5.1. Field Studies

Two main methods have been used for this approach. Researchers have either compared different soil types to determine their susceptibility to treading or they have compared the same soil to various treading densities either with or without an untreaded control.

2.5.1.1. Comparison of different soils

Drewry et al. (2000a) conducted an experiment in Southland and South Otago, New Zealand which looked at the effects of treading on four different soil groups. They studied a number of different farms, both sheep and cattle, and at each farm they sampled one paddock that was typical of the management of the farm. In this study they avoided sampling gateways, trough areas and shelter belts as these areas were deemed unrepresentative of the paddock. Climo and Richardson (1984) also used three different soil types to study the effects of stock treading in the Manawatu, New Zealand. These soils had previously shown markedly different susceptibility to treading, as distinguished by discussions with the farmers and field observations.

2.5.1.2. Comparison of treading densities

Research that has incorporated a control area includes a paper published by McDowell et al. (2003) which looked at the influence of treading on sediment and phosphorus losses in overland flow on a property that had recently been converted to dairying in South Otago, New Zealand. Their control was an untreaded cultivated field and they compared this to a treaded grass area.

Singleton and Addison (1999), and Singleton et al. (2000) are examples of studies which used diverse soil types but also different levels of treading for experiments in Waikato alone (Singleton and Addison, 1999) and in combination with Northland (Singleton et al., 2000), New Zealand. In these studies a never trodden control was compared to areas of average treading and previously pugged sites. The control samples came from under the fencelines, average treading sites represented the normal paddock and pasture conditions as advised by the farmer, and the previously
pugged sites were areas that had been pugged 18 months before, again as determined by the farmer.

Studies by Daniel et al. (2002) and Mulholland and Fullen (1991) are examples of different treading density comparisons which did not use an untreaded control. Daniel et al. (2002) looked at different stocking densities in Oklahoma, USA. They compared 12.5, 25 and 50 cows' ha\(^{-1}\) in a long-term study that used rotational grazing. Mulholland and Fullen (1991) used the idea that three distinct zones of treading arise as a result of feeding patterns to undertake a treading experiment in East Shropshire, England. They determined zone 1 to be around the feeding trough and experience the heaviest treading, zone 2 was established to stretch from the border of zone 1 to the outskirts of the paddock and receive moderate treading. Zone 3 therefore was the rest of the paddock and experienced the least amount of treading.

Studies by Mapfumo et al. (1999) and Nguyen et al. (1998) also measure the severity of treading from different stock densities, but combine this with an additional factor: the research undertaken by Mapfumo et al. (1999) compared different levels of treading to annual and perennial forages in Alberta, Canada. The different levels of treading were light, medium and heavy, and were identified using foliage. The impact of cattle treading on soil physical properties and contaminant runoff was studied by Nguyen et al. (1998) in Hamilton, New Zealand. Their comparison used different hill areas; between animal track areas, easily contoured ridges and steep inter-track areas.

2.5.2. Mechanical Simulation

Di et al. (2001) approached the study of animal treading by using a mechanical cow hoof device to simulate treading. This approach was chosen because of the difficulty to assess the effects of treading using live animals under controlled conditions when the field plots are small or when instruments have to be installed. In using the hoof all the parameters can be controlled and measured. Di et al. (2001) compared an untreaded control with areas treaded both once and twice by the mechanical hoof. Drewry et al. (2001) also used this mechanical hoof to study the effects of treading on ryegrass pasture yield. They compared an untreaded control with areas treaded after every second dry matter harvest, and areas treaded after every harvest.
2.6. Overall Research Findings

Much of the research published recently on animal treading has shown detrimental effects on soil physical properties. Both total and macroporosities decrease as a result of treading and in accordance to this, bulk density increases from treading. Soil aggregate size and stability increased with treading from grazing, as does penetration resistance. In addition both air permeability and hydraulic conductivity are decreased by treading. The amount of water in the soil has been shown to determine the amount of compaction that will occur. The magnitude of compaction also depends on the soil type and the treading event (Di et al., 2001) but the general trend is for the effects to occur in the top 10 cm of the soil and to be only significantly in the top 5 cm (Drewry et al., 1999; 2001).

Willatt and Pullar (1984) reported that soil compaction from grazing limits grass growth. Finlayson et al. (2002) also found reduced plant growth from treading stemming from reduced macroporosity and impaired drainage which in turn results in oxygen diffusion being lowered. Drewry et al. (2001) found that relative yield decreased by up to 8.8% with treading damage.

2.7. Soil Compaction in Otago

Soil compaction has become a more prevalent problem in New Zealand and in Otago as a result of increasing dairy farm conversions. The amount of compaction that occurs relates to the type of soil beneath the dairy farm (Di et al., 2001), with some soils being much more susceptible to cattle treading than others.

Hewitt and Shepherd (1997) have established a structural vulnerability index of the soils in New Zealand. This vulnerability is the ability of the soil structure to cope with stress. This structural vulnerability index is made up from four factors: phosphate retention, total organic carbon content, clay content and wetness (Hewitt
and Shepherd, 1997). The less structural vulnerability a soil has the lower its index number is.

It is therefore important that dairy farming takes place on the right type of soil; otherwise severe compaction could easily result. The Otago Regional Council and AgResearch at Invermay, Mosgiel have been undertaking research to investigate the detrimental effects of dairy cattle treading in the Otago region. One area that is experiencing soil compaction problems from conversions to dairying is Clydevale, South Otago.

The area around Clydevale, South Otago has recently, within the last 5-10 years, seen a large conversion from traditional sheep and beef farming to dairying. This was around the time dairy farmers were receiving large payouts for their milk. However since converting, many farmers have discovered that their soil is not well suited to dairying. They have experienced issues with soil compaction, and related diminishing optimal pasture growth.

The soil in this region is classified as a Mottled Fragic Pallic Soil, which is a subgroup of Pallic Soils (Bruce, 1984). On Hewitt and Shepherd’s (1997) structural vulnerability index Fragic Pallic Soils are given an index of 0.69 under the high category. This means Fragic Pallic Soils are less resistant to compaction, particularly after significant rainfall. These soils have a reputation for being structurally unstable with low porosity values and a high bulk density which is usually above 1.45 Mg m\textsuperscript{-3} (Bruce, 1984).

