Effects of Severe Cattle Treading on Soil Physical Properties and Pasture Productivity

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Abstract

Severe cattle treading can result in compaction and pugging, of which the latter was the focus of this thesis. Pugging is one of the severest forms of treading damage to soil, and occurs when soil is grazed while near saturation, resulting in plastic and liquid soil deformation. The research objectives were to quantify effects from one-off treading events, at different severities, on soil physical properties and sward characteristics, to monitor recovery from the one-off treading event, and to develop methods of estimating potential effects of treading on pasture productivity.

Three field experiments were carried out on a Te Kowhai silt loam soil (NZ soil classification, *Typic Orthic Gley*; USDA soil taxonomic classification, *Typic Endoaqualf*) supporting a mixed sward of ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). A one-off treading event of either 0 (control), 3, 9, or 24 hours was carried out using lactating Holstein-Friesian cattle (300 cows ha^{-1}) at three soil moisture contents (65%, 71%, and 81% gravimetric soil moisture content). Soil physical properties, soil surface features, and sward characteristics were monitored for up to 34 weeks after the treading event.

Longer treading durations at wetter soil conditions had increasingly detrimental effects on soil macroporosity, saturated hydraulic conductivity (K_{sat}), unsaturated hydraulic conductivity (K_{-40}), surface roughness, depths of pug prints, bare ground area, ryegrass tiller density, and herbage accumulation. Soil dry bulk density and total porosity did not change, even under the severest of treading damage, because decreases in macroporosity were offset by increases in microporosity ($r^2 = 0.63$; $P < 0.001$).

The area of bare ground increased to up to 87% of the soil surface and correlated with decreased in herbage accumulation ($r^2 = 0.73$; $P < 0.001$). Sward botanical composition did not change after treading damage, except when large patches of bare ground persisted into spring, resulting in the establishment of broad-leaved plantain (*Plantago major* L.).

Soil and sward recovered (i.e. no significant difference compared to simultaneous controls) following treading damage and when the pasture continued to be rotationally grazed. The recovery of macroporosity, K_{sat}, and K_{-40} indicated that the soil had an increased susceptibility to further treading damage for up to 13 weeks after the initial treading event. However, soil susceptibility to direct hoof damage after a one-off severe treading damage event may persist

for up to 25 weeks, as sward recovery (decreases in area of bare ground) took longer than the recovery of soil physical properties.

When the gravimetric soil moisture content was >71%, a three hour grazing caused a total decline of 1,100 kg DM ha^{-1} in pasture productivity, however, at lower soil moisture contents grazing of ≤3 hours was unlikely to cause significant pasture productivity decline. When ≥50% of soil penetrations using the AgResearch Penetrometer are ≥2 cm, a three hour grazing with 300 cows ha^{-1} is likely to result in pasture productivity decline.

Statistical models (multivariate regression models) were used to describe the relationship of soil physical and sward properties with pasture productivity after treading. Assuming that during the grazing rotation no further severe treading damage takes place before recovery is complete, the models can be used to estimate potential pasture productivity decline from a one-off severe treading event on a pugging susceptible Te Kowhai soil using variables measured immediately before or after cattle treading. The models with the best potential for practical applications were:

$DPP^{*} = -1770.98 + 196.35HR - 4.47HR^2 + 32.11AP$	$r^2 = 0.72$, $P < 0.001$
$DPP = -1057.55 + 43.17BG$	$r^2 = 0.61$, $P < 0.001$
$DPP = -863.78 + 179.10SR$	$r^2 = 0.78$, $P < 0.001$
$DPP = -701.16 - 155.89HR + 5.49HR^2 + 26.61PD + 122.68SR$	$r^2 = 0.84$, $P < 0.001$
$RT^{*} = -6.94 + 1.35HR - 0.032HR^2 + 0.16AP$	$r^2 = 0.78$, $P < 0.001$
$RT = -6.10 + 0.36HR + 0.10AP + 0.58SR$	$r^2 = 0.80$, $P < 0.001$

Where:
DPP = total decline in pasture productivity (kg DM ha^{-1})
RT = time (weeks) required until no significant difference in herbage accumulation compared to controls
HR = proposed or actual hours of treading
AP = AgResearch Penetrometer results (% of readings penetrating soil by ≥2 cm) immediately before treading
BG = proportion of bare ground (%) after treading
SR = soil surface roughness index (%) after treading
PD = mean depth of pug prints (mm) after treading
* = models using only pre-treading variables

The declines in spring pasture productivity correlated with declines in macroporosity (r^2 = 0.70, P <0.001) and K_{sat} (r^2 = 0.61, P <0.01), complementing findings from similar treading studies carried out on soils with compaction rather than pugging damage. A Treading Field Guide was constructed, using bare ground, soil surface roughness, depth of pugging, and photography, which indicated the likely pasture productivity decline. The likely pasture productivity declines were also combined with the potential benefits of using stand-off pads to derive a cost-benefit model.

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Definitions and Abbreviations

0-hour treatment	The treatment plots that had 0 hours of cattle treading. Is usually called the control plot.
24-hour treatment	The treatment plots that had 24 hours of cattle treading treatment.
3-hour treatment	The treatment plots that had 3 hours of cattle treading treatment.
65% GSM Experiment	The name given to the experiment carried out when soil gravimetric moisture content was 65%.
71% GSM Experiment	The name given to the experiment carried out when soil gravimetric moisture content was 71%.
81% GSM Experiment	The name given to the experiment carried out when soil gravimetric moisture content was 81%.
9-hour treatment	The treatment plots that had 9 hours of cattle treading treatment.
AgResearch Penetrometer	A depth penetrometer designed by AgResearch (Betteridge *et al.*, 2003) to indicate the susceptibility of soil to pugging damage.
Canopy	Above ground plant parts that absorb or intercept light.
Canopy cover	The distribution, arrangement, and inter-relationship between various components of canopy.
Control plot	The plot that was not trodden (had 0-hours of treading treatment).
Defoliation	Severing and removal of part or all herbage by grazing of animals or cutting by machines.
Defoliation height	Height of defoliation (stubble height), i.e. vertical distance between ground and severed ends.
Experimental group	A group of four plots (one of each of the treatments). This grouping was used to eliminate possible differences within a paddock (e.g. front of paddock having more historical compaction than at the back).
Grassland	A plant community dominated by grasses, herbaceous legumes and other herbaceous species.

Grazing rotation	The rotation of cattle from paddock to paddock, with a period of herbage regrowth before the subsequent grazing.
Groundcover	The fraction of ground covered by canopy when viewed vertically.
GSM	Gravimetric soil moisture content (g^1 g^{-1}). Also used to in the name for the experiments (e.g. 65% GSM experiment).
Herbage	Above-ground plant tissue.
Herbage accumulation	A direct measure of the net amount (kg DM ha^{-1}) of herbage or plant mass accumulated/grown over time (from time A to time B). The term is used in this thesis in preference to pasture production, pasture yield, or herbage production.
Herbage accumulation rate	An expression of actual measured rate of herbage accumulation over time.
Herbage consumption	Weight per unit area of herbage eaten by animals – a term used in preference to pasture utilisation.
Herbage growth	An increase in weight of new herbage material produced over time (without subtracting herbage death).
Herbage harvested	Weight per unit area of herbage cut by machinery.
Herbage mass	Quantity of herbage dry matter present per unit area at a given time.
K_{-40}	Unsaturated hydraulic conductivity (mm hr^{-1}) at the -0.4 kPa moisture tension.
K_{sat}	Saturated hydraulic conductivity (mm hr^{-1}).
Macroporosity	Volume (cm^3 cm^{-3}) of soil pores with >30 µm diameter.
Microporosity	Volume (cm^3 cm^{-3}) of soil pores with <30 µm in diameter.
Multivariate regression model	A model using more than one variable in regression to estimate an outcome. E.g. estimating potential decline in pasture productivity using proposed hours of treading and gravimetric soil moisture content. The contribution to the regression of each variable must have an individual P of <0.05
P	Statistical significance value. Levels of P <0.05, 0.01, and 0.001 were used.

Pasture	A reference to a managed area of the farm. An area of sward bound by fences and a functional unit for grazing.
Pasture productivity	The productivity of pasture from a paddock over a long period of tie. A more general term than herbage accumulation.
Post-treading variable	A variable determined after treading took place (e.g. soil surface roughness).
Pre-treading variable	A variable determined before treading took place (e.g. soil moisture).
PVC core-holder	The tool used to hold an intact and undisturbed soil core.
r.s.d.	Standard deviation of the residuals.
r^2	Coefficient of determination.
r^2 (adj.)	Adjusted (corrected) coefficient of determination.
Recovery	The process of the variable becoming similar to controls after having been affected by the treading treatment.
Recovery (full)	Taken when the variable affected by the treading treatment became no longer significantly (P <0.05) different from simultaneous control plots.
Regrowth	Production of new plant material above the defoliation height by the defoliated sward.
Residuals	The observed differences (errors) between the predicted means and observed means. The variation not explained by the model.
s.e.	Standard error of the mean.
Soil core	An undisturbed soil sample retrieved from the experimental site and held using a PVC core-holder. These cores were used for porosity, soil dry bulk density, and hydraulic conductivity analysis.
Soil dry bulk density	The weight of oven dry soil per known volume (Mg m^{-3}). The term "bulk density" was not used as it could imply moisture was included in the weight of the soil.
Soil surface roughness index	A measure of soil surface roughness using the proportional loss of chain length when laid out over the soil surface.

Soil total porosity	Total pore volume ($cm^3\ cm^{-3}$) of soil. Total porosity is the sum of micro- and macroporosity.
Stand-off pad	A purposely-designed area used to keep cattle during the "off paddock" phase of on/off grazing techniques.
Sward	A collection of foliage or a plant population. It is a holistic term that includes pasture grasses and weeds as one unit. The term is inclusive of above and below ground plant parts.
Sward canopy	Only the above ground component of sward, and is inclusive of plant distribution and arrangement.
Tiller	Aerial shoot of a grass plant, arising from a leaf axil, normally at the base of an older tiller.
Tillering	Production of tillers by grass plant or sward.
Treading treatment	The cattle treatment applied to the treatment plots.
Treatment plot	Plots used within experiments (12 per experiment) to which a treading treatment was applied (0, 3, 9 or 24 hours of treading).
Variable	A statistical term used to describe a soil or sward property/characteristic which varied (non-constant) and was included in the statistical modelling (e.g. macroporosity, soil moisture, bare ground).

Agronomical definitions are based on Hodgson (1979) and Thomas (1980).

Chapter 1.
Introduction

1. Introduction

1.1 Effects of Treading on Soil and Pasture

In New Zealand, agriculture is the primary industry, constituting 60% of the national export income (Statistics New Zealand, 2003). Currently, over half of the land area in New Zealand is in pasture and the majority is intensively grazed. Historically, New Zealand agricultural production was largely sheep, however, the sheep industry, particularly in the South Island, is currently being replaced by dairy farm development (Matthews *et al.*, 1999b). In 2003 New Zealand had 5.2 million dairy cattle, with an additional 4.7 million beef cattle (Statistics New Zealand, 2003).

It is expected that dairy production will increasingly cause detrimental effects to the soil system (Tanner & Mamaril, 1959; Horne & Singleton, 1997; Sheath & Boom, 1997). The challenge, however, is to find an equilibrium between the level of deterioration and intensity of land-use that is profitable and also sustainable (Lal, 1993; Horne & Singleton, 1997; Valentine & Kemp, 1999). The challenge of sustainable management of soil is increasing as farming techniques improve, more fertilisers are used, supplement feeding increases, and the drive by the dairy industry to increase annual production by 4% per annum over five years, will inevitably result in grazing intensification (Betteridge *et al.*, 2002).

As intensive dairy farming becomes more common, associated problems, such as soil compaction by cattle treading, grows more prevalent (Taylor *et al.*, 1997). Severe treading damage, such as pugging, occurs when the soil is trodden when soil moisture approaches saturation (Mullins & Fraser, 1980; Scholefield & Hall, 1985a; Mullholland & Fullen, 1991; Singleton *et al.*, 2000), resulting in extensive plastic deformation of the upper soil layer and compaction at lower soil depths (Scholefield *et al.*, 1985; Mullholland & Fullen, 1991; Haynes, 1995). The occurrence of severe treading damage is common on wet soils during the winter/spring months, when break-feeding (i.e. strip feeding and block grazing) or mob stocking are used.

Swards are damaged by direct crushing of herbage by cattle hooves and the burial of plants due to the plastic deformation of soil (Edmond, 1958; Brown & Evans, 1973; Drewry *et al.*, 1999; Nie *et al.*, 2001a). The consequence of damage to herbage, and the restricted growth of plant roots due to soil damage is a decline in pasture productivity (Haynes, 1995; Sheath & Boom, 1997; Pande *et al.*, 2000; Nie *et al.*, 2001a; Drewry *et al.*, 2004a). Additionally, pasture productivity may be influenced by botanical shifts to less favourable species (Edmond, 1962; Gradwell, 1966). It has also been reported that treading damage can affect the wider environment. Treading damage increases the runoff of nutrient-rich sediment to waterways (Nguyen *et al.*, 1998; Smith & Monaghan, 2003), and the consequent decline in pasture productivity and nitrogen fixation results in increased use of nitrogen based fertilisers (Mullen *et al.*, 1978; Menneer *et al.*, 2001). The decline in soil aeration caused by cattle treading has also been reported to increase the production of greenhouse gasses such as nitrous oxide and methane (Ball *et al.*, 1997; Oenema *et al.*, 1997; Bhandral *et al.*, 2003).

1.2 Research Background

Some effects of severe treading damage have been well documented by past research (e.g. Edmond, 1962; Edmond, 1963, 1964; Gradwell, 1966; Brown, 1968a, 1968b). Recent research in New Zealand has mostly described effects of treading, its processes, methods of minimising treading effects by management, and natural or mechanical amelioration (see work by Betteridge, Boom, Burgess, Drewry, Greenwood, Horne, MacKay, Paton, Sheath, Singleton, Pande, Valentine, and Ward).

The New Zealand Government has contributed to the need for research (e.g. minimisation of environmental impacts to soils) by the introduction of the Resource Management Act (New Zealand Government, 1991), and the identification of soil treading as a significant problem in the State of New Zealand's Environment Report (Taylor *et al.*, 1997). Regional Councils, have developed policy to meet government requirements by introducing soil health policies (e.g. Environment Waikato, 2005).

Despite governmental concerns and policies, research into soil pugging susceptibility indictors and subsequent decline in pasture productivity has been limited. Greenwood and McKenzie (2001) and Nie *et al.* (2001a) point out that there is little in the way of published systemic studies investigating treading effects on soil and sward, and its recovery after treading damage. Furthermore, there has been virtually no published research on predicting potential treading damage to soil and sward prior to treading damage occurring.

1.3 Research Objectives

The research objectives were:

1) To quantify damage to soil physical properties and soil surface, and the response in herbage accumulation, by a one-off severe treading event by lactating Friesian-Holstein dairy cattle at different treading durations (0, 3, 9, and 24-hours) on a Te Kowhai silt loam (NZ soil classification, *Typic Orthic Gley*; USDA soil taxonomic classification, *Typic Endoaqualf*) at a range of gravimetric soil moisture contents (65%, 71%, and 81%), and while supporting a ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) sward.

2) To monitor recovery (if any) from the one-off severe treading event of soil physical properties, soil surface, and sward productivity after the experimental site was included back into the grazing rotation whilst avoiding further severe treading damage.

3) To develop methods for estimating the potential effects of treading before grazing or after treading damage has occurred on soil physical properties and pasture productivity, using easily determined variables in statistical models and visual guides.

4) To develop tools suitable for one-farm use to assist in management and economic decision making in the context of pugging damage prevention.

1.4 Thesis Structure and Layout

The thesis begins by summarising published literature (Chapter 2), covering the effects of treading to soil physical properties, pasture productivity, and to the wider environment. Methods used in the experiments are presented (Chapter 3), followed by discussion of experimental design and site description (Chapter 4).

The results from the experiments are presented in several chapters. The immediate effects of treading to soil physical properties and on the sward for eight weeks after treading are presented first (Chapter 5) and the investigation of recovery of soil and sward is presented as a separate chapter (Chapter 6). The results from the experiments were then used to develop statistical models (multivariate regressions) for estimating the effects of treading on pasture productivity and the time required for recovery (Chapter 7). Simplification of the results into a Visual Field Guide, the implications for farm management decisions of grazing duration, and the potential benefits of using stand-off pads are also explored (Chapter 8). The final chapter presents a general summary and recommendations for further research (Chapter 9). A list of references and the appendices containing detailed results are presented at the end of the thesis.

Chapter 2.
Literature Review

2. Literature Review

2.1 Introduction

This chapter reviews the literature on the effects of cattle grazing and treading on soil and pasture. Processes of soil failure (pugging) and long-term effects on soil physical properties, herbage growth, sward characteristics, and the recovery of soil and pasture are discussed, particularly in the context of the New Zealand dairy industry.

Dairy farm production can lead to some detrimental effects on soil and pasture. The effect of cattle treading on soil has been reported to result in compaction, plant damage and soil structural loss, and most soils will have some negative response to cattle grazing (Tanner & Mamaril, 1959). Soil compaction and structure loss were identified as one of the primary forms of degradation of soil caused by cattle grazing in the New Zealand (Taylor *et al.*, 1997). The challenge, however, is to find an equilibrium between the level of deterioration and intensity of land-use that is profitable and sustainable (Horne & Singleton, 1997).

Cattle treading on wet soils may have a detrimental effect on herbage growth, animal production (Blackwell, 1993; Drewry & Paton, 2000a), earthworm populations (Edmond, 1963; Cluzeau *et al.*, 1992; Lobry de Bruyn & Kingston, 1997; Drewry & Paton, 2005), infiltration rates (Tian *et al.*, 1998; Elliott *et al.*, 2002), sward cover, and soil roughness (Russell *et al.*, 2001). Severe treading also affects the wider environment by causing sediment runoff (Betteridge *et al.*, 1999) and soil conditions that contribute to increased nitrous oxide emission (Saggar *et al.*, 2002; Bhandral *et al.*, 2003) and methane production (Oenema *et al.*, 1997; Ruser *et al.*, 1998).

Many regions of New Zealand have warm and wet climates with high producing pastures throughout the year carrying high stocking rates. Therefore, the potential for treading damage presents a formidable challenge for New Zealand farm managers (Johnson *et al.*, 1993; Horne & Singleton, 1997).

2.2 Use of Terminology

In this thesis, the term 'treading' is defined as the physical action of cattle hooves on soil and pasture. The resulting damage by cattle treading is called 'treading damage'. The term 'trampling damage' has at times been used in the literature with the same meaning as treading damage (e.g. Warren *et al.*, 1986c; Warren *et al.*, 1986d; Tollner *et al.*, 1990; Ferrero, 1991; Cluzeau *et al.*, 1992; Ferrero, 1994; Usman, 1994). However, the terms 'trampling' and 'trampling damage' were avoided here as the usual recent usage in the literature is treading and treading damage. There has, in the past, been some confusion over the use of the term 'pugging'. In this thesis, pugging was used to describe severe damage (plastic deformation) to soil as a result of treading, whereas the term 'treading damage' covers any range of severity of damage to both soil and pasture. The term 'pressing' is used in this thesis to describe a less severe type of treading damage that cannot be classed as pugging. Older literature used the term 'puddling' (e.g. Edmond, 1963; Gradwell, 1965; Mullen *et al.*, 1974; Watkin & Clements, 1978), which in this thesis is covered by the term pugging (or severe pugging). The term 'poaching' has also been used, particularly in American and some European publications (e.g. Scholefield & Hall, 1985a; Foster *et al.*, 1990; Twomlow *et al.*, 1990; Haygarth & Jarvis, 1997; Unwin, 2001). The term poaching is not in common use in New Zealand and in this thesis is covered by the term pugging.

A variety of terms are used to describe pasture conditions and sward dynamics. Herbage mass is the instantaneous measure of the total weight of herbage per unit area of ground. The term 'herbage accumulation' is used to describe the change in herbage mass between successive instantaneous measurements (i.e. net gain in herbage mass over time) whilst herbage growth is the development and increase in size of new leaf and stem tissue. The terms herbage growth and herbage accumulation, depending on the context, are used in this thesis in preference to the term 'pasture production'. The term 'pasture productivity' is a general term used in this thesis to describe productivity of herbage in, for example, a paddock. The term 'pasture' is taken to mean an area of sward that is a functional unit for grazing, where 'sward' is used to describe the plant population. Some literature uses the term pasture interchangeably to mean the sward, plant population, and the material harvested. To avoid ambiguity, the nomenclature and usage of terms for grazing studies described by Hodgson (1979) and Thomas (1980) have been adopted.

2.3 The New Zealand Dairy Industry

Agriculture is the primary industry in New Zealand and provides over 60% of New Zealand's export income (Statistics New Zealand, 2003), of which pastoral-based exports amount to 80% of the total agricultural export value (Matthews *et al.*, 1999b). Dairy farming has become more common in the lower South Island since the 1980's, with the conversion of sheep farms to intensive dairy farms (Matthews *et al.*, 1999b), where from 1996 to 1999 there was a 69% increase in the number of dairy cattle in Southland (Statistics New Zealand, 2003).

The climate in New Zealand varies from region to region, for example annual rainfall averages 275 mm in Central Otago, 1,200 mm in the Waikato, and 9,000 mm along the West Coast of the South Island (White, 1999). New Zealand, generally, has a temperate climate and, as the winters are milder than those of Europe, there is year-long outdoor grazing. The winter and early spring months have high rainfall in many areas, resulting in wet soils from July to September. Therefore, the most severe treading damage occurs during winter and early spring or when pastures are grazed intensively during prolonged heavy rainfall.

Herbage growth is slower during winter months than in late spring (Matthews *et al.*, 1999a), thus, to optimise herbage consumption on dairy farms break-feeding of cattle is often used. Break-feeding, or strip grazing, is where parts of the paddock are made available for sequential grazing events, by use of temporary electric fencing, with no back-fencing thus allowing cattle to tread on previously grazed areas. Block-grazing is where a back-fence is used and cattle are restricted to the area currently being grazed (Figure 2.1). Often break-feeding and block-grazing are carried out with feeding of supplements (Matthews *et al.*, 1999a). Break-feeding and block-grazing results in intensification of stocking density and increases the likelihood of treading damage. Concern regarding increased stocking density were noted up to 40 years ago (Edmond, 1958; Brown, 1968a). With the development of more productive pastures and greater use of fertilisers, the trend of more intensive dairy production (e.g. increases in grazing density and herd size) has continued, along with elevated concerns regarding sustainability and effects on the wider environment (Taylor *et al.*, 1997). As new and more modern farming ventures commonly carry large debt-to-profit ratios, and the return per output-unit (i.e. return per kg of milk solids) has dropped, the intensity of grazing is commonly increased to maintain profitability (Hanson *et al.*, 1998).

Figure 2.1 Block-grazing of a *Lolium perenne*/*Trifolium repens* pasture on the Netherton clay loam (*Melanic Orthic Gley*) by lactating Holstein-Friesian dairy cattle. Note and compare the earlier grazed and pugged site to the right of that currently being grazed, and the ungrazed pasture in the foreground.

2.4 New Zealand Dairy Pastures

New Zealand dairy pastures were largely established in the 1870's (Crush & Wedderburn, 2002). Early pasture was predominately based on a mixture of grasses: *Lolium perenne* (perennial ryegrass), *Dactylis glomerata* (cocksfoot), *Cynosurus cristatus* (crested dog's-tail), and *Agrostis capillaris* (browntop) (Saxby, 1956). Since the 1920's more productive *Lolium perenne* and *Trifolium repens* (white clover) species have been developed by the Plant Research Station, Palmerston North (now AgResearch Grasslands) (Levy, 1970), and these are now the main pasture species used in the dairy industry (Langer, 1973; Kemp *et al.*, 1999; White, 1999; Crush & Wedderburn, 2002), and sometimes combined with *Lolium multiflorum* (Italian ryegrass). The *Lolium* species have greater tolerance to animal treading than other grasses (Table 2.1). *Trifolium repens* is added to New Zealand pastures because it fixes atmospheric nitrogen and grows in summer (Smetham, 1973; Kemp *et al.*, 1999). *Trifolium repens* provides the equivalent value of NZ$1 billion worth of nitrogen fertiliser in New Zealand each year (Valentine & Matthew, 1999). Unfortunately, *Trifolium repens* tends to be out-competed for space when a dense grass sward develops, high rates of nitrogen (i.e. >100 kg ha^{-1} yr^{-1}) are used (Ettema & Ledgard, 1992), or under severe treading by animals (Menneer *et al.*, 2001).

Table 2.1 General ranking of tolerance to treading of some common pasture species with some reasoning for their ranking (after Kemp *et al.*, 1999).

Tolerance to treading	Species	Reason for ranking
Most tolerant ↑	Perennial ryegrass	Low growing point, prostrate tiller base
	Tall fescue	Fibrous leaves
	Italian ryegrass	
	Poa annua	Invades bare patches, prolific seed producer
	White clover	Stolons with rooted nodes, vegetative reproduction
	Browntop	
	Cocksfoot	Prostrate forms most tolerant
	Red clover	High growing point
	Yorkshire fog	Soft, easily damaged leaves
↓ Least tolerant	Prairie grass	Brittle and few tillers

2.5 Treading Damage Processes

2.5.1 Introduction

Treading damage to soil is caused by the physical action of cattle hooves. Repetitive treading when the soil is wet results in a progressive loss of soil strength (Scholefield & Hall, 1985a, 1986; Awadhwal & Singh, 1992), allowing for greater remouldability of soil over time (hence, greater damage over time) (Bodman & Rubin, 1948). The average dairy cow weighs between 300 to 550 kg and has a hoof area between 100-150 cm^2, depending on breed (Scholefield & Hall, 1986). Such weight distribution equates to a standing static load of 130 to 192 kPa, however, a walking cow exerts a greater pressure on soil due to kinetic energy and weight redistribution, and with only three, or possibly two hooves, on the ground at any one time can double the applied pressure to soil (Bowler, 1981). Scholefield and Hall (1986) showed that the pressure applied by a moving cow can exceed 250 kPa, and values between 200 - 400 kPa have been reported by Haynes (1995), well exceeding pressures applied by a farm vehicle (30 - 150 kPa) or by sheep (83 kPa) (Soane, 1970; Willatt & Pullar, 1984).

The loss of soil strength, and subsequent soil failure, is controlled by many factors: structural stability (Hewitt & Shepherd, 1997), soil texture, pasture cover, plant root distribution, soil bulk density (Tanner & Mamaril, 1959; Wood & Blackburn, 1984; Horn & Lebert, 1994), and soil moisture content (Marshall & Holmes, 1979). The rate of soil failure is dependent on the soil strength factors, however, stocking density, duration, and treading repetition causes the actual failure. Thus, treading processes, and the consequent pugging damage, are complicated and the severity of damage can vary considerably.

2.5.2 Processes of Soil Failure

If soil moisture is near saturation, soil susceptibility to pugging damage is higher than when soil is at field capacity (Bodman & Rubin, 1948; Horne & Singleton, 1997). If soil moisture is below the plastic limit, treading results in compaction (Figure 2.2) of the soil structure and decline in porosity, but causes little in the way of plastic deformation and soil remoulding (Horne & Singleton, 1997). However, as the soil moisture content exceeds the plastic limit, the predominant soil damage will increasingly shift from compaction to pugging.

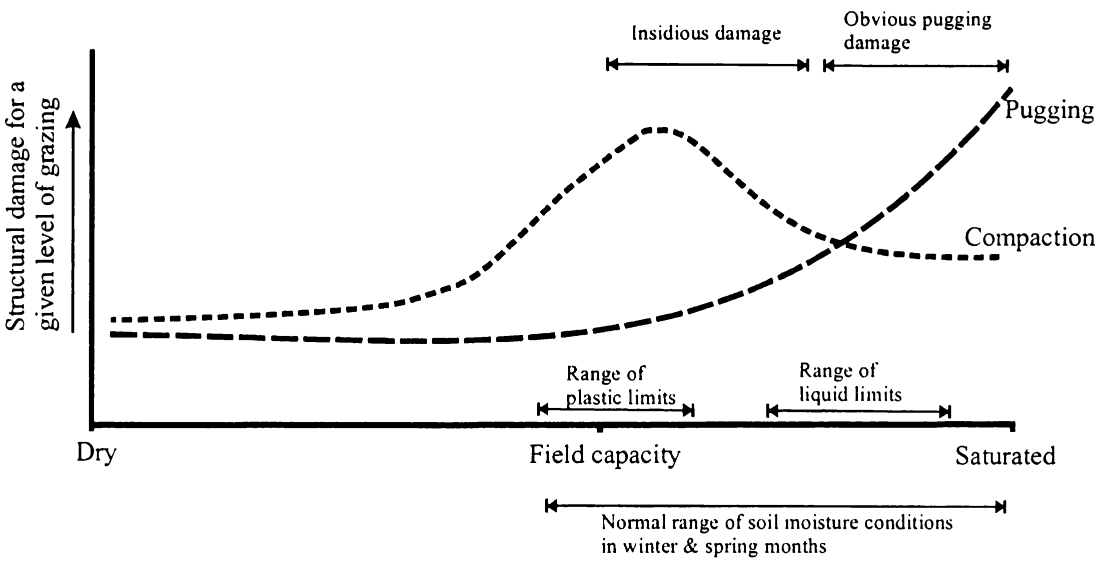


Figure 2.2 Generalised relationship between soil moisture and soil failure for a silt/clay soil, where 'insidious' damage implies detrimental changes in soil with few visible indicators (adapted from Horne & Singleton, 1997 - used with permission of P.L. Singleton).

Plastic deformation of soil is caused by a progressive loss of soil strength (when the soil moisture content is above the plastic limit) due to repetitive treading (Mullins & Fraser, 1980; Awadhwal & Singh, 1992) resulting in soil failure (Scholefield *et al.*, 1985). Plastic deformation is the irreversible displacement of soil particles by sliding action in the presence of moisture (Koenigs, 1963; Vyalov, 1986), and is often associated with the presence of free surface water (Mullholland & Fullen, 1991). Compaction differs from plastic deformation in that compaction is the re-orientation of individual soil particles and re-alignment of aggregates, resulting in a closer packed soil matrix and a decrease in the amount of air spaces (Warren *et al.*, 1986c).

During plastic deformation of soil, moisture acts as a lubricant between soil particles, reducing internal cohesion so that individual particles can begin to slide past each other (Mitchell, 1960; Marshall & Holmes, 1979). The energy for particle displacement is derived from the pressure of hoof placement on the soil and often progressive treads are needed at the same point for soil failure to occur (Scholefield & Hall, 1985a). The soil failure rate is dictated by soil strength, elasticity, and the efficiency of incorporation of free surface moisture into the soil.

The point of contact below the hoof is the point of compression and is also where vertical particle displacement occurs (Scholefield & Hall, 1985a). When the bearing capacity of the soil surface is less than the force applied by the cattle hoof, the hoof penetrates the soil surface (Mullholland & Fullen, 1991). Once the initial vertical displacement has occurred, further vertical and horizontal displacement of soil (remoulding) takes place around the hoof, resulting in a small remoulded mound of soil alongside the initial point of hoof impact (Figure 2.3). The remoulding of the soil further incorporates free soil moisture and causes destruction of pre-existing soil pores (Mullins & Fraser, 1980). However, as soil moisture content is high, and water is essentially uncompressible, the resultant damage may not show as a soil volume change. Therefore, destruction of large, water-filled, pores by plastic deformation results in rearrangement of soil moisture throughout the soil matrix (Bodman & Rubin, 1948; Koenigs, 1963), where subsequent individual spaces of soil moisture are smaller (i.e. pore size redistribution from large water-filled pores to many smaller newly formed pores).

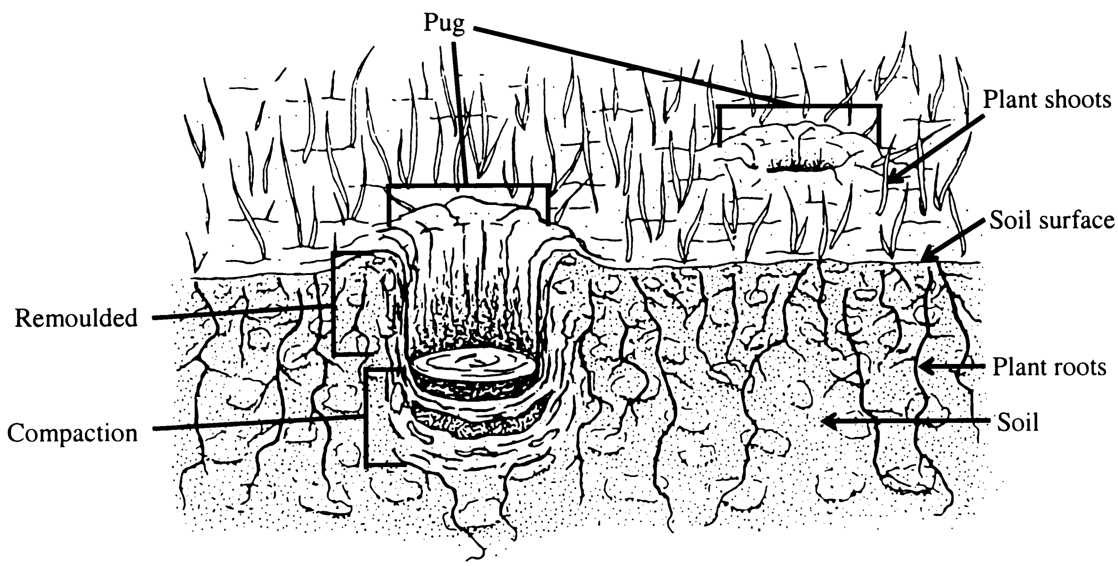


Figure 2.3 Example of an individual pug which has penetrated the soil surface (adapted from Batey, 1988 - used with permission of MAF Policy).

As the hoof progresses downward through the zone of remoulded soil, it eventually reaches a point of greater soil shear strength, after which compression, rather than remoulding, begins to predominate (Scholefield *et al.*, 1985; van den Akker & van Wijk, 1987). Hence, soil failure during repetitive treading on wet soils is likely to be a combination of plastic deformation (pugging) and compaction.

When soil moisture reaches the liquid limit, further remoulding results in the upper layer of the soil behaving like a liquid material causing greater soil deformation. However, without the addition of further moisture, the depth of plastic remoulding will be limited (Mullholland & Fullen, 1991). If during the course of soil failure and plastic remoulding there is an addition of moisture (i.e. rainfall) it results in a greater rate of failure, where the predominance of either compaction or plastic deformation depends on the rate of moisture incorporation into soil (Mullins & Fraser, 1980; Scholefield & Hall, 1985a). With addition of more moisture, each subsequent tread will result in further wetting and weakening of soil, and plastic remoulding may then occur at greater soil depth (Mullins & Fraser, 1980; Mullholland & Fullen, 1991). Of consequence, the amount of soil damage observed may vary greatly (Figure 2.4) and is largely dependent on the soil moisture content and the number of treads per soil area.

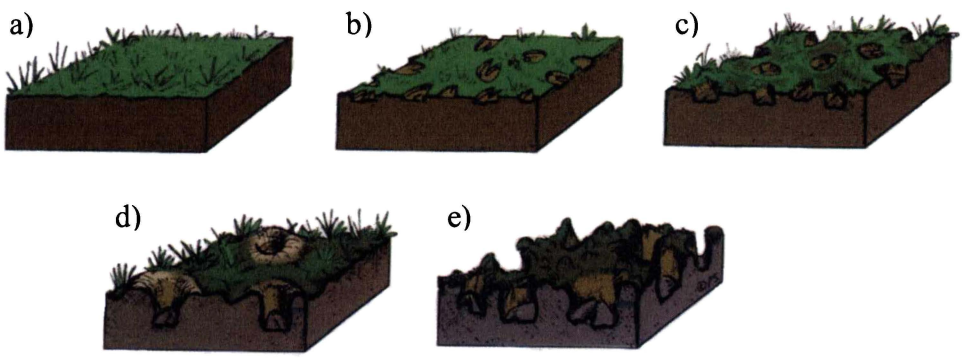


Figure 2.4 Different severities of treading damage, where a) there is no treading damage; b) slight treading damage, hoof prints pressed to 1 cm depth, pasture intact; c) moderate treading damage, hoof prints pressed to 3 cm depth, some pasture damage; d) severe treading damage, hoof prints to >3 cm depth, some plant burial, damage termed 'pugging'; e) very severe treading damage, hoof prints to >3 cm, many plants buried and destroyed, considerable plastic deformation of soil, damage termed 'severely pugged' (after Betteridge *et al.*, 2003 - used with permission of AgResearch Ltd).

As pugging and compaction are not mutually exclusive, typically the 5-8 cm of soil depth and deeper show compaction, whilst in the upper 5 cm of soil pugging damage predominates. Often the compact layer is within the rooting zone of plants (Haynes, 1995). As pugging results in soil damage that does not incur a volumetric change, the upper soil layer may not be compacted. For example, it was found that severely pugged soil in Northland, New Zealand, commonly had little in the way of compaction at the 0-5 cm soil depth despite extensive past soil structural damage, however, at the 5-10 cm soil depth typical features of compaction were present (Singleton *et al.*, 2000).

2.5.3 Soil Susceptibility to Severe Treading Damage

The vulnerability of soil to severe treading damage varies with soil types (Climo & Richardson, 1984; Hewitt & Shepherd, 1997), hence, pugging may be a greater problem for some soils than others (Scholefield & Hall, 1985a; Proffitt *et al.*, 1995a; Proffitt *et al.*, 1995b).

As pugging is the plastic or liquid deformation of soil, the susceptibility to pugging damage is determined by the ability of the soil to resist deformation (Wind & Schothorst, 1964). Resistance to deformation is a function of soil strength, over which soil moisture has a considerable influence (Koolen, 1994). Additionally, as the plastic limit is a function of soil moisture, pugging susceptibility is greater for soils that are often wet and remain wet for long periods (Edmond, 1962; Mullholland & Fullen, 1991; Taboada & Lavado, 1993). For this reason, soils that have a high plastic limit (i.e. >65%) and also rapid drainage rates, are less susceptible to pugging damage (Warren *et al.*, 1986d), whilst slow draining soils with high microporosity to macroporosity ratio (such as clay soils) are more susceptible to pugging.

Both the water infiltration rate and the soil hydraulic conductivity influence the duration that soil moisture content is above the plastic limit (Edmond, 1962; Mullholland & Fullen, 1991; Taboada & Lavado, 1993; Haynes, 1995). Therefore, soil susceptibility to pugging damage can be minimised by improving infiltration and hydraulic conductivity rates by, for example, aerating (shallow mechanical loosing) to improve drainage rates (Drewry & Paton, 2000b;

Betteridge *et al.*, 2003) and installing drainage to shorten the duration that soil is wet (Thomas *et al.*, 1990). The effect of previous severe treading may increase the soil susceptibility to further pugging damage (Gradwell, 1960; Wind & Schothorst, 1964; Gradwell, 1968; Haynes, 1995), where decreases in infiltration and hydraulic conductivity prolongs the period of susceptibility to pugging damage. Thus, pugging can be a self-perpetuating problem. For example, Climo and Richardson (1984) found that in three contrasting soil types (two silt loams and a sandy loam) in the Manawatu, New Zealand, macropore volume was decreased by 19 – 39% after simulated cattle compaction, and penetration resistance decreased rapidly over a narrow range of soil moisture contents (40 – 60% gravimetric). A decrease in macropore volume will cause a decline in soil drainage rates (Naphade & Ghildyal, 1971) and, as resistance to deformation is inversely related to soil moisture content (Koenigs, 1963), these soils are now more susceptible to further pugging damage (Climo & Richardson, 1984).

Pasture cover influences soil susceptibility to treading damage. Research has shown that greater canopy cover gives some protection from pugging damage (Brown, 1968a; Betteridge *et al.*, 1998; Pande *et al.*, 2002). Some early treading research included pre-treading herbage harvesting (e.g. early work and method by Edmond, 1958), while later work (e.g. Betteridge *et al.*, 1998) showed canopy cover and herbage mass can influence the potential treading damage. If, however, soil begins to pug early in the grazing, and herbage becomes soiled, thus is not eaten by cattle (Kellet, 1978), it potentially gives prolonged protection but not avoidance of pugging damage. Therefore, maintaining a higher canopy cover may be useful at times when the soil is susceptible to pugging damage.

Treading on dry soils may form a layer of fine soil aggregates (Warren *et al.*, 1986c; Taboada & Lavado, 1993), and cause soil compaction at lower soil depths. Soil compaction, and the layer of fine soil aggregates, caused a decrease in water infiltration and conductivity rates, and an increase in soil susceptibility to pugging damage.

Betteridge *et al.*, (2002) found a relationship between initial penetrability of soil and susceptibility to pugging, and are now developing a test for soil susceptibility to pugging damage based on a calibrated penetrometer. Similarly, reliable relationships ($r^2 = 0.81$) have been established between soil strength and drop cone penetrometer readings (Godwin *et al.*, 1991). Other research indicated that the rate of soil failure may differ between soil types, due to clay 'sensitivity' and also recommended using repetitive simulated treading to determine soil susceptibility to pugging (Scholefield & Hall, 1985a, 1986).

Repetitive soil treading needs to occur before plastic deformation takes place (Scholefield & Hall, 1985a), however, the distribution of treading, hence its repetitiveness, varies due to cattle behaviour or habit (Guthery & Bingham, 1996). Parts of a paddock may have greater susceptibility to pugging damage, not because soil conditions vary, but because of animal behaviour and farm management differences. For example, areas surrounding gates or water-troughs receive greater treading rates, and hence, are more susceptible to pugging damage, despite (initial) soil conditions being similar. Thus, the susceptibility of a soil to pugging damage encompasses an intricate set of complex and compounding factors.

2.6 The Effects of Treading Damage on Soil Properties

2.6.1 Soil Dry Bulk Density and Porosity

Soil dry bulk density and soil porosity are important physical properties. Soil dry bulk density is defined as the oven dry mass of soil within a known volume (McLaren & Cameron, 1993). Soil dry bulk density comprises two components, soil and air (measured as porosity). Soil dry bulk density is inversely related to soil porosity (McLaren & Cameron, 1993), where the denser the soil the less the porosity. Compaction infers an increase in soil dry bulk density and a decrease in total pore volume. Total porosity is the sum of the volume of all individual soil pores. Individual soil pores vary in size and may be classified into two categories; micropores (<30 μm in diameter), and macropores, (>30 μm in diameter) (Rowell, 1994). Macroporosity corresponds to terminology used with soil moisture, where at field capacity theoretically all soil pores greater than 30 μm (macropores) are drained and filled with air, whilst those smaller than 30 μm (micropores) are filled with water (Table 2.2). Some researchers use 50 μm as the cut-off between micro- and macroporosity (e.g. Carter, 1990; Rowell, 1994), however, a 30 μm cut-off is more commonly reported and will be used in this thesis.

Macropores are formed by a variety of soil processes, including soil aggregation, earthworm activity, plant root death, shrinking and swelling of soil, and under-sowing (Aubertin & Kardos, 1965; Grevers & de Jong, 1990; Goss, 1991; Knight *et al.*, 1992; Zhang & Schrader, 1993; Volkmar & Entz, 1995; Milne & Haynes, 2004a). Macropores are important for rapid drainage of soil (Beven, 1980; Beven & Germann, 1982) and aeration (Glínski & Stepniewski, 1985). Micropores do not contribute much to soil drainage rather, as they have greater matric potentials, they are important for water storage. Inter-pedal macropores contribute more to drainage than intra-pedal macropores (Habib *et al.*, 1988), however, macropore shape and continuity are also important (Beven, 1981; Luxmoore, 1981). Continuous pores are often formed by earthworm burrowing activity and plant root death (Beven & Germann, 1982). Aeration rates are important for oxygen replenishment around plant roots and, hence, root growth (Letey *et al.*, 1961a; Stolzy *et al.*, 1961; Letey *et al.*, 1962; Asady & Smucker, 1989).

Table 2.2 The moisture tension at which soil pores are air-filled (adapted from Rowell, 1994).

Pore diameter (μm)	Moisture tension (kPa)	Notes
4,000 - 30	0.075 - 10	Rapid drainage of excess water. Small soil cracks and earthworm burrows.
30	10	Maximum size of water filled pores at field capacity.
30 - 0.2	10 - 1500	Water storage for plants and very slow drainage.
0.2	1500	Maximum size of water filled pores at wilting point.
0.003	100,000	Maximum size of water filled pores at air-dry moisture content.

In six contrasting soil types (clayey to silty/sandy loam), untrodden soils had on average 13% lower soil dry bulk densities when compared to severely trodden soils (Singleton *et al.*, 2000). Differences of 21.6 % in soil dry bulk density for a sandy loam have been reported between lightly trodden and severely trodden areas (Mullholland & Fullen, 1991). Although, soil dry bulk density may increase due to severe soil treading, it is not a good indicator of structural change (Mullholland & Fullen, 1991; Zegwaard, 1998; Singleton *et al.*, 2000), as severe treading that results in pugging damage can cause the formation of new micropores, off-setting decreases in macropore volume (Gradwell, 1968; Kellet, 1978). For example, Zegwaard (1998) found that previously cattle pugged Hauraki clay loam soil had 8% (P <0.05) more micropore volume than untrodden areas.

Soil dry bulk density changes provide an indication of soil compaction, but do not show the soil pore size re-distribution that occurs in plastic deformation (Mullen *et al.*, 1974; Greenwood & McNamara, 1992), while after soil compaction there is a reduction in pore spaces, such as inter-pedal gaps, in the soil (Figure 2.5).

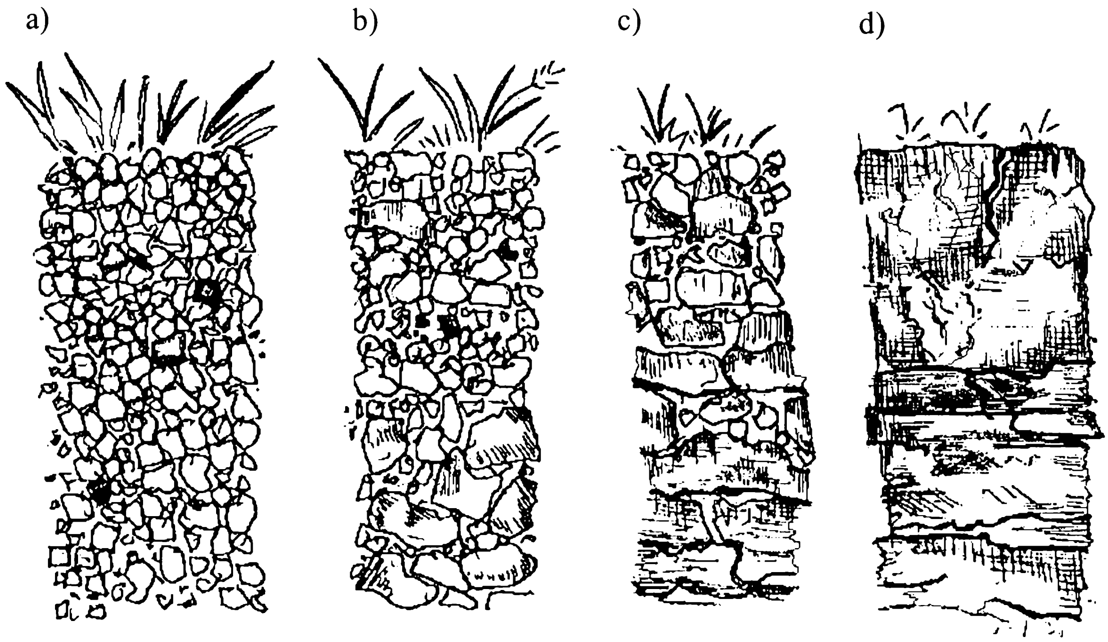


Figure 2.5 Soil profile examples of soil; a) unaffected by compaction, where topsoil is loose and crumbly, has abundant roots and earthworms; b) slightly affected, where upper of topsoil is still loose, however, some larger, firmer aggregates at 10-15 cm depth, roots not common in firmer aggregates; c) moderately affected, where larger, firmer aggregates more common, sometimes with platy appearance, root growth only around aggregates; d) severely affected, where soil surface is lumpy, aggregates are coarse or absent, few roots below 5 cm, few earthworms, soil greyish with red stains in root channels (after Betteridge *et al.*, 2003 - used with permission of AgResearch Ltd).

Soil compaction leads to decreased; root penetrability, soil aeration, gas diffusion (van Diest, 1962; Asady & Smucker, 1989; Zainol *et al.*, 1991), and nutrient and water availability, all of which have been observed to decrease root growth and development (Letey *et al.*, 1961b; Scholefield & Hall, 1985b; Asady & Smucker, 1989; Bennie, 1996; Houlbrooke *et al.*, 1997). Mechanical impedance alone may restrict root growth and herbage growth of *Lolium perenne*, even when oxygen, moisture and nutrients are not limiting (Cook *et al.*, 1996). A soil dry bulk density of 1.30 Mg m^{-3} in a clay loam was found, 78 days after compaction, to decrease shoot biomass of *Bromis inermis* (bromegrass) by 25% compared to shoot biomass from an uncompacted soil with a dry bulk density of 1.15 Mg m^{-3}, while a soil dry bulk density of 1.50 Mg m^{-3} decreased herbage accumulation by 75% (Mapfumo *et al.*, 1998). Soil dry bulk densities of greater than 1.3 Mg m^{-3}, are high compared to soil dry bulk densities reported for grazed clay/silt loams in New Zealand (Table 2.3). However, an investigation of soil compaction found that *Lolium perenne* productivity may decrease in response to soil dry bulk density increase, even when soil dry bulk density was low (<1.3 Mg m^{-3}), reporting that significant (P <0.05) herbage growth decreases occur when soil dry bulk density increases from 0.9 to 1.2 Mg m^{-3} (Houlbrooke *et al.*, 1997).

Table 2.3 Soil dry bulk densities for Te Kowhai silt loam (NZ soil classification, *Typic Orthic Gley*; USDA soil taxonomic classification, *Typic Endoaqualf*) as reported by various researchers.

Soil dry bulk density (Mg m^{-3})	Soil depth	Comment	Reference
0.93	1–4 cm	grazed pasture	(Joe, 1984)
1.11	12-15	grazed pasture	(Joe, 1984)
0.97 & 1.08	0-5 & 5-10 cm	pugged	(Drewry *et al.*, 2003)
1.09	0-5 cm	grazed	(Burgess *et al.*, 2000)
0.66, 0.83 & 0.77	0-5 cm	Untrodden [a], 'typical'[b] & pugged	(Singleton & Addison, 1999)
0.91, 1.02 & 0.98	5–10 cm	Untrodden [a], 'typical'[b] & pugged	(Singleton & Addison, 1999)
0.98, 1.13 & 1.16	5–10 cm	Untrodden [a], 'typical'[b] & pugged	(Zegwaard, 1998)

[a] untrodden areas were under fence lines
[b] 'typical' was trodden by cattle but not pugged

Macropore volume is more readily destroyed by animal treading than micropores (Beckmann & Smith, 1974; Braunack & Walker, 1985; Mullholland & Fullen, 1991). The rapid decline in macropore volume is related to the lower soil strength of macropores compared to micropores, was reported by Carter (1990) who showed that low soil strength and penetration resistance in soils correlated to high macropore volume. Therefore, macroporosity may serve as a better indicator of structural change due to treading than either microporosity or total porosity and, hence, soil dry bulk density (Greenwood & McNamara, 1992). Treading, that results in pugging damage, may result in increased micropore volume due to plastic remoulding and incorporation of soil moisture (Gradwell, 1968; Kellet, 1978).

Soil macroporosity of less than 0.10 cm^3 cm^{-3} may restrict soil aeration to a level where root growth becomes limited (Gradwell, 1965; Grable, 1971; Carter, 1988; Stepniewski *et al.*, 1994). However, other work suggests that a volume of 0.12-0.15 cm^3 cm^{-3} air-filled pores is a better limit to use where aeration and root growth may not be limited (Grable & Siemer, 1968). The cumulative effect of low macroporosity and long periods of high soil moisture content, because of slow drainage, would considerably decrease aeration and gas diffusivity.

2.6.2 Hydraulic Conductivity

Hydraulic conductivity is defined as the rate of flow of water through a volume of soil subject to a unit gradient (Gradwell, 1972). Hydraulic conductivity can be measured under saturated and unsaturated flows. Saturated hydraulic conductivity occurs when all soil pores are filled with water, including preferential pathways such as earthworm burrows (Zachman *et al.*, 1987). Saturated flow may have rapid and spatially variable flow rates (McLaren & Cameron, 1993; Rowell, 1994; Schipper & Sparling, 2000). Unsaturated hydraulic conductivity is where a moisture tension is applied, restricting hydraulic flow to smaller pores (e.g. at -0.4 kPa and -1.0 kPa hydraulic flow occurs through pores <0.75 mm and <0.30 mm, respectively), and, as the majority of soils are unsaturated most of the time, unsaturated water flow is most common. Unsaturated hydraulic conductivity is an indicator of soil structure at smaller pore sizes than with saturated flow, therefore, is an important soil property when investigating effects of cattle treading. As unsaturated hydraulic conductivity is not affected by large preferential flow pathways compared to saturated hydraulic conductivity, the results are less spatially variable, and have been suggested to be a better indicator of structural change than soil dry bulk density (Mullholland & Fullen, 1991).

Preferential pathways within soil structure, such as fractures, tend to close as soils wet and begin to swell, however, earthworm burrows are particularly persistent as they do not close-up as soils begin to swell (Dexter, 1991). As earthworm burrows also tend to be continuous pores, they are particularly important for rapid soil water movement.

Severe treading decreased pore volume and individual pore size, thereby, reducing the rate of hydraulic conductivity. Individual hoof prints may result in smearing of soil, sealing the soil surface and slowing infiltration rates (Abdel-Magid *et al.*, 1987). A comparative investigation showed that the number of preferential flow pathways was on average 33% less in grazed soils than in ungrazed soils and the rapid recovery of grazed soils was attributed to the shrink and swell nature of the soil (Dreccer & Lavado, 1993). Similarly, infiltration rates were incrementally decreased to 50% of the original infiltration rate by each consecutive cycle of simulated treading (Ferrero, 1991). Slow infiltration rates results in longer periods of saturation, or water logging, during rainfall events. Periods of saturation and water-logging have been associated with plant stress, causing slow oxygen diffusion rates through soil (Donohue *et al.*, 1984), and resulting in decreased herbage growth rates (Letey & Stolzy, 1967; Dunbabin *et al.*, 1997).

Treading has been reported to decrease hydraulic conductivities for a range of soil types (Greenwood *et al.*, 1997; MacKay *et al.*, 1999; Goudie, 2000; Drewry *et al.*, 2002). Comparative differences in hydraulic conductivities between cattle trodden, cattle pugged, and untrodden soils showed that greater proportional differences occurred for saturated than unsaturated flow (K_{-40}) (Singleton *et al.*, 2000). Differences in unsaturated hydraulic conductivities of soils, in response to severe cattle treading, have also been recorded, but were smaller than the differences in saturated flow (Drewry & Paton, 2000a; Drewry *et al.*, 2002; Drewry *et al.*, 2003). The greater differences recorded in saturated flow indicate that saturated flow is more readily affected by treading than unsaturated flow. Free-draining soils tend to have smaller differences in hydraulic flow rates between cattle treading treatments than gleyed soils (Singleton *et al.*, 2000). Drewry (2003) compared the effects of conventional grazing to conservative three-hour grazing over three years and, despite high variability, saturated flow rates gave larger and more consistent difference (~50 mm hr^{-1}) between treatments than unsaturated (K_{-40}) flow (~20 mm hr^{-1}). Reductions in saturated flow rates, due to treading, are largely attributed to the destruction of preferential flow pathways within soil macro-structure and earthworm burrows.

2.7 The Effects of Treading on the Soil Surface Properties

2.7.1 Soil Surface Roughness

Cattle treading results in hoof indentations that may penetrate or rupture the soil surface. Thus, the measurement of soil roughness is an indicator of pugging damage to soil. Several methods have been developed to measure soil surface roughness, the most common being pin-meters and profile-meters (Zobeck & Onstad, 1987), laser micro-topographic scanners (Huang & Bradford, 1990), and the least expensive method of using a length of steel roller chain (Saleh, 1993, 1994; Merril *et al.*, 2001). Estimation of soil surface roughness and micro-relief has often been done to assess wind and water erosion, and to describe cultivated soil surface features (Zobeck & Onstad, 1987; Merrill *et al.*, 1999; Clark *et al.*, 2001; Merril *et al.*, 2001; Schillinger *et al.*, 2001).

The chain method estimates surface roughness by the shortening of effective chain length, because of surface tortuosity when the chain was laid out over the soil surface (Saleh, 1993). Computer simulation of the chain method and other methods of determining soil roughness has shown the chain method to be reliable and credible (Merril *et al.*, 2001). Values obtained from the chain method are shown as a roughness index (% difference between effective length and actual length). Recently, the chain method has been used in soil treading research (e.g. Nie *et al.*, 2001a; Pande, 2002; Pande *et al.*, 2002; Drewry *et al.*, 2003).

A comparison of untrodden, lightly trodden and heavily trodden areas showed incremental increases in the soil roughness index, where roughness was 2.3, 5.4, 8.9%, respectively

(Pande *et al.*, 2002). A roughness index of 6-10% are regarded as only moderately rough (P.L. Singleton, *pers com*; Section 3.6) and values greater than 20% can be obtained after extreme cattle treading events. Soil surface roughness was found to increase with the severity of cattle treading on a hill-soil, where canopy height (pasture cover) influenced soil roughness. Soil roughness when the canopy height was 5 mm was more than double that resulting from of the same cattle treading duration when canopy height was 47 mm (Betteridge *et al.*, 1998). Pande (2002) reported a maximum soil surface roughness index for a hill-soil silt loam of 23% after treading at 200 cows ha^{-1} for up to 36 hours. Nie *et al.* (2001a), also using the chain method, reported maximum soil surface roughness index of 15.2% for 'heavily pugged' areas and pug depths up to 43 mm.

Soil surface roughness is not entirely determined by treading duration, soil moisture, and pasture features, but also by soil characteristics such as texture. For example, Drewry *et al.*, (2003) analysed contrasting soil types, namely a poorly drained Te Kowhai silt loam (*Typic Orthic Gley*; *Typic Endoaqualf*) and free-draining Kereone silt loam (*Typic Orthic Allophanic*; *Typic Udivitrand*). The Te Kowhai soil was investigated under two gravimetric soil moisture contents (53 and 70%), and was trodden by cattle (350 cows ha^{-1}) for only four hours; whereas the Kereone soil had gravimetric soil moisture content of 79%, and was trodden by cattle for 24 hours. Despite the wetter soil conditions and longer treading time for the Kereone soil, it had soil surface roughness index of 8.2% compared with 11.4 - 11.6% for the Te Kowhai soil.

Although soil roughness is usually an indication of deterioration of soil surface conditions, an increase in roughness on hill-soils has the favourable effect of creating indentations for water storage, slowing the rate of water runoff from severely trodden areas and reducing sediment loss (Warren *et al.*, 1986a, 1986b; Warren *et al.*, 1986d; Russell *et al.*, 2001). However, increased canopy cover was found to be more effective than soil roughness in reducing sediment runoff in the Warren studies, and, indeed, more favourable for soil physical conditions.

2.7.2 Bare Ground

An increase in the area of bare ground within a pasture can be caused by several processes, including plant pulling, dung pats, and plant death due to physical damage from treading and burial. Cattle treading increases the area of bare ground in pasture (Ferrero, 1994; Russell *et al.*, 2001; Elliott *et al.*, 2002). Pressing herbage into the soil and subsequent burial by the remoulded soil increases the occurrence of bare ground (Nie *et al.*, 2001a). Higher stocking densities during grazing resulted in greater herbage death, hence, more bare ground (Warren *et al.*, 1986a, 1986b).

Reported bare ground values following cattle treading were higher for clay soils (48% of soil surface) compared with a longer period of treading at the same stocking density on a free-draining soil (26%) (Drewry *et al.*, 2003). Modelling inter-rill erosion of hill clay/silt loam soils suggested bare ground may be as much as 70% after severe cattle treading (70 cows ha^{-1}, treading for up to 3 days) (Elliott *et al.*, 2002). Drewry *et al.* (2003) reported a bare ground frequency of 46% for a Te Kowhai soil after treading treatment (350 cows ha^{-1} for 4 hours). However, the creation of bare ground is not confined to wet soils. Severe animal treading of dry soil can also result in long-lasting open spaces within the sward (Kelly, 1985; Harker *et al.*, 2000).

Areas where bare ground has increased due to treading activity are more susceptible to further treading damage than are those with pasture cover (Betteridge *et al.*, 1999). As herbage in *Lolium perenne*/*Trifolium repens* swards grazed by cattle tends to be of a low density, direct contact of some cattle hooves with the soil surface occurs with greater potential damage than in a dense sward developed under sheep grazing (Climo & Richardson, 1984).

Analysis of artificially created bare ground in sheep-grazed *Lolium perenne*/*Trifolium repens* pasture showed that bare ground may persist for up to 25 weeks after creation (Marriott *et al.*, 1997), although the persistence period was less in ungrazed pastures. Additionally, bare ground persistence depends on the size of the bare area, as smaller areas have a greater edge to area ratio and tend to be colonised more rapidly by edge plants (Arnthórsdóttir, 1994). Larger areas of bare ground tend to recover mainly via seed colonisation. Large bare areas have a more hostile environment for re-colonisation, so they tend to persist for longer than smaller bare areas (Sheath & Boom, 1985c).

2.8 The Effects of Treading on Sward Parameters

2.8.1 Sward Botanical Composition

Early studies showed that sward botanical composition may change following animal treading as less treading-tolerant sward species are replaced with more tolerant, but possibly less desirable, species (Harris & Brougham, 1968). Some of the sward botanical compositional changes have been attributed to intolerance of animal treading (Edmond, 1962), however, botanical changes in swards are complex, where additional stress factors such as soil moisture and fertility exist (Sheath & Boom, 1985b), and the temperature of exposed bare soil (Sheath & Boom, 1985c) co-interact influencing the final sward botanical composition (Tothill, 1978).