Pallic Soils have a compact and blocky structure with the subsoils being heavier than the topsoils as there is usually a fragipan at about 25-60 cm depth (Bruce, 1984). A fragipan is a structure of densely packed granular sediments that has become hard to the extent that it exhibits rocklike properties which are almost impenetrable (Hillel, 1998). Other characteristics of Pallic Soils include slow permeability and usually a perched water table as the soil is only poorly to moderately well drained (Hewitt, 1993).
Pallic Soils usually occur in areas with droughty summers and wetter winters, which results in the soil having water deficits in summer and surpluses in winter (Hewitt, 1993). In addition Pallic Soils have a structure that has the potential for breakdown with continual impact (Hewitt, 1993). These features mean that under a dairy farm Pallic Soils would not be ideal as they have many properties that could lead to easy compaction.

Treading studies done on Pallic Soils have shown a reduction in both hydraulic conductivity and macroporosity with depth and an increase in bulk density with depth (Drewry et al., 1999). This is in accordance with Hewitt (1993) who reported a natural increase in density with depth in Pallic Soils.

2.8. Research Hypotheses

Since Pallic Soils have many characteristics that make them susceptible to soil compaction, dairy farming on this type of soil could lead to undesirable consequences. The aim established in Chapter 1 was to determine the effects of dairy cattle treading on soil physical properties to establish if soil compaction is occurring. As a result of the literature reviewed above this can be narrowed down to establishing the effects of cattle treading in an area that is known to experience soil compaction problems as a result of the region’s soil type. Further to this aim, research hypotheses have been formulated to address specific issues.

Hypothesis 1: That dairy cattle treading has lead to the alteration of a Pallic Soil’s physical properties, resulting in soil compaction

Hypothesis 2: That the level of soil compaction varies on a local scale.
Chapter 3

Methodology

3.1. Research Design

This study aimed to compare the difference between treaded and untreaded soils, and also to determine the difference between two paddocks. This was done by evaluating two paddocks which were thought to have different levels of compaction. The treaded areas of the paddocks were compared to each other and to a control of untreaded pasture, which was taken from under the fenceline. This approach used one soil type to compare the effects of treading to a control area. The use of two paddocks allowed the differences in compaction on a local scale to be assessed.

3.2. Site Characteristics

The study was conducted in the region of Clydevale, South Otago. Clydevale is situated 25 kilometres Northwest of Balclutha. The climate of the general Balclutha area is moderate with an average temperature of 14.3°C in summer and 5.6°C in winter (McIntosh, 1992). The Clydevale area has an annual rainfall of approximately 830 mm. Seasonally the area receives more rainfall in the summer than the winter, but the soil is characterised by water deficits in summer and surpluses in winter. At the time of sampling (May, 2004) the area was receiving higher than average rainfall (Otago Regional Council and Environment Southland, 2004).

The property where the field research was undertaken is on the Clinton-Clydevale Road (5450750N and 2239350E), and is approximately 60 metres above sea level.
Methodology

(Figure 3.1). The property was previously a sheep farm but the present owners converted it to dairying five years ago. Their herd size is 480 Friesian cows and they operate on a rotational basis for grazing (Figure 3.2). Depending on the time of year the cows are in a paddock for a period of 24-36 hours.

The soil on the farm is a Kockoe soil, part of the Clydevale Soil type which is a Mottled Fragic Pallic Soil (Bruce, 1984). Fragic Pallic Soils have water deficits in summer and surpluses in winter or spring. They are characterised by their pale colours, high slaking potential and high density (McLaren and Cameron, 1996). The Clydevale soils have developed on a deep sandy loam, textured loess and colluvium. The profiles for this soil tend to be slightly mottled and gleyed and are located over a weakly developed fragipan that is positioned at about 50-70 cm depth (Bruce, 1984).

![Figure 3.1: Map of field site location (Topographic Map 260 G45 Tapanui, 1998).](image-url)
Soil properties of two paddocks were investigated. Paddocks that had no or minimal cattle present during, or recently before sampling, were preferred as the cattle could get in the way of sampling. The paddocks chosen were paddock 7 and paddock 11 (Figure 3.2) which are located within 500 metres of each other. On initial inspection they appeared very similar (Figures 3.3 and 3.4), but these two paddocks had, in the farmer’s opinion, shown different levels of treading damage. Paddock 11 showed the greatest indication of soil compaction, while paddock 7 did not appear as badly affected.
Methodology

**Figure 3.3** Paddock 7 looking West, from the race at the eastern end of the paddock as seen in Figure 3.2.

**Figure 3.4** Paddock 11 facing East, looking towards the race at the eastern end of the paddock. The northern edge of the paddock is located in front of the stream.

Both paddocks were of similar size, with paddock 11 being approximately 4.8 hectares and paddock 7, 4.1 hectares. Paddock 11 was sown in the beginning of 2002 with Sanston and Supreme Grass, and showed some bare patches in the grass cover (Figure 3.5). This paddock has the history of back to back grass regimes. Paddock 7 however was last sown in the spring of 2000 with Tolusa Grass, and before that it had
Methodology

been cultivated for two years with swedes. On examination this paddock showed few obvious bare patches (Figure 3.6).

Figure 3.5 Grass cover in paddock 11.

Figure 3.6 Grass cover in paddock 7.
Methodology

3.3. Sampling

A stratified random sampling plan was devised to collect the samples. The paddocks were stratified into treaded and untreaded areas and it was decided that double the number of samples would be taken from the treaded areas, in comparison to the untreaded areas, as they represented a much larger area. The untreaded areas were taken 50 cm either side of the fenceline, and the rest of the paddock was determined to be treaded. The areas under the fenceline would have been in grass since the fenceline was put in, as they are close enough to the fenceline not to have been worked up with the rest of the paddock.

To locate the sample sites, the North-eastern corner was chosen as the starting point and the fence posts in the paddock were used as measures of distance around the paddock. Random numbers, from Eton Statistical and Math Tables (Anon, 1980) were used to determine firstly the number fence post the site would be taken at, then the distance to the left of this post (when facing towards the centre of the paddock), and finally the distance into the paddock the sample would be taken at. Walking strides were used as measures of distance. Both paddocks were divided into quarters so that the entire paddock had an equal chance of being sampled. This meant if a random number was larger than the distance to the middle of the paddock it was discarded.

At each site cores were taken to determine bulk density, soil water content, macroporosity and total porosity. Penetration resistance readings were also taken. These soil properties were used as their field collection was relatively easy to undertake and from the literature review they had been found to be good measures of compaction.
Methodology

3.4. In Field Methods

All of the soil properties, except penetration resistance, were collected following methods set out in Rowell (1994). Penetration resistance methods were based on Bradford (1986). Sampling took place on the 11th of May, 2004.

3.4.1. Bulk Density / Soil Water Contents

The soil water content was determined using the gravimetric method as the calculation of bulk density required the use of dried cores. It is recognised that this method is limited by the definition of a 'dry' soil, however on a reconnaissance trip a TDR had been used and was found to be slow and complicated to work, so the gravimetric method was used.