Germination of seed of volunteer species in bare ground may result in sward botanical composition change. *Poa annua* is often present in grazed swards as the result of its prolific seed production and colonisation abilities (Lambrechtsen, 1992; Kemp *et al.*, 1999), favouring occupancy of spaces created by treading activity.

Severe cattle treading can also decrease *Trifolium repens* content, as was shown by Ward and Greenwood (2002) when 250 cows ha^{-1}, on an 8-hour rotation on soil susceptible to pugging damage, eliminated *Trifolium repens* from sward. Moderate and severe cattle treading has been shown to decrease sward *Trifolium repens* content by 38 and 65%, respectively, and these reductions were greater than those recorded for *Lolium perenne* (Menneer *et al.*, 2001). The loss of *Trifolium repens* from the sward decreased nitrogen fixation rates by 28% for the moderate treading and 70% for the severe treading (Menneer *et al.*, 2001).

Botanical change has also been reported for sheep grazed swards, however, comparisons with cattle grazing may be problematic as sheep preferentially select herbage differently to cattle (Dudzinski & Arnold, 1973). Furthermore, mixed grazing of cattle and sheep on *Poa* *pratensis* (Kentucky bluegrass)/*Trifolium repens* pasture was found to alter the proportional distribution of species compared with either cattle-only or sheep-only grazing (Abaye *et al.*, 1997).

An Australian study showed that little change can occur in sward botanical composition in response to cattle treading (Nie *et al.*, 2001a), when there is limited recruitment of plants from natural reseeding. As modern New Zealand sward predominately consists of more treading tolerant plant species such as *Lolium perenne* (Kemp *et al.*, 1999), changes in sward botanical composition due to treading need not necessarily be expected. However, the dominance of treading tolerant species within a sward may only hold true if tolerant species survive the treading. If tolerant species are exterminated due to excessive treading damage large open spaces are created and less favourable, and possibly inferior plant species, may then successfully colonise (Marriott *et al.*, 1997).

Opportunistic colonisation of open spaces after severe cattle treading has been observed, where, for example, a pre-existing *Capsella bursa-pastoris* (shepherds purse) population was found to increase when heavy grazing of a *Bromus inermis/Bromus riparius* (smooth bromegrass/meadow bromegrass) sward during a dry season caused restricted re-growth of *Bromus* into open spaces (Harker *et al.*, 2000). However, the subsequent *Capsella bursa-pastoris* population declined after further grazing, suggesting that when conditions are favourable, grasses can out-compete invasive weeds (Harker *et al.*, 2000).

2.8.2 Sward Tiller Density

Tiller density is defined as the number of individual grass tillers per given area, and is an important indicator of sward vigour (Mitchell & Glenday, 1958). As treading has a direct effect on plants by the crushing effects of hooves (Edmond, 1958; Brown & Evans, 1973), tiller density can provide an indication of plant damage. Low tiller density in all seasons is an indication of low plant vigour, hence, low annual herbage productivity (Edmond, 1958; Brougham *et al.*, 1960). Tiller density varies depending on changes in herbage mass, light, water and nitrogen supplies, and canopy height (Bircham & Hodgson, 1983; Grant *et al.*, 1983; Tallowin *et al.*, 1989; Bahmani *et al.*, 2003). Hence, it is important that tiller density analysis is carried out at a consistent canopy height.

A field investigation of tiller response to cattle treading and subsequent recovery showed that there was little change in individual tiller weight, however, there was an associated reduction in tiller numbers of 54% that was linked to a 56% decrease in herbage growth rate (Pande, 2002). Pande *et al.* (2000) reported a 36% decline in all grass tiller densities (4,590 compared with 7,140 tiller m^{-2}) seven weeks after cattle treading on a Tokomaru soil. A study by Edmond (1962) on a mix sward found that ryegrass (*Lolium perenne* L.) tiller density was 75% less seven weeks after sheep treading on a silt loam.

The subsequent recovery of herbage growth rate was attributed to an increase of tiller leaf area and the emergence of replacement tillers (Pande *et al.*, 2002). However, the response of tillers may vary depending on site conditions and soil type, where an increase in dry bulk density of a clay loam soil supporting *Bromus enermis* resulted in detrimental responses expressed mainly as a reduction in herbage mass rather than tiller density (Mapfumo *et al.*, 1998).

2.8.3 Sward Productivity

Severe treading damage has been associated with a decrease in herbage growth rate and a decrease in potential herbage on offer to animals, where, for example, cattle treading on a wet silt loam hill-soil was found to result in 300-360 kg DM ha^{-1} of initial herbage on offer being pressed into the ground (Sheath & Boom, 1997). Severe cattle treading damage in winter has been associated with a decline in herbage accumulation in the following spring of 40-42% (Nie *et al.*, 2001a), a 54% reduction in herbage accumulation rate (Pande *et al.*, 2000), and a 9% decline in herbage accumulation when simulated dairy cow treading was carried out over a year (Di *et al.*, 2001; Drewry *et al.*, 2001). However, the decrease in herbage accumulation is dependent on the severity of treading damage, where, for example, light cattle treading damage (low stocking density) can result in no significant decrease in herbage accumulation (Nie *et al.*, 2001a).

Damage to the sward by the direct action of hooves has been suggested as the primary cause of a reduction in herbage accumulation following a winter grazing by sheep (Drewry *et al.*, 1999). Herbage damage has been associated with leaf death in ryegrass (Gradwell, 1965). Plant roots may also be affected by cattle treading, such that even a light grazing by cattle (50% removal of herbage mass) decreased total root mass (Mapfumo *et al.*, 2002). Soils that have a compacted layer within the profile as the result of cattle treading, have restricted root growth (Brown & Evans, 1973; Willatt & Pullar, 1984; Tollner *et al.*, 1990; Ferrero, 1991), hence, decrease potential herbage accumulation rates (Figure 2.6).

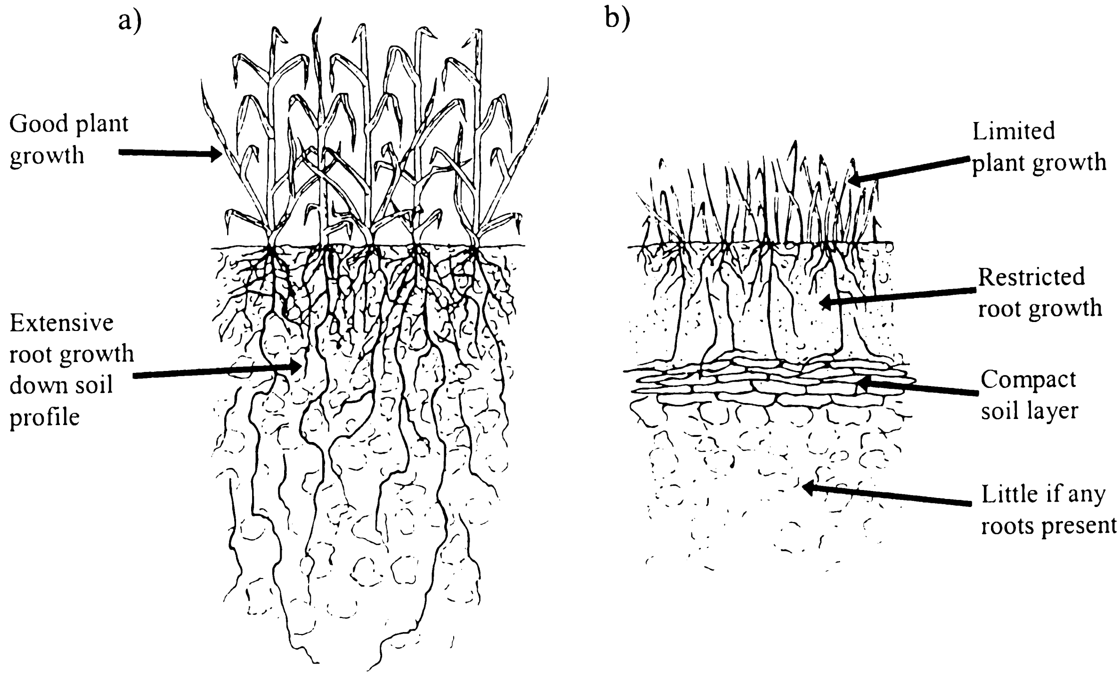


Figure 2.6 Root growth and restriction, where a) has non-restricted root growth, and b) restricted root growth and underdeveloped herbage growth due to a compacted layer in the rooting zone (adapted from Haynes, 1995 - used with permission of MAF Policy).

Plant burial by cattle treading was highlighted as the main cause of change in ryegrass tiller dynamics, which was then correlated with decreased amounts of herbage accumulated compared with controls (Pande *et al.*, 2000). The most significant declines in herbage accumulation after treading damage are commonly reported for about seven to nine weeks following treading damage, after which recovery begins to minimise differences in pasture productivity (Nie *et al.*, 2001a). Pande *et al.* (2002) reported that seven weeks after treading damage on a hill-soil, herbage accumulation was nine to 19% less (260 to 840 kg DM ha^{-1}) for trodden areas compared with controls, while Nie *et al.* (2001a) reported that 'heavy pugging' resulted in about a 40% decline (3,734 kg DM ha^{-1}) in herbage accumulation nine weeks after treading damage. Drewry *et al.* (2003) found that seven weeks after a one-off severe treading event on a Te Kowhai soil herbage accumulation in pugged areas was 331.5 kg DM ha^{-1} compared to 603 kg DM ha^{-1} for controls.

Short-term effects of severe cattle treading on herbage accumulation, however, may be misleading when extrapolated over a whole year, as more rapid herbage growth due to mineralisation of nitrogen and associated botanical compositional changes may not occur until months after the treading (Ward & Greenwood, 2002). Nie *et al.* (2001a) also largely attributed decreased herbage accumulation to plant burial, and Pande *et al.* (2002) suggested subsequent rapid sward recovery was due to tiller re-emergence from the soil.

Recognising that the effects of treading by sheep differ from cattle due to grazing habit (Abaye *et al.*, 1997) and animal weight (Willatt & Pullar, 1984), long-term sward compositional changes and individual responses of grass species in sheep grazed areas may provide some indication of the sensitivity to cattle treading damage. *Lolium perenne* and *Phleum pratense* growth rates were not significantly affected by treading of sheep during autumn and winter (Brown, 1968b). However, in contrast, *Dactylis glomerata* and particularly *Agrostis tenuis* showed decreased herbage growth during the same period, and the response of *Trifolium repens* was strongest in winter (Brown, 1968b). On hill-soils, Sheath and Boom (1985a) found that hard grazing by sheep resulted in greater annual herbage consumption even though herbage growth was less than under lax grazing. The difference in herbage consumption was attributed to the increased flow from live herbage to dead within the denser and heavier herbage mass on lax grazed sward (Sheath & Boom, 1985a).

There are few New Zealand data showing direct relationships between soil physical properties and herbage accumulation rates (Drewry *et al.*, 2002), however, there has been work carried out for cropping situations (Carter, 1988, 1990). Some recent data links herbage accumulation with soil physical conditions (Drewry *et al.*, 2002); soil macroporosity at the

0-5 cm soil depth was linked to immediate herbage growth. Macroporosity at 5-10 cm soil depth was correlated to spring growth (Drewry *et al.*, 2001), whilst Drewry and Paton (2000a) reported a macroporosity of 0.08 cm^3 cm^{-3} at 5-10 cm soil depth correlating with a 19% reduction in spring herbage accumulation.

2.9 Recovery after Treading Damage

2.9.1 Natural Recovery of Soil

Natural recovery of soils after severe animal treading damage is slow and full recovery is not always observed. Often natural recovery and soil resilience was attributed to inherent soil processes such as shrinking and swelling of clays, freezing and thawing (Koenigs, 1963), root growth, pedo-turbation, and earthworm activity (Aubertin & Kardos, 1965; Greacen & Sands, 1980; Tisdall & Oades, 1982; Abdel-Magid *et al.*, 1987; Grevers & de Jong, 1990; Awadhwal & Singh, 1992; Taboada & Lavado, 1993; Volkmar & Entz, 1995; Hewitt & Shepherd, 1997). Earthworms are important in pasture soils (Stockdill, 1982; Haynes *et al.*, 1995) that have excessive compaction, as earthworms can burrow through soil with a penetration strength up to 3.5 MPa, and where plant root elongation was decreased to 20% of the maximum (Dexter, 1987). However, after severe treading (1,000 cows ha^{-1} for 45 minutes) earthworm populations were up to 85% lower in trodden than untrodden areas (Cluzeau *et al.*, 1992), diminishing the potential recovery rate from earthworm activity (Edmond, 1963; Lobry de Bruyn & Kingston, 1997). Despite recovery of compacted soils often being attributed to earthworm activity, little validation work has been carried out. If an irrigation facility is installed, it may be possible to speed up natural processes of soil recovery by incorporating phases of irrigation to allow for re-occurring cycles of wetting and drying, to improve soil conditions at modest cost (Dexter, 1991).

To date there has been little comparative work carried out on the recovery of soil physical properties after a one-off severe treading event, especially in soils maintained as part of a rotational grazing cycle. Research has focused on recovery of soil with grazing exclusion (Stephenson & Veigel, 1987; Greenwood *et al.*, 1998; Drewry & Paton, 2000a). Typically, some evidence of recovery within months after soil compaction was found; but recovery back to pre-damage conditions takes longer (Orr, 1975; Greenwood *et al.*, 1998; Elliott *et al.*, 2002). Short-term recovery (over 21-weeks) of the Te Kowhai silt loam and Kereone silt loam soil, after one-off severe cattle treading event followed by grazing exclusion was monitored by Drewry *et al.* (2003). These workers reported that both soils were detrimentally affected by cattle treading and recovered by natural processes over five months with improvements in saturated hydraulic conductivity being most rapid, probably because of earthworm activity.

Monitoring recovery of soils excluded from further treading has been carried out over longer periods (1.5 and 2.5 years) for three previously cattle-grazed Southland, New Zealand, silt loam soils (Drewry & Paton, 2000a)and three previously sheep-grazed Australian silt loams (Greenwood *et al.*, 1998). Recovery of soil macroporosity, air permeability and hydraulic conductivity, was largely restricted to the surface 0-5 cm layer, with limited recovery at the 5-10 cm soil depth (Greenwood *et al.*, 1998; Drewry & Paton, 2000a; Drewry *et al.*, 2003). Some recovery of hydraulic conductivity after grazing exclusion has been reported after 30 days (Warren *et al.*, 1986c), while others report that full recovery (to pre-damage levels) of hydraulic conductivity can occur after six months (Elliott *et al.*, 2002). Grazed *Poa pratensis* on two silt loams soils, in the USA, which were excluded from further cattle treading, showed significant recovery in hydraulic conductivity and macropore volume in the 0 – 5 cm soil layer only after two years, but no change in the subsoil was recorded after four years (Orr, 1975). Agricultural compaction on clay loam in the USA showed little recovery after nine years (Blake *et al.*, 1976), whilst 12 years of grazing exclusion of a cattle trodden Argentinean sodic silt loam soil did not improve soil structure (Lavado & Alconada, 1994).

Comparing ungrazed areas to those stocked with 10, 15, and 20 sheep ha^{-1}, on three Australian silt loam soils over 30 years, showed only small differences in soil properties, suggesting that maintenance of pasture cover rather than soil physical properties should be given the highest priority (Greenwood *et al.*, 1997).

Soil conditions in areas excluded from grazing are different to those included in a continuous grazing rotation. Soils in a continuous grazing rotation receive regular treading damage and, therefore, have less natural recovery. The differences between soils that are in a grazing rotation and those not grazed may effect some monitoring programmes such as for nitrous oxide emissions from grazed soils (Drewry *et al.*, 2003). Recovery that has taken place in soils under rotational grazing is often offset by the effect of renewed treading (Greenwood & McNamara, 1992). Given that natural recovery of soil is slow and renewed treading offsets recovery, soils under grazed pastures will always have some soil damage due to animal treading, and natural processes will not provide full recovery of soil.

2.9.2 Mechanical Amelioration of Soil

Recovery of damaged soils may be aided by mechanical means (McLaren & Cameron, 1993). Shallow mechanical loosening of soil (also called deep-ripping, sub-soiling or aerating) is especially effective in reducing compaction (Chapman & Allbrook, 1987; Burgess, 1998; Burgess *et al.*, 2000; Drewry *et al.*, 2000; Drewry & Paton, 2000b; Olsson *et al.*, 2002; Milne & Haynes, 2004b). The use of shallow mechanical loosening with conventional tines and wing-shaped tines increased macroporosity volume by 50%, and saturated hydraulic conductivity and air permeability by 200%on a sheep grazed Waikiwi silt loam (*Typic Firm Brown* soil) (Drewry & Paton, 2000b). The effects of mechanical loosening of soil were noted up to 22 months after treatment. Shallow mechanical loosening of an intensively cattle grazed and compacted Te Kowhai silt loam decreased penetration resistance by up to 1 MPa, the degree of soil packing by 50%, soil dry bulk density by 0.2 Mg m^{-3}, and increased total porosity and macroporosity by about 9% (Burgess *et al.*, 2000). Despite improvements to soil conditions following mechanical loosening, herbage growth may not be immediately enhanced (Chapman & Allbrook, 1987). Lack of pasture response has been attributed to dry soil conditions at the time of shallow mechanical loosening (Chapman & Allbrook, 1987; Burgess *et al.*, 2000; Drewry *et al.*, 2000), although, long-term response by the sward to more favourable soil conditions after mechanical loosening will eventually improve herbage growth (Burgess *et al.*, 2000).

2.9.3 Recovery of the Sward Following Treading

Sward recovery following cattle treading tends to be more rapid than soil physical recovery, suggesting that tiller dynamics and plant growth may be a better indicators of sward damage than soil conditions (Betteridge *et al.*, 2002). However, the long-term effects of deterioration in soil physical properties on herbage growth rates are poorly understood (Drewry *et al.*, 2002). Furthermore, sward recovery from areas excluded from grazing (hence, intermittently mechanically cut) differs from those exposed to grazing, causing difficulties in developing predicative models of herbage growth (Johnson & Parsons, 1985).

The rate of sward recovery varies (Sheath & Carlson, 1998) and is largely dictated by individual species persistence and their ability to grow rapidly. As tissue turnover and formation of new tillers occurs continuously, how this plant phenomenon influences recovery from immediate cattle treading damage has not been well researched (Pande, 2002). Initial rapid recovery after severe treading is from tiller re-emergence after a short period of burial. Therefore, tiller density measured immediately after severe treading may not be a true reflection of actual tiller density (Pande *et al.*, 2002). Furthermore, areas of soil 'typically' trodden and pugged by dairy cattle (300-400 cows ha^{-1} for 12 hours) on clay/silt loam soils, appeared to have recovered after 18 months (based on visual assessment of pastures), however, assessment of soil physical properties indicate that the soil had not fully recovered (Singleton & Addison, 1999). Such findings show that 'apparent' sward recovery may not be a good indication of soil recovery.

Often after pugging damage the sward may not re-establish by natural processes (Figure 2.7), and reseeding, coupled with careful spring grazing management, has been recommended for more rapid recovery of damaged swards and to avoid long term declines in herbage growth (Awan & Kemp, 1994; Sheath & Boom, 1997).

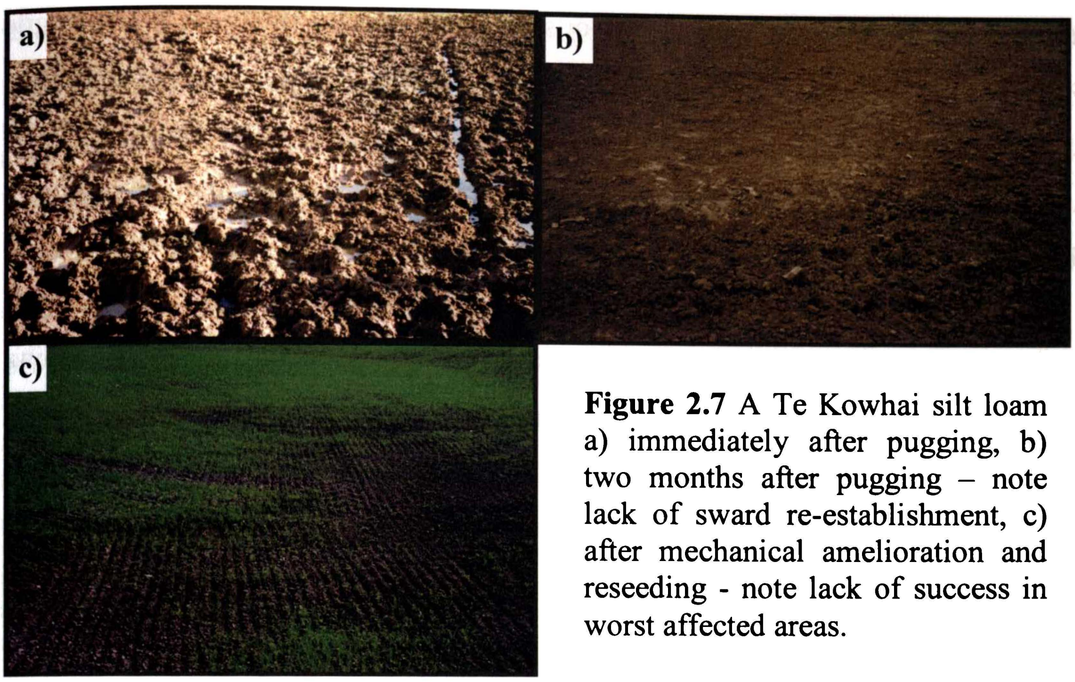


Figure 2.7 A Te Kowhai silt loam a) immediately after pugging, b) two months after pugging – note lack of sward re-establishment, c) after mechanical amelioration and reseeding - note lack of success in worst affected areas.

2.10 The Effects of Treading on the Wider Environment

2.10.1 Sediment and Nutrient Runoff

Severe cattle treading damage on hill-soils can increase sediment runoff to waterways (Campbell, 1950; Nguyen *et al.*, 1998; Sheath & Carlson, 1998; McDowell *et al.*, 2005), especially where limited pasture cover exists and regardless of soil roughness (Betteridge *et al.*, 1998). Hard grazing regimes may also increase sediment runoff from farmed hill-country to waterways more so for cattle grazed than for sheep grazed areas (Lambert *et al.*, 1985), where the former had a sediment loss of 2,740 kg ha^{-1} $year^{-1}$ and the later 1,220 kg ha^{-1} $year^{-1}$. Increasing stocking rates from 2.0 to 3.1 cows ha^{-1} over three years for undrained sites increased nitrate losses by runoff by 60% and phosphorus by runoff by 61% higher (Smith & Monaghan, 2003). If fertiliser had more regularly been used, and herbage consumption was closer to the optimum, then sediment and nutrient runoff would have been even greater (Lambert *et al.*, 1985). However, nutrient runoff tends to be spasmodic, resulting in periods of concentrated and more environmentally damaging runoff (McColl *et al.*, 1977).

Whilst most studies are carried out on moist soils, hard grazing by sheep on a dry fragile semi-arid soil has also been shown to increase sediment runoff. The increase was attributed to particle detachment by hoof action without subsequent re-aggregation because of dry conditions (Greene *et al.*, 1994). Attempts have been made to account for cattle treading in soil loss equations by the inclusion of a 'trampling ratio' (Savabi & Gifford, 1987). The creation of the trampling ratio was based on field experiments of two artificially created soils (silt loam and a clay loam), on a 5% slope, and trodden by cattle to obtain a range of treading damages (0 to 90% of soil surface trodden). The soils were placed under different levels of artificial canopy cover, subjected to simulated rainfall, and sediment runoff was measured. The trampling ratio was successfully incorporated into the modified universal soil loss equation (r^2 ~0.90) (Savabi & Gifford, 1987).

Treading of croplands, which is practised in some South Island agricultural areas, increased sediment runoff by 25% per year with a 250% increase in phosphorus loss mainly attributed to overland flow of cattle dung, compared to untrodden croplands (McDowell *et al.*, 2003). Sediment runoff from grazed pasture also tends to have elevated levels of pathogens, which adversely affects water quality (Nguyen *et al.*, 1998). An investigation in Nigeria showed that over-grazing by cattle of fragile soils resulted in the 15% decrease in soil porosity and a 59% reduction in hydraulic conductivity, which augmented erosion of these soils (Asadu *et al.*, 1999).

2.10.2 Augmentation of Greenhouse Gasses

As severe treading damage decreases soil aeration and hydraulic conductivity, it is likely it contributes to greenhouse gas production. Nitrous oxide contributes about 16% (on a CO_2 equivalent basis) of New Zealand's greenhouse gas emissions (Saggar *et al.*, 2002). Studies have shown that nitrous oxide emissions can be up to seven-fold higher in compact pasture soils (with 11% higher soil dry bulk density) than in uncompacted soils (Carran *et al.*, 1995; McTaggart *et al.*, 1997; Bhandral *et al.*, 2003). Soil properties associated with severe treading, such as decreased aeration and long periods of excessively wet conditions, have been linked to increased carbon dioxide, methane, and nitrous oxide emissions (Oenema *et* *al.*, 1997). For example, when soil volumetric moisture content exceeded 85%, nitrous oxide emission increases were 9-fold higher compared with a soil at less than 58% volumetric moisture content (Ruser *et al.*, 1998). Increased nitrous oxide production from a Scottish pastoral clay loam soil has been associated with farm vehicle compaction, where emission rates were increased up to 260 g N ha^{-1} day^{-1} (46% increase compared to uncompacted soils) and was associated with a decrease of 9% in macroporosity (Ball *et al.*, 1997). Therefore, preventing soil structure damage, and amelioration of soils where damage has occurred, could mitigate emission rates of greenhouse gases (de Klein & Clark, 2002).

2.10.3 Leaching of Nutrients

Pugging damage may lead farm managers to apply greater amounts of the nutrients that are commonly leached, such as nitrogen, to compensate for decreases in herbage accumulation. An investigation of cattle treading effects found a 15.6% decreases in spring growth (Mullen *et al.*, 1978). However, when nitrogen fertiliser was used in trodden and control areas the difference between treatments became less (4.6%), indicating that the use of nitrogen can mask some of the effects of treading on herbage accumulation (Mullen *et al.*, 1978). Additionally, it has also been reported that severe treading by cattle can decrease *Trifolium repens* content by 65% and, consequently, nitrogen fixation rates by 70% (Menneer *et al.*, 2001). The decreased herbage growth rates and organic nitrogen levels in soil may also encourage the use of increased rates of fertilisers. As the use of nitrogen fertiliser, such as urea, is extensive in New Zealand (McLaren & Cameron, 1993) and as nitrogen is readily leached, the potential for even higher rates of nitrogen usage has been recognised as a problem (de Klein & Ledgard, 2001).

2.11 Beneficial Effects of Soil Treading

Most of the above discussion covers detrimental effects of severe treading, when a number of beneficial effects from treading such as suppression of weeds, encouragement of tillering, pest population reduction, and pasture seed establishment have also been reported.

Moderate cattle treading has been noted to suppress broad-leaved weeds (Harker *et al.*, 2000). Consequently, moderate treading activity without considerable plant burial or death, may favour development of swards of treading tolerant plants such as *Lolium perenne* (Kemp *et al.*, 1999). Early winter animal treading on newly sown *Lolium perenne* pasture resulted in the pressing of the plant stem base into the soil and, over a long re-growth period, spreading of individual plants by tillering (Valentine & Matthew, 1999).

Treading has the beneficial effect of reducing sward damage by *Costelytra zealandica* (New Zealand grass grub) invasion on some soils (Betteridge *et al.*, 2003). Cattle treading and pasture rolling in late-July/early-August decreased *Costelytra zealandica* populations by 69%, whilst treading in October further decreased populations by 92% (Atkinson & Slay, 1994). Historically, a cycle of hard grazing or rolling was recommended for *Costelytra zealandica* control (Stewart & van Toor, 1983), with the best results when soil was near saturation (Cossens, 1984). However, such recommendations should be given somewhat cautiously because of the risk of soil compaction and pugging damage, although Atkinson and Slay (1994) did not find a reduction in herbage accumulation rate due to treading and rolling, except for the extreme treatment (eight passes of the roller).

Treading can open a dense sward, creating spaces where seed germination can take place (Bakker, 1985; Hume & Chapman, 1993) and allowing a rejuvenating component to the sward. Treading activity also has the beneficial effect of breaking-up sod-bound swards or those with thatch build-up, such as for *Pennisteum clandestinum* (Kikuyu grass) dominated swards common in Northland, New Zealand (Langer, 1973). As regular light cattle treading with maintenance of a low canopy cover restricts the more competitive ryegrass (Ettema & Ledgard, 1992), it may increase the establishment of *Trifolium repens* seedlings (Awan & Kemp, 1994).

The use of a moderate animal treading as part of pasture sowing has been noted by Pearson and Ison (1987) and Vallentine (1989) to improve seed contact with soil. Additionally, re-sowing on hill-soils should be preceded by hard treading, to open up the existing sward and allow better soil-to-seed contact, followed by another moderate treading event after seeding to further ensure good contact between the soil and seed (Roundy *et al.*, 1990; Hampton *et al.*, 1999). Although some seed may be pressed into the soil too deep, a light treading generally resulted in better sward establishment (Roundy *et al.*, 1990). Additionally, the creation of bare ground by a one-off severe treading, before seeding, has phytochromatic benefits by altering the ratio of red/far red light (Deregibus *et al.*, 1994).

Moderate compaction of soils with high macropore volume (e.g. soils cultivated prior to sowing of pastures or porous soils in dry regions) has been found to increase water holding capacity (Roundy *et al.*, 1990), which may lead to greater herbage growth during drier summer months compared to soils with less soil compaction (Naeth *et al.*, 1991; Douglas, 1997). However, such practices must be carried out with care, as too much compaction will have detrimental effects to aeration and hydraulic conductivity (Gradwell, 1965; Drewry & Paton, 2000a) and for soils under long-established pastures and subjected to moist climates, no benefit will be gained.

2.12 Modelling Soil and Pasture Responses to Cattle Treading

2.12.1 Introduction

The use of models to describe the response of soil or pasture has been reported in the literature. Models are often developed in response to declining pasture productivity, increasing costs, or detrimental effects on the environment (Mason *et al.*, 2003b). Development of models has commonly been restricted to processes and relationships between two variables (i.e. two pasture variables) but recently more complex farm-scale or catchment-scale models have been developed. Modelling approaches are either statistical (empirical or regressional) or mathematical (simulated or computer-based) (Flury & Riedwyl, 1988;

Fahrmeir & Tutz, 1996). The terms 'predictive', 'dynamic', 'deterministic' and 'stochastic' are also used to describe the model type, and these models are essentially mathematically based. Generally, mathematical models build upon relationships established in pre-existing statistical models, however, some reported models use a mix of both approaches (Di & Cameron, 2000; Finlayson *et al.*, 2002).

Despite the reliance of mathematical models on statistical modelling, reported soil and pasture models have predominantly been mathematical (or have large mathematical components) rather than 'pure' statistical models. The predominance of mathematical models may be a reflection of the recent drive to model environmental processes using findings from research that was not initially intended to be used for large-scale modelling. Additionally, soil and pasture modelling has been largely driven by mathematicians (for example O.J. Cacho, A.H. Elliott, J.D. Finlayson, Y. Tian) rather than soil scientists or agronomists, with the aim of deriving a 'global' explanation of processes, therefore, not being able to depend solely on statistics. Large mathematical models have considerable challenges in respect of cumulative uncertainties (Lee jr, 1973), however, attempt to overcome these by using smaller sub-models.

2.12.2 Modelling Soil Dynamics

Modelling of soil processes has predominately focused on soil chemical changes and its processes, such as leaching and fertiliser optimisation (e.g. Bear *et al.*, 1998; Bowden *et al.*, 2000; van Alphen & Stoorvogel, 2000; Viscarra Rossel & McBratney, 2000; Vellinga *et al.*, 2001; Milham *et al.*, 2004). Some models of soil chemical changes have included soil physical properties, however, primarily as supportive variables rather than primary variables (Vellinga *et al.*, 2001; Cross *et al.*, 2003).

Work on modelling soil physical properties their interaction and behaviour in response to cattle treading has been limited. However, the inclusion of soil physical properties such as soil dry bulk density, porosity, and hydraulic conductivity, have been suggested for further research (Merdun & Quisenberry, 2004). The effect of cattle treading on inter-rill erosion has been modelled using artificial precipitation on hill-soils (Elliott *et al.*, 2002). The dominant variables were bare ground area and runoff rates. The Elliott model was further developed into three sub-models to allow for sediment concentration in runoff, quantity of runoff, and change in bare ground. The combined Elliott model, however, had limited effectiveness in the estimation of sediment loading in runoff (r^2 = 0.46 - 0.61), suggesting that other, untested, variables are also important.

Modelling of cattle treading effects on the rate of water infiltration into soil has also been carried out for clayey and silty hill-soils (Tian *et al.*, 1998). The Tian model includes variables that account for soil damage, soil moisture, organic matter, and soil chemistry, and was able to accurately estimate resultant infiltration rate (r^2 = 0.53 – 0.73). Tian *et al.*, (1998) suggested that the model could be used in conjunction with catchment models and would best benefit from being incorporated into large-scale simulation models on nutrient and sediment loss from hill-soils. Several attempts to model unsaturated flow have been carried out, usually based on modified versions of the Arya-Paris model, and often claim high predictability (r^2 = 0.85 - 0.97) (Arya & Paris, 1981; Vereecken *et al.*, 1990; Vereecken, 1995; Chaudhari & Batta, 2003). These models, however, require inclusion of saturated flow rates, and properties such as pore tortuosity and soil matrix packing density are used as scaling factors (adjustable mathematical variables) (Arya *et al.*, 1999a; Arya *et al.*, 1999b; Chaudhari & Batta, 2003).

Modelling of saturated hydraulic conductivities, using soil properties such as porosity, volumetric moisture content, and texture, have also been carried out for a range of Australian soils (Paydar & Ringrose-Voase, 2004). However, the models failed to predict saturated hydraulic conductivity when land management had affected soil structure by, for example, compaction of macropores or soil crusting (Paydar & Ringrose-Voase, 2004).

2.12.3 Modelling Pasture Dynamics

Modelling of pasture productivity and herbage growth habit in response to change has been carried out more extensively than modelling of soil physical property responses. Biophysical approaches are often used to develop simulated models to describe and, hence, estimate and optimise herbage yield, daily milk yield, and farm productivity (Cross *et al.*, 2003). The common soil variables included in pasture models are moisture properties and amount of nitrogen addition. However, pasture models assume grazing under normal conditions and exclude one-off effects of, for example, severe treading damage.

Pasture productivity models have been developed, as part of the AgResearch, New Zealand, Whole-Farm Dairy Production Model, to describe herbage growth and green-dead tissue flow dynamics for *Lolium perenne* swards (McCall & Bishop-Hurley, 2003). The Whole-Farm model was extrapolated further by the inclusion of scaling factors that allow for soil fertility and the effect of sward composition on productivity patterns. Site calibration was required but the Whole-Farm model estimated pasture productivity for 40 of the 42 sites within the 95% confidence intervals of the mean (McCall & Bishop-Hurley, 2003). A similar large-scale modelling approach was also adopted by Australian researchers with the development of the Sustainable Grazing Systems Pasture Model (SGS model), a biophysical simulation model (Mason *et al.*, 2003a; Price, 2003; Sanford *et al.*, 2003). The SGS model, which was developed primarily for use by researchers, depends on a vast range of variables including stocking density (sheep), and stocking management (continuous vs rotational grazing), but soil physical variables were limited to infiltration rates and soil moisture contents (Andrew *et al.*, 2003; Johnson *et al.*, 2003; White *et al.*, 2003).

Modelling productivity of sheep-grazed native pastures in Australia showed that biophysical data indicated that evapotranspiration was a major variable (Lodge *et al.*, 2003), possibly a reflection of the dry Australian climate and, therefore, may not easily be used in New Zealand conditions. Similarly, pasture productivity simulation models developed for Texan rangelands may also be restricted by climatic conditions, however, the Texan model did try to compensate by the inclusion of 'high' rainfall (~1,000 mm yr^{-1}) areas (Kiniry *et al.*, 2002). The Kiniry model was unique as it included soil series information for 20 soil types, was based on 60 years of data, and allowed for a further 10-year period for model equilibration (Kiniry *et al.*, 2002).

Pasture productivity has been modelled, using a flexible sigmoid equation (mathematical model), to describe herbage growth (Cacho, 1993). The Cacho model was adaptable and estimations of herbage growth could be made by inclusion of values obtained statistically or algebraically from physiological simulation models (Cacho, 1993). However, the Cacho model was based on herbage growth habits and did not include treading effects to soil or pasture or allow for one-off severe events (e.g. pugging) that could a major influence on herbage growth. The model may best be used in conjunction with more complex grazing models (Cacho, 1993). Other farm-scale (or large-scale) models, that describe pasture productivity and herbage growth are limited to 'typical' conditions and become unreliable when one-off detrimental events occur (Cacho *et al.*, 1995; Finlayson *et al.*, 1995). Herbage-based variables are often the main component in pasture productivity simulation models, however, rarely accounting for how changes in non-herbage based variables (e.g. soil physics) influenced herbage-based variables. Sensitivity analysis on the determination of pasture productivity in some farm-scale models found that a better understanding of variables that effect herbage growth was required (Doyle *et al.*, 1989), including soil physical properties and treading effects.

2.12.4 Modelling Interactions between Treading, Soil, and Pasture Productivity

Modelling of cattle treading effects on soil and pasture has been limited. Tian *et al.*, (1998) and Elliot *et al.*, (2002) attempted to include cattle treading as an independent variable to describe model behaviour of soil physical properties, however, the models did not include pasture productivity estimations. Similarly, work by Savabi and Gifford (1987) on cattle treading of soil was restricted to modelling sedimentation runoff rates so that treading effects could be included as a variable in the Modified Universal Soil Loss Equation.

Pasture productivity was modelled when describing cattle treading effects for a hill-soil, initially using a statistical approach and then was further developed into a mathematical model to allow for simulation (Finlayson *et al.*, 2002). The Finlayson model uses up to 20 variables to describe herbage response to cattle treading and consists of two sub-models to distinguish between responses of herbage on slope and track areas. The Finlayson model accurately estimates subsequent pasture productivity ($r^2 = 0.73 - 0.75$, adj. $r^2 = 0.48 - 0.52$). The Finlayson model was developed for hill-soils and, possibly, only applies to situations such as that of the Ballantrae site (Finlayson *et al.*, 2002) and not to lowland sites. A multivariate regression model (statistical) has been developed to accommodate some soil physical properties (K_{40}, soil moisture, porosity), along with soil chemical properties and topography, to predict herbage accumulation (López *et al.*, 2003). The López model showed that the differences between slope and track were stronger than management treatments, thus the model use will be particular to hill-soils only.

Bromus inermis L. and *Medicago sativa* L. were analysed after simulated compaction of clay soils to develop a generalised-linear model (statistical model) of herbage response to increases in soil dry bulk density (Mapfumo *et al.*, 1998). The model was based on the use of individual variables (i.e. it was not a multivariate regression model) to accurately estimate response by herbage properties (e.g. shoot biomass, leaf area, etc) 78 days after compaction (mean $r^2 = 0.65$).

Work is in progress at AgResearch Ltd and Massey University (Betteridge *et al.*, 2002; Betteridge *et al.*, 2003) to develop a decision-support model (mathematical model) called TREAD Ready Reckoner. The model is being developed to give farmer managers a support tool to allow better decision making with regard to the use of soils susceptible to cattle treading damage. The TREAD model requires input data from the AgResearch Penetrometer, which measures the penetrability of soil, therefore, soil susceptibility to pugging damage (Betteridge *et al.*, 2003).

2.13 Sustainability of Soil Use

Sustainable use of soil is a desirable goal, but one that has been difficult to define. For soil to be successfully sustainably managed the grazing system needs to enhance the environment and long-term resource base, while providing production that is economically viable and enhances quality of life (Valentine & Kemp, 1999; van Bruchem *et al.*, 1999). In New Zealand, sustainable use of natural resources, such as soils, is covered by the Resource Management Act (RMA) (1991). The RMA was introduced to "...promote the sustainable management of natural and physical resources", where sustainable management was taken to mean "managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well being" (New Zealand Government, 1991, Part 2.5). Agricultural development and intensification has resulted in greater environmental pressure (Lilburne *et al.*, 2002), and the effects of treading have been highlighted as a concern to the continual viability of soil use (Taylor *et al.*, 1997; Sparling & Schipper, 2002). Any grazing system, irrespective of the approach, will have some detrimental effects (Horne & Singleton, 1997; Sheath & Boom, 1997), however, the first step in sustainable use of soil is avoidance of irreparable damage.

Several grazing management approaches have been put forward to avoid or minimise the effects of cattle treading damage, such as on/off grazing (Drewry, 2003), and the use of free-draining soils during the wet season (Bowler, 1981). Minimising the period of soil susceptibility to pugging damage can be achieved by soil modification, such as drainage (Haynes, 1995). Furthermore, avoidance of further treading allows for some natural soil recovery of pre-existing damage to take place. If damage is allowed to continue, soil looses its resilience and versatility, contributing to environmental decline (Asadu *et al.*, 1999). Merely introducing sustainability to soils does not imply that all resources are used sustainably. For example, no winter grazing (such as that in Europe) will greatly improve soil conditions, however, it also results in off-site feed production, harvest, transportation to site, and storage; a system fraught with energy inefficiencies and one that is possibly more detrimental to the environment as a whole (Horne & Singleton, 1997). As there are no standard solutions and as every soil system is different, the challenge posed for sustainable management of soils is formidable.

2.14 Summary and Conclusion

Agriculture is the primary industry of New Zealand, where pastoral based production amounts to 80% of the agricultural exports. Agricultural production has long been shown to have some detrimental effects on soils. As agricultural technology has developed and economic pressures have increased, the trend has been for intensification of production, causing greater potential for soil damage, such as treading damage. As the New Zealand climate allows for year-long grazing, soils are trodden by cattle when most susceptible to severe treading damage.

Pugging processes and soil susceptibility to pugging damage are complex processes. Pugging damage is the plastic deformation of soil, which destroys the soil structure. Treading that causes pugging damage also results in compaction of lower soil layers. The susceptibility of soil to pugging damage is dependent on soil strength, moisture content and soil texture; hence, some soils are more susceptible to pugging damage than are others. As pugging decreases the rate of water infiltration and movement through soil, pugging is regarded as a self-perpetuating problem. Pugging damage has been shown to decrease herbage accumulation by direct crushing of plants, burial of growing points, creation of bare ground, and causing unfavourable soil conditions for herbage growth. Initial recovery of pugged and compacted soils occurs rapidly, however, estimates of the time required for soil recovery are diverse, and full recovery has not always been observed.

The effects of severe treading damage are not limited to the pastures alone, as flow-on effects to the wider environment have also been found. Increased runoff from lack of canopy cover, sedimentation, and contamination of waterways from excreta runoff are harmful to the environment. Soil pugging and compaction are unsustainable, as pugging and compaction decreases productivity, soil versatility, and soil resilience to further damage, additional to the expense of mechanical amelioration.

Some relevant areas of the cattle treading problem have been well researched; however, the literature has indicated needs for further research. Lack of research on contrasting treatment and comparable treading damage, particularly over the full range of pugging severity, to allow for the establishment of inter-relationships between contributing factors has been noted in the literature (Nie *et al.*, 2001a). Research in the Waikato region has focused on comparative studies of soils with similar levels of pugging damage, usually obtained within three hours of heavy treading by cattle. However, there is a need to research longer treading durations, as commonly practised in the Waikato (Drewry *et al.*, 2003), and to carry out comparative analysis of damage under different cattle treading durations and soil moisture contents.

Although research has focused on direct treading damage to the sward and soil, relationships between herbage growth, treading damage and soil physical properties have been largely neglected (Nie *et al.*, 2001a; Drewry *et al.*, 2004a). Many threshold values for soil physical properties have been suggested in the literature, but have mostly been theoretical (with considerable variation), whilst little research has been based on direct plant response (Mapfumo *et al.*, 1998). A mechanism for estimating treading effects on herbage growth rates has been developed for hill-soils, and such work should also be carried out for lowlands (Finlayson *et al.*, 2002). Therefore, further research is required to determine the relationship between soil moisture, treading duration, and pasture productivity, allowing for a mechanism for prediction of treading effects on pasture productivity from pugging susceptible lowland soils. Further research is also required to determine the rate of sward recovery after a one-off cattle treading event and to establish the relationship between soil physical properties and pasture productivity.

Chapter 3.
Methods

3. Methods

3.1 Introduction.

This chapter will outline laboratory procedures, soil core retrieval methods, and the statistical methods used during the research described in this thesis. Field descriptions, experimental design, and soil descriptions are included in Chapter 4.

3.2 Soil Core Design

Soil physical properties were analysed in the laboratory using undisturbed soil cores retrieved from the experimental sites. Two types of soil cores were collected: porosity cores and hydraulic conductivity cores. Each soil core was held using a PVC core-holder (Figure 3.1). The PVC core-holders used for soil porosity cores were 5 cm high by 10 cm in diameter (393 cm^3 volume). PVC core-holders for soil cores used for hydraulic conductivity analyses were 7.5 cm high and 10 cm in diameter. The hydraulic conductivity PVC core-holders had a groove at 5 cm height from bottom to indicate soil sampling depth (hence hydraulic conductivity soil cores were also 393 cm^3 in volume). The top 2.5 cm of the hydraulic conductivity PVC core-holder was filled with sand when measuring unsaturated hydraulic conductivity (Section 3.4). Each individual PVC core-holder was numbered, and individually measured for height, diameter, and weight, as there were small variations in the dimensions of the PVC core-holders.

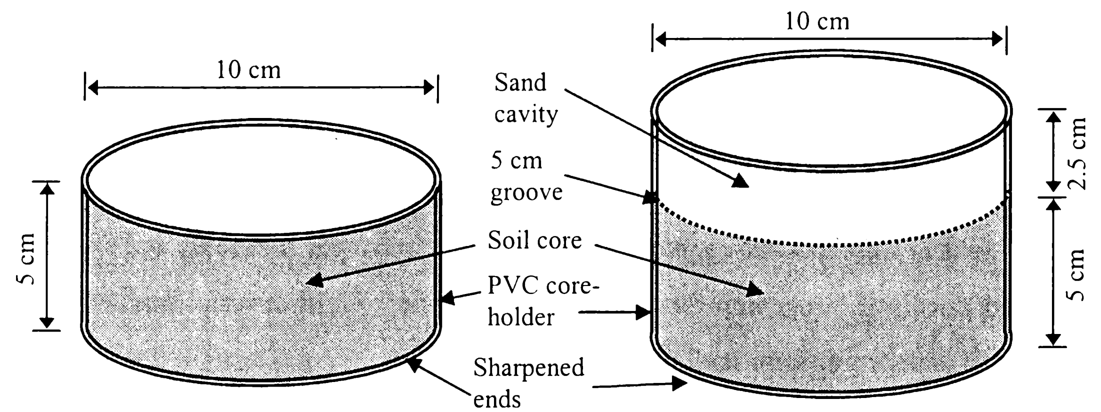


Figure 3.1 Design of the porosity PVC core-holder (left) and the hydraulic conductivity PVC core-holder (right).

3.3 Soil Core Sampling Method

Soil cores used for the porosity and hydraulic conductivity analyses were taken, using the PVC core-holders, at the 0-5 cm and 5-10 cm soil depths. The hydraulic conductivity PVC core-holders were smeared along the inside with petroleum jelly to avoid preferential edge flow during determination of hydraulic conductivity (Cameron *et al.*, 1990). The hydraulic conductivity PVC core-holders were kept separate from the porosity PVC core-holders to avoid cross-contamination of petroleum jelly.

Five within-plot sampling sites were determined, where at each sampling site four soil cores were retrieved, two for porosity analysis and two for hydraulic conductivity analysis – one of each at 0-5 cm and 5-10 cm soil depths. At each sampling site, a 1 m long trench was dug to a depth of about 30-40 cm. Soil removed from the trench was placed on tarpaulins placed alongside the trench (soil cores were retrieved from the other side of the trench) and the sward was retained for replacement after sampling. Care was taken to avoid standing on or damaging the soil surface of the area where soil cores were to be sampled, as any soil surface features, such as smearing caused by cattle, were an important part of the analysis.

A systematic core numbering system was used, where odd numbers were PVC core-holders for sampling at the 0-5 cm soil depth and even numbers for the 5-10 cm soil depth. The systematic numbering means that each group of ten cores (five at 0-5 cm and five at 5-10 cm) belonged to a single treatment plot (i.e. cores 1-10 to plot one, 11-20 to plot two, etc), preventing possible confusion in case of loss of labels from bags or cores in the laboratory.

Prior to retrieving soil cores from the 0-5 cm soil depth, herbage was trimmed to about 3 cm stubble length, with care taken to avoiding damaging the soil surface. The PVC core-holder was placed on the soil, pressed down slightly to keep it in place and, using sharp knives, the soil was carved into a cone-shape slightly larger than the PVC core-holder. Herbage caught between the PVC core-holder and the soil was cut to prevent damage to the soil. Further pressure was applied to the PVC core-holder, sliding it down the soil cone, peeling away the extra soil. Care was taken to avoid uneven downward movement, which creates cavities or soil fractures within the soil core. The porosity PVC core-holders for the 0-5 cm soil depth were continually pressed down until flush with the soil surface and the hydraulic conductivity PVC core-holders were pressed into the soil until flush with the 5 cm groove inside the holder (giving 2.5 cm spare at the top of the core). The porosity soil cores were sampled before the hydraulic conductivity soil cores to avoid possible cross-contamination of petroleum jelly.

The soil cores taken at the 5-10 cm soil depth required the carving of a plateau at 4 cm below the soil surface and about 40 cm wide (Figure 3.2). The soil core sample was taken using the same method as at the 0-5 cm soil depth, however, the PVC core-holder was pressed into the soil until there was 1 cm excess soil above the PVC core-holder (therefore, sampling at 5-10 cm soil depth). The 1 cm excess soil protected the soil core sample from damage during transportation to the laboratory.

The soil cores were placed in plastic bags, sealed, transported to the laboratory, and stored at 4 °C. Typically, soil cores were analysed in the laboratory within four days from sampling.

Figure 3.2 Porosity soil cores at the 5-10 cm soil depth before sampling (right) and immediately before removal (left).

3.4 Hydraulic Conductivity

Hydraulic conductivity is the rate of flow per unit cross-sectional area per unit hydraulic head gradient, or, essentially, the rate of flow of water through soil. Hydraulic conductivity was determined at saturated soil conditions (K_{sat}) and at the -0.4 kPa moisture tension (K_{-40}), and replicated five times (using five different cores) for each soil depth.

3.4.1 Laboratory Preparation of Soil Cores

3.4.1.1 Soil core preparation for determination of hydraulic conductivities

The bases of the hydraulic conductivity soil cores were trimmed with a shape knife, until flush with the PVC core-holder. The 0-5 cm soil cores had the herbage trimmed back to the soil surface. Care was taken to avoid damaging the surface of the 0-5 cm soil cores, as any smearing caused by cattle hooves would impair hydraulic flow and, therefore, was of interest to this study. The 5-10 cm soil cores had at least 1 cm extra soil on top for protection which was trimmed back to 2.5 cm below the top of the PVC core-holder using a specialised cutting blade (Figure 3.3).

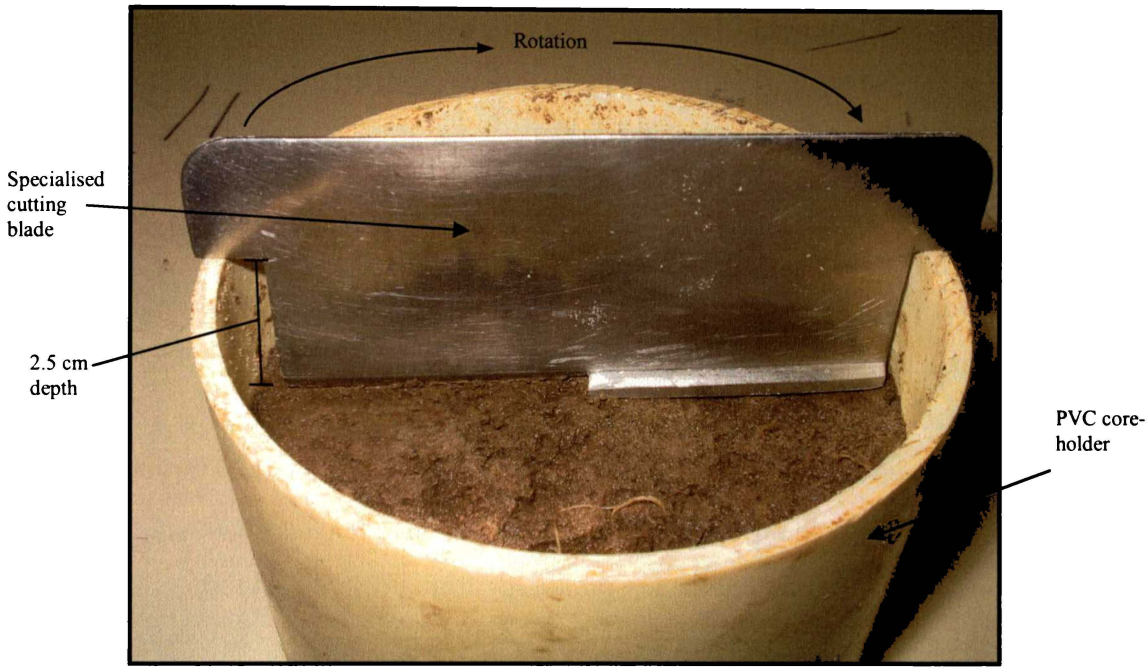


Figure 3.3 Specialised cutting blade for trimming the 5-10 cm soil depth hydraulic conductivity cores to 2.5 cm below the core edge.

3.4.1.2 Plaster of paris treatment

The process of trimming the soil core can cause smearing of the soil surface, which impedes the flow of water through the soil. Therefore, the surface smearing was removed, using a plaster of paris peel off the tops and bottoms of the soil cores (except the tops of the 0-5 cm soil cores). Any plant roots protruding from the core top or bottom were trimmed to prevent the plaster of paris sticking to them, thus limiting the risk of soil fracturing when the plaster of paris was removed. A ratio of 1.65 kg of plaster of paris to 1 L of water was used and allowed to set until viscous (similar to that of yoghurt). Two tablespoons of the plaster of paris mixture was placed on each end of the soil cores and spread without overlapping the edges of the soil cores, to prevent soil core damage when the plaster of paris was removed. Depending on the soil moisture, the plaster of paris took one to two hours to dry. After drying, the plaster of paris was lifted off the soil with a knife. At times the plaster of paris adhered strongly to the soil (due to small plant roots or small structural fractures in the soil) so care was taken to minimise fracturing of the soil or the pulling of clumps of soil from the soil core.

3.4.1.3 Formaldehyde treatment

After soil trimming and peeling a fine nylon netting was placed on the base of the PVC soil core, held in place by two rubber bands. The nylon netting prevented soil particles from falling from the bottom of the soil core and prevented the soil core from slipping out of the PVC core-holder when wet. After the nylon netting had been fitted, the soil cores were submerged in a formaldehyde solution (1.5 ml l^{-1}) and left in the fume cupboard for at least 24 hours. The formaldehyde solution agitates soil organisms such as earthworms, causing them to surface at the top of the soil core where they can be removed using a pair of tweezers. After 24 hours of formaldehyde treatment, any soil organisms remaining within the soil would have been killed by the formaldehyde solution. After formaldehyde treatment, the soil cores were placed in a tray of water to dilute any remaining formaldehyde solution.

3.4.2 Unsaturated Hydraulic Conductivity

Unsaturated hydraulic conductivity, at the hydraulic tension of –0.4 kPa (K_{-40}), was determined using disc permeameters (tension infiltrometers or tensiometers) using the method of Perroux and White (1988) and similar to the principles described by (Klute & Dircksen, 1986; Dirksen, 1991; Cook & Broeren, 1994; Clothier & Scotter, 2002). The use of the –0.4 kPa tension prevents water flow through soil pores 0.75 mm diameter and greater, giving an indication of soil structure and continuity of soil pores, while eliminating the effects of earthworm burrows and soil fractures.

3.4.2.1 Construction of equilibration sand bed

Before K_{-40} determination, soil cores were placed on the equilibration sand beds (Figure 3.4), preset at -0.4 kPa tension, for 24 hours. By using the equilibration sand beds soil cores equilibrate to the 0.40 kPa tension by the time K_{-40} was determined.

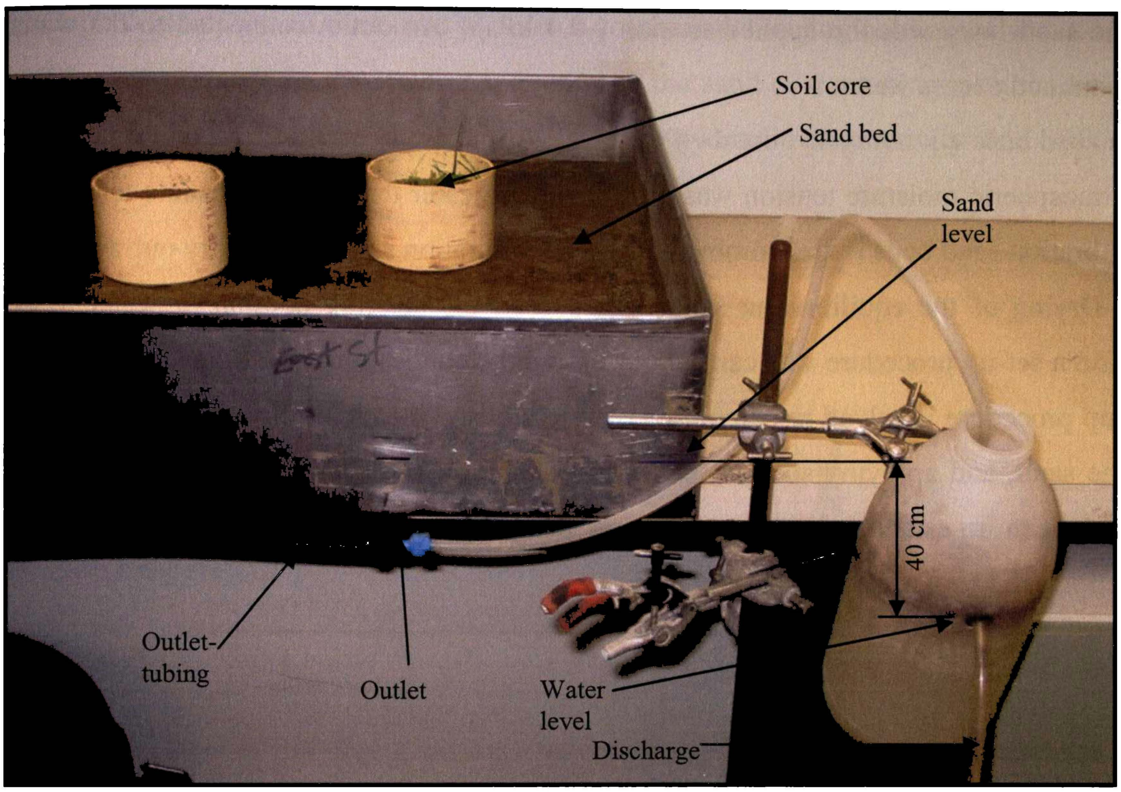


Figure 3.4 Equilibration sand bed for hydraulic conductivity soil cores.

The equilibration sand beds are based on the principle of applying moisture tension using a continuous hanging column of water under a porous material on which the soil cores are placed – the same principle was used for determination of soil macroporosity (Section 3.5). The porous material was sand which passed a 0.75 – 1.0 mm sieve (sold by commercial distributors as either castle sand or bowl sand) overlain by a nylon mesh. The hydrostatic tension between water and sand was greater than –0.4 kPa, therefore, a continuous hanging column of water will not break. The equilibration sand beds were constructed within large (0.5 m by 1.2 m) stainless steel tray that had outlets at the base on each end. To prevent sand moving into the outlet-tubing and restricting water flow, a small piece of nylon mesh was placed over the outlets before addition of sand. A 70 mm layer of sand was placed evenly over the base of the tray and a large piece of fine nylon mesh was placed over the sand, to prevent contamination of soil in the sand bed.

The outlet-tubing was connected below the water line to a water cylinder alongside the equilibration sand beds. The distance (40 cm) between the water line in the cylinder and the top of the sand layer was the applied tension (-0.4 kPa). An outlet connected to the water cylinder drained excess water.

As the atmospheric moisture tension was considerably greater than the hydrostatic tension in the equilibration sand beds it was common for the equilibration sand beds to dry out while not in use. Drying of the equilibration sand beds caused the hanging column of water to be broken and a set-up procedure was carried out before the equilibration sand beds are re-used. The set-up procedure involved re-smoothing of the sand surface, applying about 4 L of water to wet the sand, and applying suction to the outlet-tubing. Once the continuous column of water had been re-established the outlet was connected to the water cylinder and the equilibration sand beds were again ready for use.

3.4.2.2 Construction of the hydraulic conductivity sand beds

After soil cores had equilibrated on the equilibration sand beds, soil cores are ready for K_{-40} determination. To determine K_{-40} the soil cores were removed from the equilibration sand beds and placed on the hydraulic conductivity sand beds. The purpose of the hydraulic conductivity sand beds was to apply the -0.4 kPa tension to the base of the soil core during the determination of K_{-40}. As the disc permeameters apply a -0.4 kPa tension to the top of the soil core, any potential gradient across the length of the soil core was removed, therefore, allowing an equal flux of water per unit area throughout the soil core. The tension was applied to the hydraulic conductivity sand beds by a continuous hanging column of water.