A bulk density sampler was used to obtain a soil core for determination of both the bulk density of the soil and the water content. The corer was gently hammered into the soil to avoid any disturbance. A wire trimmer or a sharp knife was then used to trim the soil core so that the soil was flush with the ring. The sampler held two adjacent rings each with a depth of 3 cm and a radius of 2.7 cm. The ring used for bulk density and soil water content analysis took a soil core from 2-5 cm in depth. The core was placed in an air tight metal container to prevent changes in water content occurring during transportation back to the laboratory.

This method although simple to undertake had some limitations. The cores sometimes contained twigs or pebbles, thus disrupting the core. If this was observed in the field the sample was discarded and another sample was collected. The small corer size can be problematic, in that it can overestimate bulk density resulting from the operator being inclined to avoid cracks and channels (Rowell, 1994). Another limitation to this method was that the depth of the cores could not be changed. Research has shown that bulk density increases (Drewry et al., 1999) with depth, but this corer only went to a depth of 8 cm. Despite these limitations, this method was determined to be the best suited for this study.
3.4.2. Macroporosity / Total Porosity

The soil core used for macroporosity analysis was from 5-8 cm below the ground surface (immediately below the bulk density/water content core). The soil was extracted from the corer then cut so that it had a smooth surface at either end of the ring. A ceramic base was placed on the bottom of the core and a numbered plastic lid on the top, which was secured with a rubber band. This was to ensure none of the soil was lost between the field and the laboratory. The sealed core was then placed in an airtight metal container.

3.4.3. Penetration Resistance

A pocket penetrometer was used to measure penetration resistance. This type of penetrometer was preferred over the large cone penetrometer because of the ease and efficiency of data collection. It has been noted however, that pocket penetrometers are usually supplemental to other penetrability methods (Bradford, 1986).

Penetration measurements were taken by applying a constant force onto the penetrometer until it was inserted in the soil to the 6 mm line. The stronger spring was used in the penetrometer as some areas were expected to provide values too large for the weaker spring. At each site where soil cores were taken, five penetration resistance readings were recorded. These readings were taken from a circle with a 10 cm radius around the soil corer hole. Readings were taken by recording the number of lines the measuring plastic ring had been pushed past. The five readings at each site were then combined to get an average penetration resistance for each site.

The penetration readings were converted to penetration resistance using the NZ Soil Bureau guidelines. As the strong spring was used penetration resistance (bar) = scale reading x 1.43 (spring factor) 1 bar = 100 kN/m².

3.4.4. Soil Characteristics

A soil core with a 2 cm diameter and a 30 cm depth was taken from each paddock, to determine soil colour, texture and structure characteristics.
Methodology

3.5. Laboratory Methods

3.5.1. Gravimetric Water Content

The gravimetric method was calculated using the following formula (McLaren and Cameron, 1996). The samples were first weighed and then placed in an oven set at 105°C for 24 hours. After 24 hours the samples were reweighed to find their dry weight.

\[
W = \frac{w - d}{d - \text{container}}
\]  

(3.1)

Where: 
- \( W \) is water content
- \( w \) is wet weight of the soil plus container
- \( d \) is the dry weight of the soil plus the container

3.5.2. Bulk Density

The bulk density of the cores was calculated using the following formula once the soils had been dried:

\[
\rho_b = \frac{d}{V_r}
\]

(3.2)

Where: 
- \( \rho_b \) is bulk density
- \( d \) is the dry weight of the sample (minus the container weight)
- \( V_r \) is the volume of the sample

The volume of the brass ring was 68.7 (1 dp) cm\(^3\).
Methodology

3.5.3. Volumetric Water Content

Once the gravimetric water content and the bulk density were calculated the volumetric water content could be computed using the formula:

\[ \theta = W \times \frac{\rho_b}{\rho_w} \]  

(3.3)

Where: \( \rho_w \) is the density of water, which can be assumed as 1.0 when working in grammes per cubic centimetre density units (Murray, 2000).

3.5.4. Macroporosity and Total Porosity

Macroporosity in this study is defined as pores larger than 30 \( \mu \)m. The macroporosity of these samples was determined using tension tables (Dane and Hopmans, 2002). This process is effective as a large number of samples can be analysed at the same time, but the process is time consuming as the samples have to become saturated before suction can even be applied. In addition regular checks have to be made on the equipment during suction to ensure the suction level is correct.

The samples were placed on a piece of filter paper. The top plastic covering was left on to prevent evaporation and contamination. The samples were then placed on a porous pressure plate in a water bath and water was added to flood the pressure plates until just beneath the top of the samples. The samples were left for 96 hours to saturate, during which time the samples and the water baths were covered by plastic to prevent evaporation.

Once the samples had reached saturation they were weighed, including the brass ring, plastic disk and wet filter paper. This saturation weight represented zero soil water suction. This value was then put into equation 3.3 to obtain the volumetric water content at zero suction \( (\theta_0) \). Suction was then established to 100 cm (-10 kPa). The cores were left under suction for 48 hours. This time allowed the 100 cm of suction to drain all the macropores. The cores were weighed again and the volumetric water content at -10 kPa \( (\theta_{100}) \) was calculated, by once again slotting the weight at 100 cm suction into equation 3.3.
Methodology

The difference between $\theta_0$ and $\theta_{100}$ is the macroporosity as a percentage of total porosity. This is because volumetric water content is directly comparable to porosities expressed in the same unit (Rowell, 1994).

The total porosity calculation was:

$$n = \frac{\text{saturated weight} - \text{dry weight}}{\text{volume}}$$  \hspace{1cm} (3.4)

Where: $n$ is total porosity

The formula used for calculating macroporosity was set out by Murray (2000):

$$M = \frac{\theta_0 - \theta_{100}}{n}$$  \hspace{1cm} (3.5)

Where: $M$ is macroporosity

3.5.5. Soil Characteristics

The soil colour was noted using a standard Munsell Soil Colour Chart. The texture of the soil was determined using the procedure set out by MacKenzie (2001). The soil was wet and then placed into a particular class by the feel, sound, cohesion and plasticity. To establish the structure, soil from both paddocks was broken down and the methods set out in Smith (2003) were followed.

3.6. Data Analysis

The data in this study were analysed using the statistical package Minitab (version 12). Firstly basic descriptive statistics were generated for each soil property. Graphs were generated that showed the Inter Quartile Range (IQR) which is a measure of spread that includes the median and central tendency.
Methodology

Normal distribution plots were used to determine that non-parametric statistics would be appropriate as the samples appeared to be taken from non-normal populations. As a result the Mann-Whitney statistical test was used to test for a difference between the sample populations.
Chapter 4

Results

4.1. Overview of Findings

In general the results show that some soil properties are more influenced by dairy cattle treading than others. Gravimetric water content, bulk density, macroporosity and total porosity all showed treading effects, particularly for paddock 11. In this section the soil characteristics are dealt with first. This is followed by the results of the different soil properties both from the contrast of the untreaded and treaded areas, and the comparison between paddocks.

4.2. Soil Characteristics

The soils of this region are Mottled Fragic Pallic Soils. In paddock 7 the soil was very dark greyish brown from 0-30 cm. Paddock 11 was also very dark greyish brown in the top 15 cm but in the bottom 15 cm, the soil colour was light olive brown with dark greyish brown mottles. Soils from both paddocks had silty clay loam textures. This means that they contain approximately 60% silt, 30% clay and 10% sand. Both sets of soils had a crumb like structure, which is characteristic of A horizons.
Results

4.3. Soil Properties

4.3.1. Gravimetric Water Content

Generally the treaded areas had lower gravimetric water content values than the untreaded areas. The median (56.2 %) value for the untreaded sites was high compared to the treaded sites which had a median more than 12 % lower (43.9 %, Table 4.1). The untreaded sites had the largest IQR and overall range (Figure 4.1), but the highest value for gravimetric water content recorded 63.6 %, came from a treaded site. The medians of the treaded and untreaded areas were statistically different (p = 0.0366).

Splitting and comparing the treaded values for each paddock with the total untreaded values, the Mann-Whitney test revealed that there was a significant difference between the treaded and untreaded areas in paddock 11 but not in paddock 7 (Table 4.1). Comparing the results of the treaded areas of paddock 7 to paddock 11 in terms of gravimetric water content showed that paddock 7 had a larger range of percentage water contents and a higher median value (Table 4.1). However the difference between the two medians was not enough to make them statistically different (p = 0.2730).

4.3.2. Volumetric Water Content

Comparing the total treaded values to the untreaded, most of the descriptive statistics were slightly lower for the treaded values (Table 4.1). Both the treaded and untreaded data sets were characterised by an extreme lower value. It was unsure why these occurred so the values were kept in the analysis. The median for the untreaded sites (48.1 %) was higher than the median from the treaded values (45.9 %) but they were not statistically different (p = 0.2619). Breaking this down to comparing each paddock’s treaded areas to the total untreaded area yielded no significant differences (Table 4.1).
Table 4.1 Descriptive statistics of soil properties including Mann-Whitney p values for comparisons of treaded versus untreaded areas, paddocks 7 versus 11 and total untreaded area compared to the treaded areas of each paddock.

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Sample Number</th>
<th>Treaded / Untreaded</th>
<th>Median</th>
<th>IQR</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P value</th>
<th>P value total untreaded vs. paddock treaded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravimetric Water Content (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreaded</td>
<td>20</td>
<td>Treaded</td>
<td>43.9</td>
<td>12.4</td>
<td>27.7</td>
<td>63.6</td>
<td>0.0366</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 7</td>
<td>46.2</td>
<td>13.8</td>
<td>27.7</td>
<td>63.6</td>
<td>0.2730</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 11</td>
<td>42.9</td>
<td>11.8</td>
<td>32.0</td>
<td>46.3</td>
<td>0.6129</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 7</td>
<td>46.4</td>
<td>5.7</td>
<td>20.6</td>
<td>54.3</td>
<td>0.9698</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 11</td>
<td>45.5</td>
<td>4.7</td>
<td>41.8</td>
<td>48.2</td>
<td>0.5235</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Volumetric Water Content (%)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreaded</td>
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<td>Treaded</td>
<td>45.9</td>
<td>4.9</td>
<td>20.6</td>
<td>54.3</td>
<td>0.2619</td>
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<td>Paddock 7</td>
<td>48.1</td>
<td>9.7</td>
<td>17.6</td>
<td>56.1</td>
<td>0.0312</td>
<td>Paddock 11</td>
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<tr>
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<td>Paddock 7</td>
<td>46.4</td>
<td>5.7</td>
<td>20.6</td>
<td>54.3</td>
<td>0.0366</td>
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<td>Untreaded</td>
<td>10</td>
<td>Paddock 11</td>
<td>45.5</td>
<td>4.7</td>
<td>41.8</td>
<td>48.2</td>
<td>0.2730</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Bulk Density (Mg m⁻³)</td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Untreaded</td>
<td>20</td>
<td>Treaded</td>
<td>1.05</td>
<td>0.22</td>
<td>0.74</td>
<td>1.36</td>
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<td>Untreaded</td>
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<td>0.92</td>
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<td>0.77</td>
<td>1.16</td>
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<td>Untreaded</td>
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<td>Paddock 7</td>
<td>0.98</td>
<td>0.16</td>
<td>0.74</td>
<td>1.23</td>
<td>0.0140</td>
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</tr>
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<td>10</td>
<td>Paddock 11</td>
<td>1.07</td>
<td>0.24</td>
<td>1.03</td>
<td>1.36</td>
<td>0.0140</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Penetration Resistance (kPa)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreaded</td>
<td>20</td>
<td>Treaded</td>
<td>322</td>
<td>379</td>
<td>114</td>
<td>1430</td>
<td>0.5235</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
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<td>Paddock 7</td>
<td>322</td>
<td>551</td>
<td>114</td>
<td>1258</td>
<td>0.9698</td>
<td>Paddock 11</td>
</tr>
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<td>Untreaded</td>
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<td>Paddock 11</td>
<td>369</td>
<td>369</td>
<td>186</td>
<td>1430</td>
<td>0.5205</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 7</td>
<td>369</td>
<td>551</td>
<td>114</td>
<td>1258</td>
<td>0.5205</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 11</td>
<td>369</td>
<td>369</td>
<td>186</td>
<td>1430</td>
<td>0.5205</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Macroporosity (% vol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreaded</td>
<td>20</td>
<td>Treaded</td>
<td>15.1</td>
<td>6.3</td>
<td>9.0</td>
<td>50.8</td>
<td>0.1083</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 7</td>
<td>18.2</td>
<td>4.7</td>
<td>16.7</td>
<td>24.9</td>
<td>0.1620</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 7</td>
<td>18.4</td>
<td>7.3</td>
<td>11.2</td>
<td>31.9</td>
<td>0.1083</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 11</td>
<td>17.7</td>
<td>2.9</td>
<td>9.0</td>
<td>50.8</td>
<td>0.1620</td>
<td>Paddock 11</td>
</tr>
<tr>
<td>Total Porosity (% vol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreaded</td>
<td>20</td>
<td>Treaded</td>
<td>76.6</td>
<td>17.1</td>
<td>38.3</td>
<td>88.9</td>
<td>0.6129</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 7</td>
<td>77.6</td>
<td>17.1</td>
<td>38.3</td>
<td>88.9</td>
<td>0.6129</td>
<td>Paddock 7</td>
</tr>
<tr>
<td>Untreaded</td>
<td>10</td>
<td>Paddock 11</td>
<td>77.0</td>
<td>12.7</td>
<td>57.3</td>
<td>85.3</td>
<td>0.6129</td>
<td>Paddock 11</td>
</tr>
</tbody>
</table>
Both paddock’s treaded areas had similar volumetric water contents. The IQRs were within 1% of each other but the median volume water content was slightly higher for paddock 7 than 11. Paddock 7 had a high upper limit and also had the presence of a lower outlier that had a very small volumetric water content of 20.6%. From the Mann-Whitney statistical test it was determined that paddock 7 and 11 were not significantly different as the p value was notably more than the 0.05% level of significance (Table 4.1).