The hydraulic conductivity sand beds were constructed from stainless steel trays placed on a stand with adjustable feet (Figure 3.5). A layer of fine sand (0.75 - 1.0 mm particle diameter) was placed in the trays, and spread using a smoothing plate. Each tray had two outlets with tubing, to allow drainage. The outlet-tubing was connected to an adjustable clamp on the side of the stand, where the distance between the sand surface and the end of the outlet-tubing was the applied tension. A nylon mesh was placed on top of the outlets to prevent sand movement into the tubing. The smoothing plate was designed to follow the edge of the tray, which had been made level using a spirit level.

About 2 L of water was applied to the hydraulic conductivity sand beds to wet the sand. Suction was applied to the outlet to form a continuous hanging column of water. Care was taken to ensure that no air was trapped either in the sand or the tubing, as airlocks affect the applied tension and the rate of water flow from the hydraulic conductivity sand beds.

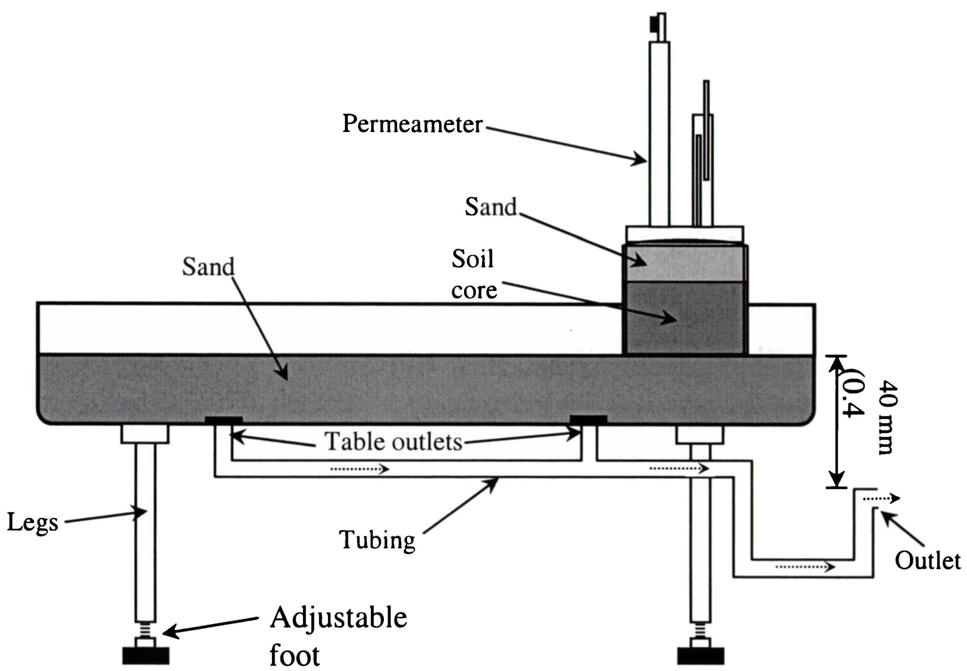
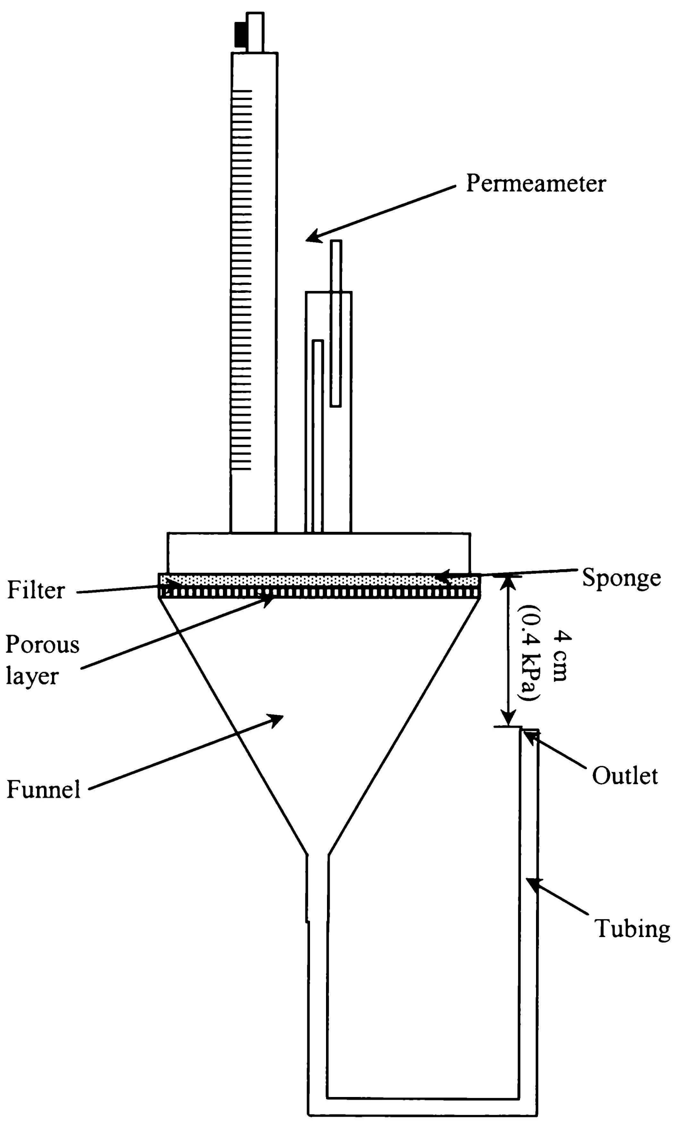


Figure 3.5 Hydraulic conductivity sand bed design with hydraulic conductivity core and disc permeameter.

3.4.2.3 Calibration of disc permeameters and hydraulic conductivity sand beds

It was noted that the applied tension of each of the permeameters were different from that indicated on the disc permeameters scale. The differences, which were not consistent over all disc permeameters, were probably due to internal friction and hydrostatic tensions. Therefore, a calibration device, using the principle of a hanging column of water, was constructed to determine the true applied tension (Figure 3.6). The device was held by a clamp-stand and consisted of a porous lid placed on a large funnel with tubing attached at the bottom. The end of the tubing was attached to an adjustable clamp, where the difference in height from the top of the porous lid to the end of the tubing was the true applied tension at the base of the disc permeameter. As temperature can also influence applied tensions (Dirksen, 1991) measurements had to be carried out in a temperature controlled room (20 °C).

a)



b)

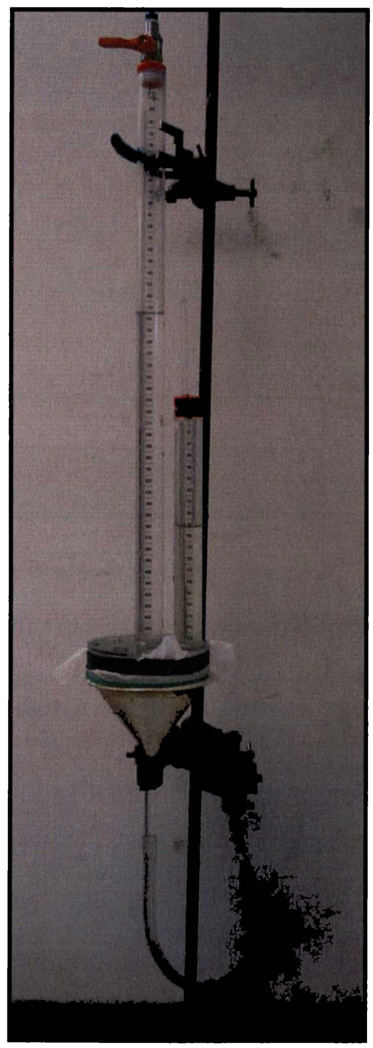


Figure 3.6 Calibration device for disc permeameters, where a) is a diagrammatic design and b) calibration device in use.

The calibrating device was submerged in water, removing all air from the tubing and funnel. A Whatman number-1 filter paper was placed on top of the porous lid, preventing the water flowing out of the device. The outlet-tubing was adjusted and accurately measured to 40 mm below the base of the disc permeameters. The disc permeameter tension was then adjusted until no flow of water occurred through the disc permeameter and the water at the end of the outlet-tubing remained at the edge of the tubing. The calibration process was repeated periodically during K_{-40} measurements to ensure the applied tension had not changed.

The calibration of the hydraulic conductivity sand beds was carried out using a pre-calibrated disc permeameter and the hydraulic conductivity sand bed outlet-tubing was adjusted until no through-flow of water occurred.

3.4.2.4 Determination of K_{-40}

Sand (sieved to 0.75 to 1 mm grain diameter) was placed on top of the soil core, filling in the spare 2.5 cm in the PVC core-holder, with a small mound above the PVC core-holder. The sand provided direct contact between the soil surface and the disc permeameters. A test run, using several PVC core-holders filled only with the sand, indicated that the mean K_{-40} of the sand was 480 mm hr^{-1}, and, therefore, not likely to influence the soil hydraulic conductivity readings (where readings were generally between 1 and 180 mm hr^{-1}). After sand was placed on top of the soil core, water was applied to wet the sand. The soil cores then remained on the equilibration sand beds for 24 hours before unsaturated hydraulic conductivity measurements.

After soil cores had equilibrated on the equilibration sand beds to -0.4 kPa tension soil cores were placed on the hydraulic conductivity sand beds with a short firm twist to ensure good contact between the sand and the soil core. The disc permeameter was placed on the sand above the soil core (Figure 3.7). Water was allowed to flow through the soil at the -0.4 kPa tension for about 5-10 minutes before commencement of the K_{-40} measurements. The K_{-40} was determined by measuring the amount of water passed through soil during a known length of time. Measurement duration was at least 30 minutes, or until all the water in the disc permeameter had been used (about 500 ml). The amount of water used and time taken was recorded for each soil core.

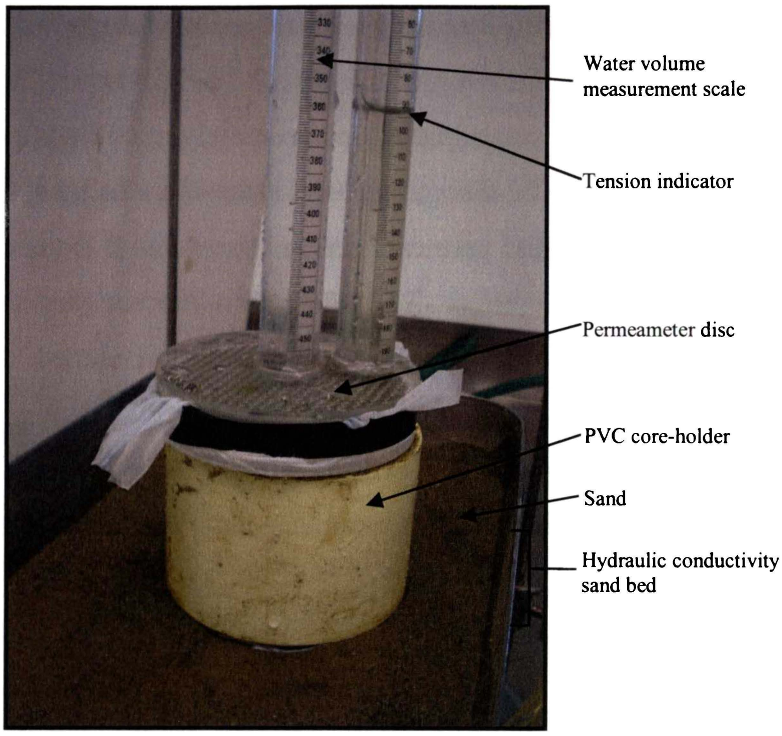


Figure 3.7 K_{-40} determination using the hydraulic conductivity sand bed and the disc permeameters.

Unsaturated hydraulic conductivity was calculated using Darcy's Law:

$$K = \frac{-q}{\Delta H / \Delta z} \qquad (3.1)$$

Where:
K = hydraulic conductivity
q = discharge per unit cross-section (water flux)
ΔH = change in hydraulic head
Δz = change in gravitational potential

The discharge rate per unit cross-section (q) was:

$$q = \frac{V}{\Delta t \pi r_c^2} \qquad (3.2)$$

Where:
V = volume of water (ml) passed through soil (while at steady state)
Δt = change in time (end time minus start time, corrected to decimal minutes)
π = Pi (3.14159)
r_c = radius (internal) of soil core (51.7 mm)

To calculate discharge rate, the readings taken from the side of the disc permeameters were converted to water volumes (the disc permeameters indicate height, rather than volume):

$$V_w = \left(\pi r_p^{\,2} h_{wp}\right) \quad (3.3)$$

Where
V_w = corrected volume of water present (ml)
r_p = radius of disc permeameter cylinder (11.72 mm)
h_{wp} = height of water in disc permeameter cylinder (read from side of infiltrometer in mm)

The volume of water passed through soil (V) was determined as the change in volume from start to end of the measurement:

$$V = V_{w1} - V_{w2} \quad (3.4)$$

Where:
V_{w1} = corrected volume of water present in disc permeameter at beginning of measurement
V_{w2} = corrected volume of water present in disc permeameter at end of measurement

To convert the water volume from the disc permeameter to flow rate of water over the entire soil core surface a constant was derived as follows:

$$C_f = \frac{\pi r_p^{\,2}}{\pi r_c^{\,2}} = 0.05165 \quad (3.5)$$

Where:
C_f = constant for conversion to flow rate per unit area

As the disc permeameter and the hydraulic conductivity sand beds both applied a tension of -0.4 kPa (and the soil core had equilibrated to -0.4 kPa), steady state flow occurred under the influence of gravity in the absence of a pressure potential gradient (Figure 3.8).

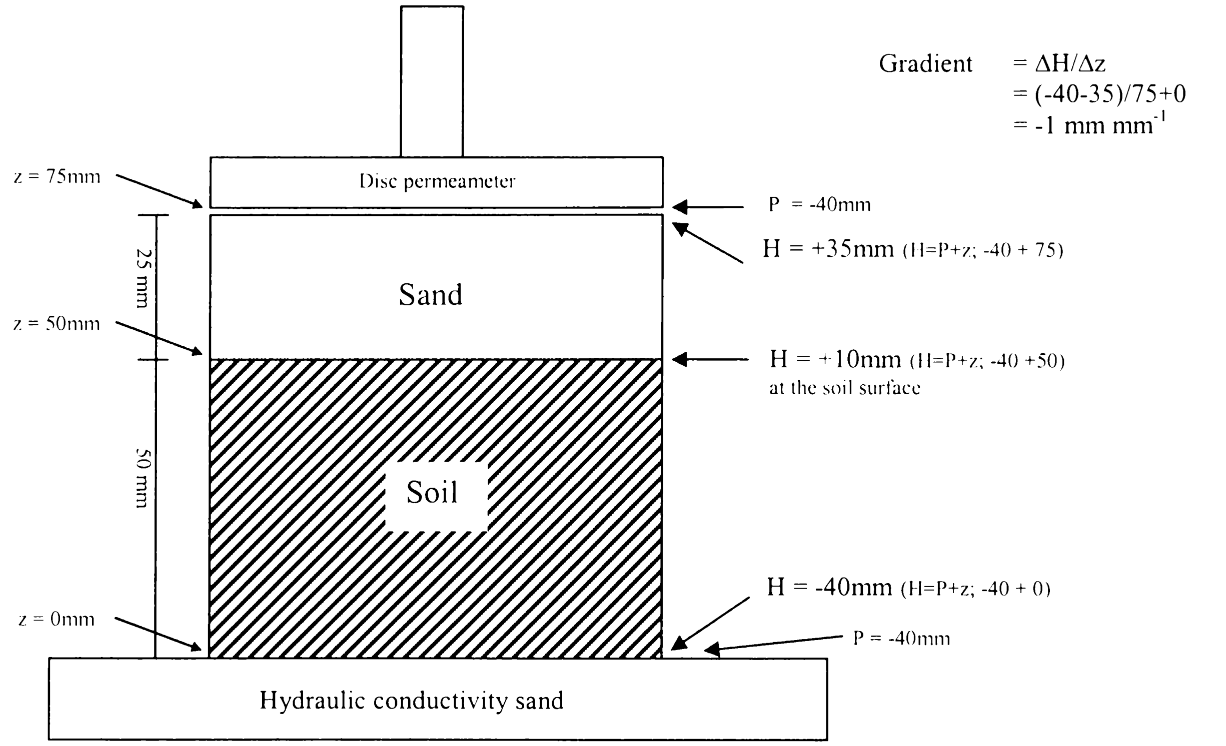


Figure 3.8 Hydraulic potentials and gradients of the soil/sand column, where H = hydraulic potential, P = pressure potential (applied tension; 0.4 kPa), z = gravitational potential.

Therefore, a uniform hydraulic potential was established through the soil core and steady state infiltration occurred. Hydraulic conductivity (K) becomes the discharge rate per unit cross-sectional area (q), that being $K=q$, hence, and hydraulic conductivity can be calculated as follows

$$K_{-0.4} = \left(\frac{V}{\Delta t / U_c} \right) C_f \tag{3.6}$$

Where:
K_{-40} = unsaturated hydraulic conductivity at -0.4 kPa (mm hr^{-1})
V = volume of water passed through soil (ml)
Δt = change in time from start to end (minutes)
U_c = unit conversion to hours (60)
C_f = constant (0.05165)

3.4.3 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K_{sat}) was determined using the same soil cores as those used for K_{-40}. Two methods were used for to determine of K_{sat}. The conventional ponding method (maintaining a constant-head using pin and beaker) was used for the 0-5 cm soil cores, and the constant-head infiltrometer (Klute & Dircksen, 1986) was used for the 5-10 cm soil cores (Figure 3.9). The 5-10 cm soil cores, which had been cut back to 2.5 cm below the top edge of the PVC core-holder, enabled the use of the constant-head infiltrometers for a quick and easy determination of K_{sat}. However, the tops of the 0-5 cm soil cores were uneven due to the nature of the soil surface in the field, therefore, the constant-head infiltrometers could not be used.

3.4.3.1 Soil core preparation

K_{sat} was determined after K_{-40}. The soil cores were submerged in water which allowed the sand used for K_{-40} analyses to slip off without causing damage to the soil surface. The soil cores were then kept submerged in water trays for half a day to allow the soil core to become fully saturated.

3.4.3.2 Determination of K_{sat} using constant-head infiltrometers

After saturation, the 5-10 cm soil cores were placed on a rack (allowing unimpaired flow of water from the base of the soil core) and the constant-head infiltrometers were placed on top of the soil core (Figure 3.9a). In order for the constant-head infiltrometers to sit properly above the soil core a spacer was used, which held the base of the constant-head infiltrometers 10 mm above the soil surface. Saturated flow was applied through the soil core and allowed to flow for about three minutes (depending on the rate of flow) before commencement of K_{sat} determination. After commencement of K_{sat} determination, saturated flow was allowed to carry on until the column of water was mostly used up or until 50 minutes had elapsed. The start volume, end volume, and time taken were recorded. The K_{sat} calculations are based on Darcy's law, however, unlike at the K_{-40} determinations, there was a constant hydraulic head, thus hydraulic gradient, was present:

$$Hg = \left(\frac{\Delta H}{\Delta z}\right) = \left(1 + \frac{h_w}{h_s}\right) = 1.2 \tag{3.7}$$

Where:
Hg = hydraulic gradient
h_w = height of ponded water and soil (60 mm)
h_s = height of soil core (50 mm)

To determine K_{sat}, the soil core area has to be determined:

$$A_s = \pi r_c^{\ 2} \tag{3.8}$$

Where:
A_s = soil core surface area
r_c = soil core radius (51.7)

Hence, K_{sat} was determined as:

$$K_{sat} = \frac{\left(\frac{V/(\Delta t / U_c)}{A_s}\right)}{Hg} \tag{3.9}$$

Where:
K_{sat} = saturated hydraulic conductivity (mm hr^{-1})
V = volume of water (ml) passed through soil (while at steady state)
Δt = change in time (end time minus start time in minutes)
U_c = Unit conversion from minutes to hours (60)
A_s = surface area of soil
Hg = hydraulic gradient (1.2)

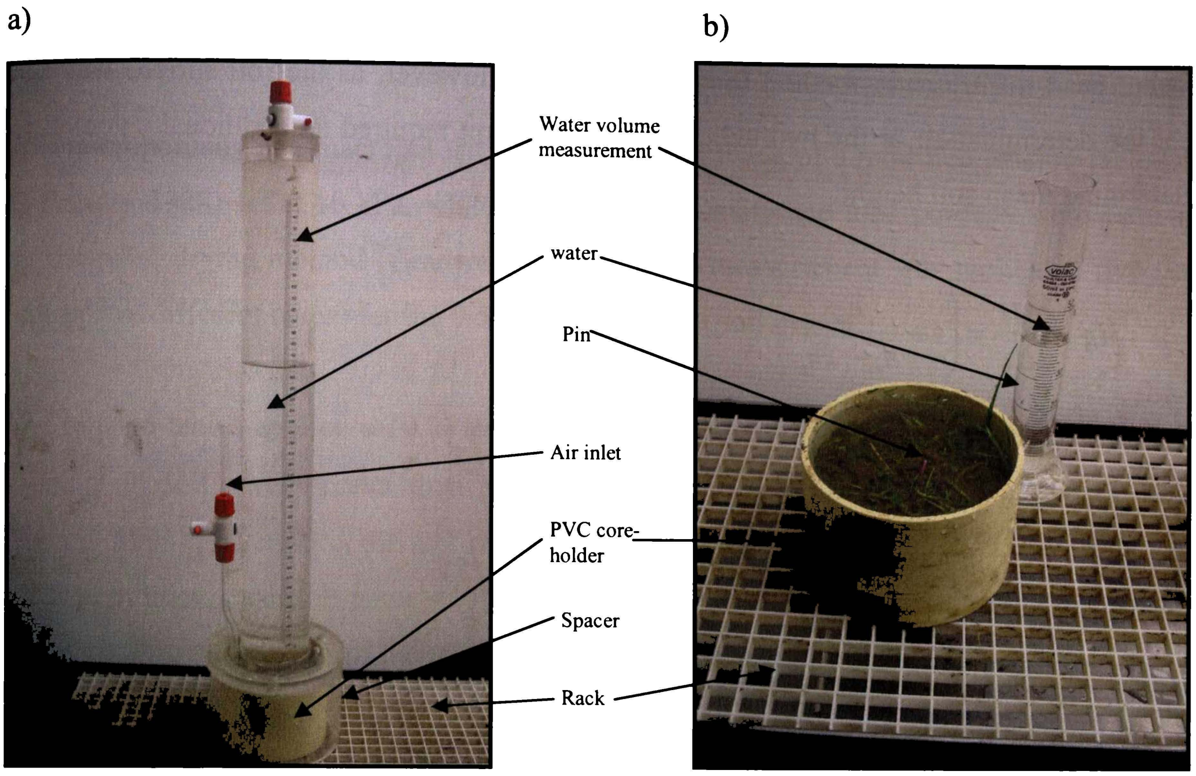


Figure 3.9 K_{sat} determination using a) the constant-head infiltrometers method and b) the conventional ponding method.

3.4.3.3 Determination of K_{sat} using conventional ponding method

After saturation the 0-5 cm soil cores were placed on a rack. To determine the average soil height of the core, five individual measurements were taken from the top of the PVC core-holder to the top of the soil core (H_s) – the average was used to calculate the hydraulic head. A pin was placed in the soil, and the height from soil surface to the top of the pin was measured (H_p). Water was applied to the soil core and allowed to flow for about five minutes before commencement of the readings (Figure 3.8b). The water level was then raised to the height of the top of the pin, after which a known volume of water was applied, maintaining the water level at the top of the pin. The time taken to pass the known volume of water was recorded. The reading should take at least five minutes, using a minimum of 25 ml of water (therefore, a core with high K_{sat} requires the application of a greater volume of water). However, in some cases the K_{sat} values were low (i.e. 5 mm hr^{-1}) and when the reading exceeded 50 minutes it was terminated, and the amount of water used was recorded.

Hydraulic conductivity was determined using the same calculation as that used for the constant-head infiltrometer method (Section 3.4.3.2). However, as the soil surface was not even, the determination of the hydraulic potential gradient required an additional calculation to determine mean soil height:

$$Hg = \frac{\Delta H}{\Delta z} = \left(1 + \frac{h_p}{h_c - \bar{x}h_e}\right) \tag{3.10}$$

Where:
Hg = hydraulic gradient
H_c = height of PVC core-holder
$\bar{x}\,h_e$ = mean height of soil core to top of PVC core-holder (sum $h_e/5$)
h_p = height of pin

3.4.3.4 Observation of continuous soil pores

The preferential flow of water through continuous soil pores (from the top to bottom of the soil core) was observed as a continual stream of water from the bottom of the soil core during K_{sat} determination. Typically, continuous soil pores were earthworm burrows, however, occasionally they were soil fractures. Continuous pores are common in soils and they have a considerable effect on the rate of saturated flow, as soil water would be able to by-pass the soil matrix.

The initial purpose of recording preferential water flow was to explain possible high flow rates, however, the data also served as an indication of the presence of continuous pores in the soil. The continuous pores recorded were only those that were able to pass preferential flow of water from the top of the soil core to the bottom (over an uninterrupted length of at least 5 cm). Continuous pores that did not span the height of the soil core or were blocked were not recorded, therefore, the data presented only serves as an indication of the amount of continuous pores in the soil.

3.5 Soil Dry Bulk Density and Porosity

Soil microporosity and macroporosity were measured using of a modified tension-table (Ball & Hunter, 1988) set at 10 kPa, while soil dry bulk density and total porosity were estimated by the oven drying method (Gradwell, 1972). Each measurement was replicated five times (using five different cores) for the 0-5 cm and 5-10 cm soil depths.

The tension-tables applied a 10 kPa moisture tension (commonly regarded as field capacity) causing all soil pores greater than 30 μm diameter to drain (McLaren & Cameron, 1993; Rowell, 1994). Therefore, the soil water volume at 10 kPa moisture tension was equal to the volume of micropores (all pores <30 μm diameter). The soil water volume can be determined by comparing the weights of the moist and oven dried soils.

Soil dry bulk density was determined as the oven dry weight of soil per volume of soil, while total porosity was determined by subtracting the volume of soil particles from the total volume of soil. The volume of macropores was estimated by subtracting the volume of micropores (that is, the water volume of soil at 10 kPa) from the total porosity.

3.5.1 Laboratory Treatment

The soil cores were trimmed at the base with a sharp flat knife until flush with the PVC core-holder (except the top of the 0-5 cm soil cores). It was found that if a sharp knife was used, and the soil was cut quickly while holding the knife at about a 20 degree angle to the PVC core-holder, the occurrence of smearing was greatly reduced, eliminating the need for the potentially destructive method of peeling using plaster of paris. Herbage was trimmed back as close to the soil as possible using scissors, and Roundup® herbicide (1:3 to water) was applied to the surface of the 0-5 cm soil cores to kill any regrowth. After estimation of the soil core volume (Section 3.5.2), the bottom of the soil core was covered with a nylon netting, held on by two rubber bands, to avoid damage to the soil core and prevent the soil slipping from the PVC core-holder. The soil cores were then treated with the formaldehyde solution as described in Section 3.4.1.3.

3.5.2 Determination of Soil Volume

Calculation of total porosity and, therefore, macroporosity and microporosity, requires the known volume of the soil core. When trimming the soil cores invariably a smooth surface cannot be obtained (due to breakage of soil aggregates, stones, etc). Furthermore, the 0-5 cm soil cores had an uneven soil surfaces. To determine the soil core volume a known volume of clover seed was added to the core surfaces, filling the gaps caused by breakage and stones. A straight-edged spattler was run along the edge of the PVC core-holder to remove excess clover seed. Complete removal of the herbage on the 0-5 cm soil cores was essential to avoid overestimation of the total soil volume. Clover seed was removed by tipping the soil core and lightly brushing the seed away with a soft brush. The clover seed was tipped into a container, sieved to remove soil clumps and re-used. The volume of clover seed used on the soil cores was subtracted from the volume of the PVC core-holder, giving the corrected-soil core volume.

The corrected-soil core volume was calculated as follows:

$$V_s = (V_c - V_{cs}) \tag{3.11}$$

Where:
V_s = corrected volume of the soil core (cm^3)
V_c = volume of PVC core-holder (cm^3)
V_{cs} = volume of clover seed used (cm^3)

3.5.3 Construction of Tension-Tables

The tension-tables were constructed from stainless steel and were 400 mm square by 150 mm high (Figure 3.10). The tension-tables had two outlets in the base. A fine nylon mesh was placed over the outlets to prevent sand and silica washing through into the outlet-tubing.

A 25 mm layer of sand (0.75 - 1.0 mm particle diameter) was placed in the tension-table. Silica was laid over the sand layer by mixing the silica dust with water to form a slurry that was carefully poured over the sand. The water percolated through the sand, leaving a moist silica layer on top. The process was repeated several times to build a 15 mm silica layer. The silica has a finer particle size and a greater hydrostatic tension than sand, thus prevented air moving into the sand layer when a 10 kPa water tension was applied.

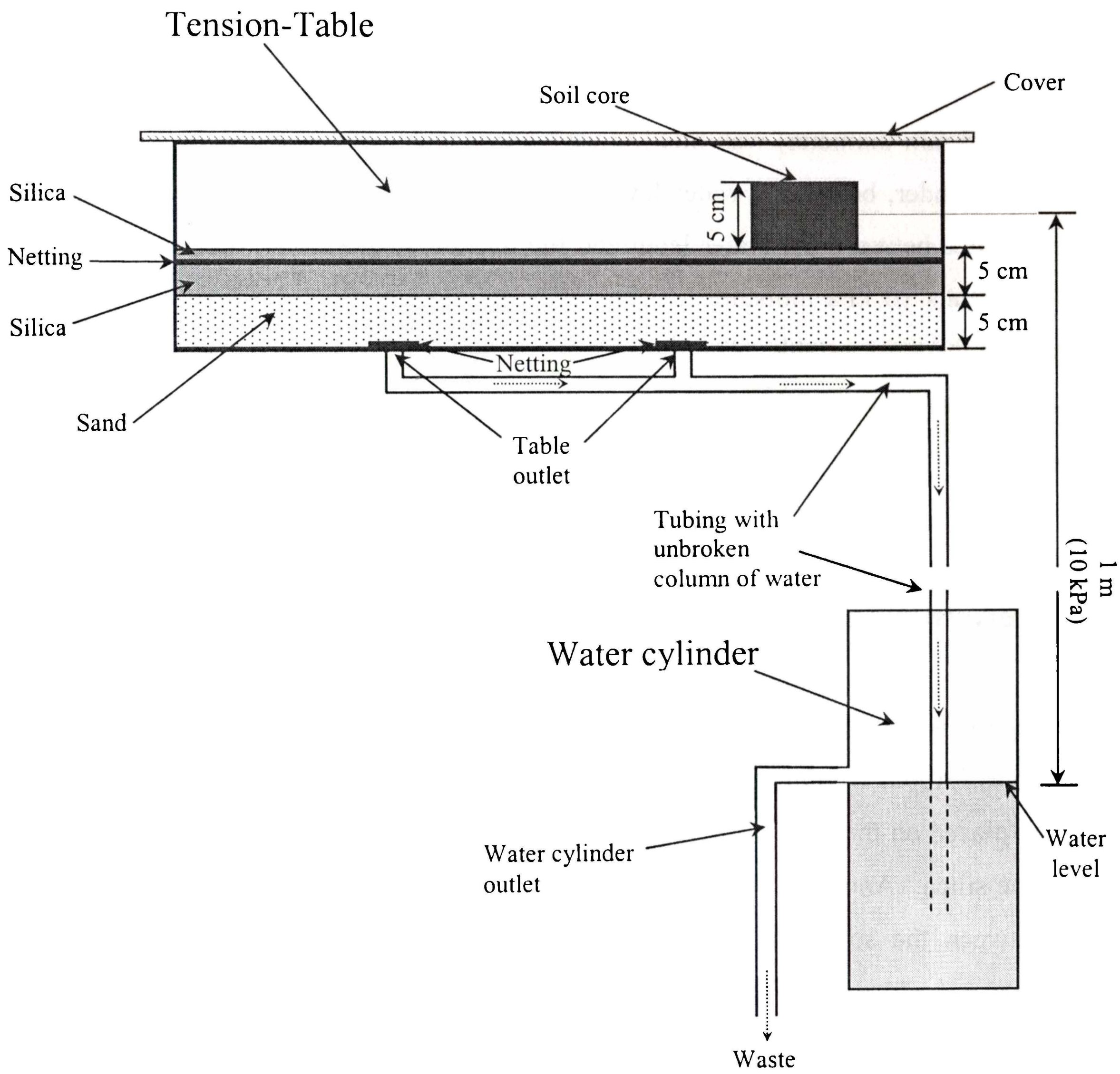


Figure 3.10 Tension-table design.

A sheet of fine nylon netting was placed over the silica, upon which a further 10 mm of silica dust was laid. The nylon netting was needed in case damage occurred to the tension-table surface. The upper silica layer could easily be removed by lifting the nylon netting, and a new silica layer deposited without the need for reconstructing the tension-table. The nylon netting also prevented black beetle adults (*Heteronychus arator*), that sometimes survived the formaldehyde treatment, from burrowing into the sand layer and breaking the moisture tension.

Clear tubing (5 mm diameter) was fitted to each outlet and the tubing ends were placed in a water-filled cylinder, below the water level. The moisture tension applied to the soil cores was the distance between the water level and the mid point of the soil core on the tension-table (1 m equals 10 kPa moisture tension). The tubing was filled with water by flushing water through the tension-table. The flushing was repeated up to five times to remove trapped air in the sand layer, as trapped air could affect the applied moisture tension. Applying large amounts (>4 L) of water and lightly tapping the tension bed aided the flushing of trapped air.

3.5.4 Determination of Soil Porosity

After soil core preparation and formaldehyde treatment, the soil cores were placed on the tension-tables. About 10 mm of water was added to the tension-table to soften the silica. Soil cores were placed on the table with a slight but firm twist to ensure good contact between the core and the silica. Another 20 mm of water was added to the tension-tables to ensure good contact between the soil core and the silica. A PVC cover sheet was placed over the tension-tables to reduce evaporation from the top of the soil cores. As the soil cores came to tension, air bubbles often appeared in the outlet-tubing, which were removed by adding a small amount of water to the tension-table and applying suction to the outlet-tubing using a syringe.

Equilibration of the soil cores was determined by periodically weighing the soil cores. Equilibration to 10 kPa tension was expected to take 10 days (Ball & Hunter, 1988), however, in practice it took between two and four weeks. When soil cores were equilibrated to 10 kPa the soil cores were weighed, oven dried at 105 °C for 24 hours, and re-weighed. Soil dry bulk density, microporosity, macroporosity, and total porosity were calculated as follows:

$$\rho_b = \rho_p\left(\frac{M_s}{V_s}\right) \tag{3.12}$$

Where:
ρ_b = soil dry bulk density (Mg m^{-3})
ρ_p = particle density (Mg m^{3})
M_s = mass of oven-dry soil core (g).
V_s = corrected soil volume (cm^3)

$$\varepsilon = 1 - \frac{\rho_b}{\rho_p} \tag{3.13}$$

Where:
ε = Total porosity (cm^3 cm^{-3})

$$\varepsilon_i = \left(\frac{(M_w - M_s)/M_s}{1/\rho_b}\right) \tag{3.14}$$

Where:
ε_i = microporosity (cm^3 cm^{-3})
M_w = mass of soil core at 10 kPa tension (g)

$$\varepsilon_a = 1 - \left(\frac{\rho_b}{\rho_p}\right) - \varepsilon_i \tag{3.15}$$

Where:
ε_a = macroporosity (cm^3 cm^{-3})

3.6 Soil Surface

3.6.1 Soil Surface Roughness Index

Soil surface roughness index was determined using the chain method (Saleh, 1993, 1994) as a quick, easy, and inexpensive method of measuring soil surface roughness. Saleh (1993; 1994) also suggested that the chain method was also sensitive to smaller changes in soil surface roughness. The principle behind the chain method is that the shortest distance between two points is a straight line (L1). As soil surface roughness increases due to treading action, the total surface distance (L2) between the two points increases due to soil surface tortuosity. The proportional difference between L1 and L2 is the soil roughness index.

Soil roughness index was determined immediately after treading treatment, and after each subsequent grazing event until no significant differences (P <0.05) were found between controls and treated sites. Soil roughness index was also determined before the treading treatment to obtain background readings of pre-treading conditions. The soil surface roughness estimates were replicated 10 times within each plot.

The method used a 1.0 m long linked roller chain (6.35 mm pitch) and a 1 m ruler. The chain was placed over the soil surface, ensuring full contact with the soil surface along the entire length of the chain (Figure 3.11). The distance between the ends of the chain (linear length) was then measured using the ruler.

Soil surface roughness index was shown as percent of chain length loss:

$$L_c\% = \left(1 - \frac{L_2}{L_1}\right)100 \tag{3.16}$$

where:

L_c = loss of chain length as a percentage

L_1 = linear length of chain (1 m)

L_2 = linear length of chain after placed on soil surface

Interpretations of the chain method have not yet been standardised. The adoption of the chain method by AgResearch, New Zealand, has resulted in the formation of an arbitrary table of classification terms (Table 3.1).

Table 3.1 Classification terms used to interpret the soil surface roughness index results from the chain method (P.L. Singleton, *pers com.* 1999).

Roughness class	% chain length loss	Mean depth of hollows	Description
1	0-5 %	<2 cm	Slightly rough
2	6-10 %	2-3 cm	Moderately rough
3	11-15 %	3-4 cm	Distinctly rough
4	16-20 %	4-5 cm	Very rough
5	>20 %	>5 cm	Extremely rough

Figure 3.11 The use of the chain method on soil with severe treading damage. Note how the chain follows the curvature of the soil.

3.6.2 Depth of Pug Prints

The depth of pug prints was an indication of soil surface roughness and the depth of plastic deformation during the treading treatment. After treading treatment, 10 well-defined pug prints (that is, a pug print not deformed by later cattle treading) were identified per plot. The depth of the pug print was measured as the top of the remoulded soil, from what was identified as the front of the hoof, to the bottom of the pug print. The pug prints that were measured were those made as the cows were removed from the treatment plots, so they represent the depth of pugging (plastic deformation) at the end of the treading treatment.

The depth of hoof skids (hoof ploughing) was also measured. A hoof skid was identified as a slip mark of at least 20 cm length, and only fully complete hoof skids were measured (that is, hoof skids not trodden on after being formed). The depth was measured from the top of the mound of soil at the front of the hoof skid to the bottom of the hoof print. The depth of the hoof skids was a measure of the amount of soil that can be displaced due to soil having been plastically remoulded. Up to 10 hoof skids were identified per plot, however, as hoof skids near the end of the treading treatment were not common, 10 measurements per plot could not always be made.

3.7 Soil Moisture Content

Moisture content was determined several times prior to treading to establish if the desired soil moisture content had been obtained for the treading experiment. At the time of the treading treatment, soil moisture content was determined for each plot. Soil moisture content was determined by obtaining a 1 kg soil sample from each plot using a 7.5 cm length soil corer. Soil samples were placed in a plastic bag and then taken immediately to the laboratory. The soil moisture samples were weighed and dried at 105 °C for 24 hours. After drying of the soil sample, the sample was cooled in a desiccator and weighed again. Gravimetric soil moisture was determined as follows:

$$\theta_m = \left(\frac{M_{ws} - M_{ds}}{M_{ds}} \right) 100 \quad (3.17)$$

Where:
θ_m = gravimetric soil moisture content (%)
M_{ws} = mass of wet soil
M_{ds} = mass of dry soil

Soil moisture is often expressed as a volumetric content and was calculated as follows:

$$\theta_v = \theta_m \left(\frac{\rho_b}{\rho_w} \right) \quad (3.18)$$

Where:
θ_v = volumetric soil moisture content (%)
ρ_b = soil dry bulk density (g cm^{-3})
ρ_w = water density (g cm^{-3})

The degree of saturation (the ratio of soil pore volume to volume of water) is a useful expression of soil moisture content and was calculated as follows:

$$S = \frac{\theta_v}{\varepsilon} \quad (3.19)$$

Where:
S = degree of saturation (%)
ε = total soil porosity

3.8 Penetration Depth – The AgResearch Penetrometer

The AgResearch Penetrometer was developed by Betteridge *et al.* (2003) as an indicator of soil susceptibility to pugging damage by cattle treading (Figure 3.12). The penetrometer was used in the three experiments in this thesis. The penetrometer has a 3 cm diameter cone-head, attached to a rod with a calibrated force spring. When a force was applied to the soil the depth of soil penetration by the cone was measured (mm of soil penetration). The principle of the method was that the force (350 kPa) that was applied to soil was similar to that of cattle hooves (Scholefield & Hall, 1986). The depth of penetration was, therefore, an indication of potential depth of penetration by cattle hooves, thus an indication of soil pugging susceptibility.

The method was still in the development stages when used in the three experiments of this thesis, and data obtained here were used to develop the penetrometer further. It has since been commercialised by AgResearch (Betteridge *et al.*, 2003).

The penetrometer was used periodically during set-up procedure (e.g. irrigation) of the experimental sites to determine soil susceptibility to pugging damage. Immediately before the treading treatment, 10 random penetrometer readings were taken from each treatment plot.

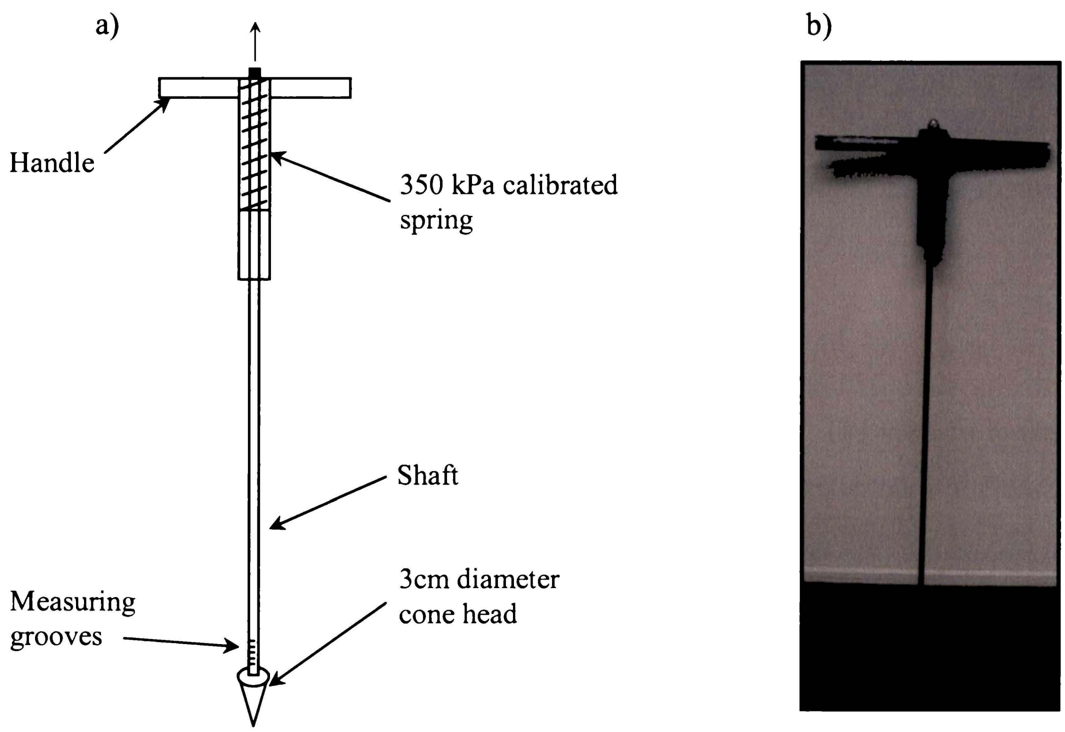


Figure 3.12 Diagrammatic (a) and photographic (b) representations of the AgResearch Penetrometer.

3.9 Soil Plastic and Liquid Limits

3.9.1 Pre-treatment and Soil Preparation for Plastic and Liquid Limits

Determination of soil plastic and liquid limits followed the 'rolling a ribbon' and casagrande methods of Thomas (1973). Plastic and liquid limits were determined for each experimental site; separately for each treatment group (a treatment group contains a full set of treatments, Section 4.4.4). A 2 kg bulk soil sample was obtained by random sampling within each treatment group, from which 150 g moist soil sample was obtained using Riffle Box Splitters. The soil sample was mixed on a glass plate using two palette knives. Stones were removed and all soil aggregates were broken-up. While mixing the soil sample, small amounts of distilled water were added to bring the soil to the plastic limit (determined by kneading a soil test-sample of soil into a ball and rolling the ball into a ribbon). When the soil appeared to be just beyond the plastic limit (i.e. test sample broke into pieces longer than 13 mm), a 30-50 g sub-sample was taken and placed in a sealed plastic bag for plastic limit analysis. The plastic limits sub-sample was left to cure overnight at 4 °C (allowing clays to adsorb more moisture).

The remaining soil sample was used for liquid limit analyses by re-mixing and wetting the sample further until the sample was just beyond the liquid limit (determined by a test run on the casagrande apparatus. The liquid limit sub-sample was then placed in a sealed labelled plastic bag and left to cure overnight at 4 °C.

3.9.2 Soil Plastic Limit

After curing of the plastic limit sub-samples, the sample was re-mixed for five minutes with two palette knives on a glass plate. A 5 g soil sample was taken from the plastic limit sub-sample, made into a ball in the palm of the hand and remoulded until the sample warms, aiding the drying of the soil sample. The ball was then rolled using the palm of the hand on a glass plate to form a 3.2 mm diameter ribbon. Rolling was carried out with even pressure for each roll. The sample was repeatedly made into a ball and rolled into a 3.2 mm diameter ribbon until the ribbon broke into 3-13 mm long pieces before reaching a 3.2 mm diameter. If the sample was too wet at the start, drying was aided by using a small hair-drier. If the sample was too dry, more distilled water was added and the sample was re-mixed for five minutes. It was preferable to start with a sample that was too wet and then dried to the plastic limit, as the hysteresis effect would be uniform for all samples. Once the plastic limit has been reached, the gravimetric soil moisture content was determined by placing the soil in a pre-weighed container, re-weighing and then drying at 105 °C. After drying, the sample was cooled in a desiccator and re-weighed again.

Plastic limit was determined for soil from the 0-5 cm and 5-10 cm soil depths and replicated three times for each treatment group. The plastic limit was calculated as follows:

$$\theta_p = \left(\frac{M_{ws} - M_s}{M_s} \right) 100 \qquad (3.20)$$

Where:
θ_p = % moisture content at plastic limit
M_{ws} = mass of wet soil (g)
M_s = mass of oven-dry soil (g)

3.9.3 Soil Liquid Limit

After curing of the liquid limit sub-samples, the sample was re-mixed for five minutes with two palette knives on a glass plate. A sample of about 30 g of soil was placed in the casagrande cup and gently pushed down by a palette knife. The sample surface in the cup needs to be near perfectly horizontal. A 2 mm groove (widening at the top of the groove) was made in the sample with the standard casagrande grooving tool. The casagrande handle was turned at a rate of two turns a second, which lifts and drops the cup repeatedly, until a 13 mm section of the groove had closed. Care must be taken, as the method is sensitive to the skill level of the operator (Sherwood & Ryely, 1970). Several test runs were carried out prior to determination of the liquid limit to gain familiarity and consistency with the method. The number of blows required to close the groove was recorded and a 5-10 g sample was taken from the casagrande apparatus to determine gravimetric soil moisture content. The casagrande cup was then emptied, the remaining sample was remixed with the unused sample, and the procedure was replicated twice more.

To determine the liquid limit, the procedure needs to be repeated at four or five different soil moisture contents (each being replicated three times) to give a range of blows required, to close the groove by 13 mm, from 10 to 40. To achieve a range of blows from 10 to 40, the sample needs to be dried using a hair-drier during the stages of remixing.

The results obtained from the casagrande apparatus were plotted on a graph (Figure 3.13) as the relationship between gravimetric soil moisture content and number of blows required to close the groove by 13 mm. The liquid limit was read from the graph as the gravimetric soil moisture content at 25 blows (Thomas, 1973) or can be calculated using linear regression of the results.

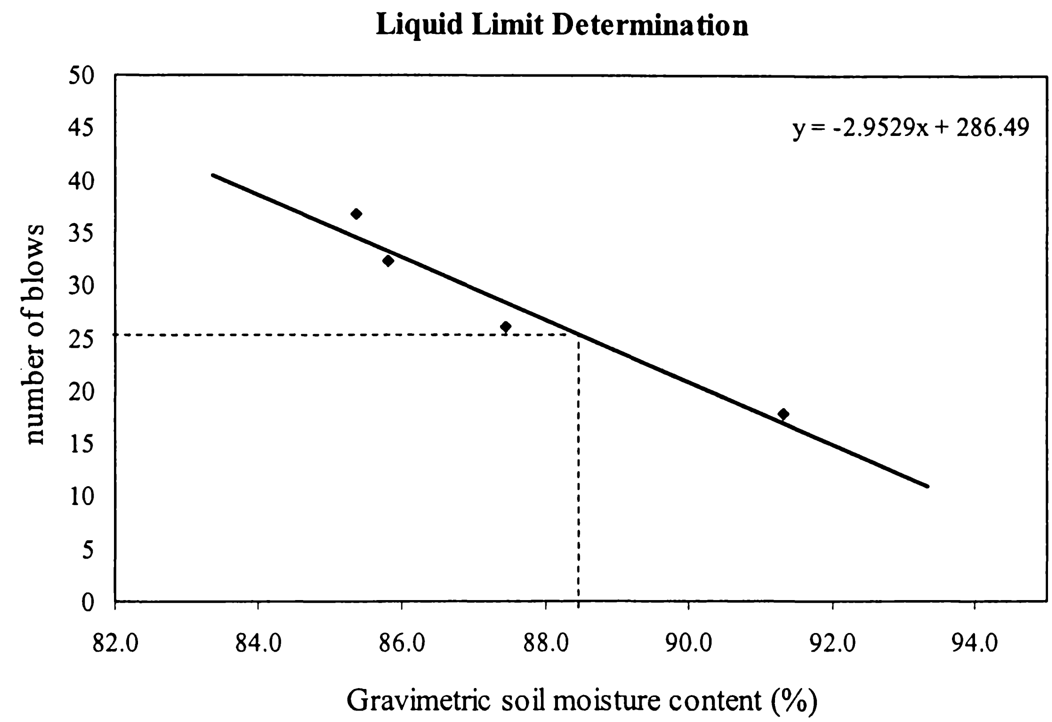


Figure 3.13 Example (81% GSM experiment, 5-10 cm soil depth) of liquid limit determination using the casagrande apparatus. Each data plot was the mean of the three replicates. Liquid limit was taken as 25 blows, which in this example was the 88.3% gravimetric soil moisture content.

Additional to the plastic and liquid limits, the plastic index was used to describe the soil and was calculated as follows.

$$PI = \theta_l - \theta_p \tag{3.21}$$

Where:
PI = plastic index
θ_l = liquid limit
θ_p = plastic Limit

The liquid index is a sensitivity measurement of vulnerability of the soil to liquid remoulding – where a liquid index of 0% is a soil at the plastic limit, and a liquid index of 100% is a soil at the liquid limit. The liquid index was calculated as follows:

$$LI = \left(\frac{FMC - \theta_l}{PI}\right)100 \tag{3.22}$$

Where:
LI = liquid index
FMC = moisture content of soil in the field

3.10 Particle Size Distribution

Particle size distribution was measured using the Malvern MasterSizer Laser Sizer (Singer *et al.*, 1988; Buurman *et al.*, 1997). The method uses laser diffraction to determine the volume of individual particles, allowing for the calculation of proportions for each particle size fraction. The advantages of the Malvern Laser Sizer method were its simplicity and minimal user-error. The Malvern Laser Sizer takes about 60,000 individual particle readings per sample. The Malvern Laser Sizer assumes particle sphericity, therefore, has a tendency to slightly underestimate clay content (Jones, 1998). However, reliable correlations (r^2 = 0.98) have been reported for comparisons between the pipette extraction method and the laser diffraction of Dutch clay soils (Buurman *et al.*, 1997).

Particle size distribution was determined at the 0-5 cm and 5-10 cm soil depths for each experimental site. Riffle Box Splitters were used to obtain a 200 g sample of moist soil from a 2 kg bulk sample for each experimental site and soil depth. Three replicate 0.5 g soil samples were obtained from the sub-sample and placed into beakers. To oxidise the organic matter, 10 mls of 10% hydrogen peroxide (H_2O_2) solution was added and the sample was left overnight in the fume cupboard. After oxidation, the beakers were gently heated to boil off excess peroxide. Care was taken to prevent the sample boiling over which results in loss of soil particles. After cooling, 10 ml of 10% calgon dispersing agent was added and the samples were allowed to stand for a further 24 hours. The samples were then treated to ultrasonic dispersion for 10 minutes. After dispersion a small sub-sample of about 3 ml was placed in the Sample Presentation Unit (an automated reservoir which runs the sample through the Laser Sizer) using a dropper. Typically, a sample run was one minute was enough to produce a data output sheet. The data output sheet presents the particle size distribution by 0.08 µm intervals, increasing to a maximum of 370 µm intervals at the larger range of particle sizes analysed (3.5 mm). The volume of particles per size fraction (clay, silt, sand) was determined by summing the relevant size intervals. Soil texture was determined by using the soil texture classes of Milne *et al.* (1991) and the particle size fractions by Standards Association of New Zealand (1986) (Table 3.2).

Table 3.2 Particle size fractions used for soil particle size distribution (Standards Association of New Zealand, 1986).

	Sand			Silt	Clay
	Coarse sand	Medium sand	Fine sand		
Size	2.0-0.6 mm	0.6-0.2 mm	0.2-0.06 mm	0.06-0.002 mm	<0.002 mm

3.11 Particle Density

Particle density was determined, using the method of Gradwell (1972), for each experimental site (separately for each treatment group) and separately for the 0-5 and 5-10 cm soil depths. A bulk sample of moist soil was obtained by random sampling from each treatment group, from which a 200 g sample was obtained by the use of the Riffle Box Splitters. The sample was dried at 105 °C for 24 hours and then lightly ground using pestel and mortar. The sample was then divided further, using Riffle Box Splitters, to obtain five replicate sub-samples (about 20-25 g each) which were placed in pre-weighed 100 ml volumetric flasks and then re-weighed.

The flasks were placed in a plastic compressor dessicator and suction was applied in three stages using an Edwards Rotary Vane Pump, model RV3. At the first stage, de-aired water (water that had previously been subjected to 0.2 Pa air pressure to remove any dissolved air, thus minimising excessive bubbling during particle density determination) was added to the soil in the volumetric flasks to just cover the soil. The volumetric flasks containing the soil and water sample were then placed inside the plastic compressor dessicator and the air pressure was lowered to 12 Pa until frothing eased (normal atmospheric pressure is about 100 kPa). At the second stage, the volumetric flask was half-filled with de-aired water and air pressure was lowered and held at 3 Pa until no air-bubbles appeared from the soil and water sample. At the third stage, the volumetric flask was filled with de-aired water to just below the 100 ml mark and placed at a 0.2 Pa air pressure until no further air-bubbles appeared from the sample. Care was taken to prevent 'over-boiling', which may occur in the early stages of the procedure.

When no air-bubbles had appeared from the soil and water sample for at least 10 minutes, the volumetric flasks were removed and placed in a water bath at 40 °C. De-aired water was added to the flasks to make the water level exactly 100 ml. After one hour, the volumetric flasks were removed from the water bath, dried, and weighed. Several blank samples were used to establish the density of water used in the experiment.

Soil particle density was calculated as follows:

$$\rho_w = \left(\frac{M_w}{V_f} \right) \tag{3.23}$$

Where:

ρ_w = density of water (Mg m^{-3})
M_w = mass of water in blank (g)
V_f = volume of flask (ml)

$$\rho_b = \left(\frac{M_s}{100 - (\rho_w (M_{sw} - M_s))} \right) \qquad (3.24)$$

Where:
ρ_p = particle density (Mg m^{-3})
M_{sw} = weight of water and soil (g)
M_s = mass of oven dry soil (g)

3.12 Herbage Accumulation

Herbage mass was estimated using the rising plate (Ashgrove pasture meter, Ashgrove Pastoral Products) method (Holmes, 1974; Castle, 1976; Earle & McGowan, 1979) (Figure 3.14). As the rising plate was a non-destructive method of determining herbage mass, readings could be taken through the entire experimental plot and the plots could be monitored for recovery whilst continuing to be rotationally grazed (Section 1.3).

L'Huillier and Thomson (1988) carried out comparisons between pasture cuts (cutting by mower and weighing green herbage) and four alternative methods of estimating herbage mass: pasture probe (Crosbie *et al.*, 1987), sward height, visual assessment (Haydock & Shaw, 1975) and the rising plate meter (Earle & McGowan, 1979). L'Huillier and Thomson (1988) found that the pasture probe and rising plate meter were the easiest to operate and were more reliable than results obtained by sward height and visual assessment methods. L'Huillier and Thomson (1988) also found that the pasture probe was marginally more reliable than the rising plate method (r^2 = 0.86 for pasture probe; r^2 = 0.84 for rising plate) in estimating herbage mass, however, the pasture probe was not used in this thesis because of high voltage power lines near the experimental sites which interfere with pasture probe readings. The rising plate meter has only recently been incorporated in some agricultural research (e.g. Gourley & James, 1997; Johnson & Morrison, 1997; Bluett *et al.*, 1998; Mosimann & Troxler, 1999; Freckleton *et al.*, 2000; Garcia *et al.*, 2000; Lile *et al.*, 2001; Tharmaraj *et al.*, 2003), and is being sold commercially.

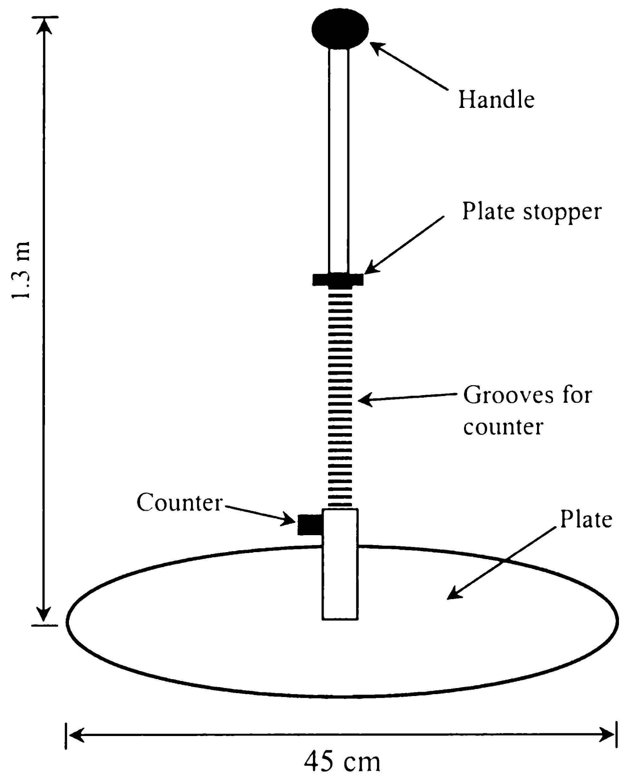


Figure 3.14 The Rising Plate.

The rationale for using the rising plate meter was that the entire plot could be analysed, without the removal of herbage, allowing the sampled site to remain part of the grazing rotation. However, if the pasture cutting method had been used in this thesis, it would have been restricted to small areas (grazing exclusion cages). The pasture cutting method is also prone to the 'mow' effect (Wagner *et al.*, 1950; Parsons *et al.*, 1984), where plant growth patterns (e.g. tillering rate) change in response to regular cuts at the same height, leading to different cattle grazing behaviour (Johnson & Parsons, 1985). To test the suitability of using the rising plate instead of the pasture cuts, an experiment was carried out which found no significant differences between the two methods ($r^2 = 0.95$; $P < 0.001$) (Figure 3.15, full data in Appendix I).

The meter was operated by placing a plate (of 0.1 m^2 area, equivalent to 5 kg m^{-2}) over the area for measurement with the central shaft protruding through the plate, touching the soil surface. The plate was raised up the shaft due to the presence of pasture. The movement up the shaft was recorded by a counter, which counts cumulative movements. Individual counter readings are dependent on the height and density of the pasture present. Earle and McGowan (1979) found that user-error could be caused when rising plate meter was used like a 'walking stick' rather than raising or lowering the rising plate meter in a vertical manner on each spot.

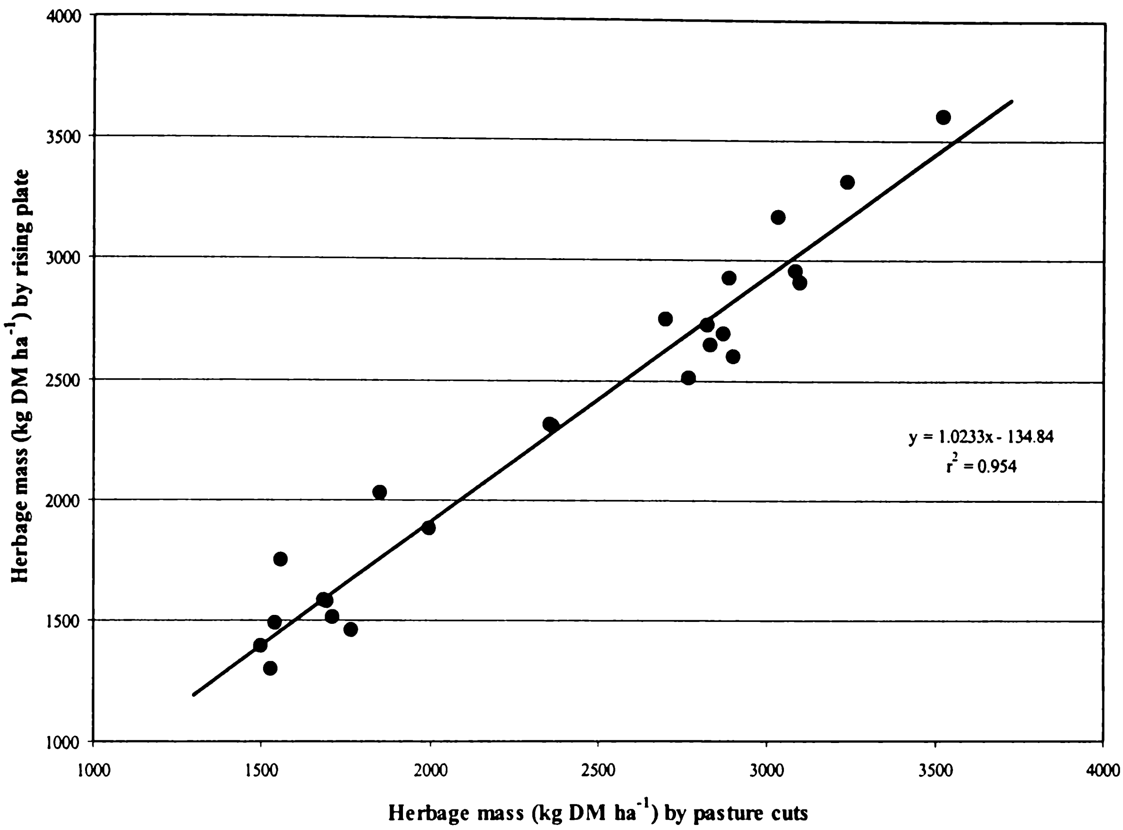


Figure 3.15 Correlation between herbage mass (kg DM ha^{-1}) determined using the rising plate meter and pasture cuts.

To estimate herbage accumulation, rising plate measurements were taken directly after a grazing event (giving the post-grazing herbage mass) and immediately before the next grazing (giving the pre-grazing herbage mass) – the difference between the post- and pre-grazing herbage mass represents herbage accumulation between consecutive grazing events. The total herbage accumulation over a period (season or year) can be obtained by summation of the appropriate herbage accumulation data.

Herbage mass was estimated for each plot from 50 plate readings randomly taken throughout the plot, avoiding areas previously used for soil core sampling. Herbage accumulation at intermediate stages between grazing events were made during the 71% and 81% GSM experiments but not the 65% GSM experiment, where only pre-and post-grazing estimates were made. As the rising plate method can be affected by rainfall on pasture (Campbell *et al.*, 1962), the measurements were not carried out during rainfall. Even though rising plate readings have been found to be repeatable during the day (L'Huillier & Thomson, 1988), plate readings were taken in the early morning and after morning dew had lifted, to avoid possible changes in pasture strength due to afternoon heating.

The results obtained from the rising plate were cumulative measurements that require conversion to herbage mass (kg DM ha^{-1}), with an additional correction to allow for seasonal variability (L'Huillier & Thomson, 1988) (Table 3.3).

Table 3.3 Seasonal calibration equations for estimating pasture dry matter yields using the rising plate method (L'Huillier & Thomson, 1988).

Season	**Herbage mass (kg DM ha^{-1}) for rising plate**
Winter-early spring *Before stem growth – generally between June and mid October*	125CMR + 640
Late spring-early summer *During stem growth, generally mid October to mid January*	130CMR + 990
Mid summer *Short period between mid January and February*	165CMR + 1480
Early Autumn *Before autumn rainfall, generally between March to mid April*	159CMR + 1180
Late autumn *After autumn rains start, generally mid April to May*	157CMR + 970

Corrected meter reading (CMR) was the average reading obtained from the rising plate and was determined as follows:

$$CMR = \frac{R_e - R_s}{R_\#} \qquad (3.25)$$

Where:
CMR = corrected meter reading
R_e = the last reading taken from the counter after taking measurements
R_s = the first reading taken from the counter before taking measurements
$R_\#$ = number of measurements taken (50)

Herbage accumulation was the difference between two sequential observations, calculated as follows:

$$HA = HM_2 - HM_1 \qquad (3.26)$$

Where:
HA = herbage accumulated (kg DM ha^{-1})
HM_1 = herbage mass at prior observation
HM_2 = herbage mass at subsequent observation
Note: herbage mass determined by calculations in Table 3.3

Often herbage accumulation is expressed as a rate over time (herbage accumulation rate) and was determined as follows:

$$HAR = \frac{HA}{t} \qquad (3.27)$$

Where:
HAR = herbage accumulation rate per day (kg DM ha^{-1} d^{-1})
t = time period between observations used to determine HA (days)

3.13 Sward Botanical Composition

The botanical composition of each treatment plot was determined before treading treatment and periodically after treading treatment. Random pasture cuts were taken using hand-held shears until at least a third of a 300 mm by 500 mm bag was filled. Each plot was walked across in a zigzag pattern and herbage was cut every five steps. The herbage cut was beside the right foot without reference to pasture conditions (but areas used for soil core sampling or affected by recent cow dung were avoided). The herbage cuts were made at ground level but avoiding inclusion of soil. The herbage samples were placed in a plastic bag and stored at 4 °C.

Dissection into herbage species was carried out in the laboratory within several days of herbage cuts being made. The herbage samples were thoroughly mixed and several randomly selected sub-samples were taken from the herbage sample and separated into species. At least 400 pieces of herbage were separated for each analysis. Soil, stones, and insects included in the herbage samples were removed. The common herbage species found in the samples are listed in Table 3.4.

The plant samples were placed in labelled oven containers and dried at 80 °C for 24 hours. After drying the samples were removed from the oven, cooled for about five minutes in a desiccator, and then weighed to 0.001 g accuracy. The sward species content data are presented as a percentage of the total dry weight of all the plant species in the sample.

Table 3.4 List of common herbage species encountered during sward botanical assessments. Not all species were found at all three sites.

Pasture Species	**Weed Species**
Ryegrass (*Lolium perenne* L.)	Broad-leaved plantain (*Plantago major* L.)
White clover (*Trifolium repens* L.)	Narrow-leaved plantain (*Plantago lanceolata* L.)
Red clover (*Trifolium pratense* L.)	Dandelion (*Taraxacum officinale* Weber)
Indian doab (*Cynodon dactylon* L.)	Californian thistle (*Cirsium arvense* L.)
Prairie grass (*Bromus willdenowii* Kunth.)	Broad-leaved dock (*Rumex obtusifolius* L.)
Paspalum (*Paspalum dilatatum* Poir.)	Curled dock (*Rumex crispus* L.)
Meadow foxtail (*Alopecurus pratensis* L.)	Creeping buttercup (*Ranunculus repens* L.)
Summer grass (*Digitaria sanguinalis* (L.) Scop.)	Hydrocotyle (*Hydrocotyle americana* L.)
Poa (*Poa annua* L.)	Yarrow (*Achillea millefolium* L.)
	Scrambling speedwell (*Veronica persica* Pior.)
	Daisy (*Bellis perennis* L.)

3.14 Grass Tiller Density

Tiller density was determined by *in situ* tiller counts within a 50 by 200 mm frame (area = 100 cm^2) after Thom *et al.* (1999). Tiller counts were made before and periodically after treading treatments. Within each plot, 10 frames were randomly located and tiller counts of grass species were made. Soil core sampling areas and areas recently affected by cow dung were avoided, as they were considered atypical of the pasture at the experimental sites.

Tiller count data were presented as tillers per m^{-2} and were determined using the following formula:

$$T\rho = T_{\bar{x}} U_c \tag{3.28}$$

Where:
$T\rho$ = Tiller density
$T\bar{x}$ = average of replicate tiller counts
U_c = unit conversion to m^2 (100)

3.15 Bare Ground Frequency Measurements

Bare ground frequency provides an estimate of the soil surface not occupied by herbage. The Point Frame Method described by Levy and Madden (1933) was used. The point frame had 10 points at 10 cm intervals (Figure 3.16), which exceeds the 5 cm minimum Levy and Madden (1933) suggested was necessary to eliminate bias in the results because of plant size. Point analysis requires precision in the readings, and Radcliffe and Mountier (1964b) suggested that sharpened needles would provide a precise observation point. Considerable discussion on the further development and usage of the point frame method was undertaken by Brown (1954), Goodall (1952), Mountier and Radcliffe (1964), and Radcliffe and Mountier (1964a; 1964b).

Bare ground was estimated immediately after a grazing, including the grazing before the treading treatment and then at each grazing after the treading treatment. Eight sets of readings were taken randomly throughout each plot. For each point, contacts with grass, weed, clover, dead material, or bare ground were recorded as the pin was pushed against the spring, moving the pin end (point) through the sward canopy. The proportion of bare ground was calculated as follows:

$$\%_{bareground} = \left(\frac{Bx}{\#_{point}} \right) 100 \tag{3.29}$$

Where:
$\%_{bare\ ground}$ = frequency of hits on bare ground
Bx = average hits on bare ground per point analysis frame
$\#_{point}$ = number of points per frame (10)

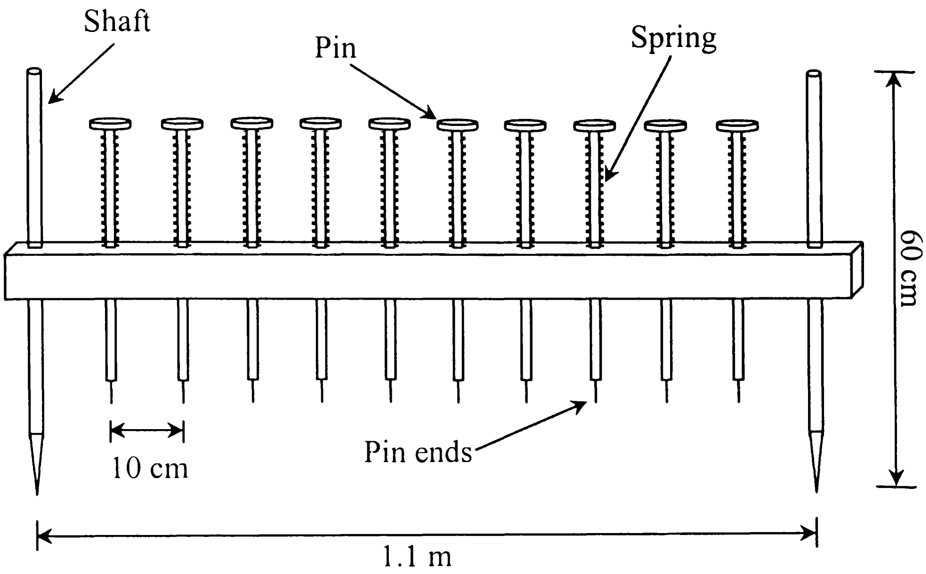


Figure 3.16 Point analysis frame used to estimate bare ground frequency.

3.16 Statistical Analysis

3.16.1 Introduction

A range of statistical tests were carried out on the data collected in this thesis using Microsoft Excel® (2002), Minitab® (2000), and GenStat® (2002). Descriptive statistics were predominately carried out on Microsoft Excel® and differences between treatments were determined by Analyses of Variance (ANOVA) using GenStat®. Minitab®, GenStat®, and Microsoft Excel® were used in conjunction to derive the regression models that used multiple variables.

3.16.2 Data Management

Field and laboratory data were entered into a standard Microsoft Excel® data sheet using pre-designed templates. When each field experiment (e.g. the 65% GSM experiment) was completed, the data sheets were linked together into an experimental master sheet. After the completion of all the field experiments, the experimental master sheets were linked into a grand master sheet. The grand master sheet was used for comparative statistics between treatments (e.g. macroporosity in the 65% GSM 3-hour treatment compared to 65% GSM 9-hour treatment) and for production of graphs. The grand master sheet was also used for two-variable regressions (e.g. bare ground compared to soil surface roughness).

3.16.3 Descriptive Statistics and Two-variable Regression

Descriptive statistics included the mean, standard deviation, and standard error of the mean. Analyses of Variance (ANOVA) was used to determine differences between treatments (having experiment/GSM as a blocking factor), and was used to derive the Least Significant Differences (LSD) of the means to indicate where significance of differences are. The ANOVA took into account experimental structure, where the within-plot variability was included with the within-treatment (treatment replication) variability. Two-variable regression (linear and polynomial/quadratic) was carried out and presented with the coefficient of determination (r^2), residual standard deviation (r.s.d.), and statistical significance (P <0.05, 0.01, 0.001).

The K_{sat} and K_{-40} data were logged transformed prior to carrying out the ANOVA due to the non-normal distribution of the variance for non-logged K_{sat} and K_{-40} data.

3.16.4 Multivariate Regression and Statistical Modelling

Statistical modelling was completed using multivariate regression (stepwise multivariate regression analysis) and carried out with the assistance of Dr A.B. Zwart. By using multivariate regressions models the relationship between easily determined variables, such as amount of bare ground and soil surface roughness, with the decline in pasture productivity can be described. The statistical models could potentially be used to estimate decline in pasture productivity prior, or immediately after, treading damage has occurred.

All statistical models were constructed using plot means, with the exception of the hydraulic conductivity models (K_{40} and K_{sat}) where treatment means were used to eliminate inherent variability. Multivariate regressions were only presented if the significance of the regression was P <0.05 and if there was potential for practical application.

A variable was included into a multivariate regression only if the variable made a statistically significant contribution to the regression, that is the inclusion of the additional variable significantly (P <0.05) improved the estimates from the multivariate regression. If a variable did not significantly (P <0.05) improve the multivariate regression, the variable was not used.

Multivariate regressions are presented with the same statistical outputs as the two-variable regressions. In the literature, multivariate models are also presented with the adjusted (corrected) coefficient of determination (adj. r^2). The adjusted coefficient of determination accounts for possible random explanation of variability by the regression because more than one variable was used. Thus, when using multiple variables in a regression the adjusted coefficient of determination may give a more reliable measure of the goodness of fit with the data and, therefore, is also presented in this thesis.

Chapter 4. Field Experimental Design and Site Description

4. Field Experimental Design and Site Description

4.1 Introduction

This chapter describes the field experimental design, soil type used, experimental site description and preparation, and the implementation of the treading treatments. The allocation of treatments and site preparation are also described.

4.2 Overview of Experimental Aim and Design

A series of treading experiments were undertaken during three consecutive winters; 1999, 2000, and 2001. In each experiment, the same experimental design was used, but the pugging susceptibility (as determined by the AgResearch Penetrometer and periodic soil moisture content sampling prior to the experiment) was different, giving a pugging susceptibility range from slightly susceptible to very susceptible. At the commencement of the experimental treading, soil samples were taken to determine gravimetric soil moisture content (GSM), giving the three experimental names: 65%, 71%, and the 81% GSM experiments. The objective of the experiments was to determine the effect of a one-off severe treading event of different durations on soil physical properties and sward, and the subsequent recovery from the one-off severe treading event within the normal farm grazing rotation whilst avoiding further severe treading damage.

Due to the large-scale nature of the research, the three experiments were not carried out in the same year and at the same experimental site, adding a component of seasonal and site variability. There were slight modifications made to the 71% and 81% GSM experiments based on experience from the 65% GSM experiment.

Each of the experiments was carried out on a Te Kowhai silt loam soil (NZ soil classification, *Typic Orthic Gley*; USDA soil taxonomic classification, *Typic Endoaqualf*), which is susceptible to severe treading damage. The treading treatments were of different durations: 0-hours (control, no treading when soil was susceptible to pugging), 3-hours (representing a short, conservative grazing), 9-hours (representing grazing during daytime), and 24-hours of treading (representing a day and overnight grazing). A short three hour cattle grazing has been suggested to prevent potentially severe treading damage when soil is susceptible to pugging damage (Drewry, 2003), and when cattle are kept on stand-off pads or farm tracks for the remainder of the day. Nine hours of grazing is common on farms between morning and evening milking. Twenty-four hours of grazing was used to represent a full cycle from morning milking to the following morning milking on a seasonal dairy farm.

The control plots served as a comparison of soil and sward that were not trodden when soil was susceptible to pugging damage. The mean height of remaining sward in the 3-hour treatment plots were used to determine the height of the mower cut for the control plots, simulating herbage defoliation by cattle. Herbage harvested was not returned to the control plots and control plots were again included along with the treading treatment plots, in the farm grazing rotation after the treading treatment.

The grazing and treading was carried out by lactating Friesian dairy cows (of mixed ages but not heifers), as these are the predominant breed of dairy cattle in the Waikato region. The stocking density was 300 cows ha^{-1}, as this is a common stocking density when break-feeding pasture in late winter/early spring (A.R. Napper, *pers com.* 1999; P.G. Laboyrie, *pers com.* 2000) and was similar to stocking density used in other research (e.g. Singleton *et al.*, 2000; Drewry *et al.*, 2003).

Treatment plots were arranged in a randomised block design with treading treatments replicated three times, giving 12 treatment plots per experimental site (four treading durations replicated three times). All plots were trodden at the same time and each plot was trodden using a different group of cattle and analysed separately for soil and pasture properties.

A number of sub-samples were taken at random from within treatment plots to better represent the plot mean. The number of within-plot replicates for each soil or pasture variable differed for each variable, for example, soil porosity was replicated five times while bare ground was replicated 10 times per treatment plot. The replication layout is illustrated in Figure 4.1 and the number of replicates for each variable is given in the methods (Chapter 3).

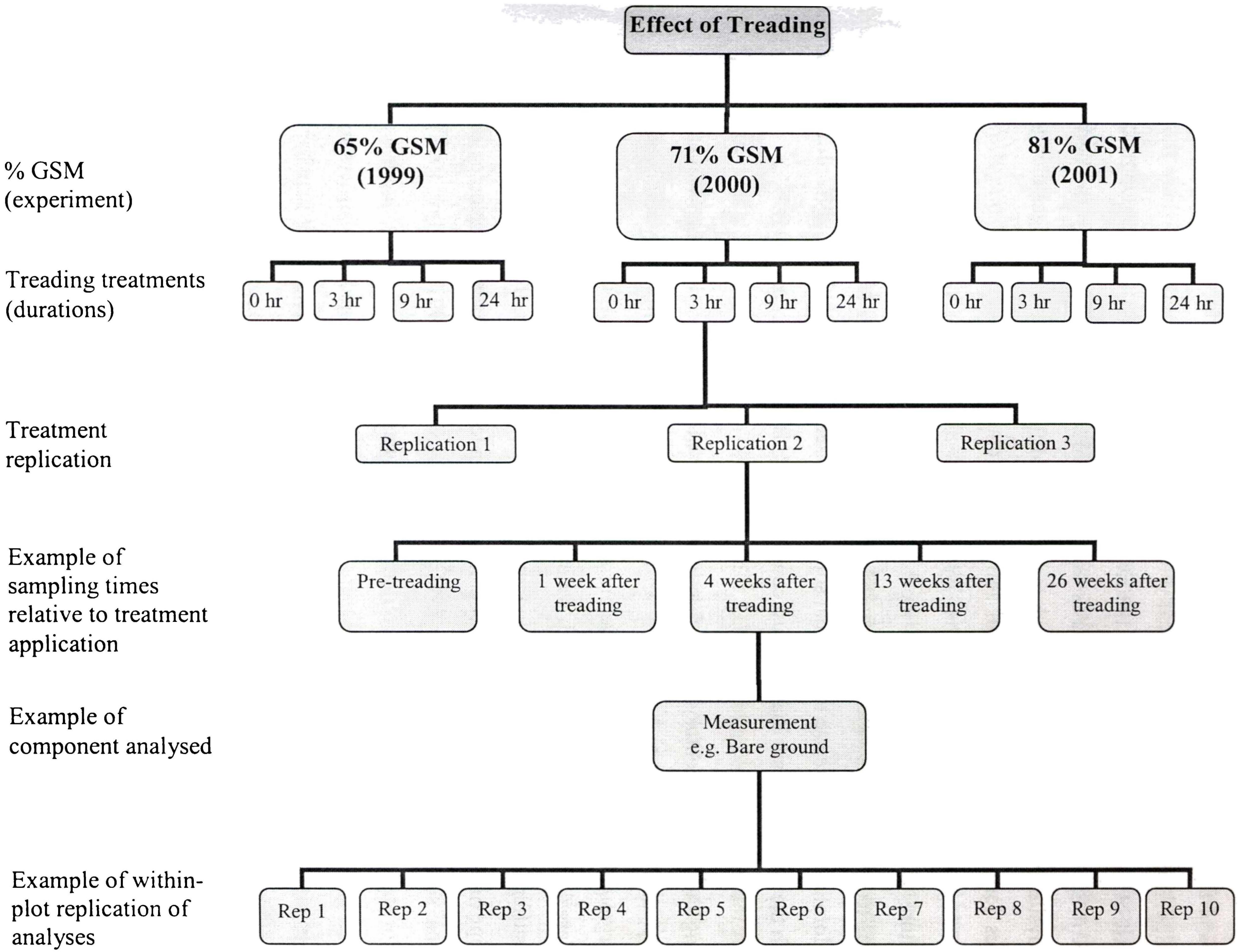


Figure 4.1 Experimental design, presented as an example for estimating bare ground at four weeks after treading treatment for the 2nd replication of a 3-hour treading treatment at 71% gravimetric soil moisture content (GSM).

4.3 Te Kowhai Soil Formation, Features, and Development

The Te Kowhai silt loam is a common soil in the Waikato region, and is extensively used for dairy cow grazing (Singleton, 1991). The soils of the Waikato Basin were formed on alluvial deposits from the Waikato River, which historically meandered through the Waikato basin (Molloy, 1993). The deposits typically formed swale-and-ridge patterns, where the swales consist of clayey/silty material and the ridges of sandy/silty material (McCraw, 2002). The Te Kowhai soil formed in the swales and is gleyed owing to the clayey (predominantly Halloysite) nature and seasonally high water table (Molloy, 1993). The ridges alongside the swales formed the Horotiu silt loam soil (NZ soil classification, *Typic Orthic Allophanic*; USDA soil taxonomic classification, *Typic Udivitrand*), which is often reported in the literature to be high producing and ideal for intensive agriculture and horticulture. As the swales tend to be more extensive than the ridges, the Te Kowhai soil is more common than the Horotiu soil. There are transitional soil types between the Te Kowhai and Horotiu soil, of which the Bruntwood silt loam is most common (M.R. Balks, *pers com.* 2004).

During the late 19th century, when farming became widely practiced in the Waikato Basin, poorly drained soils such as the Te Kowhai soil were modified by cultivation and underground drains (Crush & Wedderburn, 2002). Coupled with regional drainage schemes, this largely solved the continual high water table problem. However, the Te Kowhai soil can still suffer from slow water infiltration and, during the wet season, the water table may still become high causing surface water accumulation. If adequate drainage is implemented the Te Kowhai soil has a high potential for food production (Singleton, 1991; Molloy, 1993) and its use for intensive vegetable production and horticulture is common. Some farms on the Te Kowhai soil also have areas of the better draining Horotiu soil, and the farmers minimise winter pugging damage by grazing the Horotiu soil during times when the Te Kowhai soil has high pugging susceptibility.

4.4 Site Selection Criteria, Location, and General Information

4.4.1 Selection Criteria

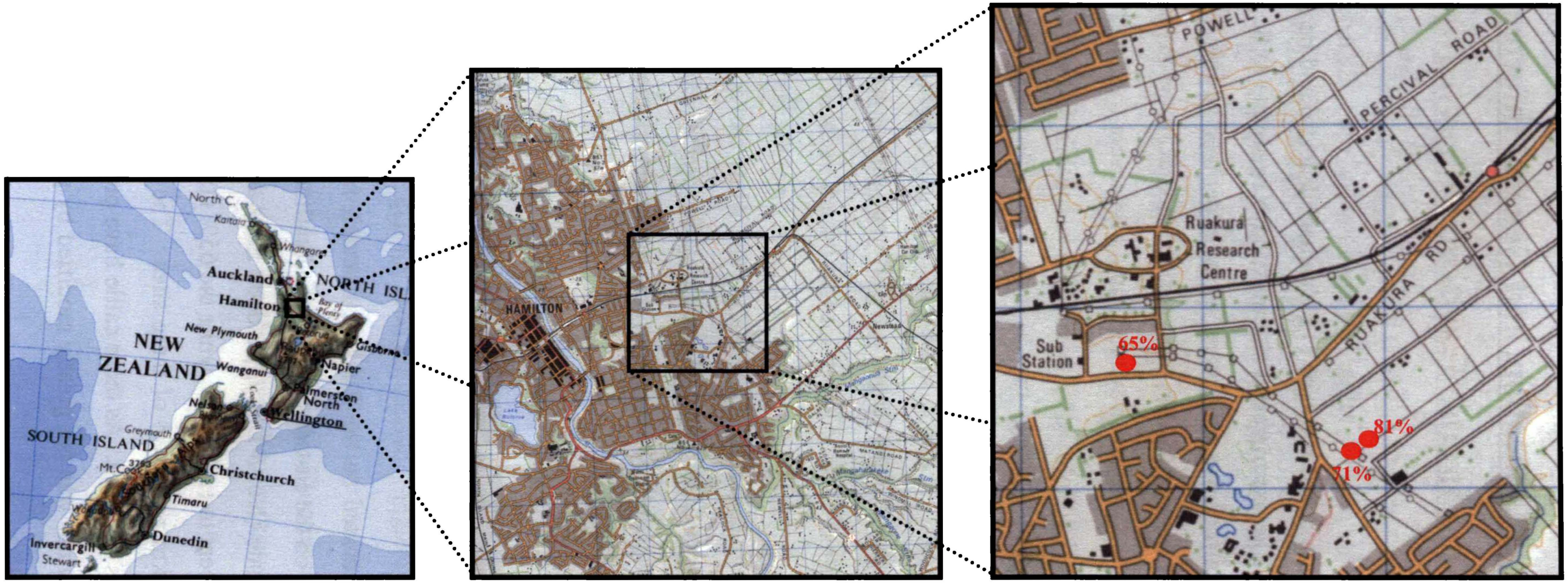
Primarily, experimental site criteria was soil type (Te Kowhai silt loam) and its current farm production type (dairy farm). The experimental site must have been able to be managed as one unit (paddock). Paddock history was considered, as the experimental sites must not have suffered recent severe treading damage (within one year of the start of the experiment). As the Te Kowhai soil is commonly pugged each winter, some past severe treading (more than 2 years ago) was inevitable.

The sward at the experimental sites had not been renovated (e.g. under-sowing) at least five years before the field experiments. Paddock shape must also have been maintained for at least five years, as soil previously under fences has different soil physical characteristics (Zegwaard, 1998; Singleton *et al.*, 2000).

The sward was a perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) mix. Areas with large amounts of established pasture weeds were avoided. For the 71% and 81% GSM experiments, availability of irrigation was essential and, therefore, became an important site selection criterion.

4.4.2 Site Locations

The experimental sites were located on the Ruakura research farms (37° 47'S 175° 19'E; altitude 40 m above sea level), on the eastern outskirts of Hamilton city, New Zealand (Figure 4.2). The 71% experimental site (No. 5 Dairy, paddock E3a) and 81% GSM experimental sites (paddock E3b) were adjacent to each other, while the 65% GSM experimental site (No. 1 Dairy, paddock G4) was 1.5 km northwest of these sites. The research farms run several small, intensely managed herds per farm. As these cattle have previously been used in small experimental plots, their behaviour was not greatly modified by placing them on small plots for the experiments in this thesis.



(Hasselberg, 1979)

Figure 4.2 Location of the 65%, 71%, and 81% GSM experimental sites.

4.4.3 Climatic Conditions

Climatic conditions at the experimental sites were temperate, however, rainfall during the three experiments was lower, and distributed over more days, than usual (Table 4.1, full data in Appendix II). Additionally, temperature was on average 0.8°C warmer and more ground frosts than usual occurred.

Table 4.1 Annual climate data and climate data during the experiments (July-January)

Year	Total rainfall (mm)	Mean max air temp (°c)	Mean min air temp (°c)	Mean grass min temp (°C)	Mean soil temp at 10 cm (°C)	Total no. of ground frosts	Total no. of rainy days
Annual	833.0[a]	17.8[a]	7.9[a]	5.8[b]	12.4[a]	47[b]	95[a]
1999	772.2	18.6	7.7	4.5	14.6	71	105
2000	627.2	18.4	8.5	5.5	14.7	56	122
2001	726.4	18.8	8.8	5.8	14.7	53	126

[a] Mean from data collected from 1971 to 2000 (July – Jan)
[b] Mean from data collected from 1996 to 2004 (July – Jan)

4.4.4 Treatment Allocation

Treatments were randomly allocated to the plots, but with some restrictions. The 9- and 24-hour treading treatment plots were prevented from being alongside each other by distributing them between the controls and 3-hour treading treatment plots. Separating the 9- and 24-hour treading treatment plots was carried out to minimise cattle behavioural changes (e.g. herding effects) that might affect treading behaviour. Herding effects of cattle in the 3-hour treading treatment was considered unlikely because cattle were pre-occupied with grazing for most of the treatment time. Cows known to be herd leaders, or 'bullies', along with those that were 'on heat' were not used in the experiment.

Treatment allocations were also restricted so a full set of four treatments (a treatment group; a group consisting of one each of the treatment types) were arranged at the front, middle, and back of the paddock (at the 65% GSM experimental site two groups of six treatment plots were used). The allocation into groups was used to account for possible differences, for example, in soil conditions at the front of the paddock compared to the back, which may influence treatment effects (H.V. Henderson, *pers com.* 1999).

At the 65% GSM experimental site, treatment plots were 18.67 m by 12.5 m (233.37 m^2 area) and were trodden by seven cows (299.95 cows ha^{-1}). At the 71% and 81% GSM experimental sites treatment plot sizes of 10.1 m by 16.5 m (166.65 m^2 area) were used and were trodden by five cows (300.03 cows ha^{-1}). At all experimental sites, the ratio of treatment plot width to length was about 1:2, representing break-feeding strips on farms.

Treatment plot boundaries were marked at each corner using treated 0.4 m long wooden pegs. The pegs were hammered to ground level to prevent possible hoof damage, and were marked with "dazzle" paint. At the time of the treading treatment, temporary electric fences were used around the plot perimeters to restrain the cattle. For each plot, one side could be opened for cattle access. The temporary electric fences were removed when the treading treatments were complete and all treatment plots were grazed as one paddock.

4.4.5 Farm Management Considerations

The experimental sites chosen had been subjected to a grazing regime representative of typical intensive dairy farm production. One of the experimental aims was to monitor soil and sward recovery from a one-off severe treading event while the experimental sites were retained within the grazing rotation. Therefore, further grazing events (Table 4.2) did take place before soil and sward recovery was complete, but additional severe treading damage did not occur after the experimental treading damage. If prior to a grazing event the site was deemed to be susceptible to pugging damage (as determined by the AgResearch Penetrometer) or rainfall was expected, grazing was avoided until the sites were no longer susceptible to pugging damage. However, because the winters when the experiments were undertaken were drier than usual, the risk of subsequent severe treading damage was considerably reduced.

Table 4.2 Dates of subsequent grazing events after experimental treading.

	Grazing dates					
65% GSM	25/6/99[a]	3/8/99	30/9/99	1/11/99	24/12/99	10/1/00
71% GSM	29/8/00[a]	6/10/00	4/11/00	24/11/00	20/1/01	29/2/01
81% GSM	6/8/01[a]	19/9/01	15/10/01	6/11/01	4/12/01	20/1/02

[a] date of experimental treading

When grazing took place, all plots were grazed simultaneously and there was no break-feeding across the experimental sites. During the field experiments farm management was 'typical', but spraying of weeds was avoided as long as was practically possible. Farm vehicle traffic was avoided due to potential compaction. A farm vehicle was used for fertiliser additions, and the farm vehicle path was marked with pegs and post-treading sampling was not made from these areas.

4.4.6 General Soil Physical Properties

The particle size distribution and soil texture (Table 4.3) were similar between experimental sites and soil depths. The range in clay content was no more than ±4.3 %. Differences in particle size distribution between the 0-5 cm and 5-10 cm soil depths were not significant ($P < 0.05$) for clay and silt. However, the average difference of 3.4% in sand content between experimental sites was significant ($P > 0.05$), but not considered to be of practical importance.

Table 4.3 Particle size distribution and textural class for each experimental site at the 0-5 cm and 5-10 cm soil depths.

Site	Soil depth (cm)	% Clay	% Silt	% Sand	Textural class
65% GSM	0-5	22.18	60.61	17.20	Silt loam
	5-10	23.92	63.45	12.63	Silt loam
71% GSM	0-5	22.41	64.40	13.16	Silt loam
	5-10	24.64	63.43	11.93	Silt loam
81% GSM	0-5	21.41	63.34	15.23	Silt loam
	5-10	20.38	65.01	10.84	Silt loam

Note: full data in Appendix III

The plastic and liquid limits were consistent between experimental sites (Table 4.4), however, the plastic and liquid limits at the 65% GSM experimental site was lower (P <0.05) than at the 71% and 81% GSM experimental sites. The differences were small and not deemed to be of any practical importance. At each of the sites, the 5-10 cm soil depth consistently had lower (P <0.05) plastic and liquid limits than the 0-5 cm soil depth. The plastic index was typical of a clay/clay loam soil (McLaren & Cameron, 1993). The soil particle densities were also similar between experiments and similar to those reported for the Te Kowhai soil (e.g. Joe, 1984).

Table 4.4 Plastic and liquid limits, plastic index, and soil particle density for each experimental site at 0-5 cm and 5-10 cm soil depths.

Site	Soil depth (cm)	Plastic limit (%g g^{-1})	Liquid limit (%g g^{-1})	Plastic index	Particle density (Mg m^{-3})
65% GSM	0-5	50.01	81.17	31.16	2.32
	5-10	45.81	75.98	30.17	2.35
71% GSM	0-5	53.96	98.58	44.62	2.31
	5-10	47.86	84.74	36.88	2.36
81% GSM	0-5	55.22	95.00	39.78	2.30
	5-10	48.57	88.55	39.98	2.36

Note: full data in Appendix III and IV

4.5 The 65% GSM Experimental Site

4.5.1 Site Description and Brief History

The 65% GSM experimental site was located on the south-western side of a 1.2 ha paddock. The drainage at the experimental site had been modified by a deep drain on the western side, between the paddock and Ruakura Road (Figure 4.4). Tile drainage had been introduced but was assumed by the farm manager not to be functional as there was no outflow from tile drain exit points and tile fragments were found in the soil during previous research (C.P. Burgess *pers com*, 1999). Recently installed, perforated underground drainage (Novaflow pipe) was used to drain a low-lying area on the eastern side of the paddock.

The experimental site had annual fertiliser additions of about 300 kg nitrogen, 40 kg phosphorus, 100 kg potassium, and 50 kg sulphur (A.R. Napper, *pers com.* 1999). The paddock had a history of pugging damage, however, no severe pugging was reported over recent years (A.R. Napper, *pers com.* 1999). Part of the paddock had been used for a soil compaction amelioration experiment and included the use of a shallow mechanical loosener (Burgess, 1998; Burgess *et al.*, 2000). Because of possible lasting effects from the mechanical loosing (Chapman, *pers com.* 1999), the area used for the previous experiment was avoided. The paddock was also used, concurrent with experiments in this thesis, for other treading related research (Singleton *et al.*, 2000; Drewry, 2003; Drewry *et al.*, 2003). The paddock had high voltage power lines overhead, although no pylons were located in the paddock. A single wooden power-pole was located in the middle of the paddock, which was at the north-eastern corner of the area used for the 65% GSM experiment.

4.5.2 Description of Soil and Sward

The soil at the 65% GSM experimental site had a dark brown (10YR 3/4) to dark olive brown (2.5 Y 3/2) A horizon, with an average depth of 22 cm (occasionally as deep as 27 cm) (Figure 4.3a). The B horizon was light grey (5Y 8/2) to pale yellow (7.5Y 8/3). The boundary between the A horizon and B horizon was distinct with occasional occlusions. The A horizon soil was polyhedral to blocky structure, with strong pedality, and firm aggregates.

The A horizon was moderately sticky, deformable, and very plastic. The B horizon soil was angular to blocky in structure with moderate pedality. The B horizon was deformable, moderately to very sticky and very plastic. About 15 to 20% of the soil profile in the B horizon consisted of bright reddish brown (5YR 5-8) mottles, which were up to 6 mm in diameter. At the time of soil description, the soil was moist, having received recent rainfall. The soil penetration resistance using hand-assessment (Milne *et al.*, 1991) was high (2.2 – 3.0 MPa) in the A horizon, and very high (3.1-4.0 MPa) in the B horizon. There was some evidence of earthworm activity in the soil, however, not as extensive as at the 71% and 81% GSM experimental sites. Plant roots were observed as deep as 20 cm and some isolated roots were found well into the B horizon.

Pasture at the 65% GSM experimental site consisted of an established ryegrass white clover mix. White clover was not common, and some other grass species had become established at the experimental site, most notably Indian doab (*Cynodon dactylon* (L.) pers.). There was some *Poa* (*Poa annua* L.) and paspalum (*Paspalum dilatatum* Poir.). Common pasture weeds were also present at the experimental site, such as broad-leaved dock (*Rumex obtusifolius* L.), Californian thistle (*Cirsium arvense* L.), and broad-leaved plantain (*Plantago major* L.). There was a notable patch of yarrow (*Achillea millefolium* L.) present, with a smattering of plants throughout the paddock. Hydrocotyle (*Hydrocotyle Americana* L.) was widely distributed at the experimental site but contributed little to the herbage mass.

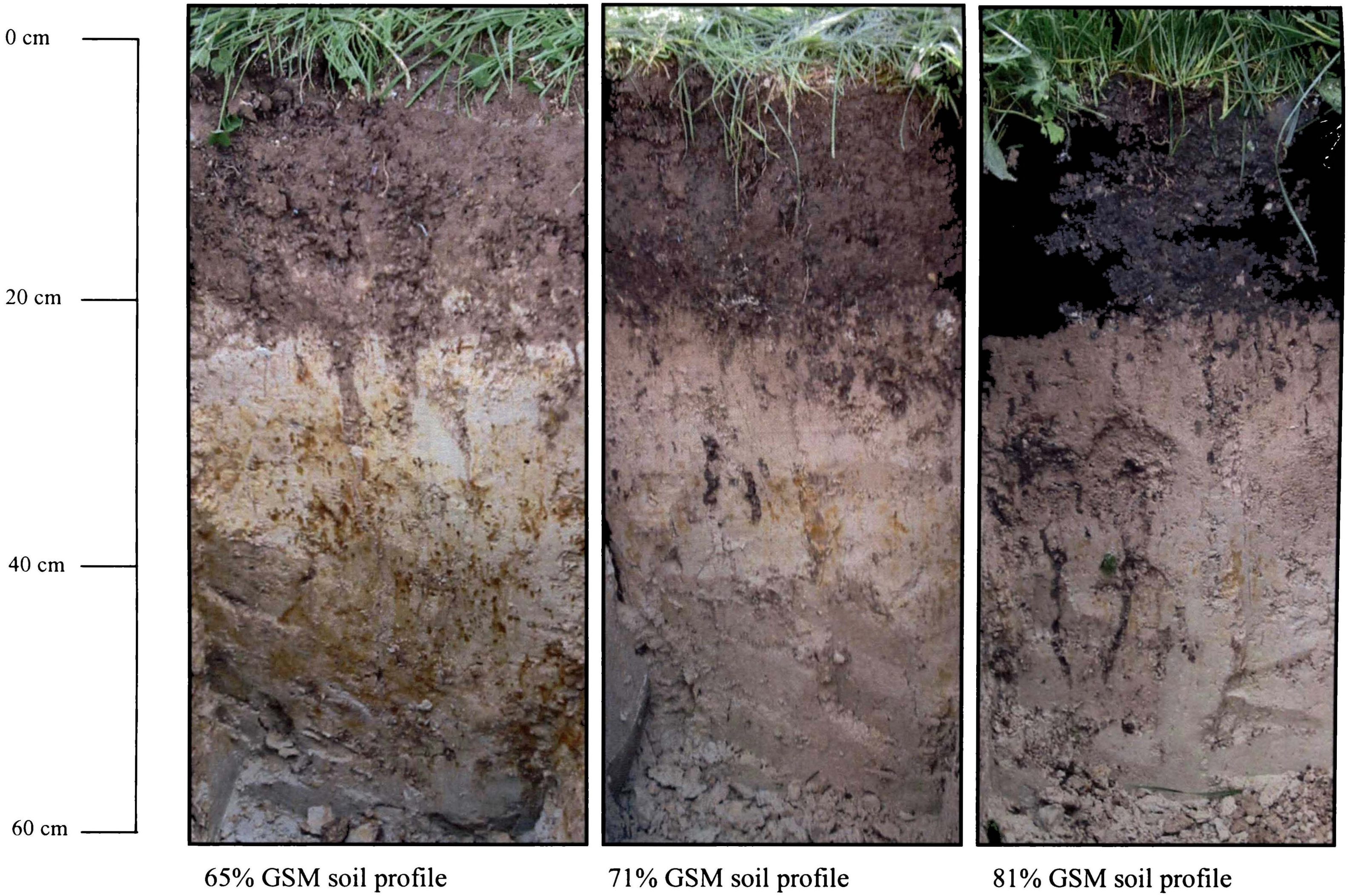


Figure 4.3 Soil profile at each experimental site.

4.5.3 Site Preparation

The treatment plots were placed in two groups of six to allow easy application of treatments (Figure 4.4). As silage had previously been fed out along the fence line, the treatment plots were placed 5 m away from the fence. The treatment plots were located more than 50 metres from the main access gate at the northern end of the paddock. There was a locked, and seldom used, access gate to Ruakura Road located in the south-eastern corner.

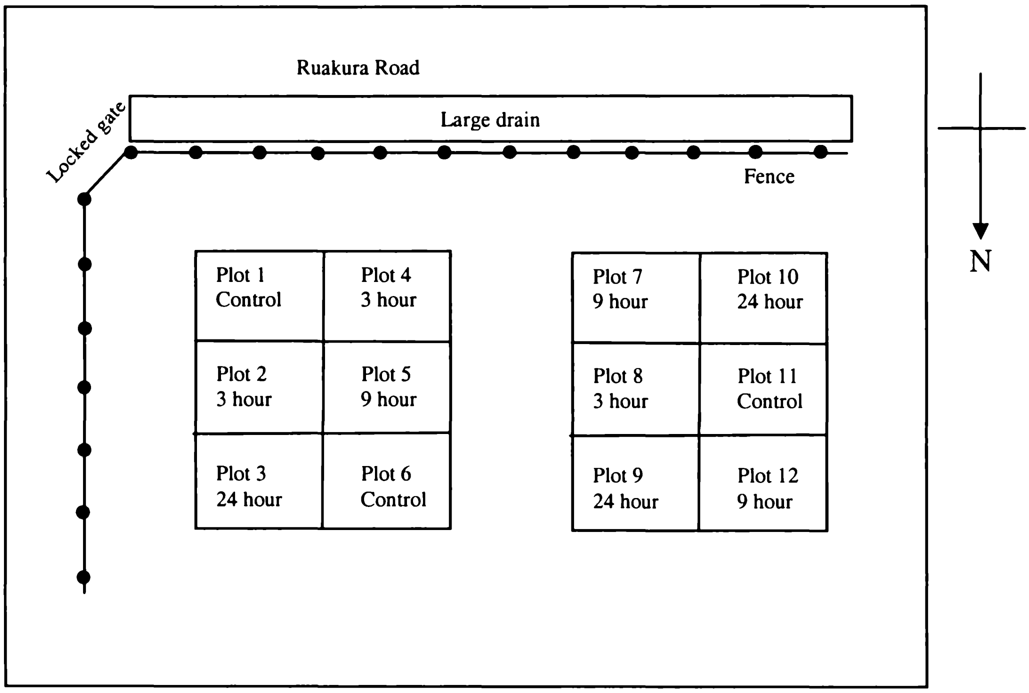


Figure 4.4 Treatment plot layout for the 65% GSM experimental site.

4.5.4 Treading Treatment and Visual Impact

The treading treatment was carried out on 25th June 1999. The gravimetric soil moisture content at the time of treading treatment application was 65% (volumetric moisture content 52%; degree of saturation 79%). Cattle were placed on the treatment plots immediately after morning milking, about 7:00 am (Figure 4.5a & 4.5b). All treading treatments had begun within 20 minutes of each other. At the time of treading treatment, there was a frost and some fog, and there was concern additional treading damage to pasture could occur because of the frost. However, the frost was light (-1.7°C grass minimum temperature, 0.3°C air temperature) and had disappeared by the time the cattle entered the treatment plots.

Soil damage was visually more noticeable in the 9- and 24-hour than in the 3-hour treatment plots, however, rupture of the soil surface was not observed. The type of treading damage was deemed 'pressing' damage, rather than pugging damage. Pressing of the soil is defined as remoulding of the soil surface with individual hoof prints visible but no breaking (rupture) of the soil surface. During the course of the 24-hour treatment, no liquid remoulding of the soil was observed.

Weather conditions two weeks after the treading treatment were sunny and dry, allowing the soil surface to dry and form small cracks. Air temperature was cool (average 13 °C), with some fogs and nine ground frosts in the two weeks after the treading treatment (Appendix II).

a)

b)

c)

d)

Figure 4.5 Stages of the 65% GSM treading treatment, where:

a) the treading treatment in process,
b) cattle being taken off a treatment plot,
c) after treading treatment,
d) 24-hour treading treatment plot.

4.6 The 71% GSM Experimental Site

4.6.1 Site Description and Brief History

The 71% GSM experimental site was located next to the 81% GSM experimental site, and both sites share a common history and description. The 71% and 81% GSM experimental sites had irrigation facilities, giving greater control of soil moisture content at the time of treading treatment. The 71% and 81% GSM experimental sites were treated as one large paddock when part of previous irrigation experiments (Barker *et al.*, 1998; Thom *et al.*, 1998a; Thom *et al.*, 2001). The 71% and 81% GSM experiments had treading damage in the past, however, no severe treading damage had occurred in recent years (P.G. Laboyrie, *pers com.* 2000). Access to the experimental site was from the southern end.

The fences on the eastern and western sides of the experimental site were semi-permanent (single wire electric Waratah fences). There was a functional herringbone tile drain system under the experimental sites (200 mm diameter pipe with 100 mm diameter branches).

At the northern end of the 71% GSM experimental site there was an old drainage feature (possible an old creek bed), about 0.5 m lower than surrounding land and running at a slight angle along the northern fence. The drainage feature still served a limited function for surface drainage.

4.6.2 Description of Soil and Sward

The soil at the 71% GSM experimental site had a brownish black (5YR 3/1 to 7.5YR 2/2) A horizon, with an average depth of 18 cm, occasionally up to 25 cm (Figure 4.3b). The B horizon was light grey (5Y 7/2). The boundary between the A horizon and the B-horizon was distinct with slight occlusions. The A horizon was blocky with some polyhedral structure, with strong pedality and slightly firm aggregates. The A horizon was moderately sticky, semi deformable to deformable, and plastic. The B horizon was angular to blocky in structure with moderate pedality. The B horizon was deformable, moderately sticky, and plastic. About 7%

of the soil profile in the B horizon consisted of bright yellowish brown (10YR 6/8) mottles, which were up to 5 mm in diameter. Some mottles appeared to have formed in old root and earthworm burrows. At the time of soil description, the soil was moist, having received recent rainfall. The soil penetration resistance using hand-assessment (Milne *et al.*, 1991) was moderately high (1.5-2.2 MPa) in the A horizon, and high (2.2-3.0 MPa) in the B horizon. Plant roots were observed as deep as 13 cm and some isolated roots penetrated into the B horizon. There was evidence of earthworm activity well into the B horizon, with old earthworm burrows readily found.

Pasture at the 71% GSM experimental site was a well-established ryegrass and white clover sward, however, white clover was not common. Other grass species were present including some *Poa*, paspalum, prairie grass (*Bromus willdenowii* Kunth.), and summer grass (*Digitaria sanguinalis* (L.) Scop).

4.6.3 Site Preparation

Site preparation differed from the 65% GSM experiment, as the usable area was smaller. Additionally, wetter soil conditions were required, and, as a second dry winter occurred, large travelling 'big gun' irrigators (Ocmis Irrigator 90 R2/1) were used to raise soil moisture content. To maximise the usable area of the paddock, treatment plots were placed against the paddock fences (Figure 4.6) and sampling was restricted to the central area of each plot. Access for cattle used for the treading treatments was via the two adjacent paddocks by lowering the Waratah fence. The areas near the water trough and gateway were not used for treatment plots.

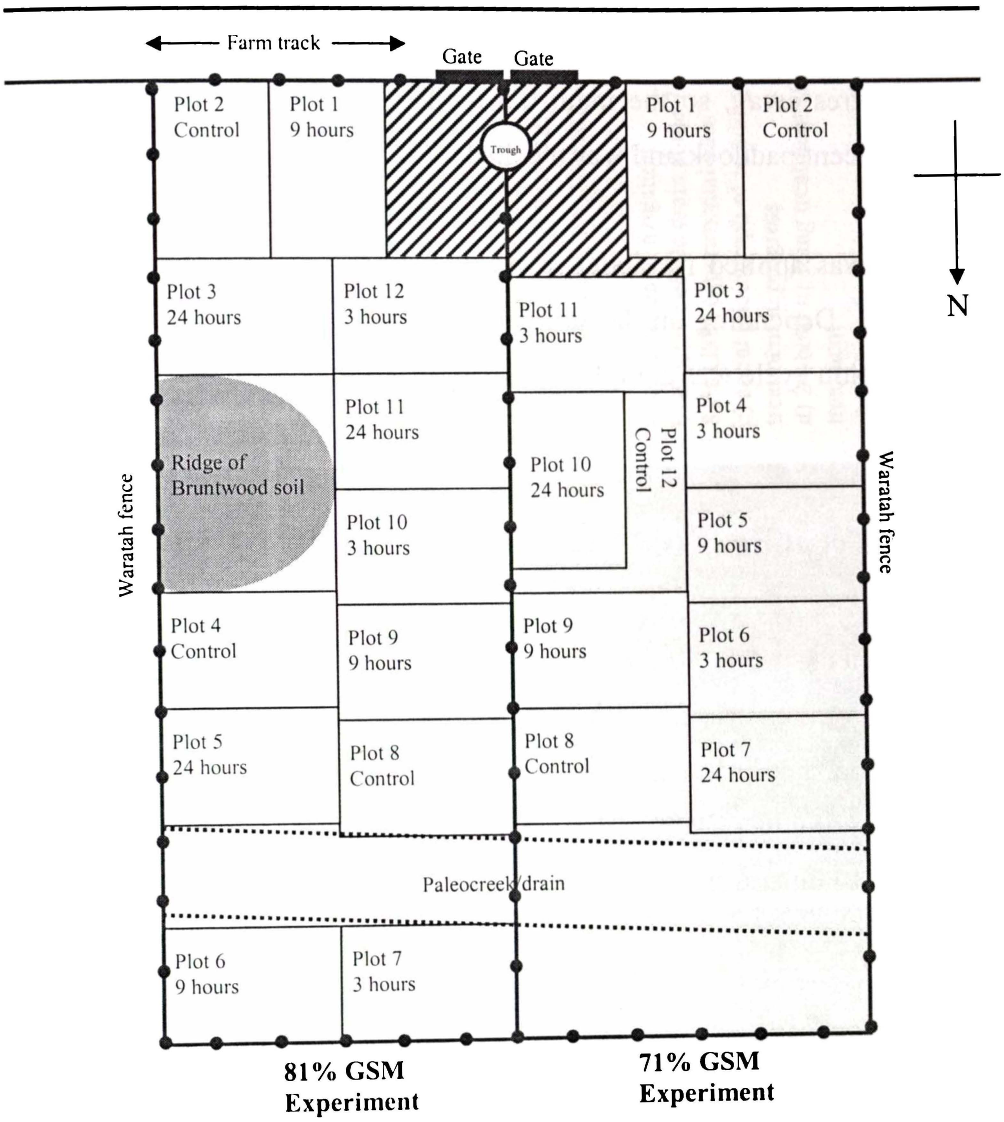


Figure 4.6 Treatment plot layout at the 71% and 81% GSM experimental sites.

Irrigation was required to increase soil moisture levels for the 71% and 81% GSM experiments. Large travelling 'big gun' irrigator, capable of 60 m^3 hr^{-1}, was used (Figure 4.7a). The irrigator was placed in a neighbouring paddock and allowed to irrigate, using a half arc, over the treatment plots. To apply even quantities of water over the experimental site, without splashing the soil, the irrigator was set to irrigate beyond the experimental site, firing water at a steep angle, so the stream of water broke up into small droplets. All though it was difficult to estimate the total amount of irrigation applied, it is likely to have been about 0.5 metres of water.

The tile drain under the 71% and 81% GSM experimental sites was functional, draining water to a creek 200 metres away, so the main tile drain (200 mm in diameter) was dug-up 30 metres into the adjacent paddock and was blocked off (Figure 4.7b).

Initially irrigation was applied for about 30-45 minutes to the 71% experimental site every day for two weeks. Depending on the soil conditions, a second irrigation cycle was carried out. The last irrigation cycle was completed the night before the treading treatments.

4.6.4 Treading Treatment and Visual Impact

The treading treatment at the 71% GSM experimental site was carried out on the 29th of August 2000. The gravimetric soil moisture content at the time of treading treatment was 71% (volumetric moisture content 51%; degree of saturation 73%). Treading occurred immediately after morning milking (Figure 4.7c). In the plots with the longer treading durations (9- and 24-hour treatments), the soil surface ruptured as the hooves penetrated the soil surface (Figure 4.7d). The visual effect was markedly different to that of the 65% GSM experiment.

Over the 24 hours after the 71% GSM treading treatments were complete there was 20 mm of rainfall followed by several days of drizzly conditions. As the soil was already wet, and infiltrations rates were decreased by the treading treatment, the additional rainfall caused ponding of water on the 9- and 24-hour treading treatment plots (Figure 4.7e), but not on the controls and the plots trodden for 3-hours (Figure 4.7f). About 21 weeks after the treading treatment remaining bare ground patches were colonised by broad-leaved plantain (Figure 4.7h).

During ponding of water, a soil slurry formed in the 9- and 24-hour treading treatment plots, reducing the soil surface roughness. In the areas of water ponding some death of plants, that had survived the treading, occurred. The temperature for the duration of two weeks following the treading was cool (mean max 15 °C). Sunny conditions after the rainfall eventually resulted in the slurry drying, forming a hard, multilayered surface with extensive cracking.

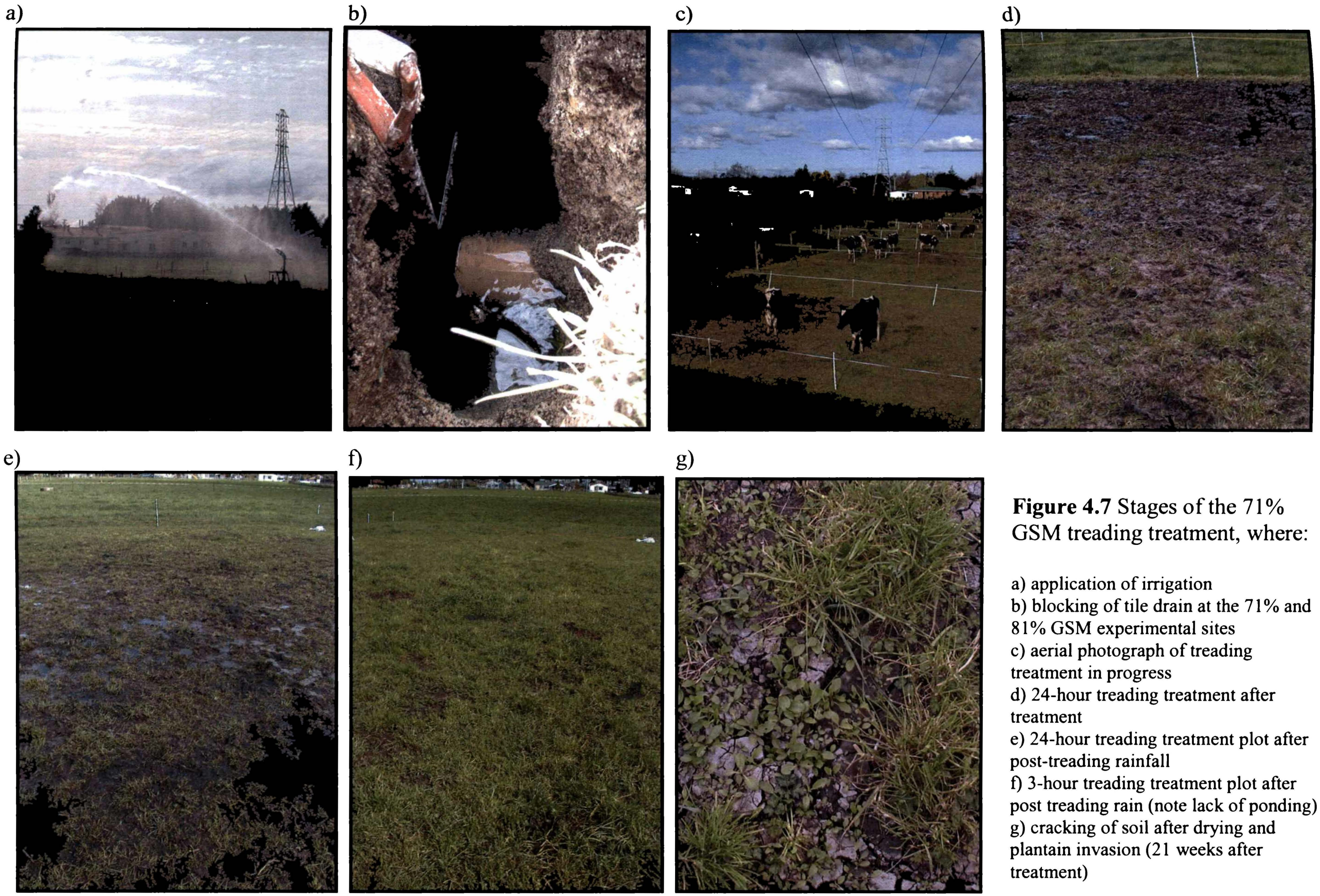


Figure 4.7 Stages of the 71% GSM treading treatment, where:

a) application of irrigation
b) blocking of tile drain at the 71% and 81% GSM experimental sites
c) aerial photograph of treading treatment in progress
d) 24-hour treading treatment after treatment
e) 24-hour treading treatment plot after post-treading rainfall
f) 3-hour treading treatment plot after post treading rain (note lack of ponding)
g) cracking of soil after drying and plantain invasion (21 weeks after treatment)

4.7 The 81% GSM Experimental Site

4.7.1 Site Description and Brief History

The 81% GSM experimental site was located next to the 71% GSM experimental site, and since these sites were similar in history (Section 4.6.1), only differences between sites are discussed here.

The old drainage feature at the northern end of the 71% and 81% GSM experimental site was at a slight angle, therefore, at the 81% GMS experimental site there was enough room to have two treatment plots between the drainage feature and the northern fence (Figure 4.6). The 81% GSM experimental site had a 20m wide ridge that terminated partway into the experimental site. The ridge soil was classified as a Bruntwood soil, a transitional soil type within the Te Kowhai/Horotiu soil suite. The area of Bruntwood soil was not used for the treading treatment plots.

4.7.2 Description of Soil and Sward

The soil at the 81% GSM experimental site had a brownish black (7.5YR 3/1) A horizon, with an average depth of 17 cm, occasionally up to 23 cm (Figure 4.3c). The B horizon was pale yellow (7.5Y 8/3). The boundary between the A horizon and the B horizon was distinct with occasional occlusions. The A horizon was blocky with some polyhedral structure, with strong pedality, and slightly firm aggregates. The A horizon was moderately to very sticky, semi deformable to deformable, slight to moderately sticky, and plastic. The B horizon was blocky in structure with moderate pedality. There were occasional (about 2%) occlusions of topsoil in the B horizon. The degree of bonding of topsoil with the soil matrix in the B horizon, and since the edges of the topsoil occlusions were not well defined, indicate that the topsoil occlusions were old and were part of a well-packed B horizon matrix. The B horizon was deformable, very sticky, and very plastic. About 7% of the soil profile at the B horizon consisted of bright yellowish brown (10YR 6/6) mottles which were about 6 mm in diameter. At the time of the soil description the soil was moist, having received recent rainfall. The soil penetration resistance using hand-assessment (Milne *et al.*, 1991) was moderately high (1.5-2.2 MPa) in the A horizon and high (2.2 – 3.0 MPa) for the B horizon. Plant roots were observed as deep as 15 cm and some isolated roots penetrated into the B horizon. There was evidence of earthworm activity, with old earthworm burrows readily found. There was evidence of topsoil transportation into the B horizon via large continuous soil pores, possibly old broad-leaved dock (*Rumex obtusifolius* L.) root channels.

Sward conditions were similar to that of the 71% GSM experimental site.

4.7.3 Site Preparation

Site preparation was similar to that for the 71% GSM experiment. The paddock had the similar dimensions, hence, a similar layout of treatment plots was used.

Winter conditions, again, were dry and site irrigation was essential to have pugging of susceptible soil. As the 81% GSM experiment was to represent very wet conditions (near saturation), more irrigation was required than for to the 71% GSM experiment (Figure 4.8a). Irrigation was also applied differently compared to the 71% GSM experiment. Two independently controlled stationary gun irrigators were placed at two strategic locations in the paddock. One irrigator was placed at the southern end of the experimental site and irrigated in a half arc, and the second was placed at two thirds of the length of the paddock (from the race), and irrigated in a full circle. Although it was difficult to calculate the total amount of irrigation applied, it is likely the have exceeded 0.7 metres of water.

During irrigation of the 81% GSM experimental site slight undulations started to pond. The irrigators were adjusted to minimise irrigation on areas with ponding, by focusing irrigation on the slightly higher areas (actual soil surface height differences were only slight). Irrigation was applied for one to three hours once every day for two and a half weeks. Closer to the treading treatment date smaller, but more frequent, irrigation cycles were applied (about two to three times per day for one hour duration). The last irrigation cycle was carried out during the night before the treading treatment began. The irrigators were removed before the treading treatment started.