![Box plots](image)

**Figure 4.1** Boxplots of a) gravimetric water content for treaded vs. untreaded data; b) gravimetric water content for paddocks 7 vs. 11 treaded areas; c) volumetric water content for treaded vs. untreaded data and d) volumetric water content for paddocks 7 vs. 11 treaded areas. The box represents the median with the 25th and 75th percentiles, the whiskers are the 10th and 90th percentiles and outliers are asterisks.
4.3.3. Bulk Density

Bulk densities for the total treaded sites were generally higher than from the total untreaded sites (Table 4.1, Figure 4.2). Comparing the medians of the treaded and untreaded data sets (1.05 and 0.92 Mg m$^{-3}$) the Mann-Whitney test determined there was a significant difference ($p = 0.0052$).

The treaded sites had the largest range of values (0.74 to 1.36 Mg m$^{-3}$, Figure 4.2). The IQR for the untreaded sites was lower than for the treaded sites, along with the 90th percentile which was quite a bit lower for the untreaded sites. When this was broken down to the differences between the total untreaded area and the treaded areas for each paddock, statistical testing revealed that this difference held only for paddock 11 (Table 4.1).

The results showed that the treaded areas in paddock 7 and in paddock 11 have different data distributions. In general the bulk density values from paddock 7 were lower than in paddock 11, particularly in terms of the inter-quartile ranges and lower limits. Paddock 7 had a lower limit of around 0.75 Mg m$^{-3}$ whereas paddock 11's lower limit was much higher (1.00 Mg m$^{-3}$, Figure 4.2). The median value for paddock 7 was 0.98 Mg m$^{-3}$ and for paddock 11 it was 1.07 Mg m$^{-3}$, statistically these values were significantly different ($p = 0.0140$).

4.3.4. Penetration Resistance

The results from the penetration resistance data demonstrated that there was a wide range of values from both the untreaded and treaded samples (Figure 4.2). The majority of the values were 500 kPa or under. The extreme value of 2545 kPa for the untreaded area may have been a calculation error, but as this was unsure the value was retained in the analysis. There appeared to be no real trends in penetration resistance between the treaded and untreaded areas. The $p$ value from the Mann-Whitney test (0.5235) concluded that there was no significant difference between the medians of the two data sets. Even when these values were separated into the different paddocks, no significant difference was shown between treaded and untreaded areas (Table 4.1).
In comparing the effects of treading between paddocks, paddock 7 had a greater interquartile range and more extreme upper and lower limits than paddock 11 (Figure 4.2). Paddock 11 also had a maximum value of 1430 kPa which was an extreme outlier and not representative of the sampled population. The median values of both paddocks, according to the Mann-Whitney statistical test were not significantly different (p = 0.9698).

![Boxplot](image)

**Figure 4.2** Boxplots of a) bulk density for treaded vs. untreaded data; b) bulk density for paddocks 7 vs. 11 treaded areas; c) penetration resistance for treaded vs. untreaded data and d) penetration resistance for paddocks 7 vs. 11 treaded areas. The box represents the median with the 25th and 75th percentiles, the whiskers are the 10th and 90th percentiles and outliers are asterisks.
4.3.5. Macroporosity

In general the total treaded sites had lower values of macroporosity than the untreaded sites. However a sample from the treaded sites gave a result of 50.8 % volume macroporosity, which was 20 % higher than any other value and 35 % higher than the median (15.1 %) for the treaded sites. The reason for this extreme value was unknown so the sample was retained in the analysis. The minimum value for the treaded sites (9 %) was significantly lower than the minimum value for the untreaded (16.7 %, Figure 4.3). The median macroporosity values for the treaded and untreaded areas were 15.1 % and 18.2 % respectively (Table 4.1) but they were not significantly different (p value = 0.1083). When the treaded areas in each paddock were compared to the total untreaded area there was a significant difference in paddock 11 (p = 0.0140).

Comparing the differences in macroporosity between just the treaded areas of paddock 7 and paddock 11, the results revealed that the inter-quartile range of paddock 7 was a lot larger and contained mostly values higher than in paddock 11’s inter-quartile range (Table 4.1). Paddock 11 had an extremely high outlier value as is shown in Figure 4.3, and this paddock also had a lower outlier value. The median macroporosity value for paddock 7 was 18.4 % whereas the median value for paddock 11 was 14.4 % but they were not significantly different (p = 0.1620).

4.3.6. Total Porosity

The results of total porosity did not show a clear reduction in the total treaded areas in comparison to the total untreaded areas. The treaded samples had values over a large scale, ranging from 38.3 % to 88.9 %. The range for the untreaded area was smaller (57.3 % to 85.3 %; Figure 4.3). The median values were similar (76.6 % and 77.0 %) so there was no significant difference (p = 0.6129). When the treaded areas of each paddock were separately compared to the total untreaded area a significant difference was seen in paddock 11 (p = 0.0321).

In relation to the difference in the level of treading between paddocks, paddock 7 and paddock 11 had similar 10th to 90th percentile ranges (Figure 4.3), but paddock 7 had a
higher IQR than paddock 11. The minimum value for paddock 7 (38.3 %) was quite a bit lower than the minimum for paddock 11 (52.0 %). Comparing the median total porosity values for the treaded areas (78.2 % and 71.3 %) found that statistically, they were not significantly different ($p = 0.1859$).