4.7.4 Treading Treatment and Visual Impact

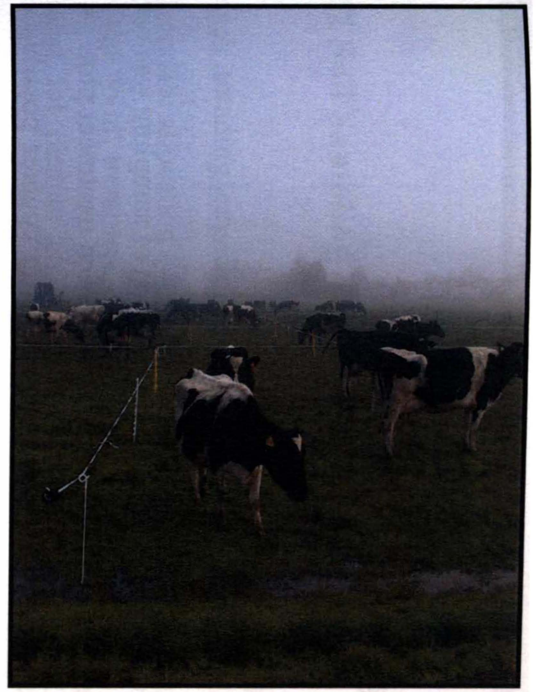
Treading treatment at the 81% GSM experimental site was carried out on the 6th of August 2001. The gravimetric soil moisture content at the time of treading was 81% (volumetric moisture content 60%; degree of saturation 89%). Cattle were allocated to the treatment plots as described for the other experiments. Early on in the experiment, it was apparent that the irrigation of the experimental site had been effective in increasing soil susceptibility to pugging damage (Figure 4.8b, 4.8c, & 4.8d). The 3-hour treading treatment plots had clear penetration of the soil surface by cattle hooves but did not have extensive plastic or liquid remoulding. On the 9- and 24-hour treatment plots plastic remoulding of soil was apparent before five hours of soil treading. After the treading was complete, there was deep penetration of cattle hooves into the soil (Figure 4.8e) and partially buried herbage was evident.

Light rainfall occurred periodically over two weeks after the treading, preventing the soil from drying. However, there was no ponding of water like what was observed at the 71% GSM experimental site. Temperature for two weeks following the treading was cool (mean max 15 °C). The climatic conditions following treading kept soil moist and soft, allowing for some buried herbage to re-emerge from the soil.

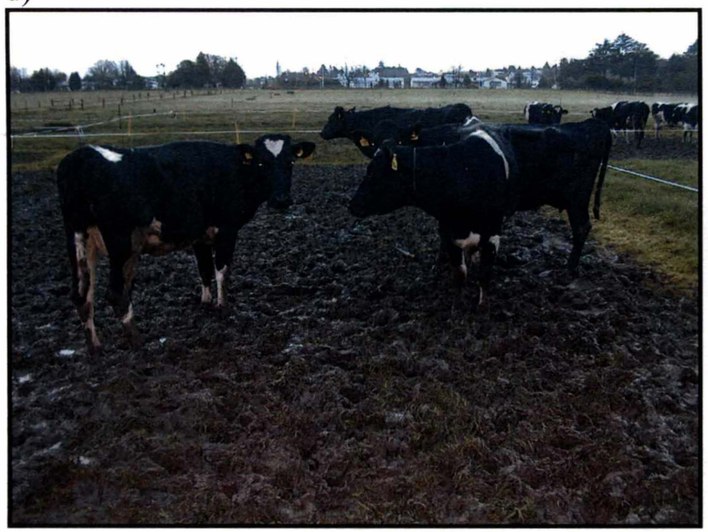
a)

b)

c)



d)



e)

Figure 4.8 Stages of the 81% GSM treading treatment, where:

a) irrigation of the 81% GSM experiment
b) partway through the 9-hour treading treatment
c) early in the treading treatment
d) nearing completion of the 24-hour treading treatment
e) aerial view of the 81% GSM experimental site after treading treatment was complete

4.8 Field Sampling Regime

4.8.1 Within-plot Allocation of Sampling Areas

For each soil and pasture property investigated within-plot replication of sampling was carried out. Within-plot replication was restricted to allocated areas with each treatment plot. A 1.8 m strip around the edge of each treatment plot was not sampled to counter possible edge effects (e.g. cattle not treading near fence lines). In addition, sward analyses was only carried out in areas not yet disturbed by soil analyses and, as it was sometimes difficult to visually see previous soil sampling sites, random soil and sward analyses were restricted to allocated strips (Figure 4.9).

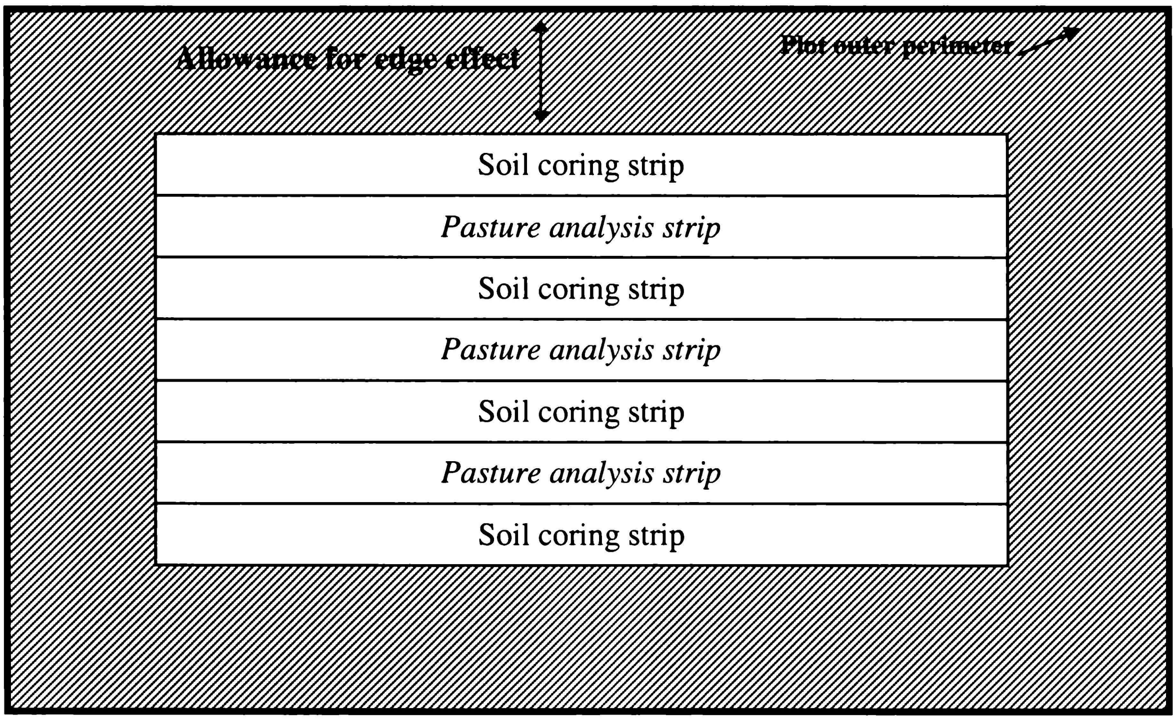


Figure 4.9 within-plot allocations for pasture and soil sampling and allowance for edge-effect along treatment plot perimeter.

4.8.2 Soil Sampling Site Determination

In each treading experiment, a template for within-plot soil coring sites was derived by random site allocation (within strips the allocated to soil coring), and then applying the same template to all treatment plots within experiment. As previous soil sampling sites could not be used for pasture analyses, the use of templates allowed for their easy location after regrowth of herbage had occurred.

Soil cores were not taken from areas affected by cow dung or by large plant roots because of the likelihood of these affecting estimation of soil properties when using a limited number of replicates (five cores per plot).

4.8.3 Sward Sampling Site Determination

Analyses of sward properties were carried out using random within-plot replication. Sward sampling sites were identified (within strips allocated for sward analyses) by the throwing of a stick and, in the case of bare ground assessment and tiller density counts, the orientation of the equipment used. Areas with noticeable cow dung were avoided.

4.9 Experimental Design Limitations

The experimental design was limiting in several aspects. The research was limited to only Te Kowhai soils, subjected to a one-off severe treading event at 300 cows ha^{-1} for no longer than 24 hours commencing at ~7:00 am. Additionally, the GSM range was between 65% and 81%. It is, however, unlikely that any pugging damage would occur on soils with <65% GSM and regional drainage schemes have been effective in preventing the high water-tables needed to maintain GSM >81% for long periods.

Due to logistic constraints associated with large field experiments, the 65%, 71%, and 81% GSM experiments were carried out in different winters on two farms using two different herds. The resultant soil and sward damage, and subsequent recovery rates, after experimental treading may differ if climatic conditions, site history, and farm management practices varied between the experiments. However, climatic conditions (Table 4.1 and Appendix II), site conditions (Sections 4.5 to 4.7), and farm management practices (Section 4.4) were similar at each of the experimental sites. Therefore, comparisons of results between experiments, particularly of soil and sward recovery, are carried out with the assumption that neither different farms nor years had an important effect on the results.

Chapter 5. Initial Effect of Cattle Treading on Soil and Sward

5. Initial Effect of Cattle Treading on Soil and Sward

5.1 General Introduction

This chapter discusses the initial (up to eights weeks for sward and immediate for soil physical properties) effects of cattle treading on soil physical conditions at the 0-5 cm and 5-10 cm soil depths, and sward characteristics for each treading treatment (0, 3, 9, and 24-hour duration) in the 61%, 71%, and 81% GSM (gravimetric soil moisture content) experiments. The data presented are the treatment means, with full data in Appendices. Differences between treatment means are presented with the statistical significance of the difference. The trends and relationships between treatments are presented with coefficients of determination (r^2) and the level of significance (*P*). Regression was carried out using the means of the replicate plots (i.e. three replicate plots per treatment and four treatments per experiment) unless otherwise indicated. Discussion is grouped for related variables, for example macroporosity, microporosity, total porosity, and bulk density. Changes (recovery) in sward and soil properties over the 35 weeks following treading treatment are discussed in Chapter Six, the experimental design was described in Chapter Four, and methods in Chapter Three.

5.2 Soil Porosity and Soil Dry Bulk Density

5.2.1 Introduction

Studies of the effects of cattle treading on soil usually include soil physical properties such as macroporosity (>30 μm), microporosity (<30 μm), total porosity, and soil dry bulk density. Much research has been carried out on soil compaction by livestock and farm vehicles (e.g. Blackwell *et al.*, 1986; Asady & Smucker, 1989; Ferrero, 1991; Mullholland & Fullen, 1991; Douglas, 1997; Drewry *et al.*, 2001) and some research on pugging damage (e.g. Gradwell, 1966; Pande *et al.*, 2000; Singleton *et al.*, 2000; Nie *et al.*, 2001a; Betteridge *et al.*, 2002; Drewry, 2003).

Macropores can be easily damaged by cattle treading as macropores have less soil strength than micropores (Carter, 1990). Soil dry bulk density and total porosity are commonly used to indicate soil compaction (Horn & Lebert, 1994), however, micropores are seldom directly mentioned in the treading research literature.

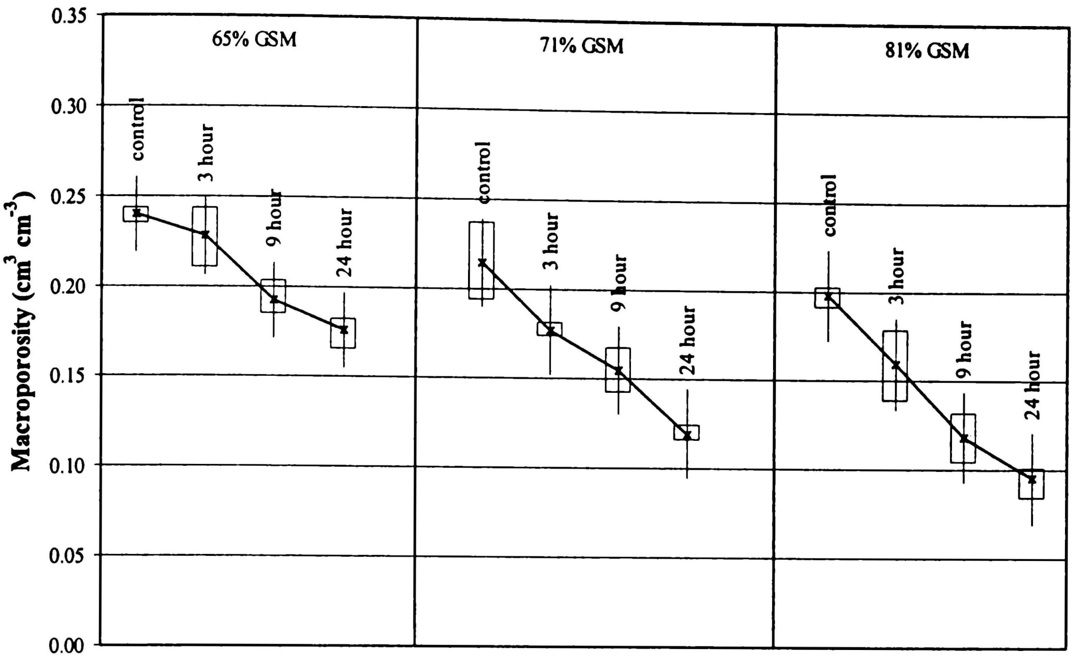
In this thesis, macroporosity, microporosity, total porosity, and soil dry bulk density were investigated to estimate the response these soil physical properties have to different treading durations and soil moisture contents. Soil cores were retrieved within three days of the treading treatment (treading treatment dates; 65% GSM – 25/6/1999; 71% GSM – 29/8/2000; 81% GSM – 6/8/2001). The full porosity and soil dry bulk density data with summary tables are presented in Appendix V.

5.2.2 Macroporosity

The treading treatments caused a decrease in macropore volume, at the 0-5 cm soil depth, in all experiments (Figure 5.1), with incremental decreases in macroporosity as treading duration increased. The greatest decrease at the 0-5 cm soil depth was in the 81% GSM 24-hour treatment, where macropore volume was 0.10 cm^3 cm^{-3} less (P <0.01) than the controls (no treading). In all experiments the mean 0-5 cm soil depth macroporosity in the 9- and 24-hour treading treatments were less (P <0.05) than the controls. The decline in macropore volume with increasing treading duration always correlated (r^2 = 0.66 to 0.75, P <0.05) regardless of soil moisture content.

Macroporosity was less affected by cattle treading at the 5-10 cm soil depth than at the 0-5 cm soil depth. In all experiments, macroporosity at the 5-10 cm soil depth was consistently decreased with longer treading duration, but treatment differences (up to 0.03 cm^3 cm^{-3}) were only significant (P <0.05) for the 81% GSM 9- and 24-hour treatments compared with controls.

a) 0-5 cm soil depth



b) 5-10 cm soil depth

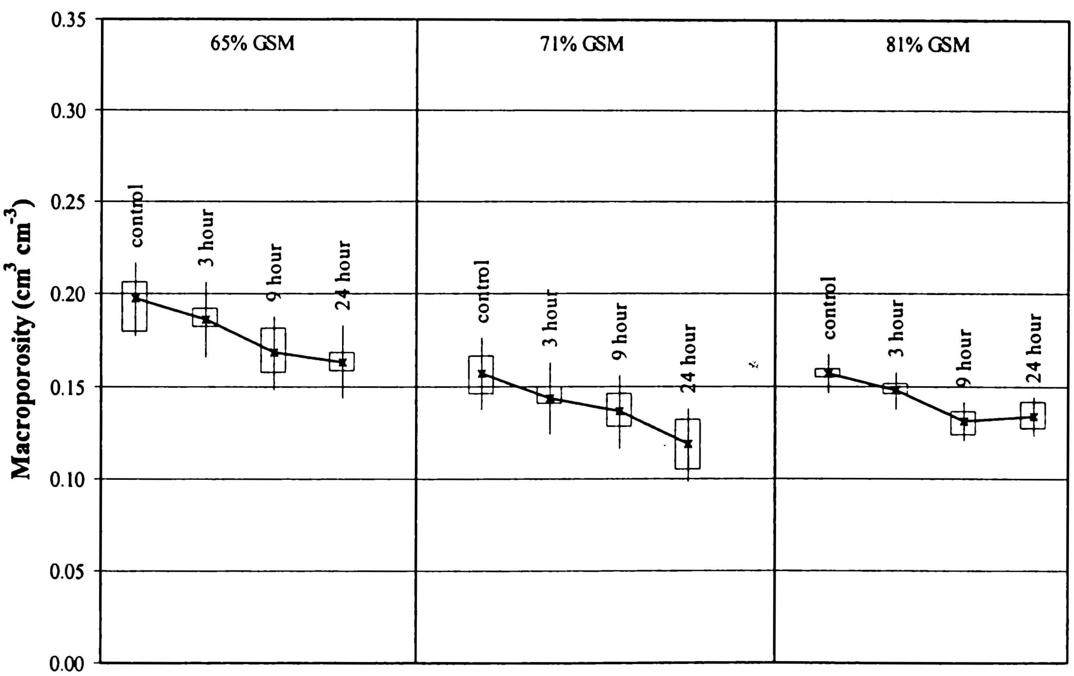


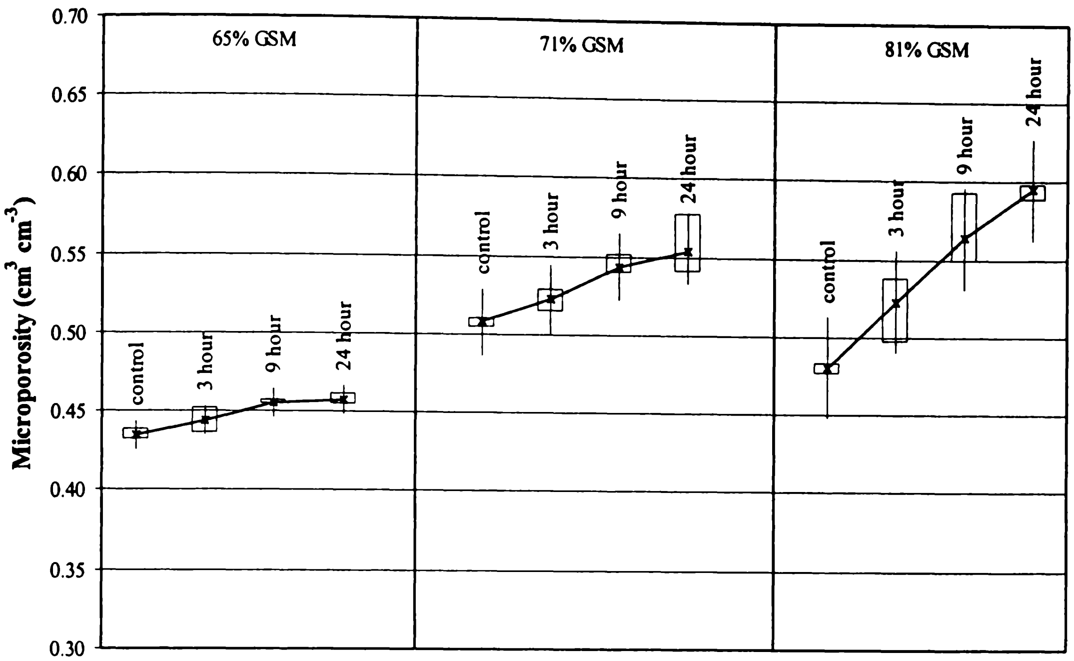
Figure 5.1 Soil macropore volumes (cm^3 cm^{-3}) at a) the 0-5 cm soil depth and b) the 5-10 cm soil depth. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.2.3 Microporosity

At the 0-5 cm soil depth, microporosity was greater in trodden areas than in controls in all experiments (Figure 5.2). The largest increase in microporosity was in the 81% GSM experiment, at the 0-5 cm soil depth, where the 24-hour treatment microporosity volume was 0.12 cm^3 cm^{-3} more (P <0.05) than the controls. The 81% GSM 24-hour treatment was more severely pugged, with more plastic and liquid soil deformation than any of the other treatments. In all experiments, soil microporosity in the 9- and 24-hour treatments were greater (P <0.05) than in controls, except for the 71% GSM 9-hour treatment. The trend of increasing microporosity at the 0-5 cm soil depth with increasing treading duration was consistent for all experiments (r^2 = 0.48 to 0.69, P <0.05).

Microporosity at the 5-10 cm soil depth in the 71% and 81% GSM experiments had smaller responses to treading than at the 0-5 cm soil depth, however, there was no change in microporosity in the 65% GSM experiment. The microporosities, at the 5-10 cm soil depth, in all the 81% GSM treatments were about 0.03 cm^3 cm^{-3} greater (P <0.05) than controls.

a) 0-5 cm soil depth



b) 5-10 cm soil depth

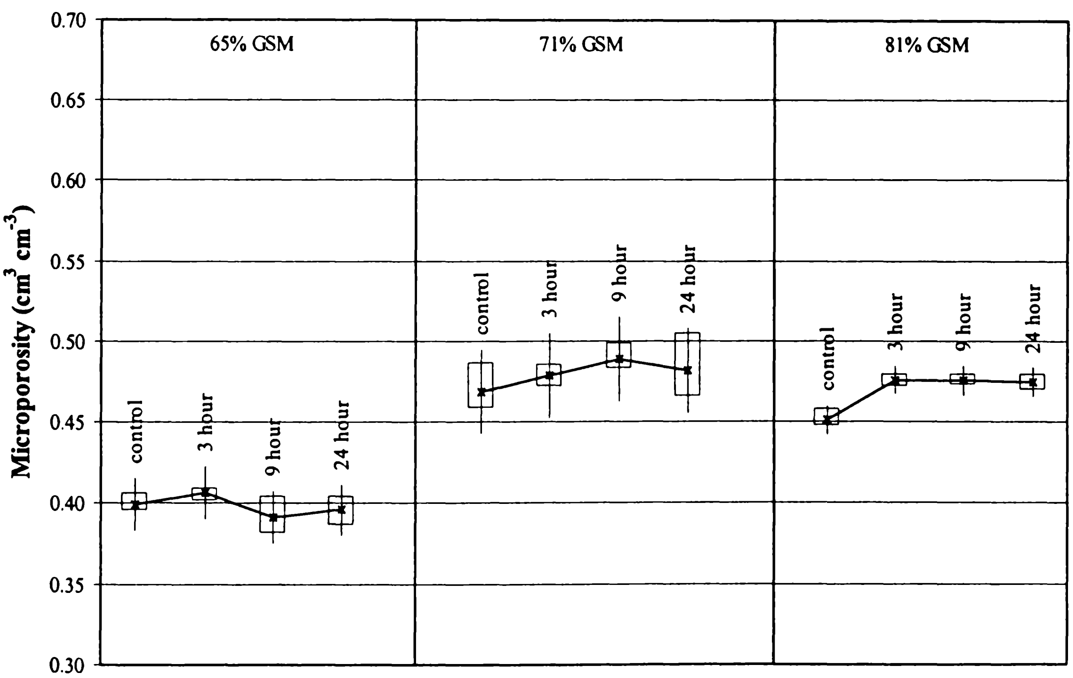
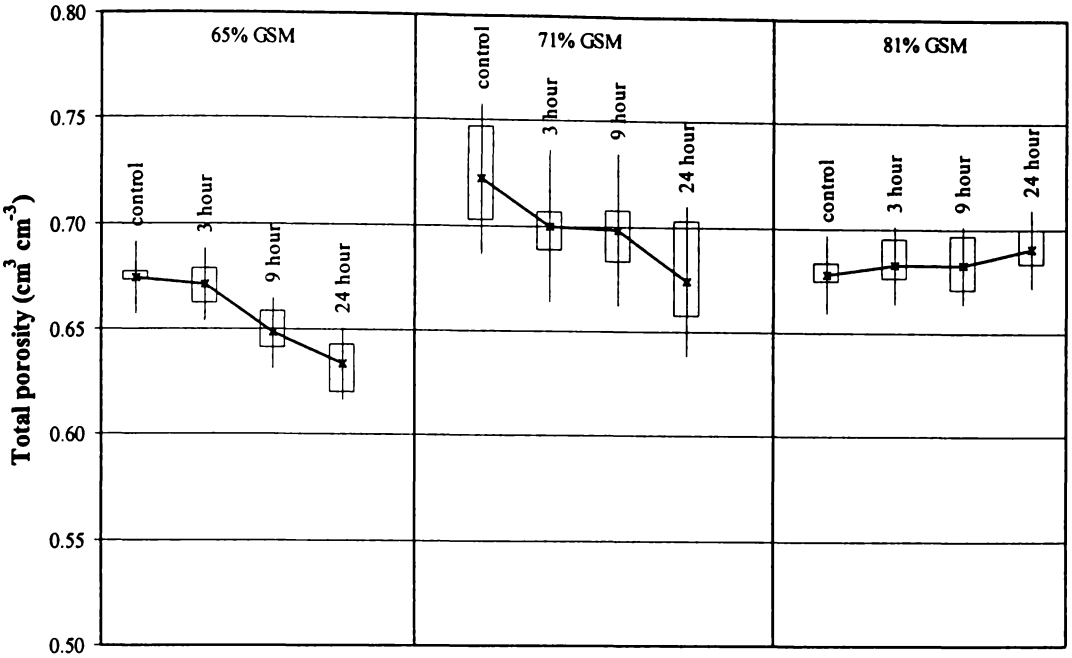


Figure 5.2 Soil micropore volumes (cm^3 cm^{-3}) at a) the 0-5 cm soil depth and b) the 5-10 cm soil depth. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values from all treatment replicates, and the asterisk the treatment mean.

5.2.4 Total Porosity and Soil Dry Bulk Density

Soil total porosity and dry bulk density at the 0-5 cm soil depth were affected by treading only in the 9- and 24-hour treatment in the 65% GSM experiment (Figures 5.3 and 5.4). In all experiments at the 5-10 cm soil depth, there were no significant differences in total porosity and soil dry bulk density between any of the treatments and the controls. Variation within treatments was high for total porosity (up to 0.10 cm^3 cm^{-3}, 16% of grand mean) and for soil dries bulk density (up to 0.28 Mg m^{-3}, 33.4% of grand mean). In the 65% GSM experiment there was a trend of decreasing total porosity (inverse of soil dry bulk density) with increasing treading duration (r^2 = 0.51, P <0.05), however, the trend was not significant in the 71% and 81% GSM experiments.

a) 0-5 cm soil depth



b) 5-10 cm soil depth

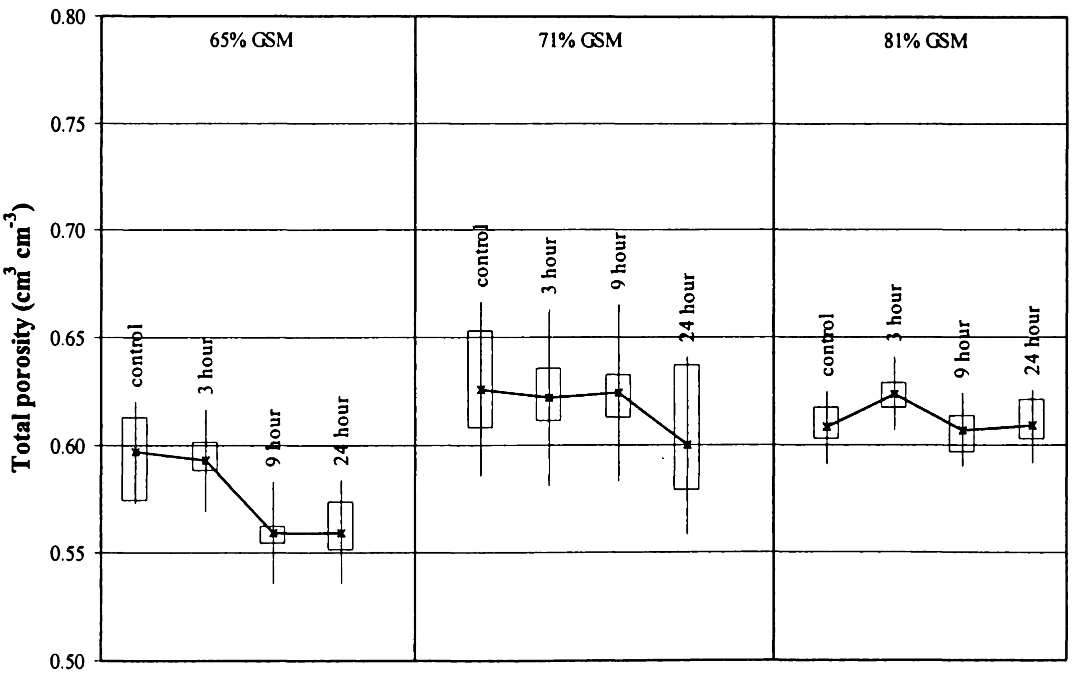
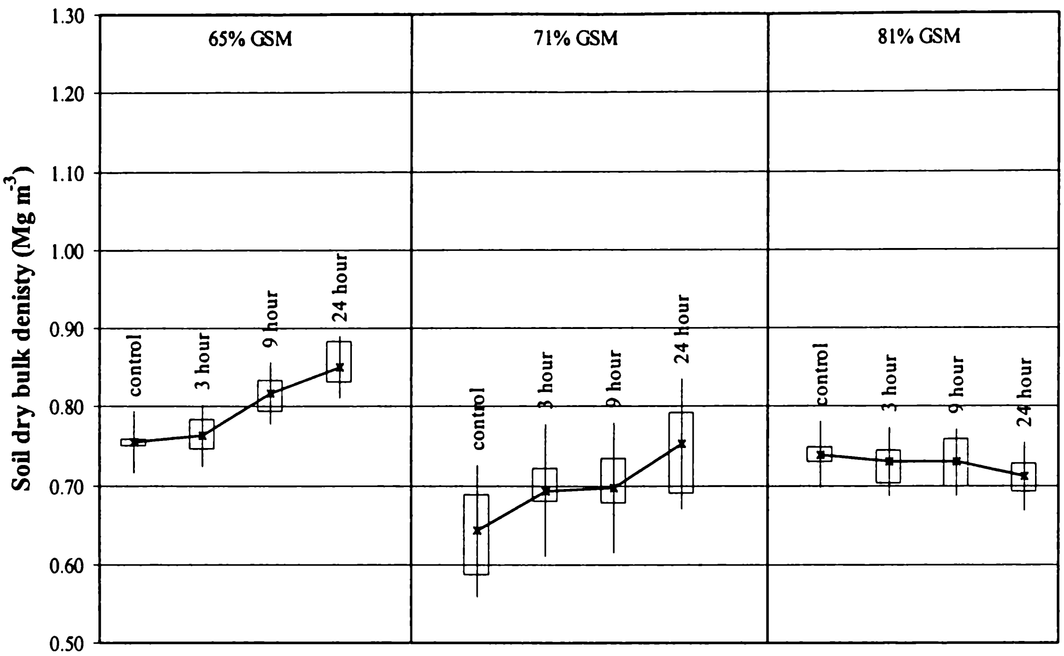


Figure 5.3 Soil total pore volume (cm^3 cm^{-3}) at a) the 0-5 cm soil depth and b) the 5-10 cm soil depth. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

a) 0-5 cm soil depth



b) 5-10 cm soil depth

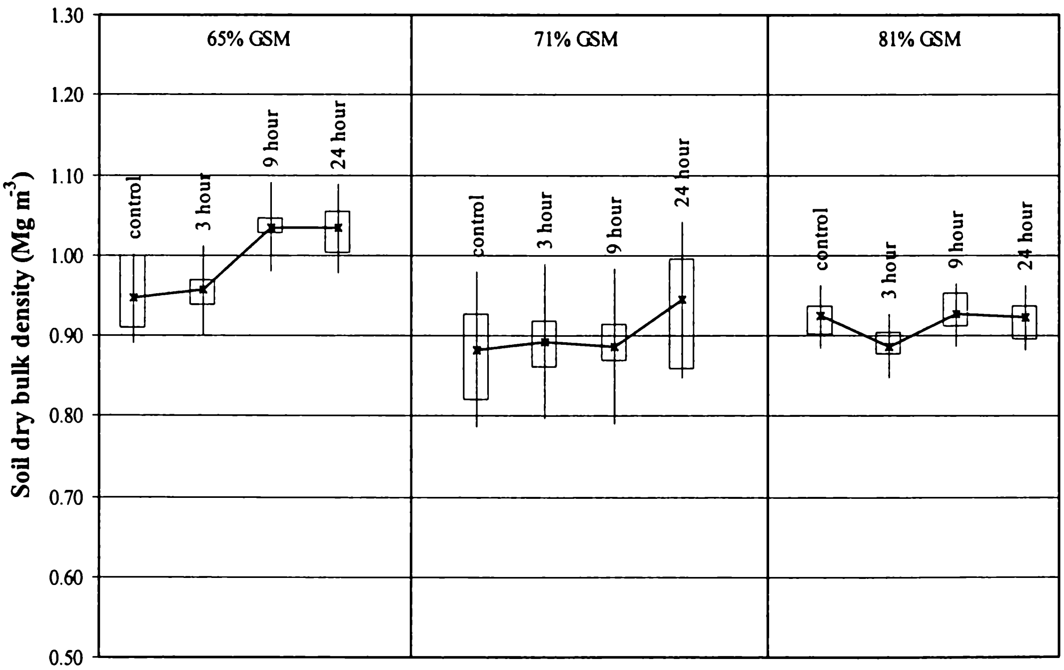


Figure 5.4 Soil dry bulk densities (Mg m^{-3}) at a) the 0-5 cm soil depth and b) the 5-10 cm soil depth. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.2.5 Discussion

Cattle treading resulting in pugging damage, generally, did not significantly alter soil total porosity or dry bulk density in these experiments. However, macroporosity decreased and microporosity increased ($P < 0.05$) in response to cattle treading.

The decline in macroporosity after treading was consistent and generally significantly different between treatments. Carter (1990) found that macropores have less resistance to compaction than micropores, and Beckman and Smith (1974) and Mullholland and Fullen (1991) suggested that macropores may be readily converted to smaller pores (micropores) by treading. Thus, macroporosity, unlike soil dry bulk density and total porosity, appears to be a good indicator of pugging damage, as was suggested by Greenwood and McNamara (1992) and Singleton *et al.* (2000).

Given the severity of the pugging damage observed in the 71% and 81% GSM experiments, smaller macropore volumes were expected than what was found. It is possible that decomposition of buried plant material during macropore volume determination in the laboratory (which takes about four weeks) resulted in some macropore formation. The high soil moisture contents (73-89% saturation) may also have given some protection to macropores as some macropores would have been water filled and sealed during the plastic deformation of the soil. The macroporosities in control plots were also greater than reported for other local Te Kowhai soils (Burgess, 1998; Singleton & Addison, 1999; Burgess *et al.*, 2000), which, again, could have contributed to a higher than excepted volume of macropores after treading.

Zegwaard (1998) and Singleton and Addison (1999) reported macroporosity values for previously pugged Te Kowhai soils similar to those in the 24-hour treatments. However, in these studies the soils had several sequential pugging events during the winter of sampling. The similarity of results between a 'whole winters worth' of pugging damage to a one-off severe pugging event like that of the 24-hour treatments in this thesis indicates that the end-of-winter treading damage may largely have been derived from a single, initial, severe treading damage event. The subsequent treading damage events may have prevented or nullified recovery rather than caused more damage to macroporosity.

The mean macropore volume was not decreased beyond the suggested minimum of 0.10 cm^3 cm^{-3}, below which plant growth may be limited by slow aeration (Gradwell, 1965; Grable, 1971; Carter, 1988; Stepniewski *et al.*, 1994). However, the macroporosity treatment mean, at the 0-5 cm soil depth in the 81% GSM 24-hour was 0.10 cm^3 cm^{-3}, and some individual soil cores had values of less than 0.06 cm^3 cm^{-3}, suggesting sporadic areas of anaerobic conditions. Grable and Siemer (1968) suggested that a macroporosity of less than 0.15 cm^3 cm^{-3} may begin to restrict root growth, therefore, some herbage growth restriction would have occurred after the 9-hour and 24-hour treatments in the 71% and 81% GSM experiments.

The lack of change in soil dry bulk density and total porosity after a one-off severe treading event is of particular note. In the 65% GSM experiment soil dry bulk density and total porosity changed slightly in response to the treading, but not in the 81% GSM experiment - which had the severest form of treading damage. When plastic and liquid deformation (pugging) occurred in the 81% GSM experiment, the soil had a high moisture volume (89% degree of saturation), thus the soil void space was largely filled with water. When soil was plastically remoulded, and as soil moisture is essentially incompressible, soil moisture would have been redistributed throughout the soil matrix (Mullins & Fraser, 1980; Scholefield & Hall, 1985a). The remoulded soil would retain most of its void space by the formation of new micropores (because of the redistribution of soil moisture) and not register a decrease in total pore volume. The re-distribution of soil moisture, therefore, would result in a decrease in macropore volume and an increase in micropore volume. As total porosity and soil dry bulk density are inversely related (McLaren & Cameron, 1993), soil dry bulk density did not increase either. The small response in the 65% GSM experiment indicates that some compaction occurs when gravimetric soil moisture content is near 65%.

Evidence from findings from this thesis, however, indicates that pugging damage can happen independently of compaction at the 0-5 cm and 5-10 cm soil depths. Therefore, care must be taken when examining pugging damage effects on soil physical properties, as no change in total porosity does not necessarily imply that no damage has occurred or that soil conditions are favourable for plant root growth. The finding from the 71% and 81% GSM experiments clearly indicates that total porosity and soil dry bulk densities are poor indicators of past treading damage (as suggested by Mullholland & Fullen, 1991; Singleton & Addison, 1999; Singleton *et al.*, 2000) and, possibly, give no indication at all of past pugging damage. The results from all experiments also supports the later stages of the illustration (Figure 2.2) of pugging and compaction processes by Horne and Singleton (1997).

Other treading research has typically shown increases in soil dry bulk density after treading damage (Gradwell, 1966; Stephenson & Veigel, 1987; Singleton & Addison, 1999; Singleton *et al.*, 2000; Drewry *et al.*, 2003). However, these studies may have been carried out at sites damaged by many treading cycles at different soil moisture contents and, thus resulting in compaction damage.

The decrease in macroporosity and increase in microporosity has implications for the aeration of soil as micropores contribute little to internal soil airflow (Glínski & Stepniewski, 1985). As micropores have more water retention potential than macropores (Rowell, 1994), an increase in micropore volume results in soil remaining wetter for longer, and thus soil remaining susceptible to further pugging damage for longer after rainfall events (Edmond, 1962; Mullholland & Fullen, 1991; Haynes, 1995).

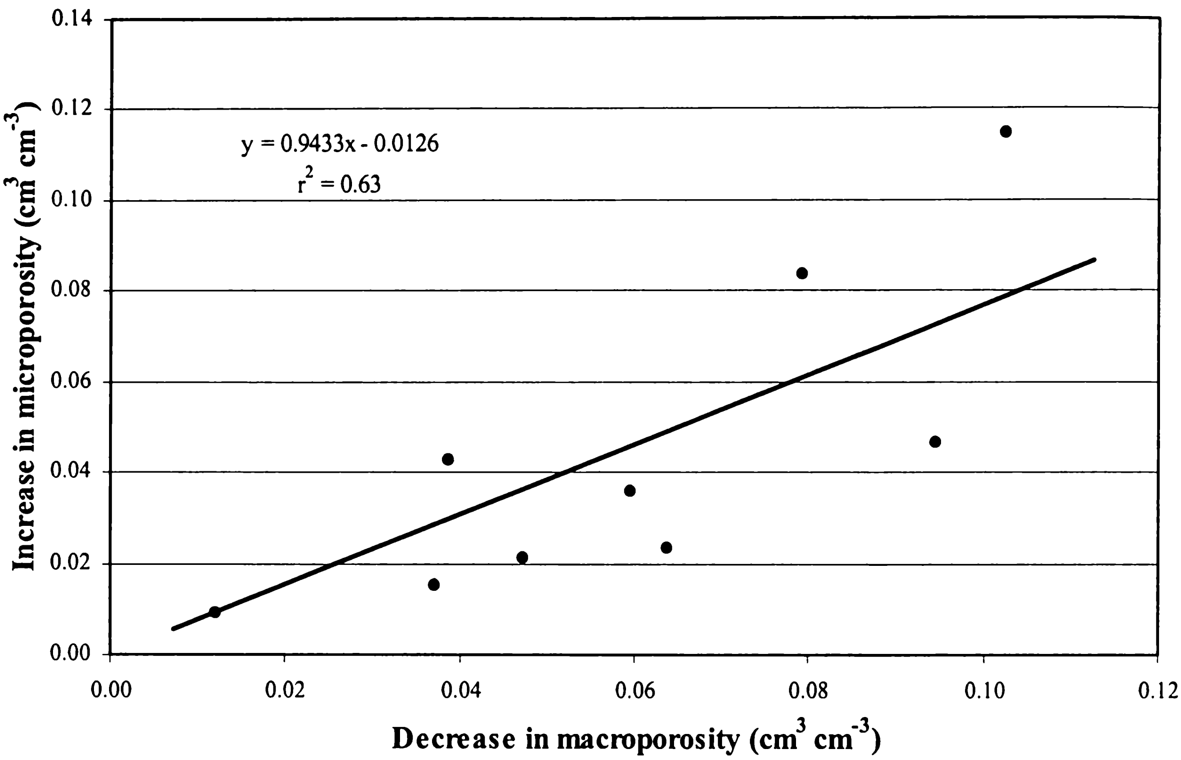


Figure 5.5 Correlation, using treatment means at the 0-5 cm soil depth, between the decrease in macroporosity (compared with controls) and the increase in microporosity after treading treatment.

5.3 Unsaturated and Saturated Hydraulic Conductivity

5.3.1 Introduction

Soil hydrological properties, such as saturated hydraulic conductivity (K_{sat}) and unsaturated hydraulic conductivity at 0.40 kPa tension (K_{-40}), are important as they provide indicators of the rate of water movement through soil and how long soil remains wet. High soil moisture content reduces soil strength (Koolen, 1994) so when soil is trodden it has less resistance to deformation (Wind & Schothorst, 1964), resulting in pugging damage (Mullins & Fraser, 1980; Mullholland & Fullen, 1991). Pugging damage has been reported to limit the ability of soil to rapidly drain excess soil water (Greenwood *et al.*, 1997; Drewry *et al.*, 2002), which contributes to pugging becoming a self-perpetuating problem (Haynes, 1995).

Singleton and Addison (1999) found that for a Te Kowhai soil K_{-100} may be 24% slower, and K_{sat} 95% slower, in previously pugged areas than 'typical' areas, whilst Drewry *et al.* (2003) found that K_{sat} was also 95% slower than undamaged areas after a one-off severe treading event on a Te Kowhai soil. Greenwood *et al.* (1998) reported that K_{-40} may be as little as 5 mm hr^{-1} in soils with pugging damage.

In this thesis, soil hydrological properties that were investigated to determine the response to a one-off severe cattle treading damage event were K_{sat} and K_{-40}. The K_{sat} represents flow of water through a saturated soil, and is sensitive to macro-structures such as earthworm burrows and soil fractures and, therefore, could be a good indicator of changes in soil structure due to cattle treading. The K_{-40} represents water flow through soil pores <0.75 mm diameter and does not include preferential flow through earthworm burrows and other large continuous soil pores. The soil K_{-40} is an indicator of soil structure at smaller pore sizes than with saturated flow and is recognised as an important soil property when investigating effects of cattle treading (Mullholland & Fullen, 1991).

The soil cores used for measuring hydraulic conductivity were retrieved from the field at the same time as those used to determine soil porosity and dry bulk density (Section 5.2.1). Full K_{-40} and K_{sat} data with summary tables are presented in Appendices VI and VII. The number of continuous pores were also recorded (observed as a continuous stream of water from bottom of the soil core during K_{sat} determination) to help explain fast K_{sat} readings and to serve as an indication of the occurrence of continuous pores (such as earthworm burrows) (full data in Appendix VIII). As K_{-40} and K_{sat} data were typically variable and skewed from normal (Schipper & Sparling, 2000) they are presented log transformed.

5.3.2 Unsaturated Hydraulic Conductivity

The K_{40} at the 0-5 cm soil depth was slower (P <0.05) than controls for the 65% and 81% GSM 24-hour treatments (Figure 5.6). Although K_{40} data were highly variable, especially in the 71% GSM experiment, there was a trend of decreasing K_{40} with increasing treading duration at the 0-5 cm soil depth in the 65% GSM experiment (r^2 = 0.54, P <0.01) and 81% GSM experiment (r^2 = 0.44, P <0.01).

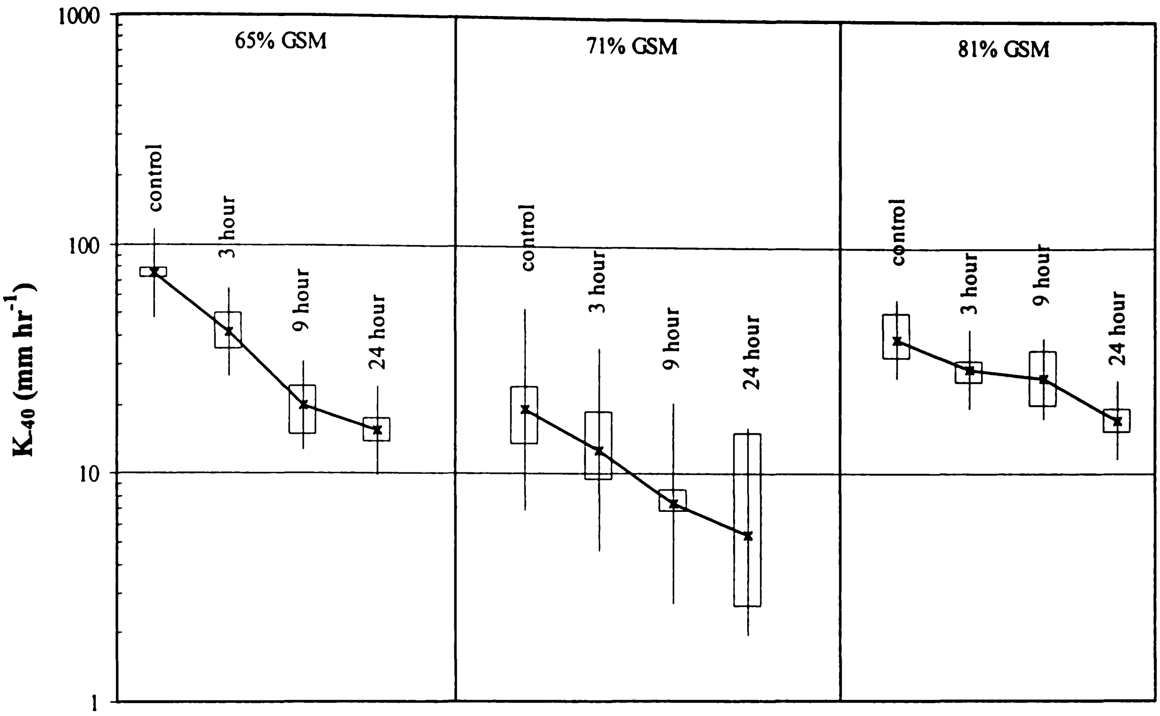
At the 5-10 cm soil depth the K_{40} of some treatments were as much as 55% slower than controls, however, significant differences (P <0.05) occurred only in the 81% GSM experiment. In the 81% GSM experiment the trend of decreasing K_{40} at the 5-10 cm soil depth with increasing treading duration was significant (r^2 = 0.57, P <0.05).

5.3.3 Saturated Hydraulic Conductivity

The K_{sat}, at the 0-5 cm soil depth, was slower (P <0.05) in the 24-hour treatments than controls in all experiments, and the 65% GSM 9-hour was also slower (P <0.05) than controls (Figure 5.7). Differences (P <0.05) in K_{sat} values between treatments were often not significant because of the high data variability, a common problem also reported by Schipper and Shepherd (2000). In each experiment at the 0-5 cm soil depth there was a significant trend of decreased K_{sat} with increasing treading duration (r^2 = 0.24 to 0.54, P <0.05).

In the 71% and 81% GSM experiment, at the 5-10 cm soil depth, K_{sat} was slower in the 24-hour treatments than in the controls. The decrease in K_{sat} in the 71% GSM 24-hour was 2,700 mm hr^{-1}, the largest decrease for any of the treatments at either soil depth. The trend of decreasing K_{sat} at the 5-10 cm soil depth with increasing treading duration was significant in the 71% GSM experiment (r^2 = 0.89, P <0.01) and in the 81% GSM experiment (r^2 = 0.47, P <0.05), but not in the 65% GSM experiment.

a) 0-5 cm soil depth



b) 5-10 cm soil depth

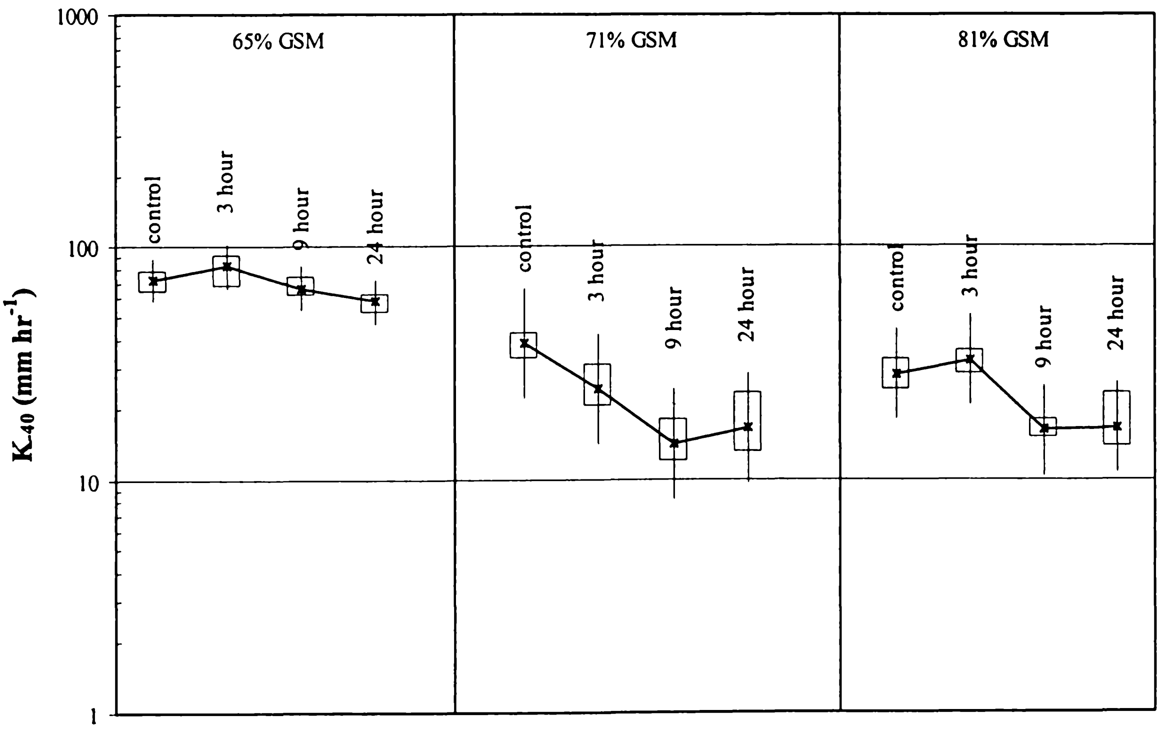
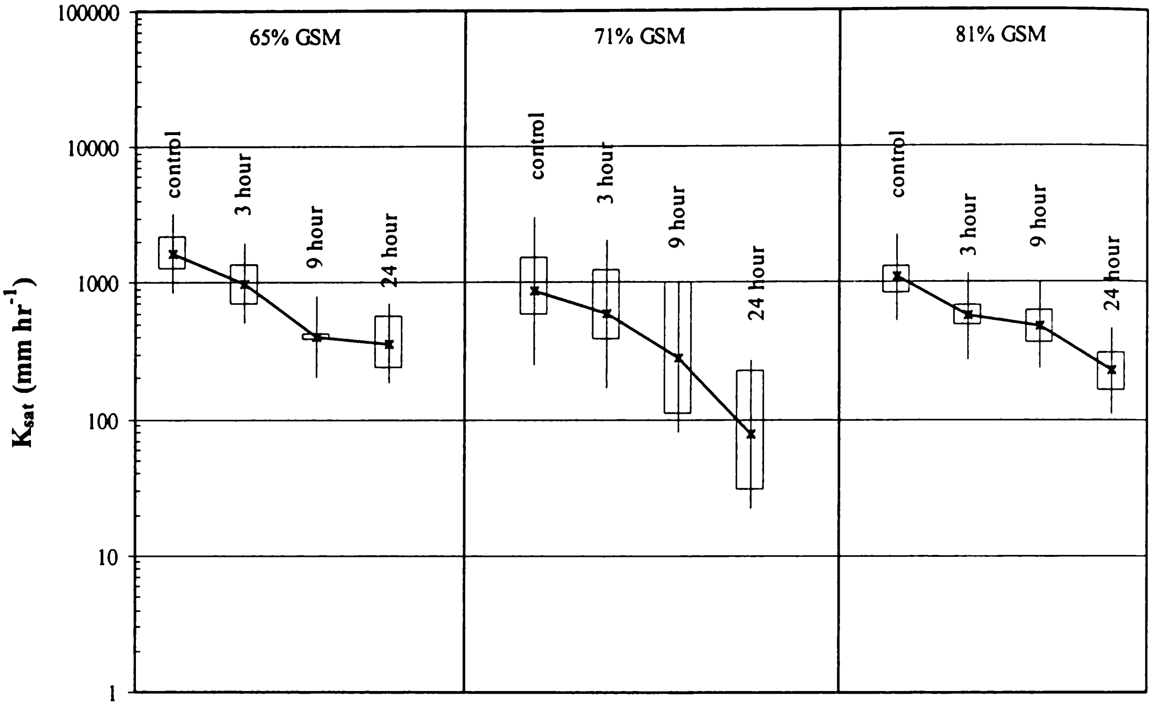


Figure 5.6 Unsaturated hydraulic conductivity (mm hr^{-1}, log scale) at a) the 0-5 cm soil depth and b) the 5-10 cm soil depth. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values (P <0.05), and the asterisk the treatment mean.

a) 0-5 cm soil depth



b) 5-10 cm soil depth

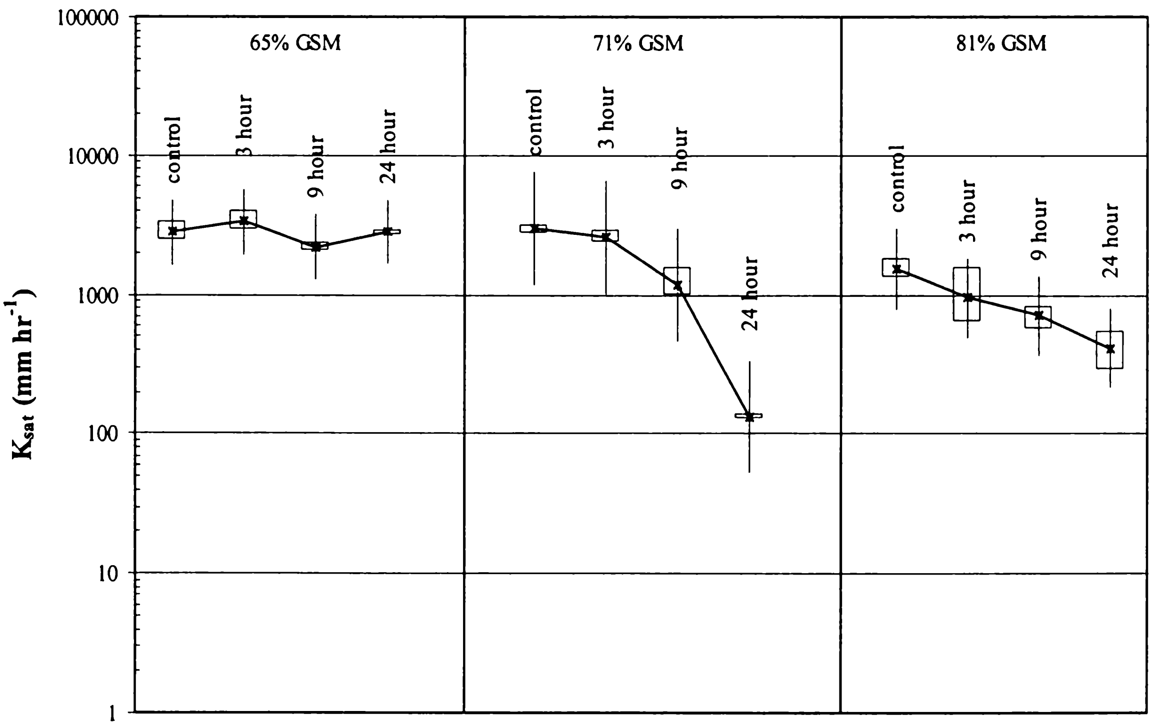


Figure 5.7 Saturated hydraulic conductivity (mm hr^{-1}, log scale) at a) the 0-5 cm soil depth and b) the 5-10 cm soil depth. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.3.4 Continuous Pores

Continuous pores are important for the rapid movement of water down the soil profile as they allow preferential flow of soil water though the soil (Zachman *et al.*, 1987). During the laboratory measurements of K_{sat} the number of continuous pores per soil core (observed as a continuous stream of water coming out of the bottom of the soil core) was recorded. The number of continuous pores were recorded to help explain fast K_{sat} readings and to serve as an indication of the occurrence of continuous pores (such as earthworm burrows) in the soil that exceed 5 cm (the height of the core). As near-surface continuous pores are typically destroyed by treading, they provide an indication of soil structure damage caused by treading. After the treading treatments, most continuous pores were found at the 5-10 cm soil depth (Figure 5.8). The density of continuous pores in all the 24-hour treatments were less than half of controls. There was a significant overall trend (using treatment means) of decreasing continuous pores with increasing treading duration (r^2 = 0.40, P <0.05), however, the trend was less variable when data from the 65% GSM experiment were excluded (r^2 = 0.53, P <0.01).

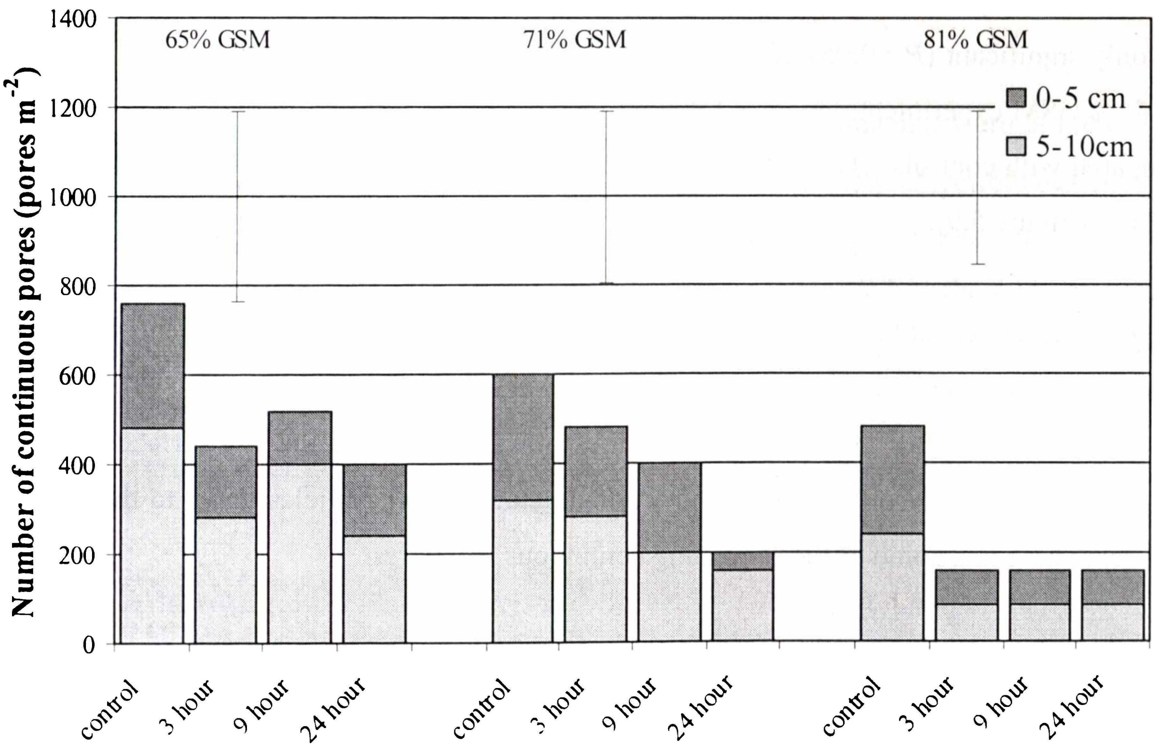


Figure 5.8 Mean number of continuous soil pores (>5 cm in length) observed during the determination of K_{sat}. The error bars ($lsd_{5\%}$) refer to the total number of continuous pores per treatment.

5.3.5 Discussion

The K_{sat} and K_{-40} at the 0-5 and 5-10 cm soil depths decreased due to cattle treading in all experiments, except at the 5-10 cm soil depth for the 65% GSM experiment. For each experiment, the longer the treading duration the greater the decline in K_{sat} and K_{-40}. The treading treatments resulted in soil remoulding, which destroyed macropores and continuous pores, and consequently decreased the rate of water movement into and through the soil. Decreases in K_{sat} and K_{-40} at the 0-5 cm soil depth were possibly caused by: the loss of soil structure due to the weight of cattle, or soil smearing by cattle hooves (Abdel-Magid *et al.*, 1987), or fine sediment being dislodged and deposited in large continuous pores (Russell *et al.*, 2001).

The small decreases in K_{sat} and K_{-40} at the 5-10 cm soil depth in the 71% and 81% GSM experiments indicates that treading damage was only beginning to affect the soil at 5-10 cm. Hoof penetrations of up to 8 cm were observed in the 71% and 81% GSM experiments, therefore, some penetration by cattle hooves of the 5-10 cm soil depth did occur. However, the only significant ($P < 0.05$) effect of treading at the 5-10 cm soil depth was for the K_{sat} in the 71% GSM experiment, where a 2,900 mm hr^{-1} decrease occurred in the 24-hour treatment compared with controls. The responses to treading of K_{sat} and K_{-40} were related ($r^2 = 0.59$, $P < 0.001$) (Figure 5.9).

The decrease in K_{sat} at the 5-10 cm soil depth, in the 71% GSM 24-hour treatment, when there was no decrease at the 0-5 cm soil depth might have been caused by rainfall (20 mm) that occurred 24 hours after the treading. The effect of rain falling on the soil surface may have removed some of the soil smearing and washed detached soil particles down to the 5-10 cm soil depth blocking some of the remaining continuous soil pores.

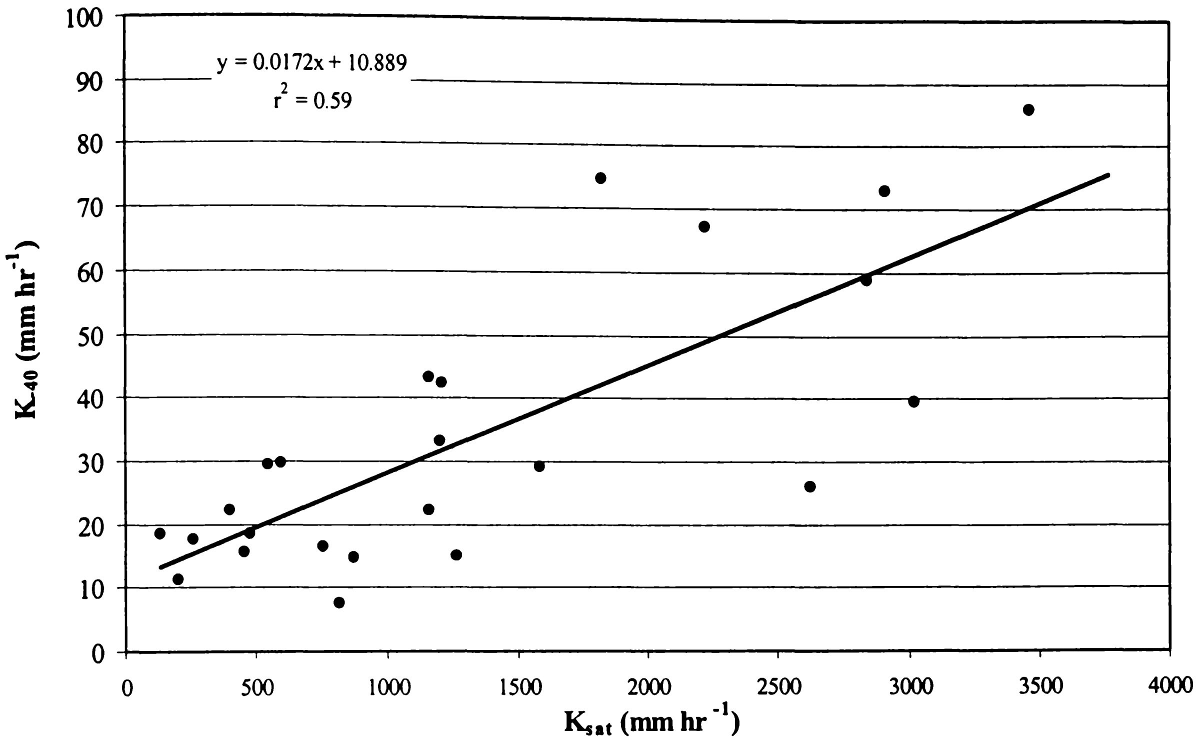


Figure 5.9 Correlation between K_{sat} and K_{40} using treatment means from the 0-5 cm and 5-10 cm soil depths.

The greatest differences in the number of continuous pores after treading were at the 0-5 cm soil depth when trodden for nine or 24 hours. The greatest density of continuous pores in untrodden areas was at the 5-10 cm soil depth. The soil K_{sat} is sensitive to the presence of earthworm burrows (Zachman *et al.*, 1987) and other macropores. When the number of large continuous pores were plotted against the rate of K_{sat} there was a linear relationship ($r^2 = 0.63$, $P<0.01$) (Figure 5.10).

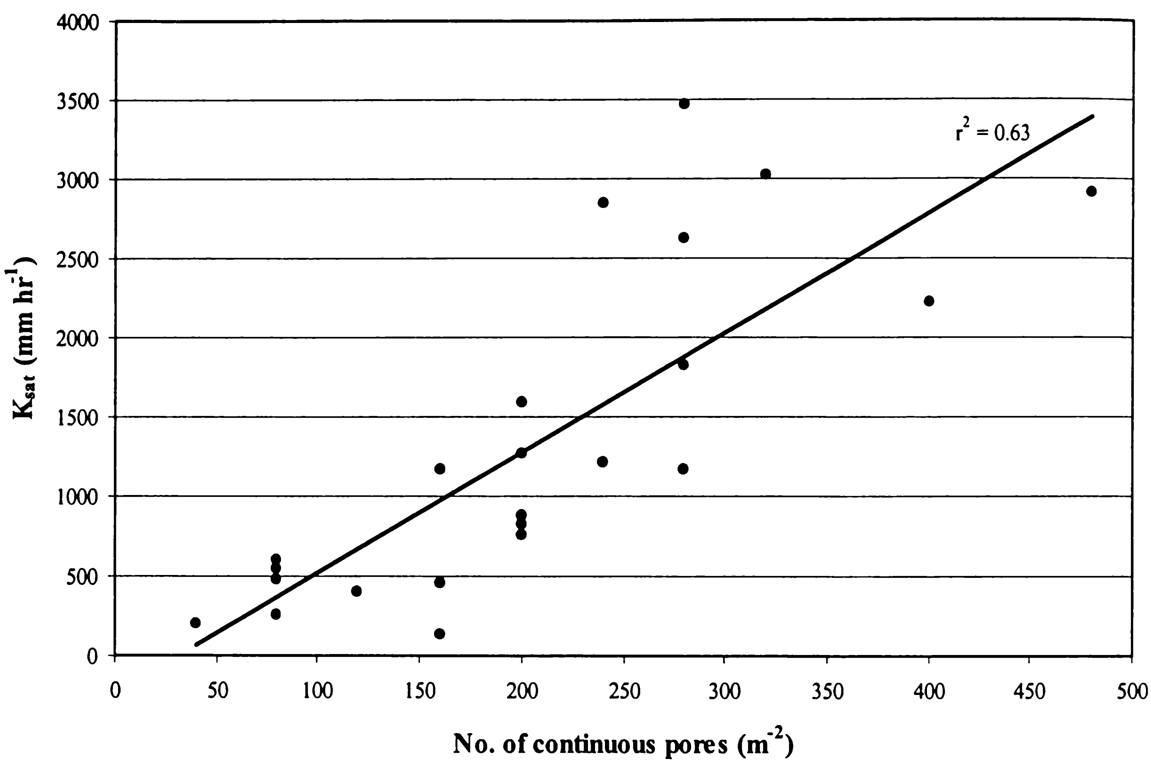


Figure 5.10 Correlation between treatment means for the observed number of continuous pores at the 0-5 cm and 5-10 cm soil depths and K_{sat} results.

The decreases in K_{-40} after treading indicates that treading damage was not confined to the soil macrostructure and that the microstructure was also affected. There were very few soil pores greater than 75 mm after the 24-hour treading treatment.

A slower rate of soil water movement may result in extended periods of anaerobic conditions in the soil after heavy rainfall events. Anaerobic soil conditions are the result of a slow rate of gaseous exchange in soil which can cause decreased root growth (Letey *et al.*, 1961b; Stolzy *et al.*, 1961) and decreased pasture productivity (Donohue *et al.*, 1984).

The declines in K_{sat} and K_{-40} were similar for each treading duration across all experiments, despite the differences in severity of pugging damage between the experiments. The similar response in K_{sat} and K_{-40} suggests that when gravimetric soil moisture content was greater than 65% declines in K_{sat} and K_{-40} are not sensitive to soil moisture.

The correlation between increased hours of treading and decreased rate of K_{sat} and K_{-40} suggests that K_{sat} and K_{-40} are important indicators of change in soil quality, despite inherent variability in results (Schipper & Sparling, 2000). It has been suggested that inherent variability common to hydraulic conductivity measurements may be useful in differentiating micro-sites giving more detailed descriptions of soil changes (López *et al.*, 2003). Variability in soil hydraulic properties, despite the (visually) uniform effect of cattle treading damage, indicates that damage to soil structure was not uniform throughout the soil.

A decrease in K_{sat} and K_{-40} slows the rate of infiltration of water after rainfall events, increasing the probability of water ponding and, for sloping land, more runoff and soil erosion (Nguyen *et al.*, 1998; Russell *et al.*, 2001; Elliott *et al.*, 2002). The decreased rate of water flow through soil results in soil remaining susceptible to more pugging damage for longer periods (Edmond, 1962; Taboada & Lavado, 1993). The decrease in hydraulic conductivity may, therefore, contribute to pugging becoming a self perpetuating problem (Haynes, 1995). Consequently, improvements to soil structure that increase the rate of soil moisture movement could shorten the duration of pugging damage susceptibility (Drewry & Paton, 2000b; Betteridge *et al.*, 2003).

5.4 Soil Surface Properties

5.4.1 Introduction

Cattle treading results in the plastic deformation of soil, causing indentations and hoof penetration of the soil surface. Soil surface roughness is a visible effect of cattle treading damage. Soil surface roughness can be determined using the chain method of Saleh (1993; 1994) and by the measurement of the depth of individual pug prints (e.g. Nie *et al.*, 2001a, 2001b). Pug and skids depths (hoof ploughing) also serves as an indication of the amount of soil that was displaced.

Generally, the area of pug prints (frequency of hits), rather than the depth of pug prints, have been reported (e.g. Sheath & Boom, 1997; Nguyen *et al.*, 1998; Sheath & Carlson, 1998; Betteridge *et al.*, 1999). The chain method has been recently adopted in treading research to provide a soil surface roughness index (e.g. Nie *et al.*, 2001a; Pande, 2002; Drewry *et al.*, 2003).

The soil surface roughness index, depth of pug prints, and depth of skids (hoof ploughing) were determined immediately after treading (65% GSM – 26/6/1999, 71% GSM – 30/8/200, 81% GSM – 7/8/2001). There were no pugs or skids on the controls plots. The full soil surface roughness and pug/skid data with summary tables are presented in Appendix IX.

5.4.2 Soil Surface Roughness Index

Generally, a soil surface roughness index of greater than 5% indicate some soil surface damage (P.L. Singleton, *pers com.* 1999; Section 3.6.1). The soil surface roughness index had little within-treatment variability (Figure 5.11). The mean soil surface roughness index of all control plots was 4.5% (s.e. 0.35) and was taken to be 'typical' of grazed, but unpugged, soil surface conditions.

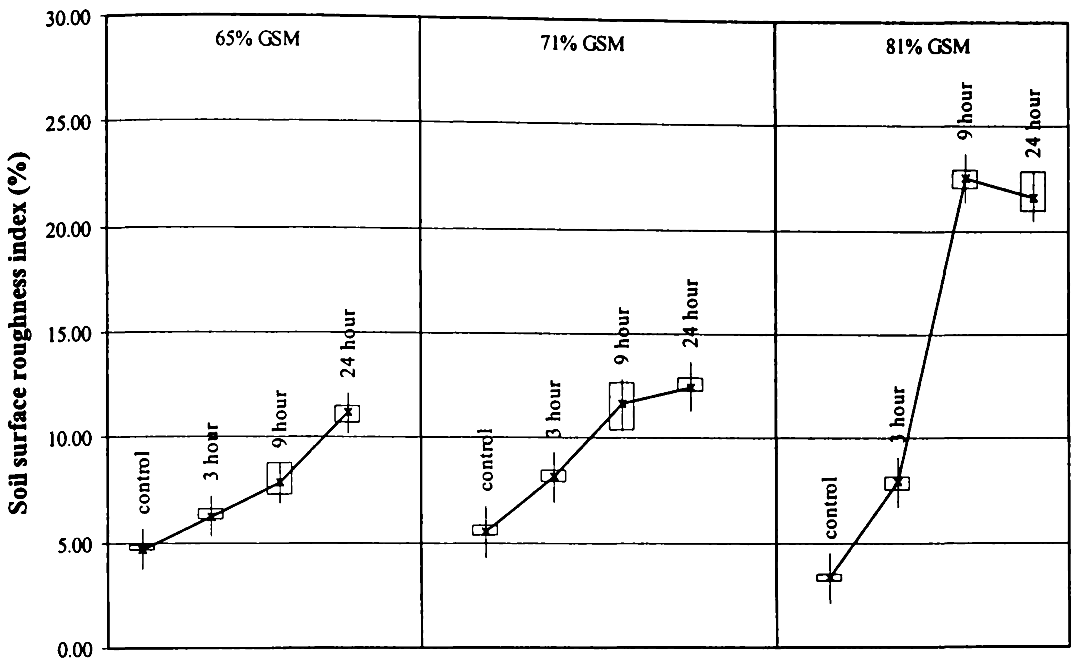


Figure 5.11 Soil surface roughness index (%) immediately after treading treatment. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

In the 65% and 71% GSM experiment, the 3-, 9-, and 24-hour treatments were moderately to distinctly rough (see Section 3.6.1 for description of terms), while the 81% GSM 9- and 24-hour treatments, exceeding 20%, were extremely rough. The surface disturbance in the 65% GSM experiments was subjectively called 'pressing' rather than pugging damage.

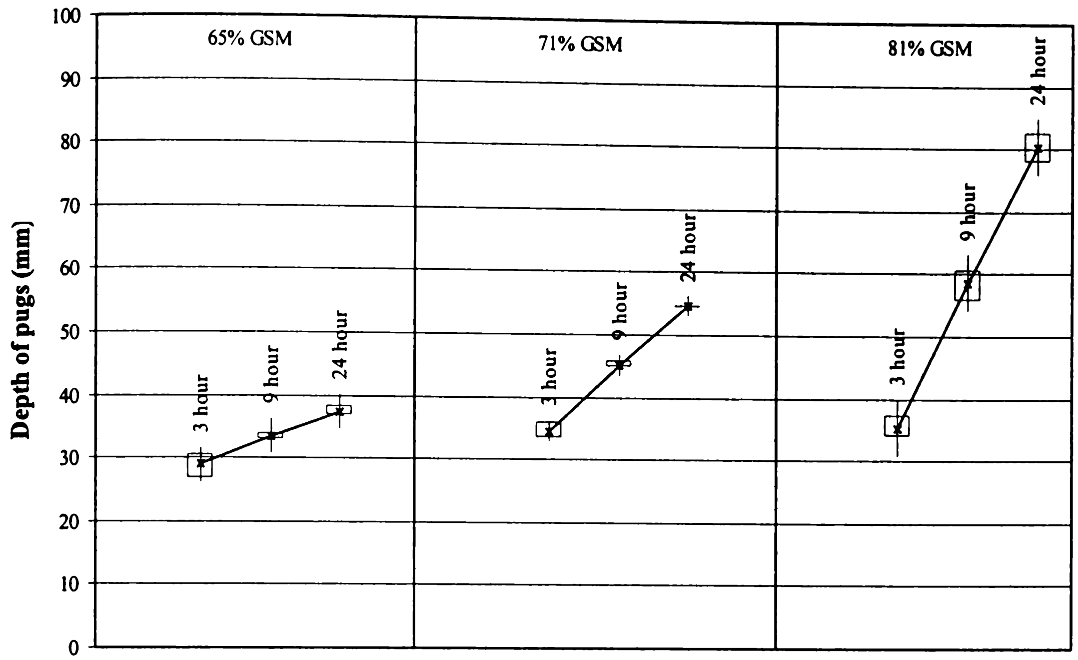
All treatments, except the 65% GSM 3-hour, had more ($P < 0.05$) soil surface roughness than controls. The 81% GSM 9- and 24-hour treatments had similar soil surface roughness (ranged from 22 to 23%), which was greater ($P < 0.05$) than in the 65% and 71% GSM 9- and 24-hour plots. In each of the experiments the 24-hour treatments had greater ($P < 0.05$) soil surface roughness than the 3-hour, and the 65% GSM 24-hour treatment had greater ($P < 0.05$) soil surface roughness than the 9-hour treatment. The largest increase ($P < 0.001$) in soil surface roughness (19% compared with controls) was in the 81% GSM 9- and 24-hour treatments.

5.4.3 Pug and Skid Depths

In each experiment, mean pug depth increased (P <0.05) with increasing treading duration (Figure 5.12a). In each experiment pug depths in the 9- and 24-hour treatment plots were deeper than in the 3-hour treatments (P <0.05), except when comparing the 65% GSM 3- and 9-hour treatments. The greatest depths (mean 80 mm) of pugs were recorded in the 81% GSM 24-hour treatment, whilst the least were in the 65% GSM 3-hour (mean 29 mm). Depth of pugging increased as treading duration increased (r^2 = 0.82 to 0.96, P <0.001).

The mean depth of hoof skids increased with treading duration and soil moisture (Figure 5.12b). The greatest depth of hoof skids was in the 81% GSM experiment 24-hour treatment, where the mean depth was 106 mm. A trend of increasing hoof skid depth with increasing treading duration was apparent in the 81% GSM experiment (r^2 = 0.91, P <0.001) but not in the 65% and 71% GSM experiments. The 71% GSM experiment showed no treatment differences (P <0.05), suggesting that hoof skid depth is possibly influenced by other independent variables such as cow momentum.

a) Depth of pug prints



b) Depth of hoof skids

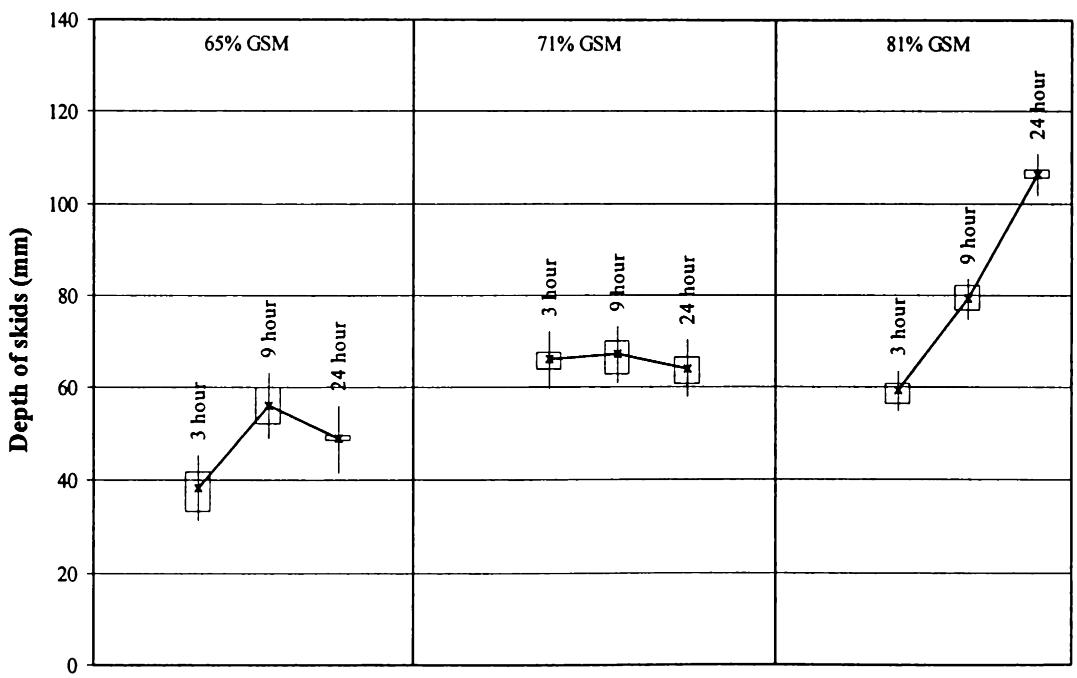


Figure 5.12 Depth of a) pugs and b) skids (mm) immediately after treading treatment. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.4.4 Discussion

Soil surface roughness is an indication of damage to the soil surface in response to repeated treading. Soil surface roughness, from a farm manager's perspective, is a visual indication of treading damage to soil. Attempts have been here to quantify soil surface roughness using the roughness index and depth of pug prints.

Both soil surface roughness and soil pug depths indicate that extensive damage and surface disfiguration had occurred regardless of soil moisture content. Even a conservative three hours of grazing resulted in soil surface damage, implying that short treading durations, aimed at avoiding damage when soil is susceptible to pugging, may still result in some damage.

The chain method of determining soil roughness is usually used in rill erosion studies (Zobeck & Onstad, 1987; Merril *et al.*, 2001), and the consistency in soil surface roughness index results from this thesis indicate that the chain method is also usable for treading research studies. The chain method distinguished between treading treatment durations, even when they were of short duration. There was a reliable correlation between mean soil surface roughness index and depth of pugs (r^2 = 0.79, P <0.001) indicating that the soil surface roughness index can be used independently as a measure of soil surface disturbance by cattle pugging (Figure 5.13). The correlation between skid depth and soil surface roughness index (r^2 = 0.62, P <0.001) was more variable than the correlation between pug depths and roughness. Nie *et al.* (2001a) reported that pugging depth increased (P <0.05) with greater intensity of cattle treading; from 8.7 mm (7 hours at 64 cows ha^{-1}) to 43.0 mm (7 hours at 267 cows ha^{-1}). Nie *et al.* (2001a) also reported the corresponding soil surface roughness index values, which are similar to findings of this thesis (Figure 5.13). The consistency of the results indicates that the chain method can be used as a reliable indicator of soil surface roughness caused by cattle treading.

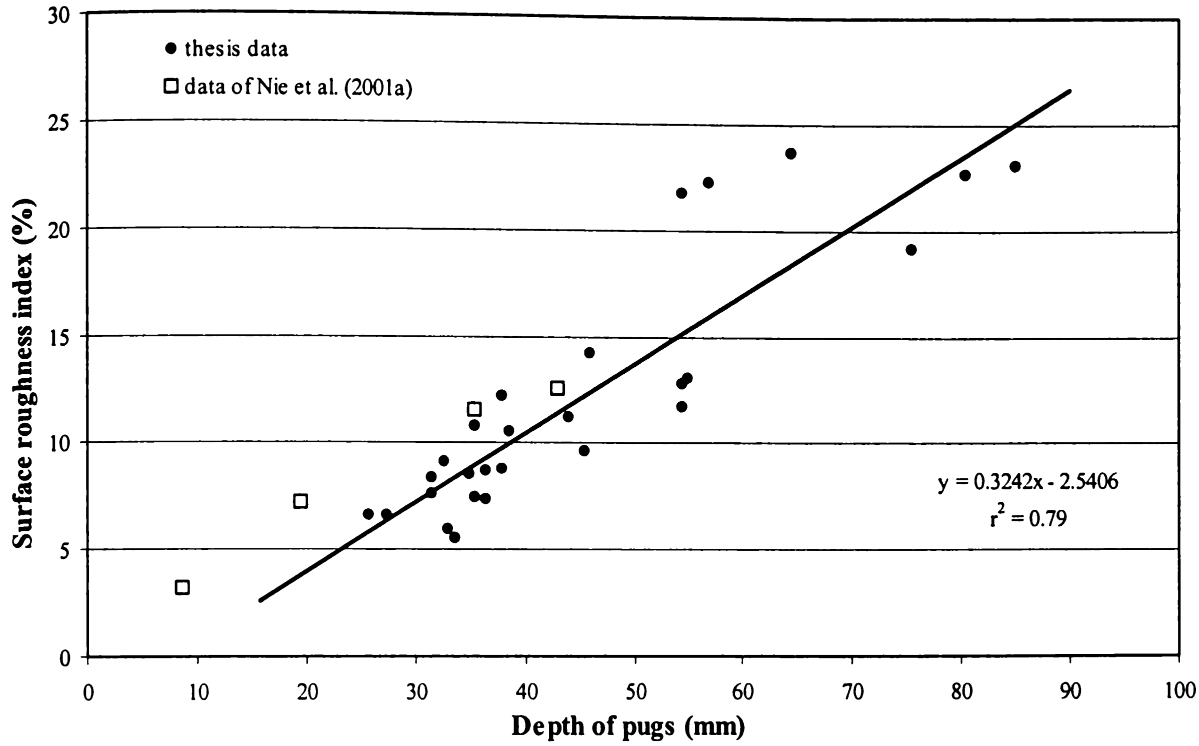


Figure 5.13 Correlation between soil surface roughness index (%) and observed depths of pugs (mm) immediately after cows were removed for all experiments shown as plot means. Regression is on the results from this thesis only.

5.5 Sward Properties

5.5.1 Introduction

The effect of cattle treading was not limited to soil physical properties or the soil surface. The sward was also affected directly, and indirectly, by cattle treading. Repetitive cattle treading on soil results in crushing of herbage tissue (Brown & Evans, 1973) and, when plastic remoulding occurs, burial of plants. Treading damage to swards can be estimated from tiller density counts, assessment of bare ground, and sward botanical compositional changes.

Increased bare ground after severe treading was readily visible but, even though bare ground increases have been reported (e.g. Edmond, 1962), it has is seldom been quantified. Tiller density declines after severe treading damage have been reported (e.g. Edmond, 1962) and may be an important indicator of pasture vigour decline due to treading damage (Pande, 2002).

Long term botanical shifts have been shown to occur in response to grazing and treading (Harris & Brougham, 1968; Hutchinson & King, 1980; O'Connor & Roux, 1995), however, short term botanical changes have been postulated (Edmond, 1966), but are not often observed (e.g. Edmond, 1962; Nie *et al.*, 2001a). Tissue crushing will have an immediate effect on pasture productivity, where most significant proportional declines are often reported about seven to nine weeks following treading damage (Nie *et al.*, 2001a; Betteridge *et al.*, 2002; Drewry *et al.*, 2003).

In this thesis the proportion of bare ground, the botanical composition, tiller density, and herbage accumulation of the sward were investigated to determine responses to treading damage. Each variable was measured on different dates (Table 5.1) in each experiment. The full results for bare ground, botanical composition, tiller density, and herbage accumulation, with summary tables, are presented in Appendix X to XIII.

Table 5.1 Dates of analyses of sward properties.

	Date of treading	Bare ground	Herbage accumulation[a]	Tiller density	Botanical composition
65% GSM	25/6/99	26/6/99	16/8/99	6/8/99	21/8/99
71% GSM	29/8/00	30/8/00	24/10/00	5/10/00	26/10/00
81% GSM	6/8/01	7/8/01	1/10/01	16/9/01	5/10/01

[a] eight week herbage accumulation, calculated to given dates.

5.5.2 Proportion of Bare Ground

Treading treatment caused an increased proportion of bare ground for all treatment plots in all experiments, and was greatest in the 81% GSM 24-hour treatment (Figure 5.14). As interplant spaces already existed within the sward, pre-treatment and control measurements were carried out to determine 'typical' bare ground values. The mean proportion of bare ground for all experiments prior to treading was 25% (s.e. 1.14). Immediately after treading, there was more (P <0.05) bare ground in all trodden plots than in controls. Except for the comparison between 71% GSM 9- and 24-hour treatments, all other treatment comparisons were significant (P <0.05). There was a trend of increasing bare ground with increasing treading duration (r^2 = 0.93 to 0.97, P <0.001) over the three experiments.

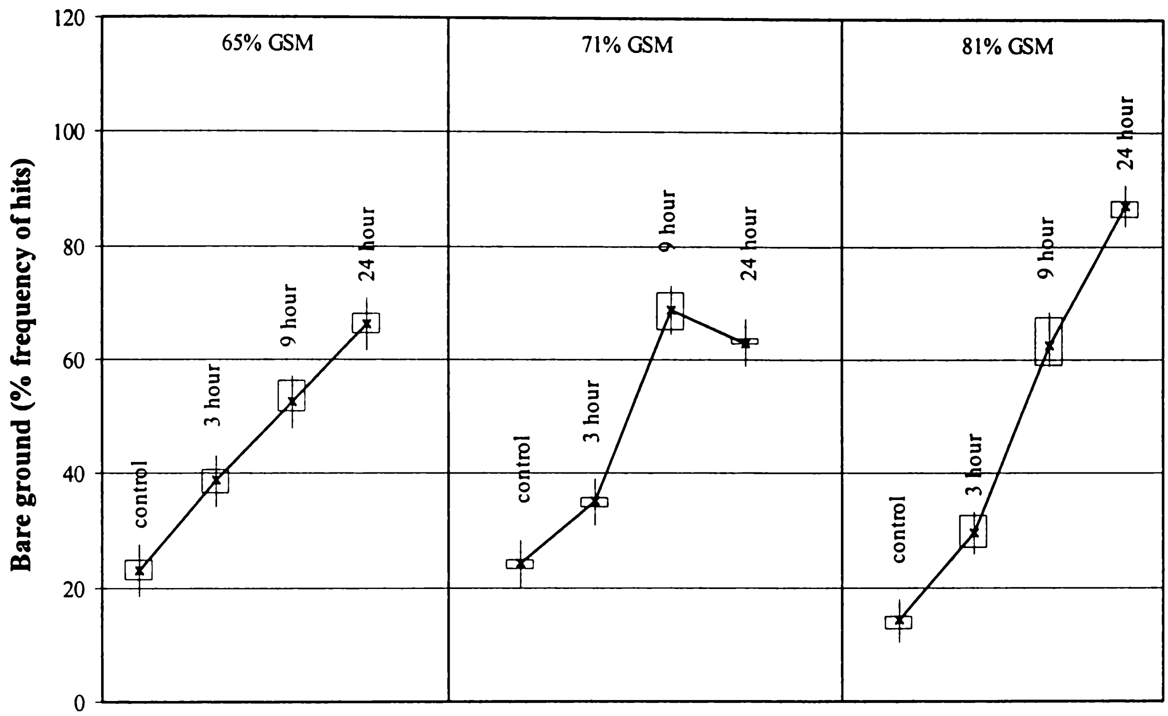


Figure 5.14 The proportion of bare ground (as % frequency of hits) assessed using the point analyses frame. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.5.3 Sward Botanical Composition

The sward in each experimental site before treading treatment was predominantly ryegrass (about 80% of DM) with less than 20% of dry matter as white clover, weeds, other grasses, and dead material (Figure 5.15). The 65% GSM experimental site had the largest proportion of ryegrass, while the 71% and 81% GSM experimental sites had more ($P < 0.05$) weeds than the 65% GSM experiment. White clover was present at all sites but typically was less than 3% of sward dry matter. In each experiment, botanical composition did not change up to eight weeks after treading. There was a tendency for smaller proportions of dead material in plots trodden for longer, however, this was only significant ($r^2 = 0.60$, $P < 0.01$) in the 81% GSM experiment.

Other grass species were found in all experimental sites, of which *Poa* (*Poa annua* L.) was most common with some prairie grass (*Bromus willdenowii* Kunth.), summer grass (*Digitaria sanguinalis* (L.) Scop.), paspalum (*Paspalum dilatatum* Poir.), and foxtail (*Alopecurus pratensis* L.) present. Throughout the 65% GSM experimental site there was an established population of Indian doab (*Cynodon dactylon* L.), representing 4.6% of the total sward dry matter before treading. Indian doab is winter dormant (Taylor, 1980; Lambrechtsen, 1992) and, as several frosts occurred shortly after the treading treatment of 65% GSM experimental site, the proportion of Indian doab had decreased to less than 0.1% of dry matter eight weeks after treading.

The proportion of sward weeds at each experimental site was variable. Typical pasture weeds were dandelion (*Taraxacum officinale* Weber), creeping buttercup (*Ranunculus repens* L.), broad-leaved dock (*Rumex obtusifolius* L.), and yarrow (*Achillea millefolium* L.). The sward at the 65% GSM experimental site had some hydrocotyle (*Hydrocotyle americana* L.), however, this did not contribute significantly to sward dry matter. The sward at the 71% and 81% GSM experimental sites also contained broad-leaved plantain (*Plantago major* L.), which was not found in the sward at the 65% GSM experimental site.

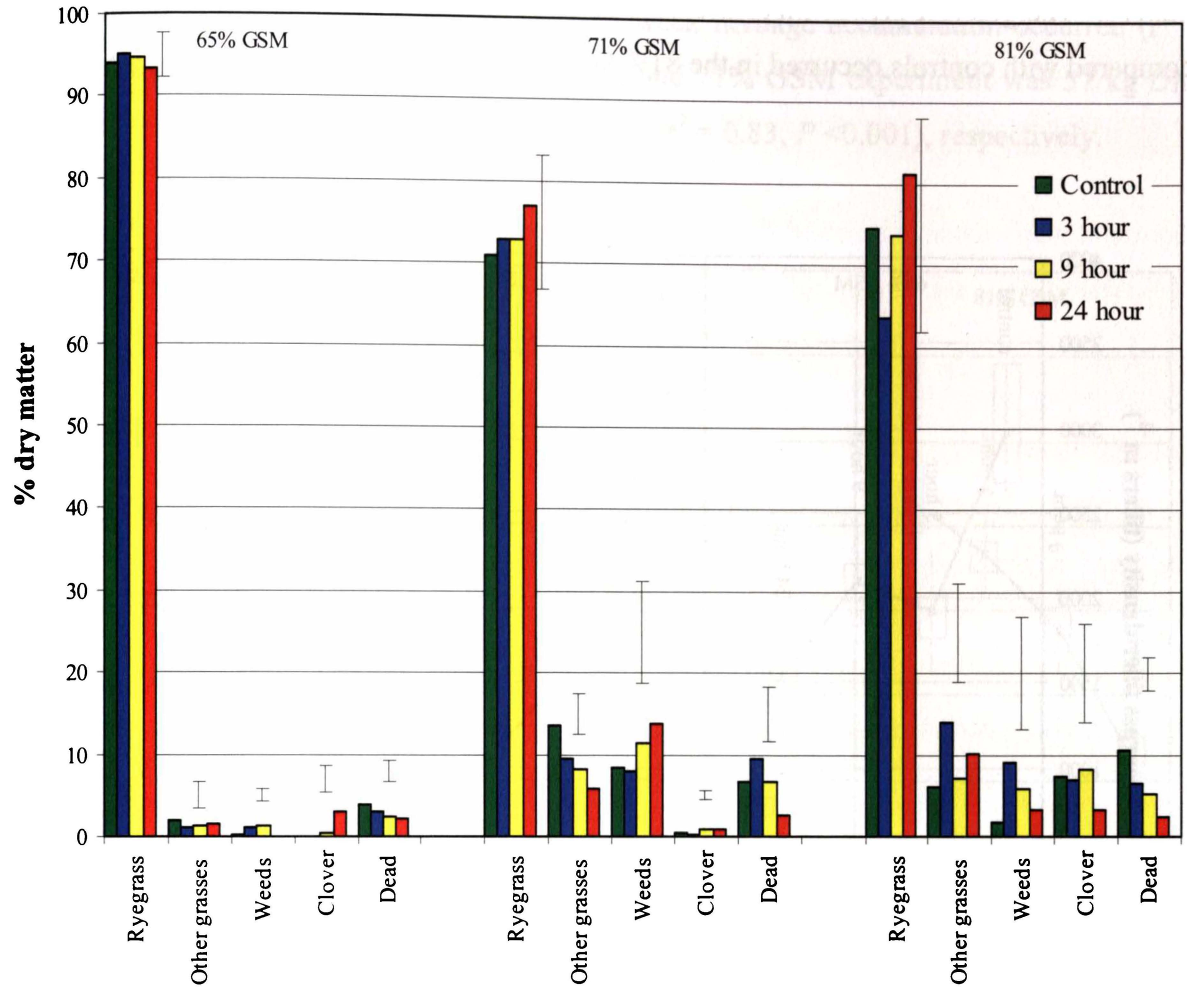


Figure 5.15 Sward botanical composition eight weeks after treading as a percentage of total dry matter.

5.5.4 Ryegrass Tiller Density

The longer the treading duration and the greater the soil moisture content the greater the decrease in tiller density six weeks after treading treatment (Figure 5.16). Tiller density for the 9- and 24-hour treatment plots was 27 to 66% less ($P < 0.05$) than the controls in the three experiments. The 3-hour treading treatment plots also had lower ($P < 0.05$) tiller density than the controls in the 65% GSM experiment.

Tiller density was greater in the 65% GSM experiment, possibly because of the earlier timing of the experiment (end of June rather than early August) or because of different paddock history. The greatest proportional decrease in tiller density with increasing treading duration compared with controls occurred in the 81% GSM experiment.

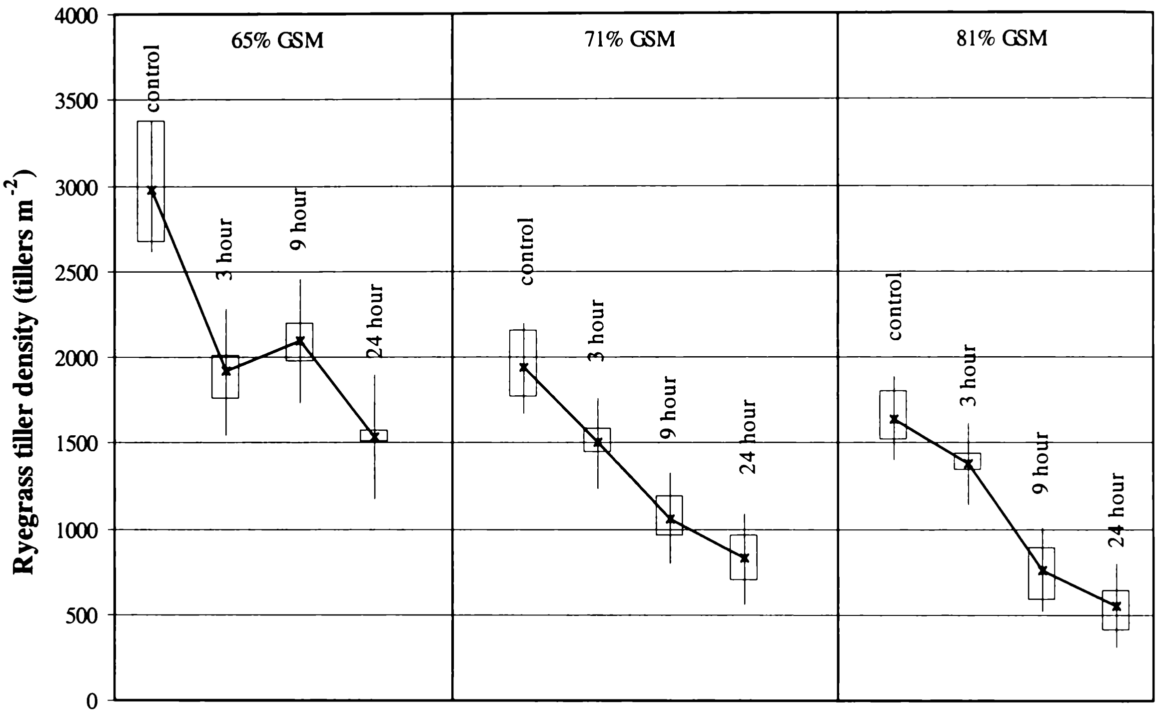


Figure 5.16 Ryegrass tiller density (tillers m^{-2}) six weeks after treading treatment. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.5.5 Early Pasture Productivity Response

Herbage accumulation eight weeks after treading treatment was least on the 9- and 24-hour treatments for all experiments (Figure 5.17), with the 24-hour treatment plots accumulating less ($P < 0.05$) herbage than the 3-hour and the control treatment plots. The greatest decrease in herbage accumulation (2,140 kg DM ha^{-1}) compared with controls, was in the 81% GSM 24-hour treatment plots.

There was a trend of decreasing herbage accumulation with increasing duration of treading in all experiments. The trend was greatest for the 81% GSM experiment, where for every hour of treading an 89 kg DM ha^{-1} decrease in eight week herbage accumulation occurred (r^2 = 0.85, P <0.01). The rate of decrease in the 65% and 71% GSM experiment was 57 kg DM ha^{-1} hr^{-1} (r^2 = 0.60, P <0.01) and 22 kg DM ha^{-1} hr^{-1} (r^2 = 0.83, P <0.001), respectively.

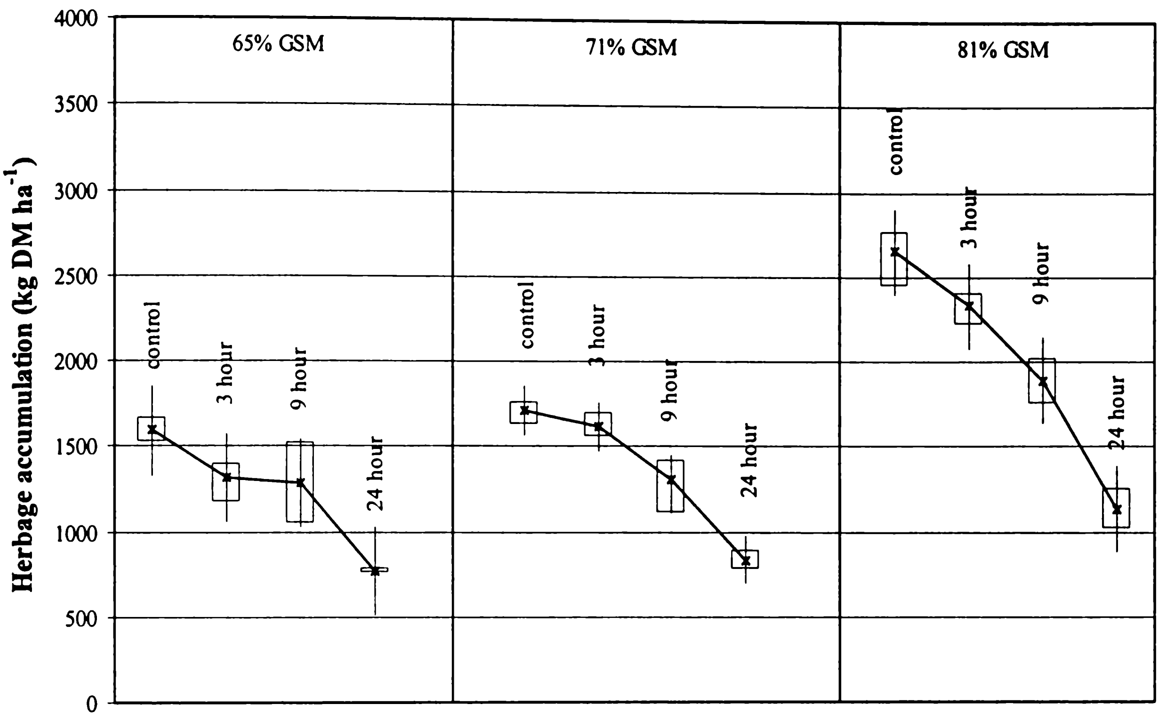


Figure 5.17 Herbage accumulated (kg DM ha^{-1}) by eight weeks after the treading treatment. The box represents data distribution between upper and lower quartiles, the whiskers are the $LSD_{5\%}$ values, and the asterisk the treatment mean.

5.5.6 Discussion

A one-off severe treading event increased (P <0.05) bare ground and decreased (P <0.05) tiller density and herbage accumulation, but did not alter the composition of the sward within the six weeks following treading.

Severe treading for 24-hours caused a drop in herbage accumulation, confirming findings by other researchers have linked treading damage to decreased pasture productivity in the first eight weeks following treading damage (e.g. Edmond, 1970; Bryant *et al.*, 1972; Pande *et al.*, 2000; Nie *et al.*, 2001a). The decline in herbage accumulation has been attributed to the direct effect of treading on herbage, causing crushing and burial (O'Connor, 1956; Edmond, 1958; Brown & Evans, 1973). However, it is difficult to separate the effects on herbage growth of direct plant damage from the indirect effects of soil compaction.

Ryegrass tiller density in trodden plots had not recovered six weeks after treading. Other researchers (e.g. Nie *et al.*, 2001a; Pande *et al.*, 2002) have attributed the lower density of tillers after treading as the result of tiller death, tiller burial, and decreased plant tillering rate due to tissue damage. Decreased tiller density immediately after treading has also been reported by Brougham *et al.* (1960), Edmond (1962), and Nie *et al.* (2001a). However, Pande *et al.* (2002) postulated that some tillers buried by treading may re-emerge from soil, therefore, determining tiller density immediately after treading may not be a true reflection of the number of surviving tillers. The lower tiller density six weeks after treading reported in this thesis serves as an indication of potential pasture productivity loss (Brougham *et al.*, 1960). However, the correlation between ryegrass tiller density and herbage accumulation (as a % of control herbage accumulation) at eight weeks was variable but significant ($r^2 = 0.29$, $P < 0.01$) (Figure 5.18).

Bare ground increases during grazing and treading by herbage defoliation, followed by plant crushing, plant burial into remoulded soil, and subsequent plant death. The increase in bare ground resulted in a loss of potential pasture productivity. Results from this thesis show a correlation between bare ground after treading and herbage accumulation (as a % of control herbage accumulation) at eight weeks for all experiments ($r^2 = 0.73$, $P < 0.001$) (Figure 5.19). The amount of bare ground after treading provides a visual indication to farm managers of the damage inflicted on the sward and soil, and could provide a visual guide to the likely decline in pasture productivity.

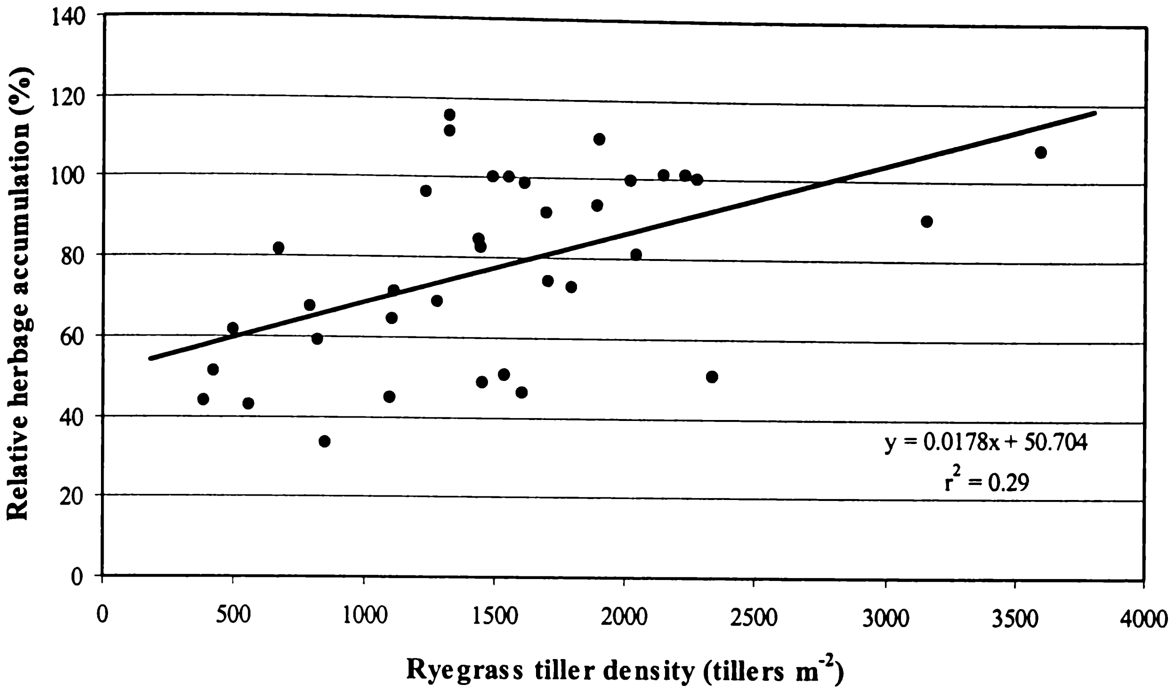


Figure 5.18 Correlation between tiller density and relative herbage accumulation (as a % of control herbage accumulation), using plot means of all experiments, at eight weeks after treading treatment.

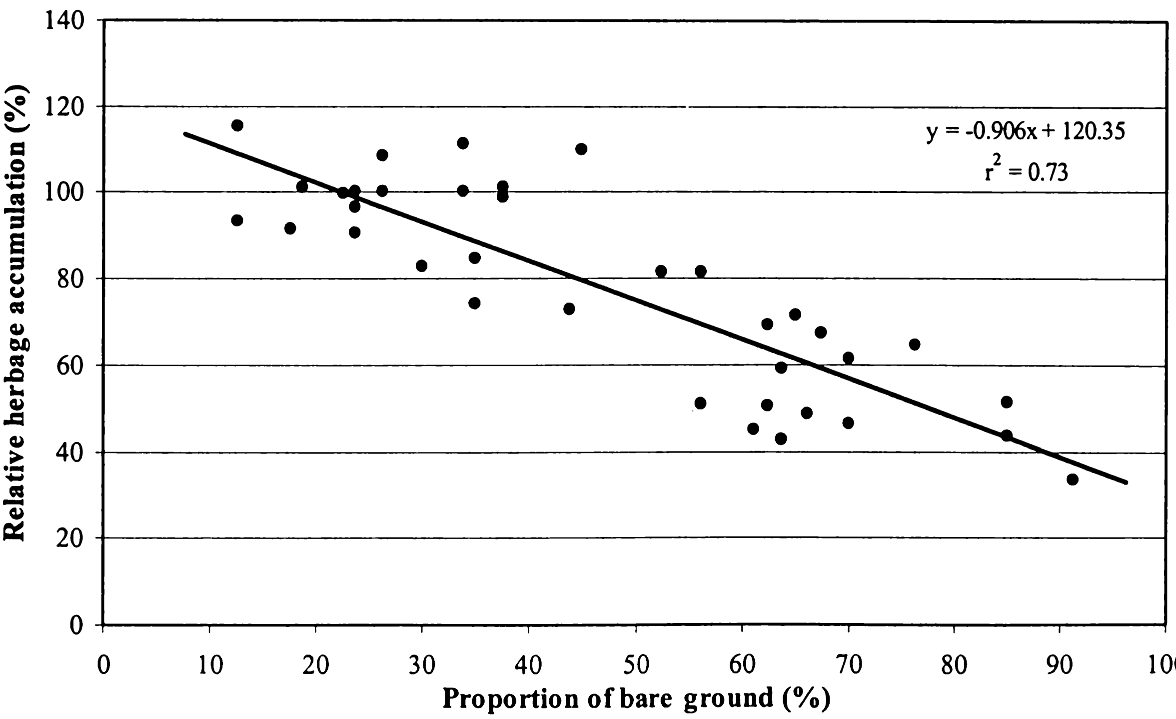


Figure 5.19 Correlation between the proportion of bare ground and herbage accumulation (as a % of control herbage accumulation), using plot means of all experiments, at eight weeks after treading treatment.

Betteridge *et al.* (1998) and Pande *et al.* (2002) found that taller plant canopy results in less treading damage than when the canopy cover was short. When ground is bare the damage from treading is directly on soil, resulting in greater damage than when soil is covered by plants (Betteridge *et al.*, 1999; Pande *et al.*, 2002). This thesis shows that the greater the amount of bare ground after severe treading event, the less herbage mass and canopy cover there will be eight weeks after treading, exposing the soil to further direct treading damage.

The botanical composition of trodden plots did not alter in response to a one-off severe treading event and other reports suggest that long term grazing (years to decades) are needed to result in a botanical shift towards more treading tolerant pasture species such as ryegrass (Harris & Brougham, 1968; Kemp *et al.*, 1999). The effect of a one-off severe treading damage event, even where bare ground was increased to 87% of the soil surface, did not change botanical composition eight weeks following treading. The lack of change in botanical composition eight weeks after treading damage may be partly because the dominant sward species (ryegrass) is treading tolerant (Kemp *et al.*, 1999).

White clover is more susceptible to treading damage than ryegrass (Curll & Wilkins, 1983), and white clover content declines more than ryegrass when severe treading damage occurs (Menneer *et al.*, 2001). Sward white clover content was already small (<3% of sward DM) when the experiments in this thesis were carried out, possibly a reflection of past treading damage (Curll & Wilkins, 1983) or use of nitrogen fertilisers (Ettema & Ledgard, 1992), so findings from this thesis do not further the understanding of white clover resilience to cattle treading.

Annual *Poa* is a prolific seeder (Parham & Healy, 1985; Kemp *et al.*, 1999) and increases in *Poa* content during spring, in swards where ryegrass density has been decreased, can occur (Korte *et al.*, 1984; Sheath & Boom, 1985b). As sward botanical composition was determined partway through spring (between September and November), it was expected that *Poa* would colonise the open spaces created by the treading. However, there was no evidence that *Poa*, or any other grass species, colonised open spaces in the eight weeks (spring time) after treading in the 65%, 71%, and 81% GSM experiments. One reason may be that the *Poa* population was too small to take advantage of the bare ground that had developed.

5.6 Summary and Conclusion

A one-off severe treading event by cattle on soil susceptible to pugging caused changes in soil physical properties and sward characteristics. Longer treading durations had increasingly detrimental effects on macroporosity, microporosity, K_{sat}, K_{-40}, pore continuity, soil surface roughness, bare ground, ryegrass tiller density, and herbage accumulation. Treading caused more damage at the greater gravimetric soil moisture content (81% GSM) than at the lowest gravimetric soil moisture content (65% GSM). However, soil dry bulk density, total porosity, and sward botanical composition did not change as a result of treading.

Macroporosity was sensitive to treading damage and decreased as much as 0.10 cm^3 cm^{-3} with increasing treading duration. Decreases in macroporosity were matched by increases in microporosity, thus total porosity did not change. The increases in microporosity are probably due to the redistribution of soil moisture, which was held in macropores prior to treading, resulting in the formation of new micropores. The inverse relationship of macroporosity and microporosity changes (and lack of change in total porosity) indicates that predominantly pugging, not compaction, took place in the top 10 cm of soil in all experiments. The macroporosities at some sampling sites immediately after the treading were less than 0.10 cm^3 cm^{-3}, indicating that soil aeration may have been limiting plant root development (Gradwell, 1965; Grable, 1971; Carter, 1988; Stepniewski *et al.*, 1994). The K_{sat} and K_{-40} immediately after treading was up to 91% slower in trodden plots than controls, indicating that soil structure was detrimentally affected by the treading.

A one-off severe treading event caused as much as a 56% decline in herbage accumulation compared with controls in the first eight weeks after treading. The slower rate of herbage accumulation in trodden plots was attributed to hooves causing tissue crushing and plant burial. The increase in bare ground and decrease in tiller density in trodden plots were clearly associated with a decline in sward productivity.

The experiments from this thesis suggest that macroporosity is a better indicator of treading damage when pugging has occurred rather than compaction. Soil dry bulk density and total porosity are not suitable as indicators of pugging damage. Decreases in K_{sat} and K_{-40} were substantial (as much as 91%), however, data variability was large, limiting the usefulness of K_{sat} and K_{-40} as reliable indicators of pugging damage. Soil surface roughness and the proportion of bare ground were reliable indicators of treading damage and have the advantage of being easily and visually determined.

The effect of a one-off severe treading event when the soil was susceptible to pugging damage made the soil more susceptible to further pugging damage as shown by decreased K_{sat} and K_{-40} and increased microporosity in pugged areas, causing soil to remain wetter for longer after rainfall. The increase the area of bare ground exposed soil to more direct hoof contact compared with plots that maintained more herbage cover.

Chapter 6. Recovery of Soil and Sward Following Cattle Treading

6. Recovery of Soil and Sward following Cattle Treading Damage

6.1 General Introduction

This chapter reports on the natural recovery of the soil and sward over 34 weeks following the treading treatment. The recovery of soil physical properties at the 0-5 cm and 5-10 cm soil depths, and sward characteristics are discussed for each treatment (0, 3, 9, and 24-hour treading treatments) in the 65%, 71%, and 81% GSM (gravimetric soil moisture content) experiments. As the 5-10 cm soil depth was not always affected by the treading treatment, and differences were seldom significant, only brief mention is made in the text (full data are in Appendices V to XIII). All results discussed are the treatment means unless otherwise indicated. The methods used are discussed in Chapter three and initial effects of treading are discussed in Chapter five.

Due to logistic constraints associated with undertaking the fieldwork, the three field experiments were carried out over three different winters. The rates of soil and sward recovery in each of the three field experiments could vary depending on climatic conditions in each of the three years. However, as climatic conditions, such as soil temperature, and rain amount and distribution (Table 4.1 and Appendix II), were similar during the recovery periods for each of the experiments, it is unlikely that climate differences had an important effect on recovery rates.

Recovery of soil and sward characteristics was assumed when results from treatment plots were no longer significantly different ($P < 0.05$) from control plots. All plots (including the controls) were rotationally grazed after the treading treatment so recovery took place under 'typical' farming conditions. The control plots showed some seasonal trends over time which are also discussed.

6.2 Soil Porosity and Soil Dry Bulk Density

6.2.1 Introduction

Monitoring of soil porosity and soil dry bulk density recovery after treading damage has usually been carried out in the context of long term management change, for example excluding soil and sward from grazing after having been grazed for many years (e.g. Orr, 1975; Stephenson & Veigel, 1987; Greenwood *et al.*, 1998; Drewry & Paton, 2000a; Drewry *et al.*, 2004b). Comparative literature on the recovery of soil after a one-off severe treading event was limited to a few investigations (e.g. Drewry *et al.*, 2003) but extrapolation was possible from other investigations monitoring changes in trodden soils over time (e.g. Gradwell, 1960).

Drewry *et al.* (2003) investigated short term recovery of soil dry bulk density and macroporosity of a Te Kowhai soil after a one-off severe treading, however, only studied one treading duration at one soil moisture content, and did not maintain rotational grazing of the trodden soils. Gradwell (1960) investigated changes in soil macroporosity caused by winter treading by sheep on the Manawatu silt loam, however, the Gradwell study determined macroporosity at a moisture tension of 50 cm (thus macropores were about ≥43 μm in diameter). Other natural amelioration studies (e.g. Singleton & Addison, 1999; Drewry & Paton, 2000a; Singleton *et al.*, 2000; Elliott *et al.*, 2002; Drewry *et al.*, 2004b) investigated changes in soil porosities after extended periods of treading damage, not after a one-off severe pugging damage event.

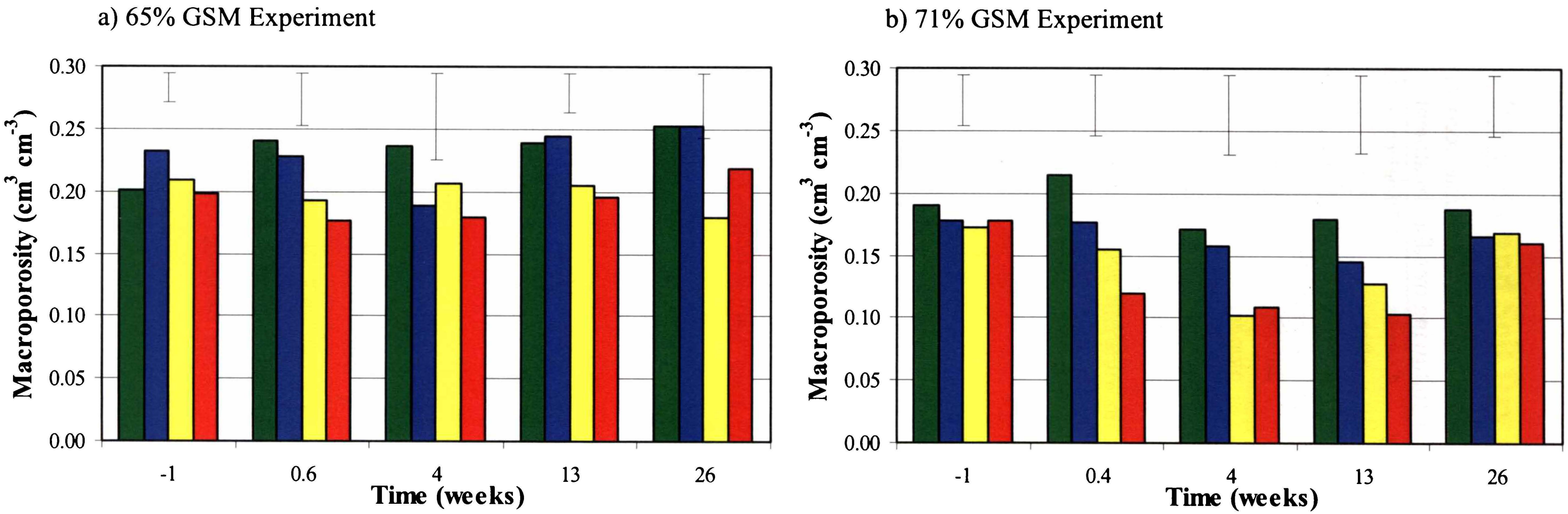
The recovery of soil porosity and dry bulk density in this thesis was monitored at set intervals (Table 6.1) as changes in macroporosity, microporosity, total porosity, and soil dry bulk density after treading treatment. The full data, including 5-10 cm soil depth, and summary tables are presented in Appendix V.

Table 6.1 Dates for sampling of soil cores that were used to determine recovery in soil porosity, dry bulk density, and hydraulic conductivity following treading treatment.

Experiment	Before treading	Date of treatment	Immediately after treading	4 weeks after treading	13 weeks after treading	26 weeks after treading
65% GSM	17/6/99	25/6/99	29/6/99	22/7/99	23/9/99	17/12/99
71% GSM	22/8/00	29/8/00	1/9/00	28/9/00	23/11/00	19/2/01
81% GSM	28/7/01	6/8/01	9/8/01	6/9/01	9/11/01	1/2/02

6.2.2 Macroporosity

Macroporosity (>30 μm pore diameter) generally recovered (i.e. no significant differences between treatment and control) between four and 13 weeks after treading treatment (Figure 6.1). Macroporosities at the 0-5 cm soil depth were less (P <0.05) in all 24-hour treatments than controls up to 13 weeks after the treading. No significant differences in macroporosity between treatment plots and controls were present 26 weeks after treading.