![Box plots](image)

Figure 4.3 Boxplots of a) macroporosity for treaded vs. untreaded data; b) macroporosity for paddocks 7 vs. 11 treaded areas; c) total porosity for treaded vs. untreaded data and d) total porosity for paddocks 7 vs. 11 treaded areas. The box represents the median with the $25^{th}$ and $75^{th}$ percentiles, the whiskers are the $10^{th}$ and $90^{th}$ percentiles and outliers are asterisks.
5.1. Introduction

The purpose of this research was to determine if dairy cattle treading has been affecting the soil’s physical properties and resulting in compaction. This chapter discusses the results in relation to the two hypotheses (Section 5.2). The implications of these results for farm management are also examined (Section 5.3).

5.2. The Effects of Dairy Cattle Treading on Physical Properties of Soil

5.2.1. Bulk Density

Bulk density was the one property that showed a significant difference between all sets of comparisons which suggests that in this region bulk density is the soil property most sensitive to treading by dairy cattle.

Treading was found to have had a more severe impact on the bulk density of paddock 11’s soil, than paddock 7’s, when comparing the total untreaded values of bulk density to each paddock’s treaded values. This finding was reiterated in the comparison between the treded areas only of the two paddocks, as bulk density was
Discussion

the only soil property to show a significant change between paddock 7 and paddock 11.

A significantly higher bulk density for paddock 11 indicates that there is less pore space in the soil which means that the soil is compacted to a greater extent in paddock 11 than paddock 7. This could be the reason for the less than optimal pasture growth of paddock 11. This could also explain the differences in grass cover seen between the two paddocks, where paddock 7 was seen to have less bare ground in amongst the grass than paddock 11 (Figures 3.5 and 3.6).

The increase in bulk density under areas of treading is in general agreement with the literature (e.g. Greenwood and McKenzie, 2001; Daniel et al., 2002; Donkor et al., 2002), except Greenwood and McNamara (1992) who suggested that bulk density is an inaccurate measure of compaction. The findings from this study go against those of Greenwood and McNamara (1992).

An increase in bulk density is an indication that soil compaction is occurring as bulk density takes into account pore space (McLaren and Cameron, 1996). Thus an inverse relationship between bulk density and porosity should exist as an increase in bulk density is indicative of a decrease in porosity which makes the soil more compacted. The affect of this increased bulk density is that there is less pore space in the soil and the outcome of this is a poorer environment for root growth, as the roots can be cut off from the underlying soil where water and nutrients are stored (U.S. Department of Agriculture, 2001). This also has negative implications for water movement in a soil (Brady and Weil, 1996). This is because the decrease in pore space results in restricted movement of water from one pore to another (Hillel, 1998).

Bulk density has been shown to be most affected in the 0-5 cm zone of the soil (Di et al., 2001; Drewry et al., 2001). Measurements taken in this study were within this zone (2-5 cm depth). It may have been helpful to take samples at increasing depths to find out if the bulk density increased, and if so by how much, as increasing bulk density has been shown to occur in other studies on Pallic Soils (Drewry et al., 1999). This increase with depth happens as with depth the content of organic matter


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decreases and there is less aggregation and root penetration. The weight of the overlying layers also increases the bulk density (Brady and Weil, 1996).

Drewry et al. (2000a) demonstrated that after treading bulk density was greatest in Fragic Pallic Soils out of a number of different soil types. Fragic Pallic Soils had an average bulk density of 1.11 Mg m\(^{-3}\) which was higher than the values for Perch-Gley Pallic Soils (1.06 Mg m\(^{-3}\)), Orthic Gley (0.96 Mg m\(^{-3}\)) and Firm Brown Soils (0.97 Mg m\(^{-3}\)). This current study was also conducted on Fragic Pallic Soils so the significant changes in bulk density could be because of the soil type. This could indicate that the bulk density of Fragic Pallic Soils is vulnerable to change.

5.2.2. Porosity

Significant decreases in macroporosity and total porosity were only evident in the comparison of total untreaded areas to each paddock’s treaded area. In this comparison it was found that paddock 11’s porosity values had been significantly decreased as a result of treading. This once again indicates that treading has had a more severe impact on paddock 11 than paddock 7. In addition, even though there was no significant difference between the median macroporosity values for the treaded areas of paddocks 7 and 11, the range of values for the paddocks was very different. This result also indicates that treading is having more of an influence in paddock 11.

This finding of some decrease in macro and total porosity from treading fits with the literature and supports the inverse relationship between bulk density and porosity, which demonstrates porosity decreases when bulk density increases (McLaren and Cameron, 1996). This relationship is weak however since neither macro nor total porosity showed significant decreases between the total treaded and untreaded areas. The relationship to bulk density and treading is not as strong as many other similar studies have found (e.g. Climo and Richardson, 1984, Singleton and Addison, 1999; Drewry et al., 1999; 2001). Macroporosity has in many treading studies been the main indicating factor of soil compaction, because a lack of large pores impedes the water flow in the soil (Beven 1980 cited in Drewry et al. 1999). Possibly in the future
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as a result of longer term treading total porosity and macroporosity will show more of a decrease.

The treaded macroporosity data had the presence of two extreme high outliers. The high values go against the literature’s findings of usual macroporosity values and could be explained by perhaps a possible miscalculation, as a number of steps were required to reach the final macroporosity calculation. Another possible reason could be that small twigs or stones were within the sample but went undetected.

The median macroporosity for the treaded area of paddock 11 was 17.1 % of the total soil porosity, so the macroporosity is high. This indicates the soil is still far away from being severely compacted. It would take a long time with intensive grazing to bring this down to less than 10 % which has been identified as the level that implies compaction or a limit to pasture growth (Climo and Richardson 1984; Drewry et al., 2001).

5.2.3. Water Contents

A significant change in water content as a result of treading was seen in the gravimetric values, but not the volumetric. For gravimetric water content the untreaded sites yielded the highest median values. As these sites have not been exposed to the treading of the cattle to compress the pores in the soil, their ability to store water has not been decreased. This result is in line with all the findings set out in the review of grazing effects on soil physical properties compiled by Greenwood and McKenzie (2001).

A significant change in gravimetric water content was found for paddock 11 once the total untreaded areas were compared to each paddock’s treaded areas. The untreaded areas had significantly higher water content than the treaded area of paddock 11. This reinforces that the impact of treading is having more of an effect on paddock 11 than paddock 7.

As mentioned in Chapter 2, the amount of compaction that can occur in a soil depends on the moisture content. When a soil is dry there is a large amount of particle
interlocking and frictional resistance to deformation (Hillel, 1998). When a soil is moist however it is more susceptible to compaction as the water in the soil weakens the particle bonding and acts to lubricate the particles as the pore spaces become water filled rather than air filled (Drewry et al., 1999). The samples from this study were quite wet, so the soil is susceptible to compaction.