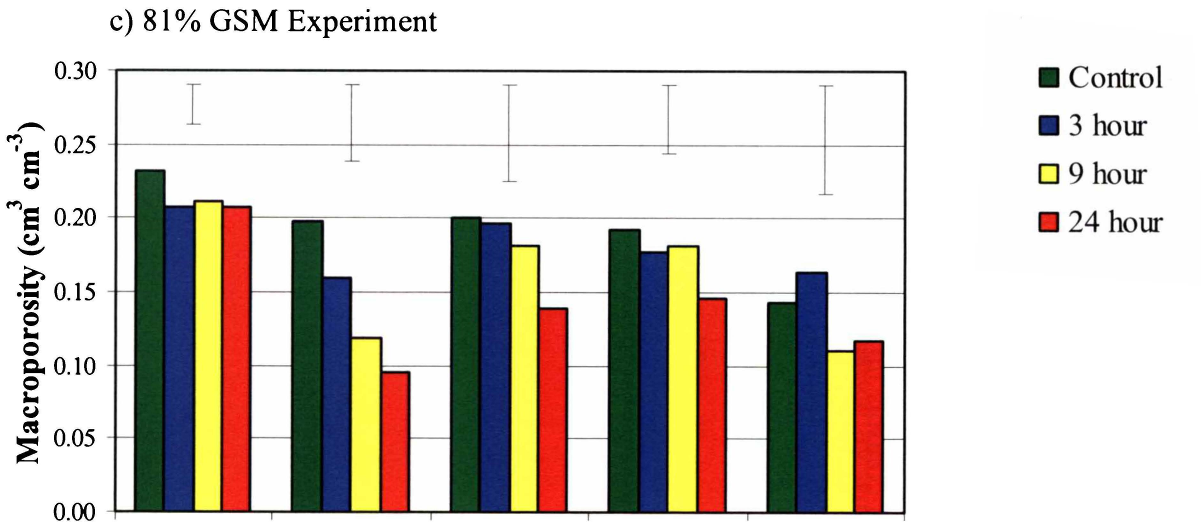


Figure 6.1

Macroporosity ($cm^3\ cm^{-3}$) at the 0-5 cm soil depth before treading and up to 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each column is the mean of the treatment, error bars are the $LSD_{5\%}$.

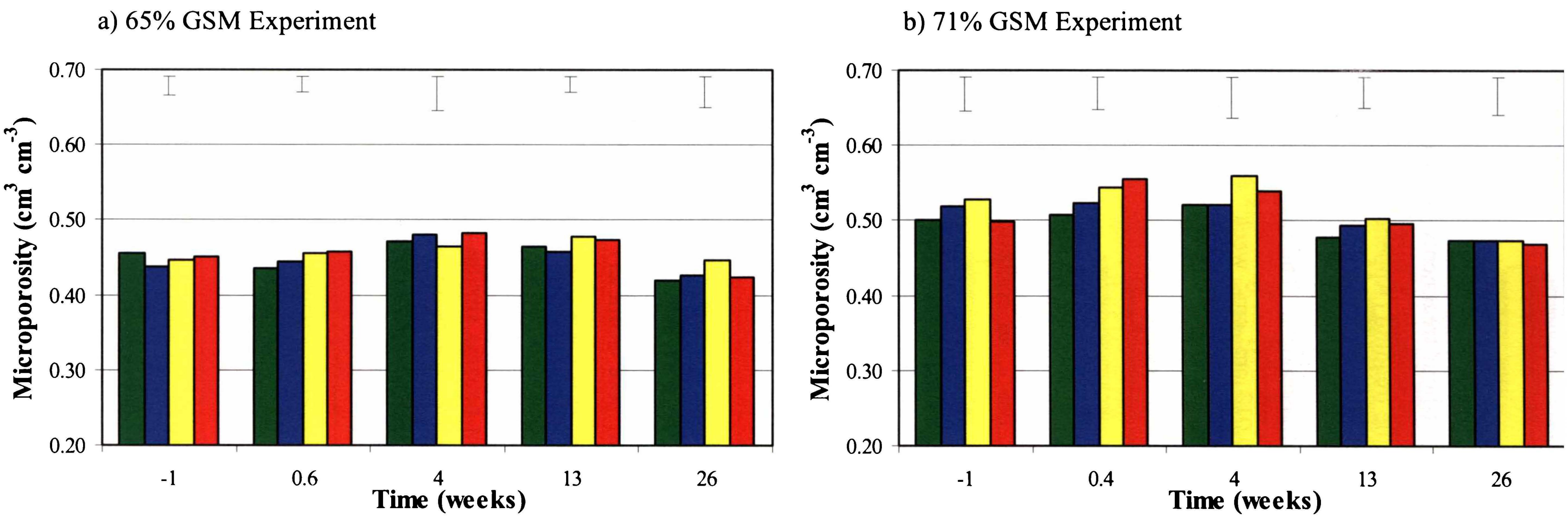
At the 5-10 cm soil depth, in the 81% GSM 9- and 24-hour treatments, macroporosity had recovered, compared with controls, by 26 weeks after the treading (Appendix V).

The rate of macroporosity recovery varied between experiments. The macroporosity in the 81% GSM 24-hour treatment recovered at a rate of 0.013 cm^3 cm^{-3} $week^{-1}$ for the first four weeks then slowed tenfold to less than 0.001 cm^3 cm^{-3} $week^{-1}$. The 71% GSM experiment had a slow macroporosity recovery over 26 weeks.

In the control plots, at the end of the 65% GSM experiment (26 weeks), macroporosity at 0-5 cm soil depth had increased from 0.20 to 0.25 cm^3 cm^{-3}. In contrast, with the onset of summer macroporosity in the 81% GSM control plots at the 0-5 cm soil depth had decreased (P <0.05) from 0.23 to 0.14 cm^3 cm^{-3} and at the 5-10 cm soil depth from 0.16 to 0.11 cm^3 cm^{-3}.

6.2.3 Microporosity

At the 0-5 cm soil depth, microporosity (<30 μm soil pore diameter) in the 65% and 71% GSM 9- and 24-hour treatments, and the 81% GSM 9-hour treatment, were not significantly greater than controls by four weeks after treading treatment (Figure 6.2). Microporosity at the 0-5 cm soil depth in the 81% GSM 24-hour treatment became similar to controls 13 weeks after treading. At the 5-10 cm soil depth only the 81% GSM 9- and 24-hour treatments had increased (P <0.05) microporosity, and both had become similar to controls by 13 weeks after treading.



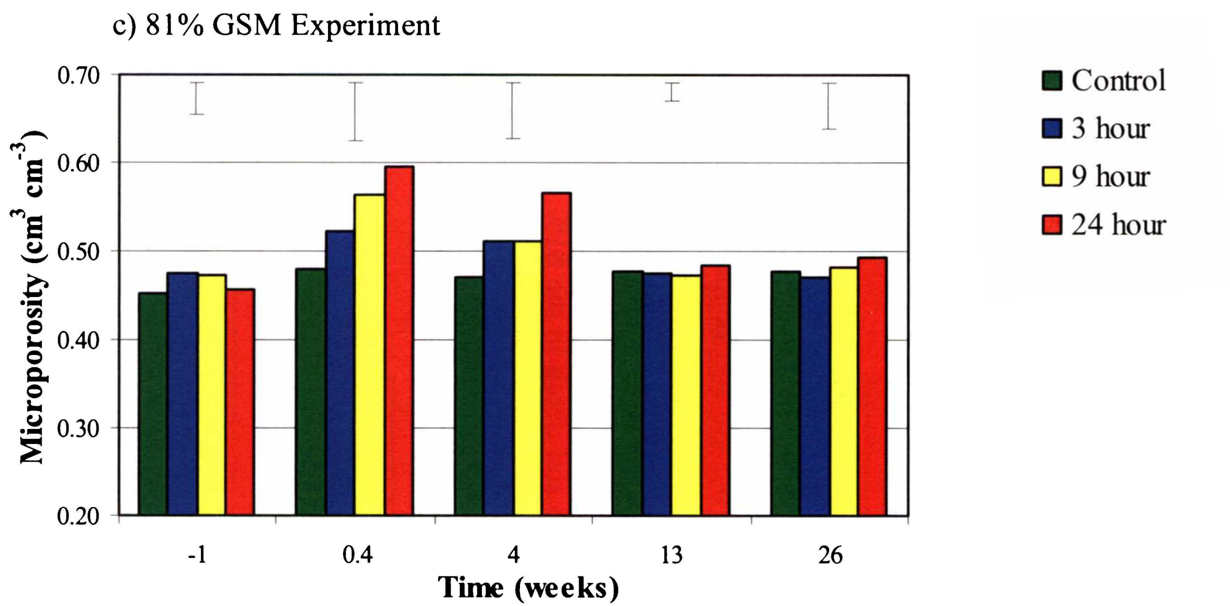
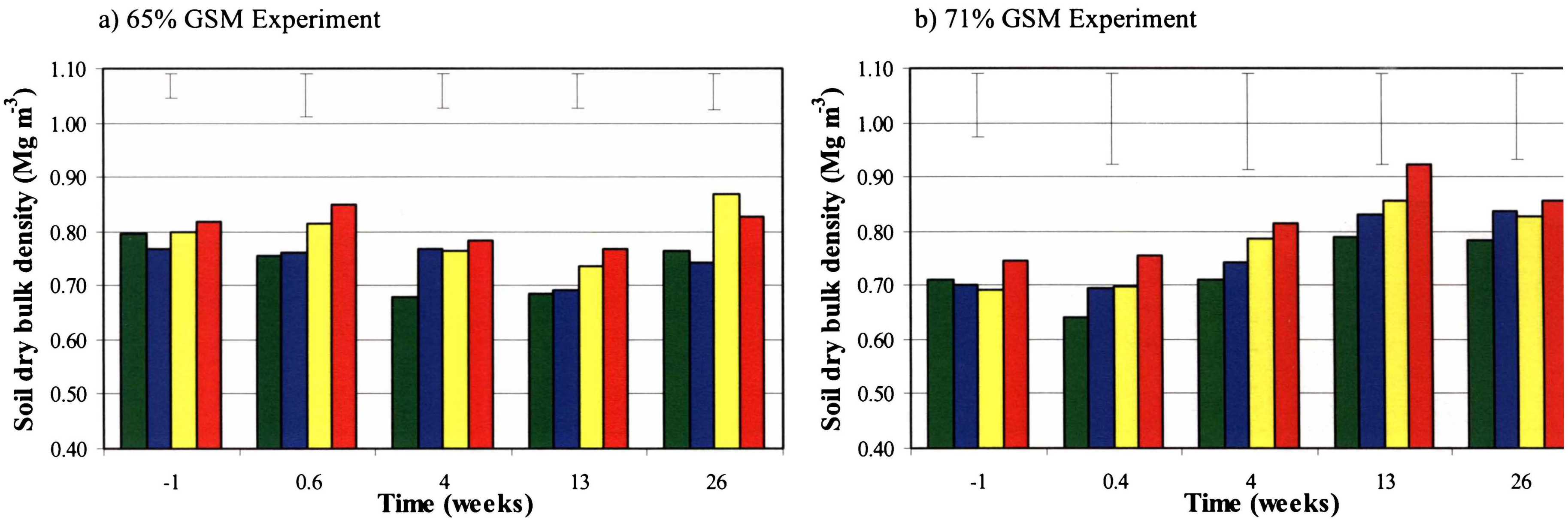


Figure 6.2
Microporosity ($cm^3\ cm^{-3}$) at the 0-5 cm soil depth before treading and up to 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each column is the mean of the treatment, error bars are the $LSD_{5\%}$.

6.2.4 Total Porosity and Soil Dry Bulk Density

Soil dry bulk density and total porosity in the 65% GSM 9- and 24-hour treatments had recovered by 13 weeks after treading treatment (Figures 6.3 and 6.4). As there were no other significant differences immediately after treading in soil dry bulk density and total porosity in the other experiments, no recovery was observed for other treatments.

The soil dry bulk density in the 81% GSM experiment increased from 0.73 to 0.87 Mg m^{-3} at the 0-5 cm soil depth and from 0.95 to 1.02 Mg m^{-3} at the 5-10 cm soil depth with the onset of summer (13 weeks after treading).



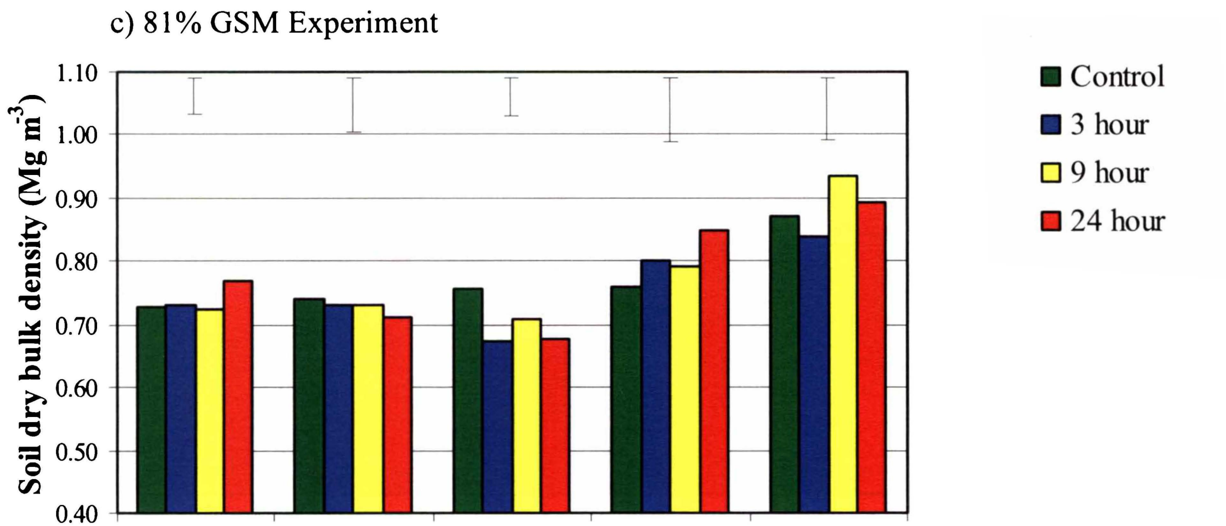
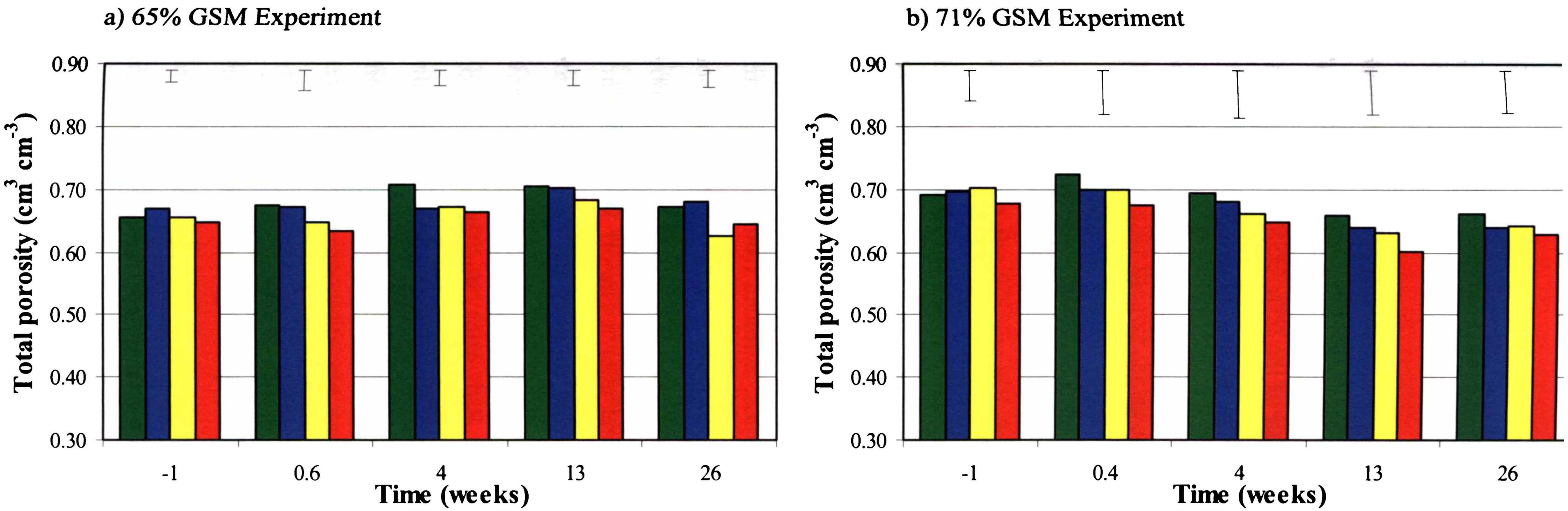


Figure 6.3

Soil dry bulk density (Mg cm^{-3}) at the 0-5 cm soil depth before treading and up to 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each column is the mean of the treatment, error bars are the $LSD_{5\%}$.



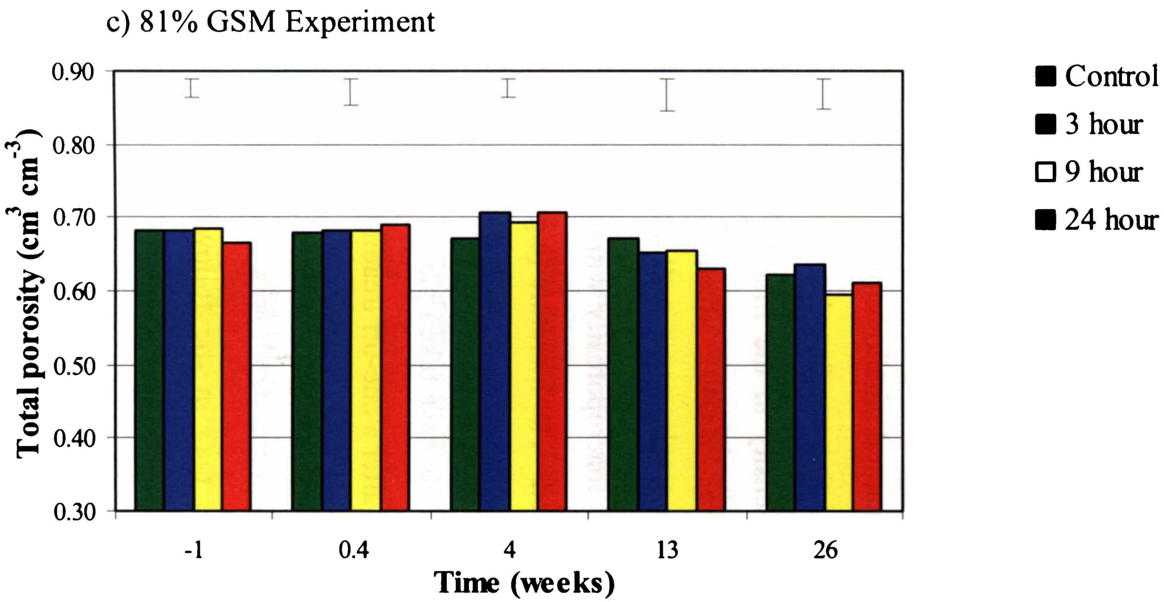


Figure 6.4

Total porosity (cm^3 cm^{-3}) at the 0-5 cm soil depth before treading and up to 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each column is the mean of the treatment, error bars are the $LSD_{5\%}$.

6.2.5 Discussion

After a one-off severe treading event, soil macroporosities and microporosities recovered under the 'typical' grazing management. The recovery time took longer when more severe treading damage had occurred. The least damaged soils (all of the 65% GSM treatments and the 3-hour treatments in the 71% and 81% GSM experiments) recovered within four weeks of treading. Macroporosity and microporosity from more severely damaged soils (24-hour treatments in the 71% and 81% GSM) took between 13 and 26 weeks to recover.

Drewry *et al.* (2003) reported that macroporosity of a Te Kowhai soil, which was not grazed after the treading treatment, took about 14 weeks to recover, while Gradwell (1960) reported recovery to pre-pugging conditions took about 17 weeks for a Manawatu silt loam soil. Some researchers have found that soil with cumulative damage events (possibly a combination of compaction and pugging) may take up to a year or longer to recover (Orr, 1975; Greenwood *et al.*, 1998; Singleton & Addison, 1999; Singleton *et al.*, 2000; Elliott *et al.*, 2002). However, natural amelioration of South Island silt loams soils, excluded from further grazing after cumulative treading damage events, had most of the recovery in macroporosity and soil dry bulk density in the first 17 weeks after grazing exclusion (Drewry & Paton, 2000a; Drewry *et al.*, 2004b). Results from this thesis show that after a one-off severe treading damage event it was possible to retain the site in the grazing rotation and have full natural recovery in macroporosity within 26 weeks. However, further pugging damage must have been avoided. The literature (e.g. Orr, 1975; Greenwood *et al.*, 1998; Singleton & Addison, 1999; Singleton *et al.*, 2000; Elliott *et al.*, 2002) suggests that if multiple severe treading damage events have taken place, a longer time may be required for full recovery than would be the case after a one-off treading event.

At the 0-5 cm soil depth, in all experiments, recovery in macroporosity was faster in the first four weeks than in the following nine weeks. Initial recovery may be driven by re-aggregation of soil particles after several cycles of wetting and drying (rainfall events were mostly sporadic after the experiments), resulting in reformation of soil structure (Dexter, 1991; Taboada & Lavado, 1993; Lavado & Alconada, 1994). Renewed earthworm activity has also been suggested to aid recovery of soil structure after treading damage (Drewry *et al.*, 2003). Initial recovery may also be assisted by decomposition of buried herbage, resulting in the formation of continuous macropores (Goss, 1987).

Increased microporosity leads to greater soil moisture content at field capacity, thus making the soil more susceptible to further pugging damage (Mullholland & Fullen, 1991; Haynes, 1995). The recovery rate of microporosity suggests that increased susceptibility to pugging damage may be as long as 13 weeks after a one-off severe treading. If pugging damage occurs in early to mid winter, the soil will be more susceptible to further pugging damage than unpugged areas for the remainder of the wet season.

Macroporosity at the 5-10 cm soil depth had a slower rate of recovery in the first four weeks compared with the 0-5 cm soil depth. The possible processes that drive the faster rate of recovery in the first four weeks at the shallower soil depth may not be present to the same extent at the 5-10 cm soil depth. For example, wetting/drying and plant root activity are weaker at the 5-10 cm soil depth than at the soil surface. The slow initial recovery at the 5-10 cm soil depth suggests that at this soil depth was more susceptible to cumulative damage, as has been suggested by Singleton and Addison (1999).

The changes in soil physical properties, observed in this series of experiments with the onset of summer may indicate seasonal change. However, results from some investigations indicate that the opposite seasonal changes to those observed in this thesis were also possible (e.g. Rodd *et al.*, 1999; Drewry *et al.*, 2003). Similarly, seasonal changes in macroporosity of control plots were not consistent between experiments (i.e. soil macroporosity in the 81% GSM experiment decreased but in the 65% GSM experiment increased with the onset of summer). This suggests that seasonal changes in soil physical properties such as soil dry bulk density and macroporosity are variable and poorly understood. As seasonal changes may influence recovery of soil (or perceived recovery), and as there appears to be a general lack of published results on seasonal changes in soil physical properties, further study is recommended. Seasonal changes in soil physical properties highlight the importance of having simultaneous control plots as comparisons to be able to distinguish recovery processes from normal seasonal change. The possibility of seasonal changes in soil properties should be considered when designing monitoring programmes.

6.3 Unsaturated and Saturated Hydraulic Conductivity

6.3.1 Introduction

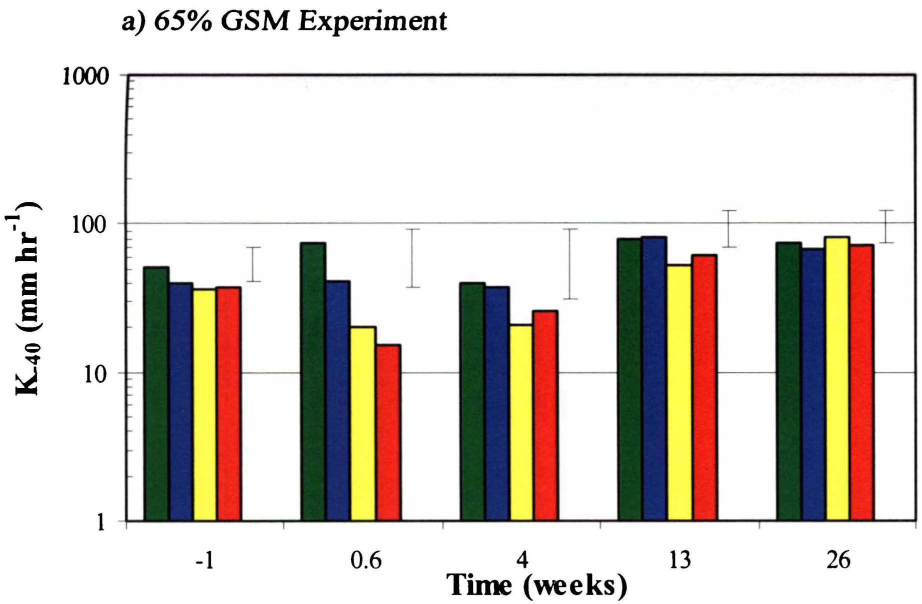
Investigations into recovery of unsaturated hydraulic conductivity (K_{-40}) and saturated hydraulic conductivity (K_{sat}), after grazing exclusion on soils trodden for many years, have been reported (e.g. Warren *et al.*, 1986c; Warren *et al.*, 1986d; Greenwood *et al.*, 1998; Drewry & Paton, 2000a). However, investigations of recovery of K_{-40} and K_{sat} after a one-off severe treading event have not often been reported. Seasonal changes in hydraulic conductivity for pastoral soils have also been noted in the literature (e.g. Watt & Crouchley, 1985), however, the causes have seldom been investigated. Studies similar to the research presented in this thesis are, thus, limited to a few investigations (e.g. Drewry *et al.*, 2003).

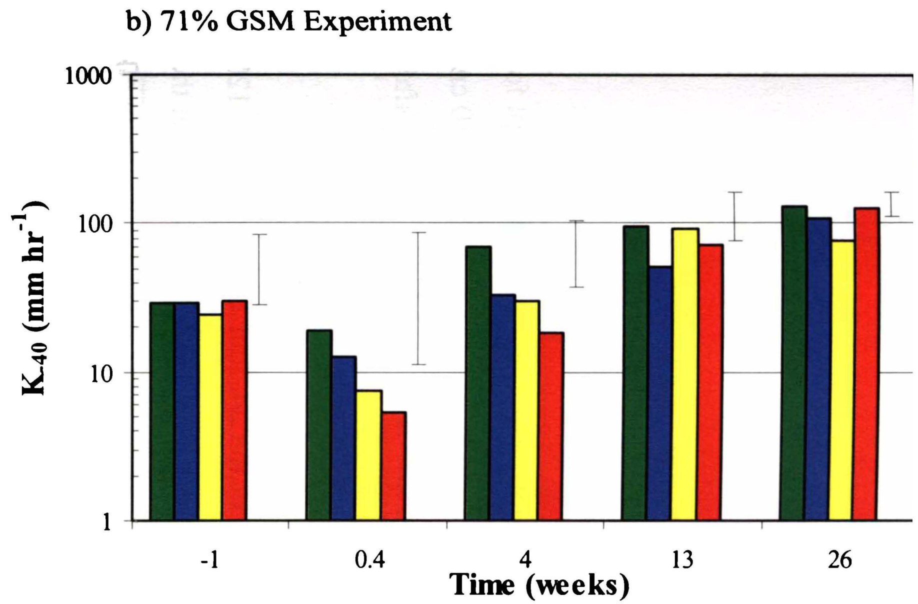
In this thesis, the recovery in K_{-40} and K_{sat} is represented by changes after treading treatment that were monitored at the same sampling times as those used for soil porosity (Table 6.1). The full data, including the 5-10 cm soil depth, and summary tables are presented in Appendices VI and VII.

6.3.2 Unsaturated Hydraulic Conductivity

The K_{-40} at the 0-5 cm soil depth in the 65% and 81% GSM experiments recovered at a mean rate of 7 mm hr^{-1} $week^{-1}$ over the four weeks after the treading treatment (Figure 6.5). The difference between the controls and the 71% GSM 24-hour treatment was not significant immediately after the treading, but with less variable data became significant four weeks after treading, becoming not significant again 13 weeks after treading.

At the 0-5 cm soil depth, in all experiments, K_{-40} in the control plots had a mean increase (P <0.05) of 2.67 mm hr^{-1} $week^{-1}$ with the onset of summer.





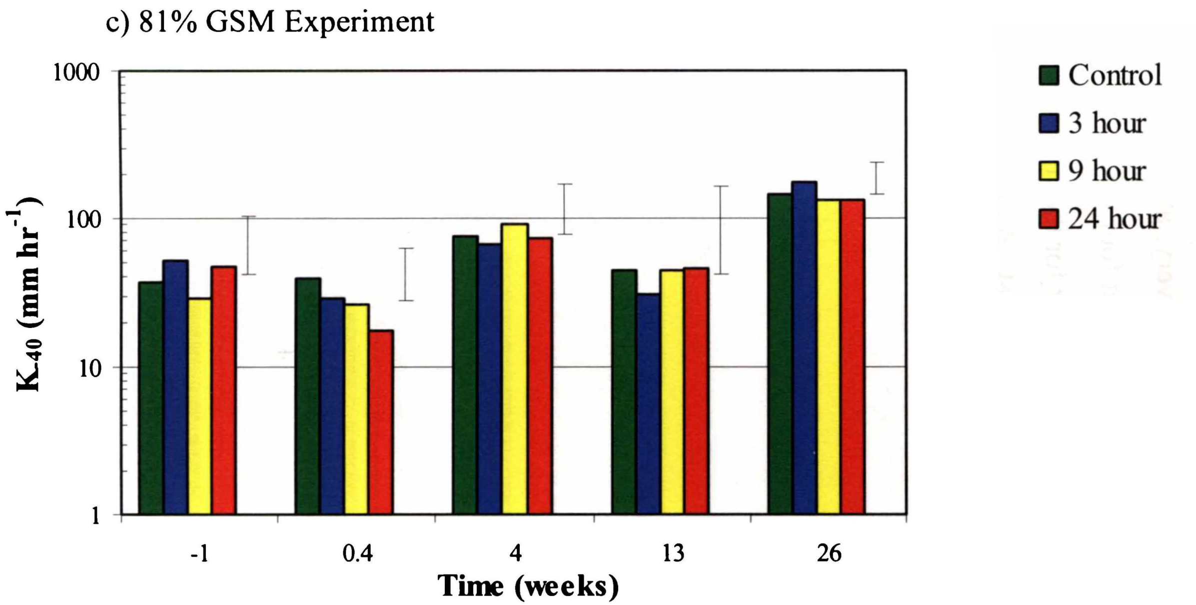


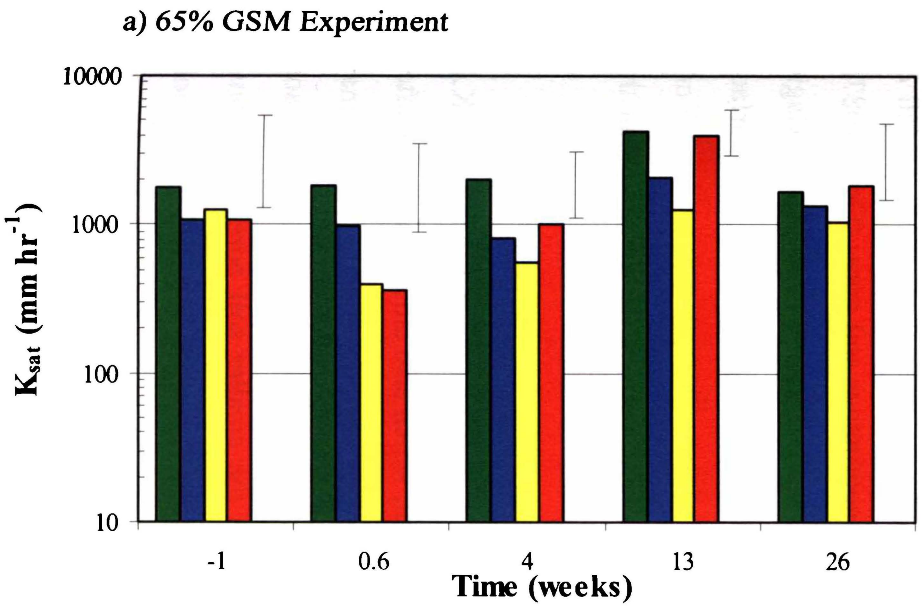
Figure 6.5

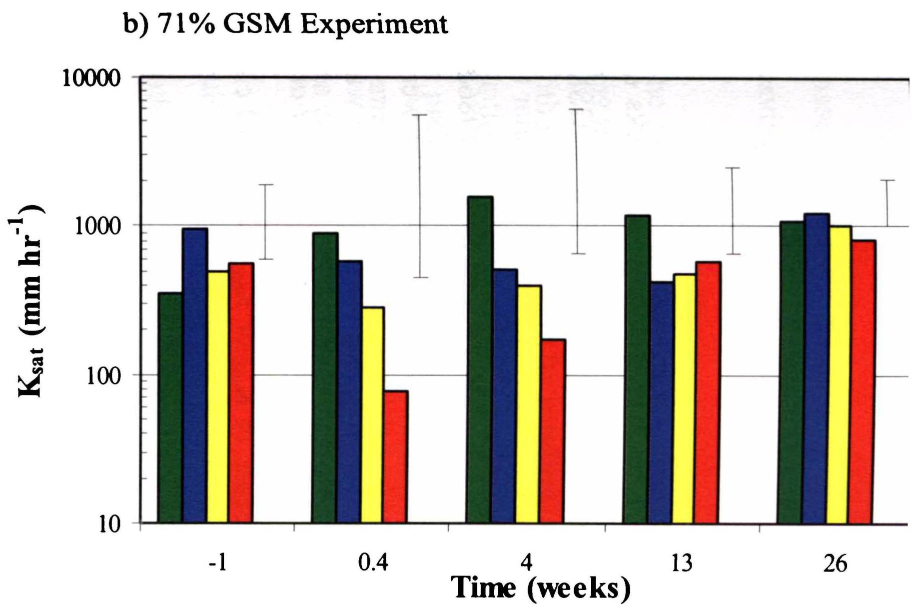
Unsaturated hydraulic conductivity (K_{40}) in mm hr^{-1} at the 0-5 cm soil depth before treading and up o 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each column is the mean of the treatment, error bars are the $LSD_{5\%}$.

6.3.3 Saturated Hydraulic Conductivity

The K_{sat} had recovered in all treatments within four weeks of treading (Figure 6.6), except for K_{sat} in the 65% GSM 9-hour treatment that took 26 weeks to recover. The K_{sat} at the 5-10 cm soil depth in the 71% and 81% GSM 24-hour treatments had recovered by 13 weeks after treading.

The mean rate of K_{sat} recovery, at the 0-5 cm soil depth, in the 24-hour treatments was 120 mm hr^{-1} $week^{-1}$ over the first four weeks. The rate of recovery for the 9-hour treatments at the 0-5 cm soil depth was faster for the first four weeks (about 200 mm hr^{-1} $week^{-1}$) slowing to 40 mm hr^{-1} $week^{-1}$ between weeks four and 13.





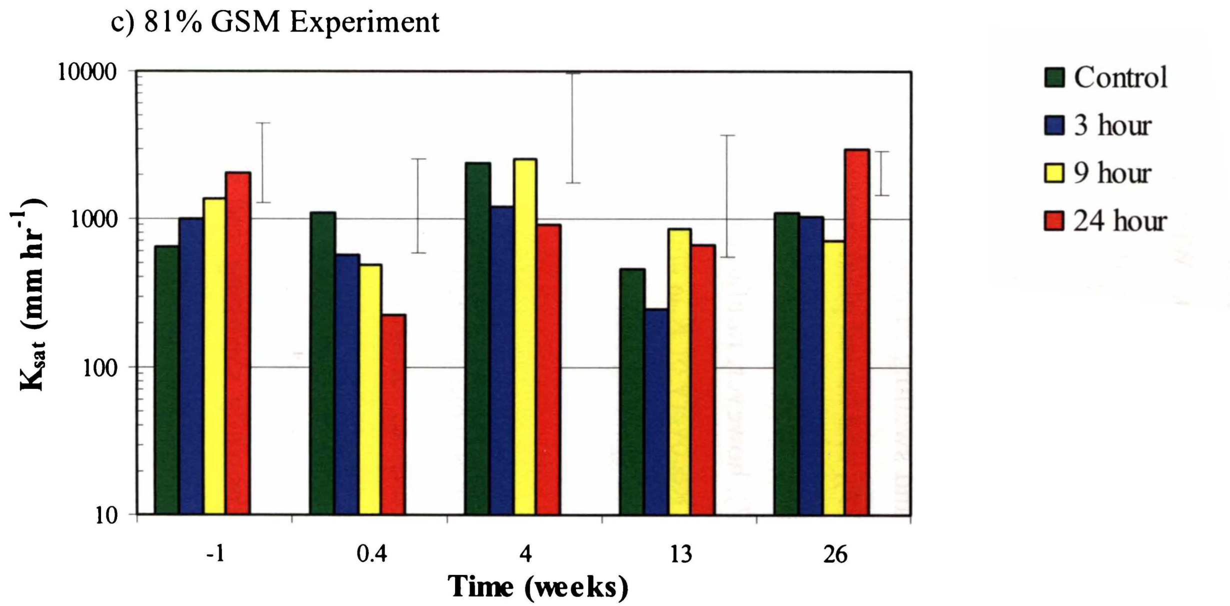


Figure 6.6

Saturated hydraulic conductivity (K_{sat}) in mm hr^{-1} at the 0-5 cm soil depth before treading and up to 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each column is the mean of the treatment, error bars are the $LSD_{5\%}$.

6.3.4 Discussion

The K_{-40} and K_{sat} of the surface 0-5 cm of soil, generally, recovered within four weeks of treading treatment. However, the 9- and 24-hour treatments in the 71% and 81% GSM experiments took up to 13 weeks to recover. The K_{-40} and K_{sat} recovery rates were similar to those reported for soils excluded from grazing after treading damage (Warren *et al.*, 1986d; Drewry *et al.*, 2003), while Greenwood *et al.* (1998) reported that at least six months were required before full recovery in K_{sat} occurred. Other studies suggested a longer time was required for recovery in hydraulic conductivity following severe treading damage (Nie *et al.*, 2001a; Elliott *et al.*, 2002). When treading caused a decrease in K_{-40} or K_{sat} at the 5-10 cm soil depth, up to 13 weeks were required for recovery.

Recovery in K_{-40} and K_{sat} may be driven by similar processes as those for recovery of soil porosities, and include earthworm activity (Watt & Crouchley, 1985; Drewry *et al.*, 2003), shrinking and swelling of clays, plant rooting activity (Aubertin & Kardos, 1965; Tisdall & Oades, 1979), and buried plant material decaying to form continuous soil pores (Goss, 1987). Soil smearing at the surface by cattle hooves results in slower infiltration rates (Abdel-Magid *et al.*, 1987), however, rainfall events and plant activity may assist recovery from soil surface smearing. Recovery of K_{-40} and K_{sat} was slower at the 5-10 cm soil depth than at the 0-5 cm soil depth, suggesting that the former was more susceptible to cumulative damage than the latter.

Seasonal trends were apparent in the K_{-40}, but not the K_{sat} data. The seasonal increase in K_{-40} may be because of formation of small continuous soil pores, which also aid soil recovery after treading damage. The lack of seasonal change in K_{sat}, despite seasonal changes in K_{-40}, may indicate that the large soil pores (>0.75 mm diameter) are influenced by different soil processes (possibly shrinking and swelling of soil) than the smaller soil pores. Seasonal increases in hydraulic conductivity with the onset of summer, and its implications for soil management (e.g. land-based effluent disposal), have been reported before (e.g. Balks, 2000). Watt and Crouchley (1985), when investigating the use of an *in situ* method for determining infiltration rates, found seasonal changes in K_{-40} and K_{sat}. They commented that these changes were at times opposite to each other. Watt and Crouchley (1985) postulated that phases of earthworm activity and soil shrinking and swelling could increase K_{sat} whilst leaving K_{-40} comparatively unchanged.

The rates of recovery of K_{-40} and K_{sat} after a one-off severe treading event indicate that soil was more susceptible to further pugging damage for up to 13 weeks after treading compared with soil not damaged by treading. Grazing before K_{-40} and K_{sat} have fully recovered requires caution, as Haynes (1995) points out that treading damage will become cumulative if recovery is prevented from taking place. Thus, there is merit in avoiding further treading after soil damage has occurred, by using block grazing instead of strip grazing to maximise recovery in the early stages after treading damage occurs.

Full recovery in K_{sat} and K_{-40} after a one-off severe treading event was difficult to gauge as both K_{sat} and K_{-40} were spatially variable, limiting its use for determination of soil quality (Schipper & Sparling, 2000). Because of large inherent variability, K_{sat} and K_{-40} are not good indicators of soil recovery, despite the importance of hydraulic conductivity for soil susceptibility to pugging damage.

6.4 Soil Surface Properties

6.4.1 Introduction

Soil surface roughness is a visual indicator of damage inflicted on soil by cattle treading. The impact of cattle treading on soil surface roughness has been reported by Betteridge *et al.* (1999), Nie *et al.*(2001a; 2001b), and Drewry *et al.* (2003), however, none of these studies report on recovery of soil surface roughness after treading damage. Reporting on the recovery of soil surface after treading damage is limited to a study by Pande (2002) on a hill-soil.

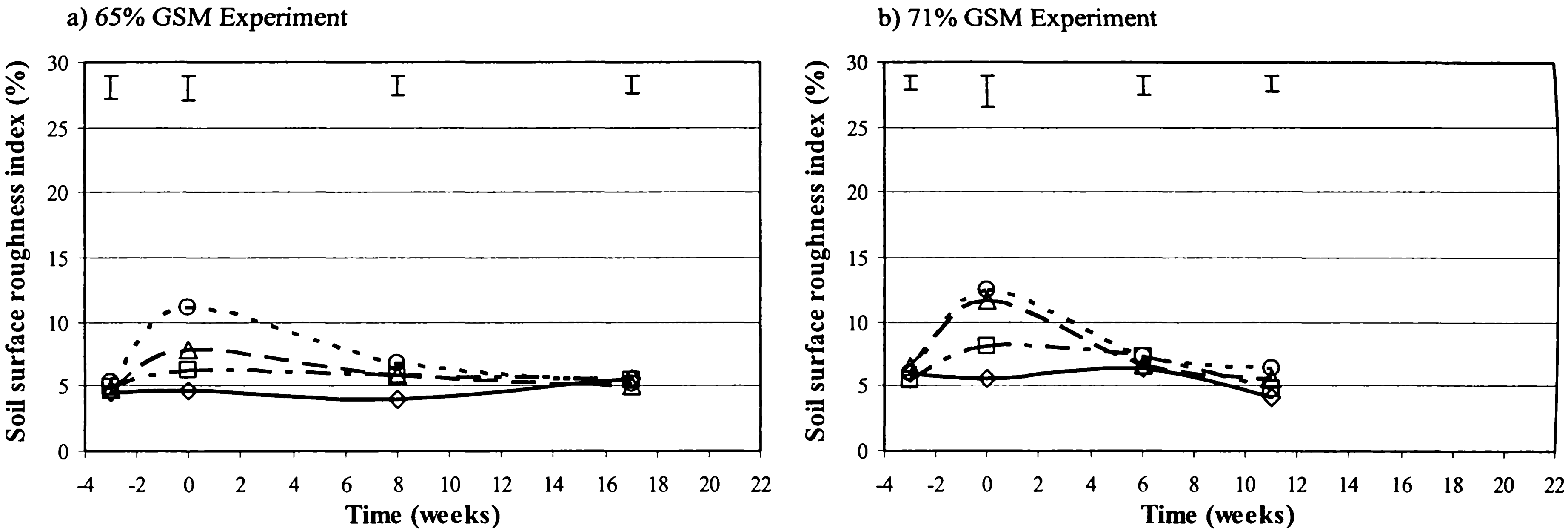
Soil surface roughness in this thesis was analysed periodically (Table 6.2) to determine if recovery took place following treading treatment. The full data and summary tables are presented in Appendix IX.

Table 6.2 Dates for soil surface roughness index determinations.

	Date of analysis							
	Before	Treading	After					
65% GSM	5/6/99	26/6/99	24/8/99	1/11/99				
71% GSM	2/8/00	30/8/00	10/10/00	5/11/01				
81% GSM	15/7/01	7/8/01	10/9/01	19/9/01	15/10/01	6/11/01	5/12/01	18/12/01

6.4.2 Soil Surface Roughness Index

Recovery of soil surface roughness in all treatments occurred within 17 weeks in the 65% GSM, six weeks in the 71% GSM, and 20 weeks in the 81% GSM experiment (Figure 6.7).



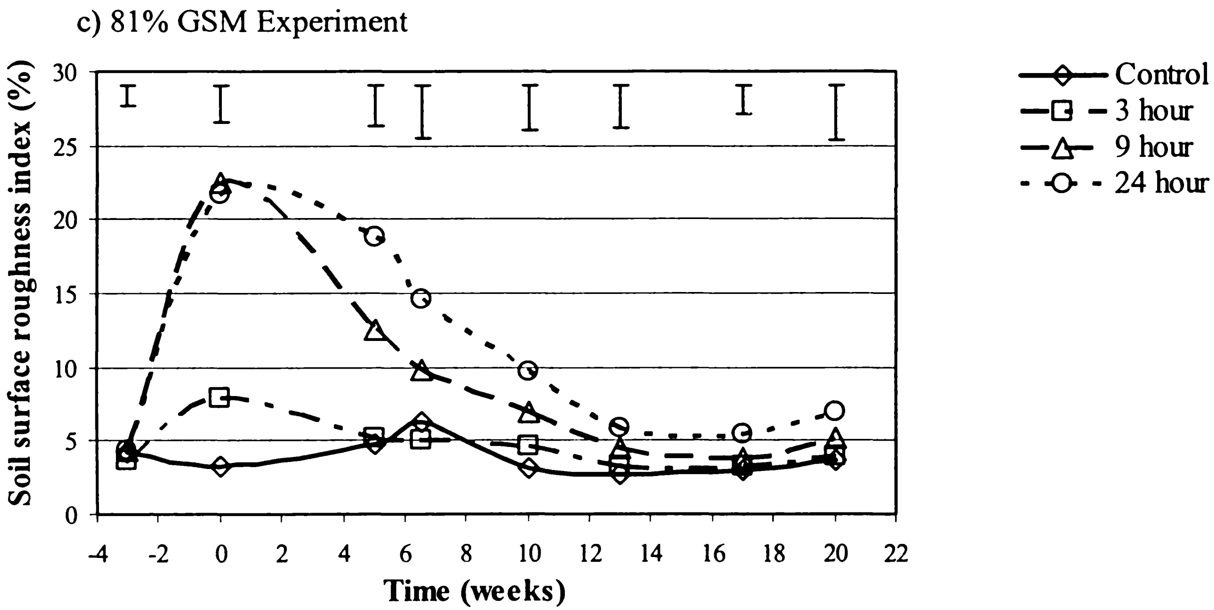


Figure 6.7

Soil surface roughness index (%) before treading and up to 20 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each point is the treatment mean, error bars are the $LSD_{5\%}$.

During the 71% GSM experiment, 20 mm of rainfall occurred the day after treading treatment (followed by several days of drizzle), resulting in water ponding on the soil surface and slurry formation (Section 4.5.4). The soil slurry caused the mounds created by the pugging to collapse, thus differences (P <0.05) in soil surface roughness had dissipated before the first grazing event six weeks after treading treatment. During the 81% GSM experiment, dry weather (Appendix II) was more conducive to retaining soil surface roughness, therefore, soil surface roughness in this experiment took the longest of all experiments to recover (up to 20 weeks after treading for the 24-hour treatment).

6.4.3 Discussion

Pande (2002) reported that soil surface roughness for a hill-soil had mostly recovered by five weeks after treading, considerably faster than the maximum recovery time of 20 weeks found in the 81% GSM experiment. The different rate of soil surface recovery after treading damage reported by Pande (2002) may be because of soil type differences and, possibly, that rainfall occurred after treading in Pande's experiment. Recovery of soil surface roughness may be driven by several factors, including climate and the effect of a rotational grazing by cattle. Rainfall after severe treading damage can result in rapid 'recovery' of the soil surface, as observed in the 71% GSM experiment, where the ponding of water resulted in the pug prints loosing their shape. Drying out of soil may preserve the soil surface shape, however, soil cracking and flaking, caused by periodic drying and then wetting, results in infilling of individual pug prints. The predominate factor in recovery of soil surface roughness was presumed to have been subsequent treading, where the tops of remoulded soil are either crushed under the weight of cattle or knocked-off and pushed into the pug prints. Recovery of soil surface roughness did not correspond with the recovery of other soil properties or of the sward.

6.5 Sward Properties

6.5.1 Introduction

The proportion of bare ground, botanical composition, tiller density, and the amount of herbage accumulated were used as indicators of sward recovery. The scientific literature has considerable information on sward establishment, growth, and morphological change in response to grazing management (e.g. Campbell, 1966; Parsons *et al.*, 1983; Sheath & Boom, 1985a; Thom, 1991; Proffitt *et al.*, 1993; Murphy *et al.*, 1995; Lawson *et al.*, 1997; Thom *et al.*, 1998b; Bahmani *et al.*, 2003). There have been less studies reporting on sward response to a one-off severe treading event (e.g. Edmond, 1962; Edmond, 1966; Pande *et al.*, 2000; Nie *et al.*, 2001a; Elliott *et al.*, 2002; Pande *et al.*, 2002; Drewry *et al.*, 2003). Greenwood and McKenzie (2001) commented that there is little in the way of systematic studies to determine pasture productivity response to cattle treading damage.

Elliott *et al.* (2002) reported on bare ground recovery after a one-off severe treading event, however, in contrast to the experiments in this thesis the Elliott study was carried out using beef cattle grazing on hill-soils. Marriott *et al.* (1997) investigated the recovery of artificially created bare ground patches in swards, however, the study did not allow for the associated soil damage that occurs when bare ground was created by pugging, which may have an important influence on the rate of sward recovery.

The creation of bare ground after severe treading may encourage weed colonisation (Harker *et al.*, 2000), but botanical changes reported in the literature for grazed swards are typically long term shifts to more treading tolerant species (Harris & Brougham, 1968; Kemp *et al.*, 1999). Similar studies by Edmond (1962; 1966) and Nie *et al.* (2001a) have suggested that botanical change in response to a one-off treading event may not be important.

Pande *et al.* (2000; 2002) and Drewry *et al.* (2003) monitored changes in the rate of herbage accumulation after a one-off severe treading event, however, the Drewry study had only one intensity of treading damage while the Pande study was carried out on a hill-soil. A study by Nie *et al.* (2001a) gives some relevant comparisons to the study in this thesis, however, different climatic and soil conditions in Victoria, Australia, may mean the findings by Nie are not directly relevant to a Te Kowhai soil in the Waikato region of New Zealand.

In this thesis, the monitoring of sward recovery or change in the proportion of bare ground, botanical composition, tiller density, and herbage accumulation was carried out for up to 34 weeks after treading treatment (Table 6.3). The full data and summary tables are presented in Appendices X to XIII.

Table 6.3 Dates of sward analysis of bare ground, botanical composition, tiller density, and herbage accumulation.

Date of analysis

Bare ground

	Before	At treading	After					
65% GSM	5/6/99	26/6/99	24/8/99	1/10/99	28/11/99	24/12/99	13/1/00	31/3/00
71% GSM	2/8/00	30/8/00	10/10/00	5/11/00	26/11/00	22/12/00	21/1/01	29/2/01
81% GSM	15/7/01	7/8/01	19/9/01	15/10/01	6/11/01	30/11/01	18/12/01	19/1/02

Sward botanical composition

	Before	After		
65% GSM	23/6/99	21/8/99	26/11/99	
71% GSM	25/8/00	26/10/00	20/1/01	23/4/01
81% GSM	4/8/01	5/10/01	16/12/01	

Tiller density

	Before	After		
65% GSM	23/6/99	6/8/99	18/11/99	9/1/00
71% GSM	25/8/00	5/10/00	13/1/01	25/3/01
81% GSM	4/8/01	16/9/01	16/12/01	

Herbage accumulation [a]

	Before	After treading							
65% GSM	23/6/99	22/8/99	29/9/99	30/10/99	27/11/99	23/12/99	10/1/00	2/2/00	
71% GSM	29/8/01	12/9/00	5/10/00	1/11/00	23/11/00	9/1/01	19/1/01	29/2/01	11/4/01
81% GSM	6/8/01	13/8/01	28/8/01	17/9/01	15/10/01	5/11/01	29/11/01	17/12/01	8/1/02
						81% GMS (cont.)		17/1/02	22/2/02

[a] *note*: herbage accumulation was determined for the growth period from the previous date to the given date. The 'before' treading herbage accumulation date represents at least two weeks of growth.

6.5.2 Proportion of Bare Ground

Sward recovery (decrease in bare ground) started within six weeks after treading treatment (Figure 6.8) in all experiments. The 24-hour treatments took the longest time to recover, taking between 19 and 25 weeks for bare ground frequency to become similar to that of the controls. The bare ground surface area decreased by a mean rate of 1.3% week^{-1} in each treatment for all experiments. With the onset of summer (about 15 weeks after treading), the amount of bare ground in control plots did not significantly change.

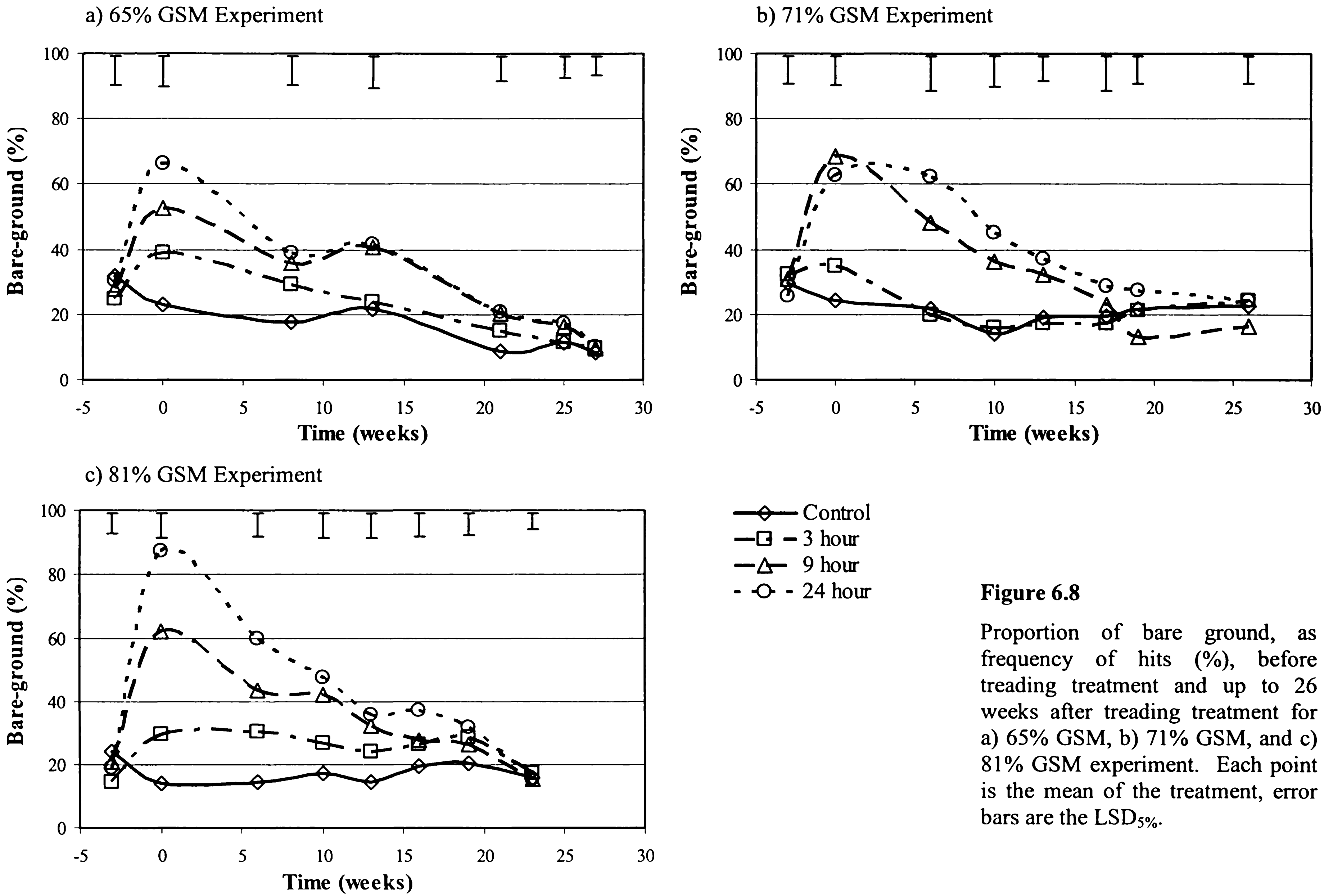


Figure 6.8

Proportion of bare ground, as frequency of hits (%), before treading treatment and up to 26 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Each point is the mean of the treatment, error bars are the $LSD_{5\%}$.

6.5.3 Sward Botanical Composition

During summer (18 – 21 weeks after treading), sward botanical composition remained unchanged in the 65% and 81% GSM experiments, however, by 34 weeks from treading treatment the proportion of weeds exceeded (P <0.05) the controls in the 71% GSM 9- and 24-hour treatments (Figure 6.9). The increased weed content in the 71% GSM treatment plots compared to controls was largely broad-leaved plantain (*Plantago major* L.) invading open spaces caused by the treading (Figure 4.7g).

Increasing broad-leaved plantain content was noticed in the 21 week analysis, however, as creeping buttercup (*Ranunculus repens* L.) content had declined by then there was no significant increase in overall weed content until 34 weeks after treading treatment. The proportion of weeds increased to about 46% of dry matter in the 71% GSM 9- and 24-hour treatments, as the proportion of ryegrass in these treatment plots declined to less (P <0.05) than controls. After the 34 week botanical composition analyses the 71% GSM experimental site was sprayed with a mixture of MCPB (4-[2-Methyl-4-chlorophenoxy] butyric acid) and 24DB (4-[2,4-dichlorophenoxy] butyric acid) at 300 ml ha^{-1} for each.

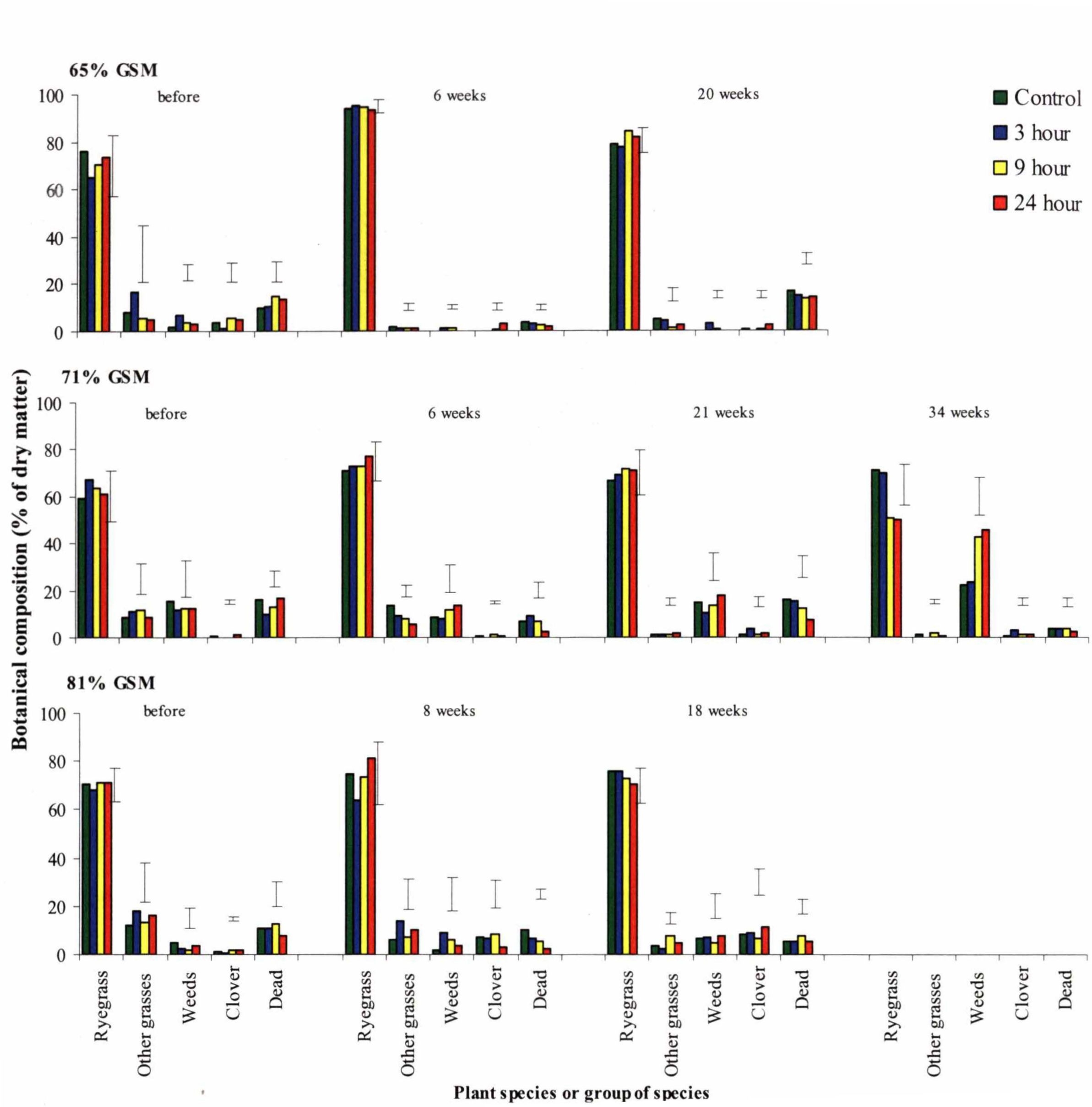


Figure 6.9 Botanical composition (% of dry matter) for the 65%, 71%, and 81% GSM experiments before and at given times after treading treatment.