The volumetric water contents of this study did not show significant changes as a result of treading. The expected result of treading on volumetric water content is for a significant decrease to occur, but this was not seen in this study. Possibly a study that compared changes over time would demonstrate changes in volumetric water content stemming from cattle treading, as there could be seasonal influences on the water content.

5.2.4. Penetration Resistance

The literature provides evidence of treading increasing penetration resistance, however this study shows that the median penetration resistance did not increase significantly. Despite this, the 10th to 90th percentile range of values for the treaded area was much larger than for the untreaded. This indicates that treading is having some localised influence on penetration resistance even if it is not significantly increasing it.

When penetration resistance is above 2 MPa it has been shown that root growth will be limited and if values exceed 3 MPa then root growth is prevented (Sumner, 2000). Only one sample average in paddock 7 gave a penetration resistance of over 2 MPa, and those samples were taken from an area that was under a tree and clear of grass, thus possibly influencing the result. The ground sampled appeared dry and hard as the tree branches prevented it from receiving the same amount of precipitation as the other sites in the paddock. Bare ground lacks grass roots to break up the soil and decrease the penetration resistance. In addition it has been demonstrated that areas with high bulk density have high penetration resistance (Bradford, 1986). The bulk density at this site was 1.06 Mg m$^{-3}$ which was one of the highest values from that paddock.
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A possible reason that these results are not in agreement with findings from other treading studies could be in the conversion of the reading of the penetrometer to actual recordable measurements. Other studies have used cone penetrometers (Mulholland and Fullen, 1991; Mapfumo et al., 1999) and these may give slightly different readings. In addition Greenwood and McNamara (1992) also found no significant difference in penetration resistance as a result of animal treading. Their explanation for this was the varying water contents of the soil studied, as they note the negative influences of soil water content on penetration resistance can be substantial. The soil water content of the soil sampled in this study was high, so this may explain the insignificant changes in penetration resistance.

5.2.5. Soil Characteristics

A variation between the two paddocks was seen in terms of the soil colour at the 15-30 cm depth. The results show mottles evident in soil from paddock 11 but not paddock 7. It is not uncommon for the soil colour to vary from spot to spot in the same horizon (Brady and Weil, 1996) and this variation can be explained by the moisture content of the soil (McLaren and Cameron, 1996). This could explain the difference in soil colours observed in this study, as the two paddocks had different moisture contents. The presence of mottles in paddock 11 could also be explained by the soil moisture regime or it could be related to the soil formation (McLaren and Cameron, 1996). Usually mottles are indications of poor drainage (Cornforth, 1998). The type of soil in this area is Mottled Fragic Pallic (Drewry et al., 2000), so it would be expected that some mottling would occur.

5.3. Limiting Factors

When the total untreaded areas were compared to the treader area of each paddock separately this study found that a number of soil properties in paddock 11 have been significantly influenced by cattle treading, but the same effect has not been seen in paddock 7. However when just the treader areas of the two paddocks were compared this significant difference was not found. The lack of significant changes from


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treading could be the result of the study design used in this research. Factors that could limit the results are; sample size, selection of parameters, time and the selection of the control area.

5.3.1. Sample Size

This lack of significant difference may have been because of the small sample size. Perhaps with a larger number of samples a slightly different relationship may have been found. With a small number of samples there is always the possibility that they are unrepresentative of the larger area. Singleton et al. (2000) found that at least 20 samples from each regime are needed to show a difference. In a publication by AgResearch on managing treading damage the recommendation is also that 20 samples are taken to assess soil properties.

5.3.2. Selection of Parameters

Other soil properties not studied in this research may have indicated a significant change in values from the untreaded to the treaded areas. Such properties include soil aggregate size, air permeability and hydraulic conductivity. These have all been used in treading related studies as indicators of compaction. Air permeability however is very sensitive not only to changes in treading but also to earthworm movement and natural amelioration (Drewry et al., 2001). Saturated hydraulic conductivity is an important measure of the drainage capacity of the soil, so a useful measure of compaction (McLaren and Cameron, 1996).

5.3.3. Time

Another possible reason for the lack of significant treading results on a broad scale could be the fact that the sampled area had only been converted to a dairy unit 5 years ago. These results may indicate that it takes a longer time period for the soil to become compacted as a result of cattle treading. Daniel et al. (2002) found that after 10 years of treading by cattle the soil properties of bulk density, penetration resistance and infiltration rate had been significantly impacted on. For this reason a longer term research project may yield more conclusive results. The lack of a significant treading relationship in paddock 7 and between the treaded areas of both paddocks can be
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explained by the fact that the magnitude of effects from treading varies depending on
the treading periods (Di et al., 2001). However treading effects are also influenced by
the soil properties of texture, organic matter and water content (Mapfumo et al.,
1999).

5.3.4. Control Area

The area used for taking untreaded samples was from 50 cm either side of the
fenceline that from visual inspection appeared untreaded. There is however a
possibility they could have encountered a small degree of treading, and this may have
influenced the results. Other studies have used fenced off areas as the control
(Drewry and Paton, 2000a) or a cultivated field (McDowell et al. 2003), but some
have also used areas under long established fencelines (Singleton and Addison, 1999;
Singleton et al., 2000). Perhaps the width from under the fence was too large, and
should have been reduced to about 30 cm. This would increase the likelihood of the
area being free of treading.

5.4. Implications for Farm Management

The structure of a soil is an important determinant of the amount of compaction that
will occur (Veseth 1988; Hewitt and Shepherd, 1997; Cornforth, 1998). Fragic Pallic
Soils are relatively structural vulnerable which means they are more susceptible to
compaction than other soil types (Hewitt and Shepherd, 1997). Therefore
management of farms located on Fragic Pallic Soils (such as this one) is of particular
importance to ensure the structural vulnerability is ultimately decreased, or at least so
that the vulnerability does not increase.

Of the factors used to describe this vulnerability only soil wetness and soil organic
matter can be easily controlled by management and even these can only be controlled
in part. Every possible action should be taken to reduce the risk of soil compaction.
There are a number of ways the soil moisture content can be controlled. Firstly
artificial drainage can be used. This removes excess water from the soil and can be
done either by surface or subsurface drains (McLaren and Cameron, 1996). The
Discussion

The second method is to regulate irrigation. Using this method requires the soil moisture content to be measured and the amount of moisture needed for optimal growth to be known (Cornforth, 1998). Ideally successful irrigation would avoid plant stress, but not produce a saturated soil. The critical level of moisture for compaction for the general farm area should be calculated to ensure that the water content is kept below this level.

Treading of soils when they are very wet should be avoided in order to limit the amount of damage inflicted onto the soil (McLaren and Cameron, 1996). Fragic Pallic Soils are known to have moisture surpluses in winter (McIntosh, 1992) so during this season the length of time the cattle are on a paddock should be reduced.

Soil organic matter content can improve soil structure through decomposing of organic matter producing gums which stabilise the soil (Cornforth, 1998). In the break down of organic matter fats and waxes are produced which help bind soil aggregates together and resist wetting (McLaren and Cameron, 1996). Organic matter levels are higher in pastoral farming than crop farms, but these higher levels still need to be maintained particularly as once levels are decreased it takes a long time for levels to build up again (McLaren and Cameron, 1996).

One method that is currently being employed at the study site which will aid organic matter content is the spraying of cattle manure back onto the pasture (Cornforth, 1998). The application rate of this needs to be high in order to result in an increase in organic matter. A problem arises from this method however, as compacted soils have low infiltration rates, so high application rates result in surface runoff. Runoff of water and manure has the potential to pollute nearby waterways. It is important to get the hydraulic loading rate correct for each specific area, and the best way to accomplish this is to measure the infiltration rates where the areas manure land application will occur.

Another method for increasing organic matter content is termed ‘green manuring’. This involves growing a green crop such as lupins and then ploughing the plants back into the ground before they are harvested. This process works by supplying an easy source of organic matter directly into the ground (McLaren and Cameron, 1996).
Discussion

Bulk density is the main indicator of the effects of treading at this location so it is important to manage this soil property. Less intensive grazing regimes have been shown in the literature to cause smaller increases in bulk density (Mapfumo et al., 1998; Daniel et al., 2002). A grazing regime that involves fewer cattle per paddock and for a shorter duration is required to minimise bulk density changes. This would be particularly beneficial in autumn, as other studies have shown bulk density values to be worse in autumn than in spring (Mapfumo et al., 1999), so decreasing the time that the cattle are on a paddock for in autumn may help alleviate compaction effects. This may mean that stocking rates have to be decreased, but it will result in less damage to the soil.

Porosity is important to manage, and a method that has increased porosity is shallow mechanical loosening of the soil. This process, otherwise known as subsoiling, involves dragging cutting disks through the subsoil which break up the compacted regions, thus increasing porosity (Burgess et al., 2000; Drewry and Paton, 2000a). Although this process alleviates soil compaction, it needs to be undertaken every 40 weeks; otherwise the soil reverts back to the compacted state (Burgess et al., 2000).

If soil compaction can vary on a local scale a key concern for farm management is predicting where the susceptible areas are. To undertake this a monitoring system needs to be put in place. Each paddock needs to be monitored in terms of water content and organic matter, to assess soil structure that indirectly influences compaction, and bulk density which has shown to be the indicator of increasing compaction at this location. This monitoring is required to be systematic in order for changes to be noted. The monitoring programme needs to take into account weather conditions as these can be used to interpret changes seen in the soil properties (Cornforth, 1998). The implication of treading effects varying locally signifies that soil management is important, but this can be rather difficult. It is however important that action is taken to limit treading effects otherwise the soil compaction problem could become serious, and in turn, limit the future options for the farm.
6.1. Introduction

This research aimed to determine the effects of dairy cattle treading on soil physical condition in the Clydevale area of South Otago, New Zealand. Soil compaction from dairy farming is a current issue in this region. The soil physical properties of bulk density, gravimetric water content, volumetric water content, penetration resistance, macroporosity and total porosity were measured in order to give a range of variables that could change and indicate the effects of treading. Soil samples were taken and analysed to see if there was a difference between treaded and untreaded areas. In addition comparison was undertaken between two paddocks to see if the effects of treading varied on a local scale.

6.2. Key Findings

A number of key conclusions have emerged from this study. A major outcome was that this soil, when looked at as a whole does not show that severe compaction is occurring. Only two of the six sampled soil properties, bulk density and gravimetric water content, changed significantly when untreaded areas were compared to treaded areas. For a soil to be considered compacted as a result of treading it usually shows a significant change in the values of a number of soil properties.
Conclusion

Treading is however having a detrimental effect on the soil as the bulk density has significantly increased as a result of cattle treading. If no soil properties had changed significantly then it could be deduced that the treading of the cattle on the soil is having no effect. However since two properties have significantly changed then this indicates that treading has the potential to lead to compaction. As this study site has only been a dairy farm for 5 years, in the future treading could lead to severe compaction.

Cattle treading is resulting in soil compaction in paddock 11. Bulk density, gravimetric water content, macroporosity and total porosity all showed significant changes as a result of treading. However the values from the treaded areas do not indicate severe compaction. The level of treading effects does vary significantly on a local scale however this variance was only evident through comparing the untreaded areas from both paddocks to the treaded areas for each paddock separately.

Bulk density is the most sensitive indicator of treading effects in this study. In both sets of comparisons the bulk density has shown to increase as a result of treading. In contrast, macroporosity which according to the literature is the most sensitive indicator of compaction appears to be less sensitive than bulk density.

Effective management of the soil physical properties in this area is essential if soil compaction is to be avoided. Some soil properties have shown significant changes as a result of treading. Managing the structure of a soil is important in preventing soil compaction from occurring. This is particularly important for this region as the soil type makes it vulnerable to structural degradation.

6.3. Future Research

As this study progressed a number of potential avenues for further research were identified and include long term monitoring, seasonal studies, and different design methods. A year long study would be beneficial as it would allow more time to look
Conclusion

at these soil properties to see if there is a seasonal variance. This would resultantly indicate when cattle treading is having the most effect on soil physical properties.

Bulk density was shown in this study to increase significantly due to treading. It would be interesting to study the effect depth has on the level of increase at this site. Studies in other locations have shown an increase in bulk density levels with depth.

The study farm was only converted to a dairy unit 5 years ago. An alternative study design which may give a greater indication of how much change dairy cattle treading has caused, could compare soil samples from this dairy farm to samples taken from an adjacent sheep farm. This would allow the level of soil damage from the sheep farm to be compared to the dairy farm. The amount of difference should be the effect caused by dairying.

As many of the soil properties sampled did not show a significant change as a result of treading, a future area of research would be to look at a number of other soil properties that were not sampled in this study. Such soil properties could include soil aggregate size, air permeability and infiltration rate, as these have been shown in other studies to be affected by cattle treading. Ultimately, a long term study is needed to show the progressive effects of treading at this location.
References


References


References


References


References


References


Appendix

Raw Data: Paddock 7 and Paddock 11
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