6.5.4 Ryegrass Tiller Density

Where decreases in ryegrass tiller density had occurred after treading treatment, tiller density took up to 21 weeks to recover to the same density as that of controls (Figure 6.10). In the 71% GSM experiment, tiller density was determined in March, 34 weeks after treading, and showed a decline over the summer, which is typical for ryegrass species in New Zealand (Korte, 1986; Thom *et al.*, 2003).

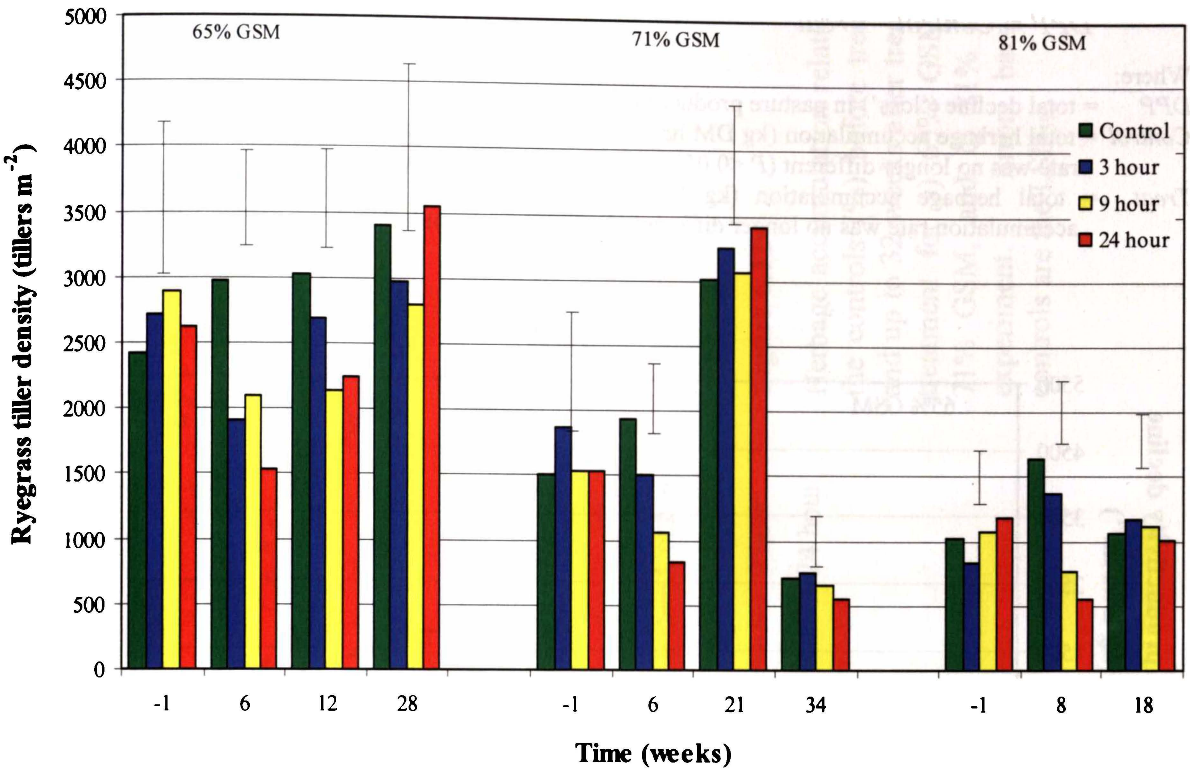


Figure 6.10 Ryegrass tiller density (tillers m^{-2}) before treading and up to 34 weeks after treading treatment for each experiment. Each column is the treatment mean, error bars are the $LSD_{5\%}$.

6.5.5 Herbage Accumulation

After an initial decline, herbage accumulation gradually recovered (i.e. the rate of herbage accumulation became no longer significantly different to that of controls). There were no significant differences in the rate of herbage accumulation between trodden plots and controls by 14, 19, and, 22 weeks after treading treatment for the 65%, 71%, and 81% GSM experiments, respectively. The 'total decline' in pasture productivity is defined as the cumulative differences in herbage accumulation (kg DM ha^{-1}) in controls compared with treatments plots from the time of treading treatment until the time when there was no differences (P <0.005) in herbage accumulation rate between control and treatment plots (Figure 6.11). The total decline in pasture productivity can be expressed as:

$$DPP = Control - Treat \tag{6.1}$$

Where:
DPP = total decline ('loss') in pasture productivity (kg DM ha^{-1})
Control = total herbage accumulation (kg DM ha^{-1}) in control plots before treatment plots herbage accumulation rate was no longer different (P <0.05) from control herbage accumulation rate
Treat = total herbage accumulation (kg DM ha^{-1}) in treatment plots before treatment plots herbage accumulation rate was no longer different (P <0.05) from control herbage accumulation rate

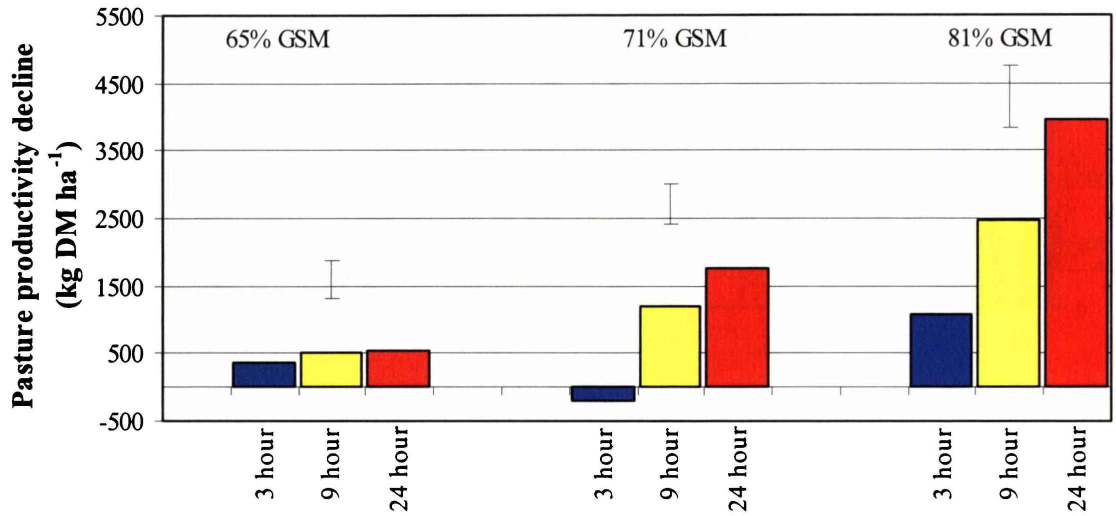
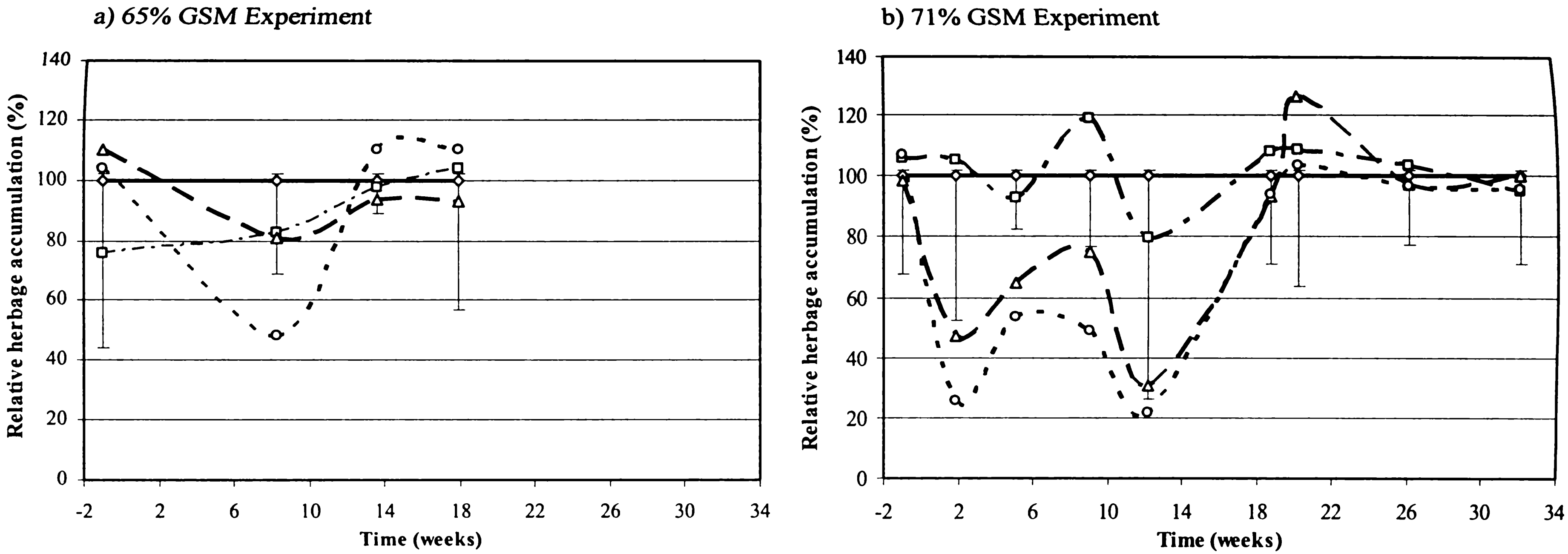


Figure 6.11 Total decline (kg DM ha^{-1}) in pasture productivity in treatment plots compared with control plots until herbage accumulation had recovered (14, 19, and 22 weeks for the 65%, 71%, and 81% GSM experiments, respectively). Error bars are the $LSD_{5\%}$. The 71% GSM 3-hour treatment had no pasture productivity decline.

Recovery in herbage accumulation was assessed in two ways: the relative herbage accumulation at each time of measurement compared with controls (Figure 6.12) and cumulative differences compared with controls (Figure 6.13). If recovery had occurred, relative herbage accumulation of treatment and control plots become similar (Figure 6.12) and cumulative differences between treatment and control plots no longer increase (Figure 6.13).

The 81% GSM 3-hour treatment was the only 3-hour treatment of all experiments to have a significant decline in pasture productivity compared with controls. Herbage accumulation in treatment plots relative to controls was not consistent over time, and appeared to have phases of recovery and decline before full recovery occurred. The occurrences of greater than 100% relative herbage accumulation (Figure 6.12) compared with controls (e.g. the 119% at week 9 in the 71% GSM 3-hour treatment) were due to variation within the data and these differences were not significant (P <0.05) from controls.



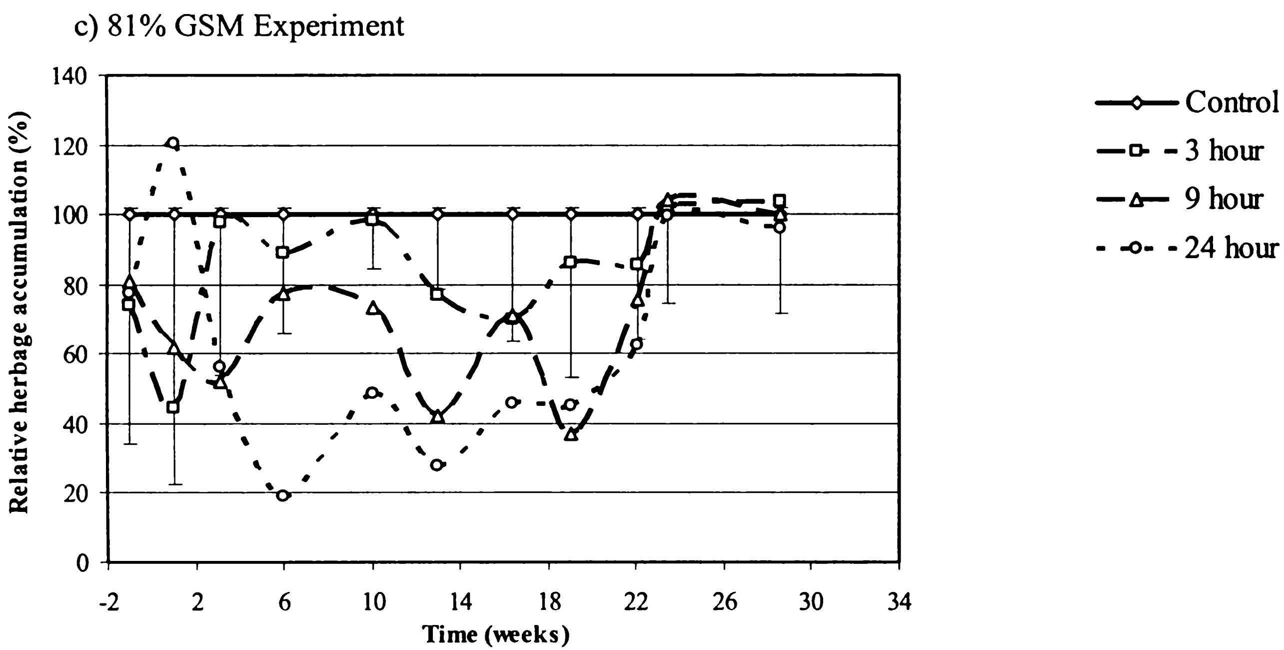
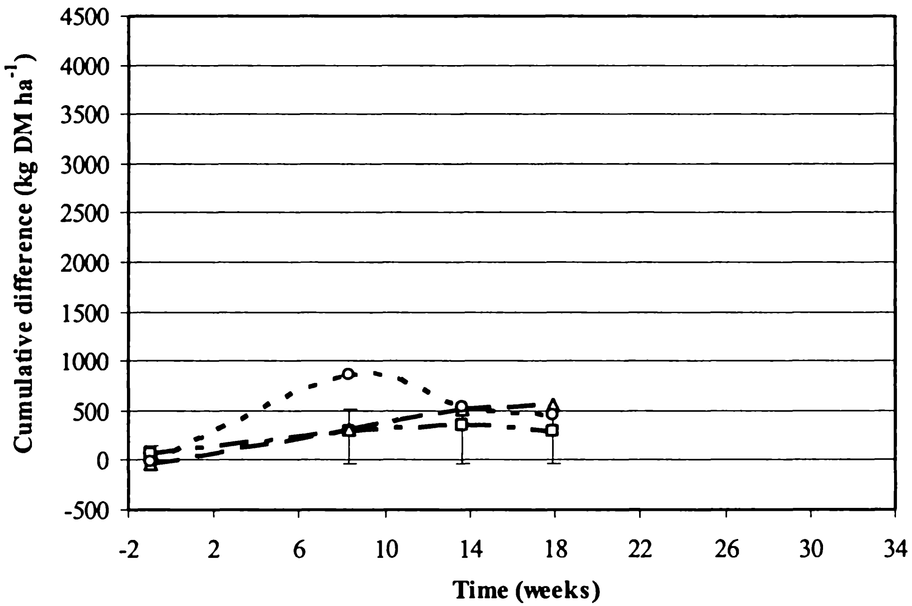


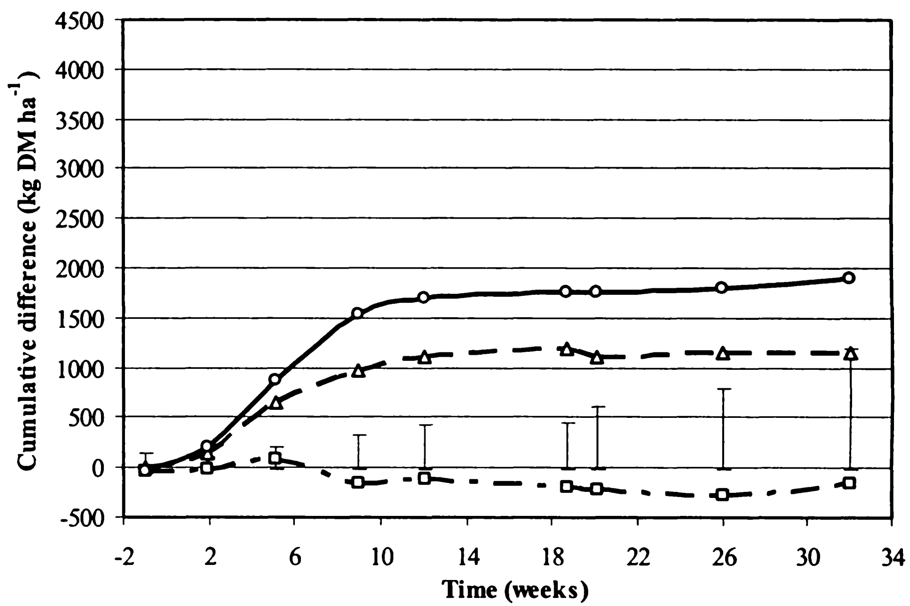
Figure 6.12

Herbage accumulation relative to the controls (%) before treading and up to 32 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Error bars on controls are the $LSD_{5\%}$.

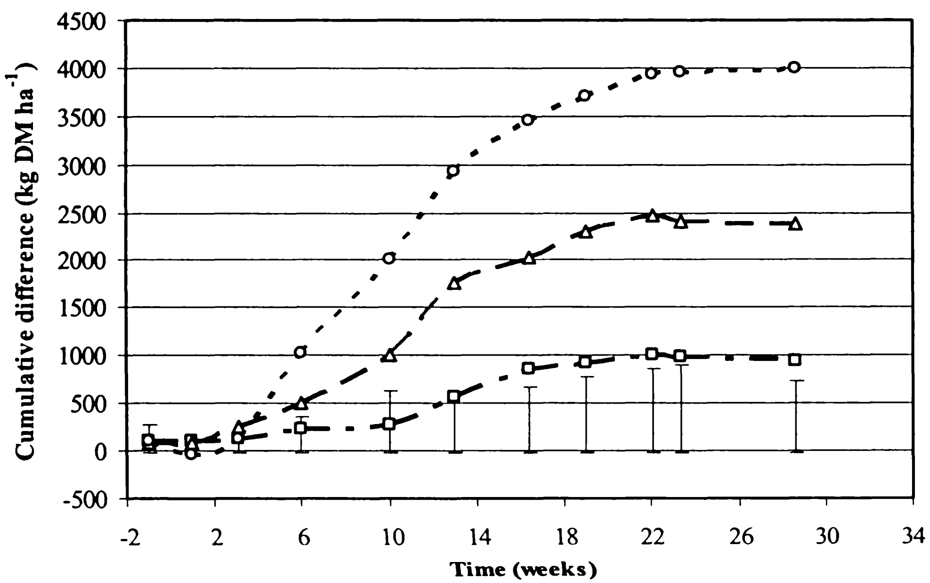
a) 65% GSM Experiment



b) 71% GSM Experiment



c) 81% GSM Experiment



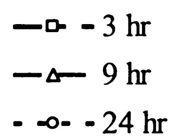


Figure 6.13

Cumulative differences (amount of 'loss') in herbage accumulated relative to the controls (kg DM ha^{-1}) before treading and up to 32 weeks after treading treatment for a) 65% GSM, b) 71% GSM, and c) 81% GSM experiment. Error bars on the zero line is the $LSD_{5\%}$.

6.5.6 Discussion

Monitoring of bare ground, ryegrass tiller density, and herbage accumulation indicated sward recovery from a one-off severe treading damage event could occur if pasture continued to be rotationally grazed.

The proportion of bare ground decreased (due to sward recovery) at a similar rate (1.31% week^{-1}) in all experiments, despite the different levels of damage inflicted. However, the rate of decrease in bare ground were about tenfold slower than the recovery coefficients of 9.17% week^{-1} found by Elliot *et al.* (2002). The amount of bare ground in severely damaged (81% GSM 24-hour) areas took up to 25 weeks (from July/August to November/January) after treading treatment to become similar to controls, therefore, large areas of bare ground were present during spring. Appearance of previously buried tillers from surviving plants would have begun the recovery process (Pande *et al.*, 2002) followed by vegetative spread by surviving plants and seed germination (Marriott *et al.*, 1997). The infilling of bare ground by herbage was found to take longer than the artificially created bare ground patches reported by Marriott *et al.* (1997). The slower rate of infilling of bare ground created by cattle treading, compared with artificially created bare ground patches, indicated that the associated soil damage slows the rate of sward recovery. Seedling recruitment in large patches of bare ground was more probable than for smaller patches (Marriott *et al.*, 1997), however, the unfavourable soil conditions caused by treading may have been detrimental to seedling survival and subsequent establishment (Sheath & Boom, 1985c; Hume & Chapman, 1993).

The large open spaces created by treading increased the possibility of colonisation by weeds and less productive grass species (Burke & Grime, 1996). Sward composition did not change in the 65% and 81% GSM experiment, showing the resilience of ryegrass to treading (Kemp *et al.*, 1999). Other research on the effects of a one-off treading event has also shown that there may not be a botanical shift if the sward consists of established ryegrass and white clover plants (Edmond, 1966; Nie *et al.*, 2001a). Others have noted some decline in white clover content following sward damage by cattle treading (Curll & Wilkins, 1981; Menneer *et al.*, 2001).

The increase in weed content in the 71% GSM experiment 34 weeks after treading was probably derived from seed germination, as the amount of broad-leaved plantain before treading was low (1.4% of sward DM). The extent of the broad-leaved plantain invasion, and the lack of seeding of broad-leaved plantain observed near the experimental site, suggests that a large seedbank was present in the soil before the experiment. The 81% GSM experiment was located next to the 71% GSM experiment but there was no increase in the content of broad-leaved plantain in the 81% GSM experiment. The 71% GSM experiment tended to have fewer but larger open spaces (possibly due to the slurry formation during post-treatment rainfall) than the 81% GSM experiment. Gap colonisation by edge plants may not be as effective for large patches of bare ground, such as at the 71% GSM experiment, compared with smaller patches (Arnthórsdóttir, 1994; Bullock *et al.*, 1994). Additionally, because the treading in the 71% GSM experiment was carried out three weeks later than for the 81% GSM experiment, the proportion of bare ground in spring for the 71% GSM 9- and 24-hour treatments was higher than in the 81% GSM experiment. The greater proportion of bare ground in spring allowed for the possibility of seed germination and weed establishment in the 71% GSM 9- and 24-hour treatments before ryegrass was able to spread vegetatively into the gaps. Therefore, the timing of severe treading damage is an important factor influencing botanical compositional change.

The density of ryegrass tillers was lower in the 9- and 24-hour treatments compared with the controls in all experiments, generally recovering to the control plot level within 28 weeks of a one-off severe treading. Thus, pasture vigour (Mitchell & Glenday, 1958) was reduced for up to 28 weeks after treading, extending well into the spring growth period.

Recovery of the rate of herbage accumulation began between six and 12 weeks after treading damage, and took up to 22 weeks for full recovery to occur. The total cumulative differences in herbage accumulation before recovery was complete was as much as 3,940 kg DM ha^{-1}. These differences were considerably greater than the cumulative differences of 746 and 840 kg DM ha^{-1} reported by Drewry *et al.* (2003) and Pande *et al.* (2002). The cumulative losses in herbage accumulation caused by the treading damage represents farm production loss (assuming milksolids price of $5.33 kg, 2001/2002 season, and that 15 kg DM is needed to produce 1 kg milksolids, Penno, 1999) and if treading damage was similar to that at the 81% GSM 24-hour treatment, of $21,000 per hectare due to damaged pasture.

The 3-hour treatments represented a conservative grazing (used in conjunction with stand-off pads) and is recommended for soil susceptible to pugging damage (Betteridge *et al.*, 2003; Drewry *et al.*, 2003). Only the 81% GSM 3-hour treatment produced significantly less (about 1,100 kg DM ha^{-1}) than did controls. The decrease in herbage accumulation in the 81% GSM 3-hour treatment indicates that when gravimetric soil moisture content was high (>71%), treading results in some pasture productivity declines. However, at lower gravimetric soil moisture contents (≤71%) conservative three hour grazing at a stocking density of 300 cows ha^{-1} on a Te Kowhai soil, may not result in a decrease in pasture productivity.

The decrease in herbage accumulation after treading damage may result from tissue crushing and burial of herbage (O'Connor, 1956; Edmond, 1970; Brown & Evans, 1973), and was probably the main cause of the decrease in herbage accumulation in the first eight weeks after treading damage. Soil physical damage will also decrease herbage accumulation but may not be apparent until spring growth occurs, when rapid herbage growth becomes limited by soil physical properties such as aeration and root penetration (Drewry & Paton, 2000a; Drewry *et al.*, 2004a). In the 71% GSM 9- and 24-hour treatments, herbage accumulation continued to decline for 12 weeks after treading before recovery began, where the decline may have been caused by poor soil conditions (e.g. decreased soil aeration due to slow soil water movement and low macroporosity) after treading damage.

6.6 Summary and Conclusion

The results presented in this chapter indicate that macroporosity, microporosity, K_{-40}, K_{sat}, soil surface roughness, proportion of bare ground, tiller density, and herbage accumulation will eventually recover after a one-off severe treading event when the site is retained in a grazing rotation without further pugging damage. The time required for recovery varied depending on the severity of damage to the sward and soil, but was generally complete in all treatment plots by 26 weeks after treading damage occurred. The 65% GSM experiment was carried out in early winter (25th of June), therefore, had recovery for the longest period over the winter compared to the 71% and 81% GSM experiment (which were on 29th and 6th of August, respectively). However, the 65% GSM experiment recovered the fastest (mostly within one month after treading damage) of all the field experiments.

When treading damage occurred at the 5-10 cm soil depth, the time required for recovery was similar to the 0-5 cm soil depth, regardless of the severity of damage. At severely pugged sites (e.g. 81% GSM 24-hour), recovery of macroporosity in the first four weeks after treading was faster than over the next nine weeks. If multiple treading damage events occur at the same site, recovery may take longer than the 26 weeks found in this thesis (Orr, 1975; Greenwood *et al.*, 1998; Singleton & Addison, 1999; Singleton *et al.*, 2000; Elliott *et al.*, 2002). It has been postulated that recovery of macroporosity and microporosity was driven by re-aggregation of soil particles, earthworm activity, and decomposition of buried herbage (Goss, 1987; Dexter, 1991; Taboada & Lavado, 1993; Lavado & Alconada, 1994). The processes that drive soil porosity recovery may also drive recovery of K_{-40} and K_{sat}, as the former appeared too recovered more quickly than K_{sat} (4 weeks and 13 weeks, respectively).

Recovery of soil surface roughness caused by cattle treading occurred within 20 weeks and was dependent on climatic conditions after pugging damage. Heavy rainfall, before the soil dries and sets hard, may result in a rapid decline in soil surface roughness. If the remoulded soil dries after treading damage, the decline in soil surface roughness may largely be driven by subsequent cattle treading during grazing, resulting in the tops of the remoulded soil either being broken off or crushed flat by cattle hooves.

The proportion of weeds in the sward increased (P <0.05) between 21 and 34 weeks after treading treatment in the 71% GSM experiment, but not in the 65% and 81% GSM experiments. The change in botanical composition at the 71% GSM experimental site reflected the presence of large open spaces in spring when weed colonisation was more likely.

Herbage accumulation in all experiments eventually recovered to that of the controls, however, recovery time varied depending on the severity of treading damage. The largest decline in pasture productivity (3,940 kg DM ha^{-1}) before full recovery had occurred was in the 81% GSM 24-hour treatment, the most severe treatment used. The beginning of the recovery of herbage accumulation in severely damaged areas (such as the 71% and 81% GSM 24-hour treatments) did not occur until 12 weeks after treading. Full recovery in herbage accumulation relative to controls took up to 22 weeks after treading treatment.

The 3-hour treatments in the 65% and 71% GSM experiments did not cause a decline in herbage accumulation compared to controls, while the 81% GSM 3-hour treatment plots had lost 1,130 kg DM ha^{-1} on average. Therefore, treading caused by a conservative three hour grazing, with 300 cows ha^{-1} on a Te Kowhai soil, at gravimetric soil moistures of 71% and less may not affect pasture productivity. However, when gravimetric soil moisture content exceeds 71% a decline in herbage accumulation may occur if treading takes place.

The increase in microporosity and decreases in K_{-40} and K_{sat} for more severely damaged areas lasted up to 13 weeks before recovery was complete, therefore, soil was more susceptible to further pugging damage over this time. However, bare ground took up to 25 weeks to be revegetated, resulting in soil being more directly exposed to hoof damage then in undamaged areas, and extending susceptibility to further treading damage beyond 13 weeks.

The changes in soil dry bulk density and hydraulic conductivities with the onset of summer suggest that some soil physical properties change with season. Changes in hydraulic conductivities with the onset of summer have been reported (Watt & Crouchley, 1985), however, little has been reported on porosities or soil dry bulk density. The changes observed in this thesis show a steady increase in K_{-40} with onset of summer, although soil porosity and soil dry bulk density appear to undergo different seasonal trends in each experiment, suggesting a complex process. Given the lack of published data on seasonal changes in soil physical properties, further studies would be beneficial as seasonal changes may influence recovery rates and the management of soil.

Chapter 7.
Statistical Modelling of Potential Pasture and Soil Damage by Treading

7. Statistical Modelling of Potential Pasture and Soil Damage by Treading

7.1 General Introduction

This chapter presents statistical models based on the results presented in earlier chapters. The statistical models were developed to estimate potential pasture productivity decline, either before commencement of grazing (using pre-treading variables such as grazing duration and soil moisture content) or after grazing (using post-treading variables such as bare ground, soil surface roughness, and depth of individual pug prints). Statistical models have also been developed to estimate the time required for soil and pasture to recover from treading damage.

Soil physical properties influence herbage accumulation thus the interrelationship between macroporosity, saturated hydraulic conductivity and spring herbage accumulation will be presented. The interrelationships between soil treading damage variables with saturated hydraulic conductivity will also be presented.

7.2 Estimating Pasture Productivity Decline due to Treading Damage

7.2.1 Introduction

A decline in pasture productivity usually occurs in response to treading damage (Sheath & Boom, 1985a; Sheath & Boom, 1997; Di *et al.*, 2001; Drewry *et al.*, 2001; Nie *et al.*, 2001a; Betteridge *et al.*, 2003), however, mechanisms for estimating the decline have largely been unexplored in the literature.

The inclusion of different soil moistures contents and hours of treading in the experimental design used in this thesis allows for the establishment of predictive relationships using multivariate regressions to estimate decline in pasture productivity from a one-off severe treading damage event. Soil moisture content, AgResearch Penetrometer results, and proposed hours of treading are 'pre-treading variables' that can be used in a 'pre-treading model' to estimate pasture productivity decline, should the planned grazing occur.

After treading, the amount of bare ground, soil surface roughness index, and depth of pug prints are easily determined 'post-treading variables'. Post-treading variables can also be combined with pre-treading variables to estimate the decline in pasture productivity following treading damage. The models assume that the site will have subsequent grazing events before recovery is complete but that none of the grazing events resulted in severe treading damage.

The decline in pasture productivity is defined as the total cumulative difference in herbage accumulation (kg DM ha^{-1}) in treatment plots compared with controls until the measurement date when treatment plot yields were no longer significantly different ($P < 0.05$) from controls (that is, herbage accumulation had recovered to the level of the control plots).

7.2.2 Pre-treading Statistical Model

The 'hours of treading' independently accounted for most of the variability in pasture productivity decline after treading damage (Table 7.1). Gravimetric soil moisture content and AgResearch Penetrometer results generally accounted for the same variability in pasture productivity decline, thus are presented in the models alternately. The penetrometer results were more easily determined than gravimetric soil moisture contents. Combining penetrometer results with hours of treading in the model gave a significant relationship (Figure 7.1a), while the inclusion of gravimetric soil moisture content instead of penetrometer results gave a similar result (Figure 7.1b). When either the penetrometer results or gravimetric soil moisture contents are used, the square of the hours of treading ($hours^2$) was also included. By including the square of the hours of treading, the curvature in the pasture productivity decline data, with increasing treading durations, is taken in account.

Table 7.1 Pre-treading models for estimating the decline in pasture productivity (kg DM ha^{-1}) on a Te Kowhai soil when trodden at gravimetric soil moisture content of 65% or greater.

Equation	r^2	r^2 (adj)	r.s.d.	*P*
DPP = 215.94 + 84.18HR	0.41	0.39	960.77	<0.001
DPP = -1770.98 + 196.35HR - 4.47HR^2 + 32.11AP	0.72	0.70	676.00	<0.001
DPP = -7065.88 + 196.36HR - 4.47HR^2 + 97.00GSM	0.73	0.70	672.68	<0.001

r^2 = coefficient of determination
r^2 (adj) = adjusted (corrected) coefficient of determination
r.s.d. = residual standard deviation
P = significance of the equation
DPP = decline in pasture productivity (kg DM ha^{-1}) compared to controls
HR = proposed hours of treading
HR^2 = the square of the proposed hours of treading
AP = AgResearch Penetrometer results (% of readings penetrating soil by ≥2 cm) immediately before treading
GSM = gravimetric soil moisture content (%) immediately before treading
Note The individual significance of each variable contribution to the multivariate regression was *P* <0.05

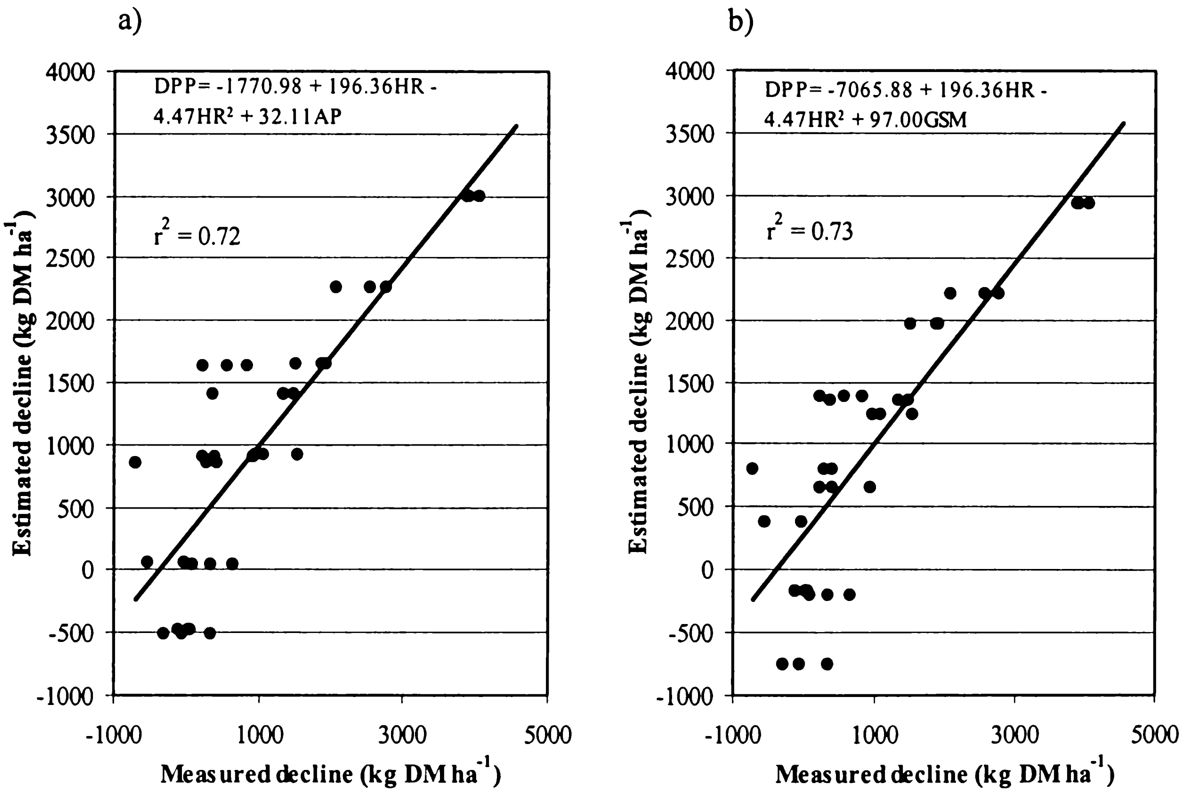


Figure 7.1 The relationship between measured and estimated decline in pasture productivity (DPP) including a) AgResearch Penetrometer results or b) gravimetric soil moisture content, where HR is hours of treading, HR^2 is the square of the hours of treading, AP is the AgResearch Penetrometer (% of readings penetrating soil by ≥2cm), and GSM is gravimetric soil moisture content (%).

7.2.3 Post-treading Statistical Model

Often, in on-farm situations, treading damage may have already occurred and it would be useful to estimate the consequent impact on pasture productivity. An estimation of the decline in pasture productivity after treading damage can be compared with the financial cost of, for example, mechanical soil amelioration.

Given that treading damage has already occurred, variables including those that directly measure treading damage can also be used to estimate the ensuing decline in pasture productivity. The soil surface roughness index gave the strongest individual correlation with the decline in pasture productivity (Table 7.2). The inclusion of AgResearch Penetrometer or gravimetric soil moisture content variables with soil surface roughness further improved the estimation of the decline in pasture productivity.

The proportion of bare ground, like soil surface roughness, is a visible effect of treading, however, soil surface roughness gave more reliable predictions of the decline in herbage productivity. The best fit of the experimental to the estimated data were derived by combining hours of treading, depth of pug prints and soil surface roughness (Figure 7.2). As bare ground correlates well with other variables, such as soil surface roughness index, the combination of other pre-treading and post-treading variables with bare ground did not significantly (P <0.05) account for more variability in the estimates of pasture productivity decline. Because models with less variability can be derived by using combinations of pre- and post-treading variables that do not include bare ground it is suggested that soil damage (roughness, pug depths) are better indicators of pasture productivity response to treading damage than herbage damage (bare ground).

Table 7.2 Post-treading models for estimating the decline in pasture productivity (kg DM ha^{-1}) on a Te Kowhai soil when trodden at gravimetric soil moisture content of 65% or greater.

Equation	r^2	r^2 (adj)	r.s.d.	*P*
DPP = -1057.55 + 43.17BG	0.61	0.60	775.36	<0.001
DPP = -863.78 + 179.10SR	0.78	0.78	580.51	<0.001
DPP = -2953.91 + 164.07SR + 31.03GSM	0.81	0.80	557.11	<0.001
DPP = -1298.31 + 163.60SR + 11.07AP	0.81	0.80	551.39	<0.001
DPP = -701.16 - 155.89HR + 5.49HR^2 + 26.61PD + 122.68SR	0.84	0.82	521.50	<0.001

r^2 = coefficient of determination
r^2 (adj) = adjusted (corrected) coefficient of determination
r.s.d. = residual standard deviation
P = significance of the equation
DPP = decline in pasture productivity (kg DM ha^{-1}) compared to controls
BG = proportion of bare ground (%) after treading
SR = soil surface roughness index (%) after treading
GSM = gravimetric soil moisture content (%) immediately before treading
HR = hours of treading
HR^2 = the square of the hours of treading
AP = AgResearch Penetrometer results (% of readings penetrating soil by ≥2 cm) immediately before treading
PD = mean depth of pug prints (mm) after treading
Note The individual significance of each variable contribution to the multivariate regression was *P* <0.05

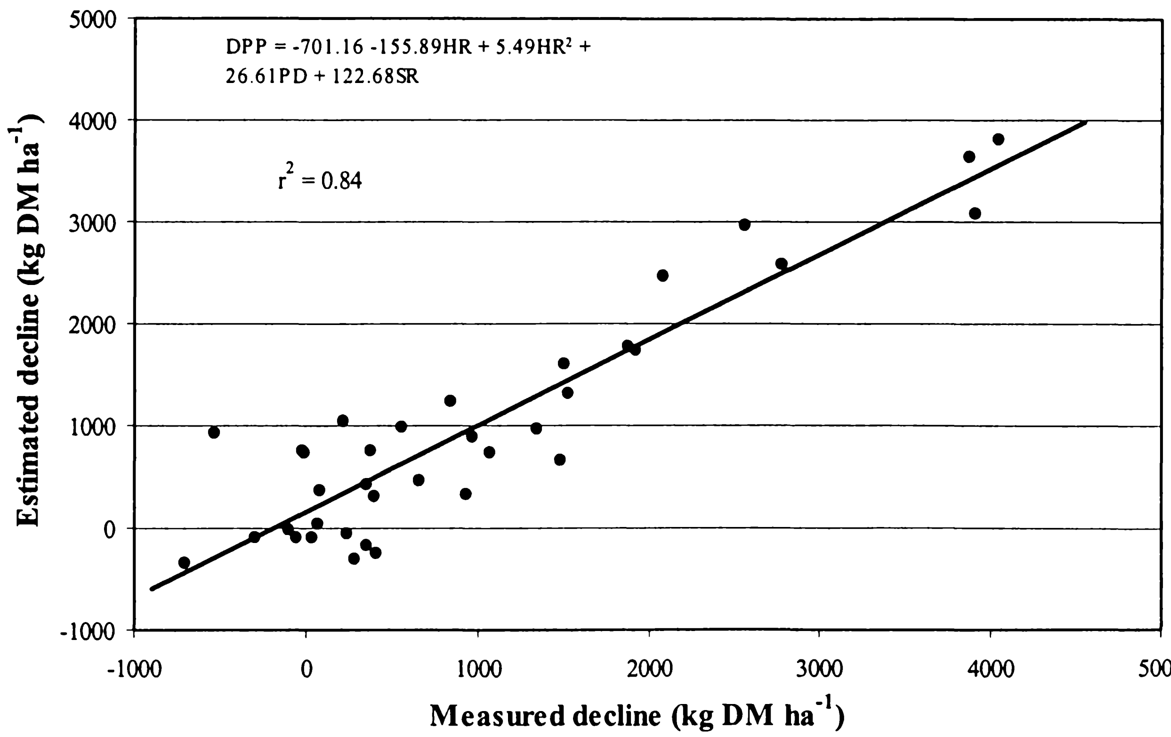


Figure 7.2 The relationship of measured decline in pasture productivity (DPP) with estimated decline, where HR is hours of treading, HR^2 is the square of the hours of treading, PD is pug depths (mm) and SR is the soil surface roughness index (%).

7.2.4 Other Treading Models

Finlayson *et al.* (2002) produced a simulation model using up to 20 variables (including some effects of treading damage) to estimate pasture productivity after multiple treading events on hill-soil tracks or slopes. Unfortunately, data from this thesis could not be used to test the Finlayson model, as the model requires other data that were not collected in this thesis's experimental design. For example, the Finlayson model simulated multiple treading events either tracks and slopes, and included variables such as vegetation index, number of treads per area, and herbage senescence, whereas this thesis monitored a single severe treading event where the reliable variables were bare ground, soil surface roughness, and depth of pug prints. Finlayson *et al.* (2002) point out that their model is limited to hill-soils, and modelling pasture productivity response to treading damage for lowland soils needs to be carried out.

Betteridge *et al.* (2003) presented a simplified graph from the TREAD Ready Reckoner model indicating the potential pasture productivity decline from pastures trodden when considered susceptible to pugging damage using the AgResearch Penetrometer. The graph defines the proportional decrease in herbage accumulation likely during the first month after treading damage considering grazing duration and stocking density. As all experimental sites in this thesis were determined by the penetrometer to be susceptible to pugging damage, a comparison with the results of this thesis can be made (Table 7.3).

Table 7.3 Proportional (%) decline in potential herbage accumulation during the first month after treading damage as measured and estimated results using the TREAD Ready Reckoner

Hours of treading [a]	Estimated [b] (%)	65% GSM [c] (%)	71% GSM [c] (%)	81% GSM [c] (%)
3 hours	22	17.4	1.2	20.9
9 hours	52	19.4	43.3	38.3
24 hours	>60	51.7	60.0	38.8

[a] treading at 300 cows ha^{-1}
[b] estimated decline using the TREAD Ready Reckoner model of Betteridge *et al.* (2003)
[c] measured decline at each experimental site calculated to one month regrowth of regrowth after treading

As the TREAD Ready Reckoner model does not consider soil moisture content (or greater proportions of penetrometer penetrations exceeding 2 cm soil depth), separate estimates of herbage accumulation decline for each experimental site could not be made. The TREAD Ready Reckoner model tended to overestimate the decline in herbage accumulation for the pastures used in this thesis. As the TREAD Ready Reckoner model was designed to be generic (for use over a range of soil types), it may overestimate herbage accumulation decline while accounting for soils that are more susceptible to pugging damage than the Te Kowhai soils used in this thesis.

The TREAD Ready Reckoner model estimated potential herbage accumulation decline during the first month after treading damage. However, results from this thesis indicate that herbage accumulation declines are more variable one month after treading than at two months. For example, in the 71% and 81% GSM experiments herbage accumulation (per measurement date) in the 24-hour treatments only became significantly different ($P < 0.05$) from the 9-hour treatments six weeks after treading damage, and the herbage accumulation decline in the 81% GSM 24 hour-treatment increased from 38.8% in the first month to 63% at two months. Thus it may be more useful to model proportional decline in herbage accumulation for two months after treading damage.

The models (Section 7.2) in this thesis differ from the TREAD Ready Reckoner model because they estimate the total herbage accumulation decline (kg DM ha^{-1}) from a severe treading event up to when pasture productivity has fully recovered, thus estimating the overall decline in farm productivity rather than a proportional loss at one month after treading damage occurred.

Even though estimates of likely pasture productivity declines can be made using the TREAD Ready Reckoner model, having models specific to soil type, such as the models presented in this thesis for the Te Kowhai soil, may give more reliable estimates of herbage accumulation decline than generic models. The inclusion of soil moisture in the models from this thesis allows for greater accuracy over a range of soil conditions than the TREAD Ready Reckoner model does. However, models presented in this thesis apply to Te Kowhai soils only, whilst the TREAD Ready Reckoner model is more versatile.

7.3 Estimating Recovery Time for Pasture Productivity

7.3.1 Introduction

The management of previously pugged pastures would be improved by the knowledge of pasture productivity recovery time. The recovery time indicates how long care must be taken by farm managers for recovery of pasture productivity to be complete. Research of soil recovery after treading damage has often been based on long-term (years to decades) changes in soil (e.g. Greenwood *et al.*, 1997; Greenwood *et al.*, 1998; Drewry & Paton, 2000a; Drewry *et al.*, 2004b), or on a one-off treading damage event followed by grazing exclusion (Drewry *et al.*, 2003). A search of the literature found no models incorporating recovery time for pasture productivity following one-off severe treading damage events as described in this thesis.

In this thesis, the time needed for pasture productivity to recover to the level of the controls was estimated using the pre-treading and post-treading variables. Recovery in pasture productivity was defined as the number of weeks after treading treatment until there was no significant difference between treatment and control plots in herbage accumulation assessments over sequential measurements. Recovery was observed at six different time intervals, which resulted in some clustering of data.

7.3.2 Recovery Statistical Models

The hours of treading (with hour^2) individually accounted for most of the variability in the time required for pasture productivity to recover (Table 7.4). The combination of hours of treading with gravimetric soil moisture content resulted in a better fit to the measured data, however, the relationship was skewed because recovery of pasture productivity in the 81% GSM 3-hour treatment took 14.3 weeks whereas pasture productivity in the 65% and 71% GSM 3-hour treatments were not significantly affected by the treading. By including the square of the gravimetric soil moisture content an allowance (P <0.05) is made for the curvature in the relationship, resulting in more reliable estimates of recovery time. The best estimations of time required for recovery of pasture productivity using pre-treading variables were the combination of hours of treading, hours of treading squared, and the AgResearch Penetrometer results (Figure 7.3a).

Table 7.4 Pre-treading and post-treading models estimating the time required for pasture productivity to recover from treading damage.

Equation	r^2	r^2 (adj)	r.s.d.	*P*
Pre-treading				
$RT = -0.036 + 1.75HR - 0.043HR^2$	0.57	0.54	6.02	<0.001
$RT = -21.85 + 1.82HR - 0.046HR^2 + 0.30GSM$	0.67	0.64	5.32	<0.001
$RT = -93.59 + 1.63HR - 0.040HR^2 + 2.20GSM - 0.012GSM^2$	0.72	0.68	5.06	<0.001
$RT = -6.94 + 1.35HR - 0.032HR^2 + 0.16AP$	0.78	0.76	4.34	<0.001
Post-treading				
$RT = -5.94 + 0.31BG$	0.60	0.59	5.73	<0.001
$RT = -1.73 + 0.30PD$	0.68	0.67	5.12	<0.001
$RT = -3.95 + 1.22SR$	0.70	0.69	5.00	<0.001
$RT = -6.10 + 0.36HR + 0.10AP + 0.58SR$	0.80	0.78	4.18	<0.001

r^2 = coefficient of determination
r^2 (adj) = adjusted (corrected) coefficient of determination
r.s.d. = residual standard deviation
P = significance of the equation
RT = time (weeks) required for no significant difference treatment in herbage accumulation rate to be found (recovery).
HR = proposed or actual hours of treading
HR^2 = the square of the proposed or actual hours of treading
GSM = gravimetric soil moisture content (%) immediately before treading
GSM^2 = the square of the gravimetric soil moisture content (%) immediately before treading
BG = proportion of bare ground (%) after treading
PD = mean depths of pugs prints (mm) after treading
SR = soil surface roughness index (%) after treading
AP = AgResearch Penetrometer results (% of readings penetrating soil by ≥2 cm) immediately before treading
Note 1 The individual significance of each variable contribution to the multivariate regression was $P < 0.05$
Note 2 Models assume recovery from a one-off severe treading event and that the site was returned back into the grazing rotation, and that further severe treading damage was avoided

The depth of individual pug prints and soil surface roughness gave the best estimation of recovery time. The best estimations of time required for recovery of pasture productivity using post-treading variables was the combination of soil surface roughness index, hours of treading, and AgResearch Penetrometer results (Figure 7.3b). However, the best post-treading recovery model was only marginally better for estimating pasture productivity recovery time than the pre-treading recovery model.

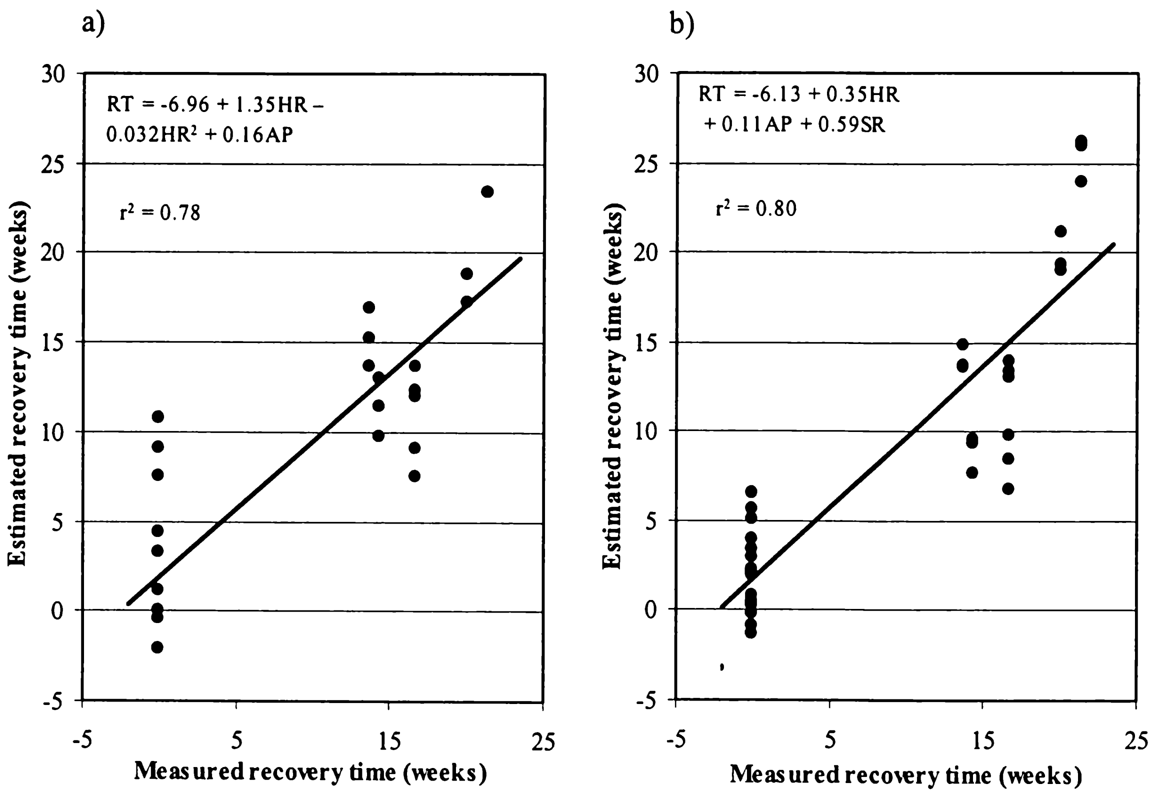


Figure 7.3 The relationship between measured and estimated pasture productivity recovery time (RT) using a) a pre-treading model and b) a post treading model, where HR is hours of treading, HR^2 is the square of the hours of treading, AP is AgResearch Penetrometer, and SR is soil surface roughness index (%).

7.4 Potential Application of the Pasture Productivity Decline and Recovery Models

The statistical models are derived from data in this thesis, therefore, the use of the models is restricted to the research parameters: Te Kowhai silt loam, stocked at 300 cows ha^{-1}, supporting a ryegrass and white clover sward, for a maximum 24 hour grazing commencing at about 7:00am, within the gravitational soil moisture (GSM) of 65% to 81%.

Te Kowhai soil moisture contents during the winter/spring period are likely to be within the susceptibility range of pugging. A GSM of ≥65% would, in all probability, be a common occurrence during the winter/spring period, particularly since 65% GSM occurred without irrigation during a winter drier than usual, and that pugging damage, more severe than observed in the 65% GSM experiment, on Te Kowhai soils is not uncommon. Farms with effective drainage installed may avoid soils reaching 81% GSM for more than brief periods by preventing the water-table from rising.

Extrapolating the models beyond the GSM range used in this thesis will probably not be necessary. The highest GSM used was 81% (89% saturation) and wetter soil conditions would last only for short durations because of rapid drainage, even for soils severely damaged during a previous grazing (e.g. K_{sat} at the 0-5 cm soil depth in the 81% GSM 24-hour treatment had increased by 300% to 920 mm hr^{-1} four weeks after treading treatment). The pasture productivity declines in the 65% GSM experiment were small compared to the 71% and 81% GSM experiments, therefore, a one-off 24 hour grazing on soil with less than 65% GSM is not likely to result in a decline in pasture productivity due to pugging damage.

The models may be able to be extended to other soils commonly used for dairy grazing which have similar soil properties to the Te Kowhai or are within the same soil classification order (gley soil). However, testing of the models would be required to determine if estimated pasture productivity declines and recovery times are within the 95% confidence range.

The models may have a limited use for a grazing beginning in the evening. The experimental design restricted the commencement of grazing to the morning (~7:00am) and a full days grazing had occurred before cattle grazed overnight. Treading behaviour differs between day and night as cattle lie down at night (Krohn & Munksgaard, 1993), resulting in less treading activity and a slower rate of soil and sward damage. However, assuming an overnight grazing commences about 6:00pm, it may be possible to use the models to estimate treading effects for the first three to four hours, when cattle are pre-occupied with feeding and not resting (Singh *et al.*, 1993; Crook, 2002). However, using the models to estimate pasture productivity declines and recovery times from, for example, a 12 hour grazing beginning in the evening would require further testing to factor-in the reduced overnight treading activity.

The models assume that stocking density was 300 cows ha^{-1}, which is a common stocking density on dairy farms in winter when soils are susceptible to severe treading damage under break-feeding and blocking-grazing systems. For stocking at densities similar to 300 cows ha^{-1} a modification could be made to the hours of treading by accounting for the proportional differences in stocking density. The modification can be applied two ways (using an example of 200 cows ha^{-1} for 5 hours): dividing the 'hours of treading' coefficient by 300 and multiplying by 200 (e.g. the model 215.94 + 84.18HR becomes 215.94 + 56.12HR where HR remains 5 hours), or dividing the actual hours of treading (5 hours) by 300 and multiplying by 200 (e.g. the model remains unchanged but hours of treading [HR] changes from 5 to 3.33). The post-treading variables would not be greatly affected by the change in stocking density as they are a direct measure of resultant treading damage. However, care should be taken when extrapolating beyond the stocking densities used in this thesis because the intercept coefficient (e.g. 215.94 in the example above) remains unchanged, and by adjusting the hours of treading the assumption is made that treading behaviour was not altered by the change in stocking density and the change in the duration of feed availability (rate of herbage consumption).

The most practical models to determine decline in pasture productivity and recovery time will be models that use the hours of treading, bare ground, or soil surface roughness, which are easily determined and do not require expensive specialised equipment. However, model reliability will be greater when a combination including GSM or AgResearch Penetrometer results are used. Simpler determinations of the potential decline in pasture productivity can be derived using the Treading Field Guides (Section 8.4).

7.5 Relationship between Soil Physical Properties and Spring Herbage Accumulation

7.5.1 Introduction

Nie *et al.* (2001a) and Drewry *et al.* (2004a) reported that research describing the influence of soil physical properties on dairy pasture herbage accumulation has been limited. Work by Mapfumo *et al.* (1998) showed a clear relationship between increasing soil dry bulk density and decreasing herbage growth. However, Mapfumo's work focused on soil compaction, as indicated by soil dry bulk density, and did not take into account other soil physical properties, such as macroporosity and hydraulic conductivity.

The relationship between soil physical properties and spring herbage accumulation has been researched by Drewry and others (e.g. Drewry & Paton, 2000a; Drewry *et al.*, 2001; Drewry *et al.*, 2002; Drewry *et al.*, 2004a), who found that macroporosity was correlated with herbage accumulation in spring. The soils used researched by Drewry and others generally increased in dry bulk density after treading which, as well as macroporosity declines, may also have influenced herbage accumulation.

Drewry *et al.* (2002) purposely avoided soils with pugging damage, thus limiting the influence of direct hoof damage on plants, thus keeping their study in the context of compaction not pugging. In contrast, the soil damage in the 65%, 71%, and 81% GSM experiments indicated that treading damage was mainly due to pugging (soil plastic deformation with no significant loss of total soil pore volume) not compaction, as there was little or no change in soil dry bulk density.

The aim of this section, therefore, is to determine if there is a relationship between soil physical properties (i.e. macroporosity and K_{sat}) and spring herbage accumulation for pugged soils similar to that reported by Drewry *et al.* (2002) for compacted soils. The effect of direct hoof damage on herbage could not be eliminated in the work from this thesis, as pugging without herbage damage cannot occur. Thus, the relationship of soil physical changes to the decline in spring herbage accumulation presented here is unique, but is also limited to a predominantly pugged soil situation.

7.5.2 Macroporosity and Saturated Hydraulic Conductivity Correlations

Soil macroporosity and K_{sat}, immediately after the treading treatment, were compared with the decline in herbage accumulated (relative to controls) eight weeks later (spring herbage accumulation). In each treatment inherent variation in soil physical properties was high, thus treatment means (n=12; 4 treatments over 3 experiments), rather than plot means, were used in the analysis. The use of absolute differences (kg DM ha^{-1}) in herbage accumulation gave more reliable correlations than proportional difference (%) so the former were used.

The coefficients of determination (r^2) were greater when relating macroporosity at the 0-5 cm soil depth to spring herbage accumulation (Figure 7.4) than for the relationship at the 5-10 cm soil depth (Table 7.5). There was a significant relationship between K_{sat} at the 0-5 cm soil depth and at the 5-10 cm soil depth and the decline in spring herbage accumulation. However, there was no correlation between K_{-40} at either soil depths and the decline in spring herbage accumulation. When K_{sat} was averaged over the 0-5 cm and 5-10 cm soil depths, there was a better fit between experimental and estimated spring herbage accumulation. However, averaged macroporosity over the 0-5 cm and 5-10 cm soil depths gave larger residual standard deviations than when correlating only the macroporosity at the 0-5 cm soil depth with spring herbage accumulation.

As there was a correlation between macroporosity and K_{sat} (r^2 = 0.67; P <0.01), using both in a multivariate regression did not (significantly) explain more of the variation in the spring decline in herbage accumulation.

Table 7.5 Relationship between soil physical properties and the decline in spring herbage accumulation.

Equation	r^2	r^2 (adj)	r.s.d.	*P*
$DSH = 2857.03 - 15202.65MA_{5\text{-}10}$	0.37	0.31	479.54	<0.05
$DSH = 121.58 - 0.37K_{sat5\text{-}10}$	0.51	0.46	424.62	<0.01
$DSH = 1237.05 - 0.89K_{sat0\text{-}5}$	0.55	0.50	407.46	<0.01
$DSH = 2730.68 - 13515.29MA_{0\text{-}10}$	0.61	0.57	378.75	<0.01
$DSH = 1352.46 - 0.63K_{sat0\text{-}10}$	0.61	0.58	376.29	<0.01
$DSH = 2373.80 - 10684.10MA_{0\text{-}5}$	0.70	0.67	331.42	<0.001

r^2 = coefficient of determination
r^2 (adj) = adjusted (corrected) coefficient of determination
r.s.d. = residual standard deviation
P = significance of the equation
DSH = decline in spring herbage accumulation (kg DM ha^{-1})
$MA_{0\text{-}5}$ = macroporosity ($cm^3\ cm^{-3}$) at the 0-5 cm soil depth
$MA_{5\text{-}10}$ = macroporosity ($cm^3\ cm^{-3}$) at the 5-10 cm soil depth
$MA_{0\text{-}10}$ = the mean of the macroporosity ($cm^3\ cm^{-3}$) at the 0-5 cm and 5-10 cm soil depths
$K_{sat0\text{-}5}$ = saturated hydraulic conductivity (mm hr^{-1}) at the 0-5 cm soil depth
$K_{sat5\text{-}10}$ = saturated hydraulic conductivity (mm hr^{-1}) at the 5-10 cm soil depth
$K_{sat0\text{-}10}$ = the mean of the saturated hydraulic conductivity (mm hr^{-1}) at the 0-5 cm and 5-10 soil depths
Note The individual significance of each variable contribution to the multivariate regression was $P < 0.05$

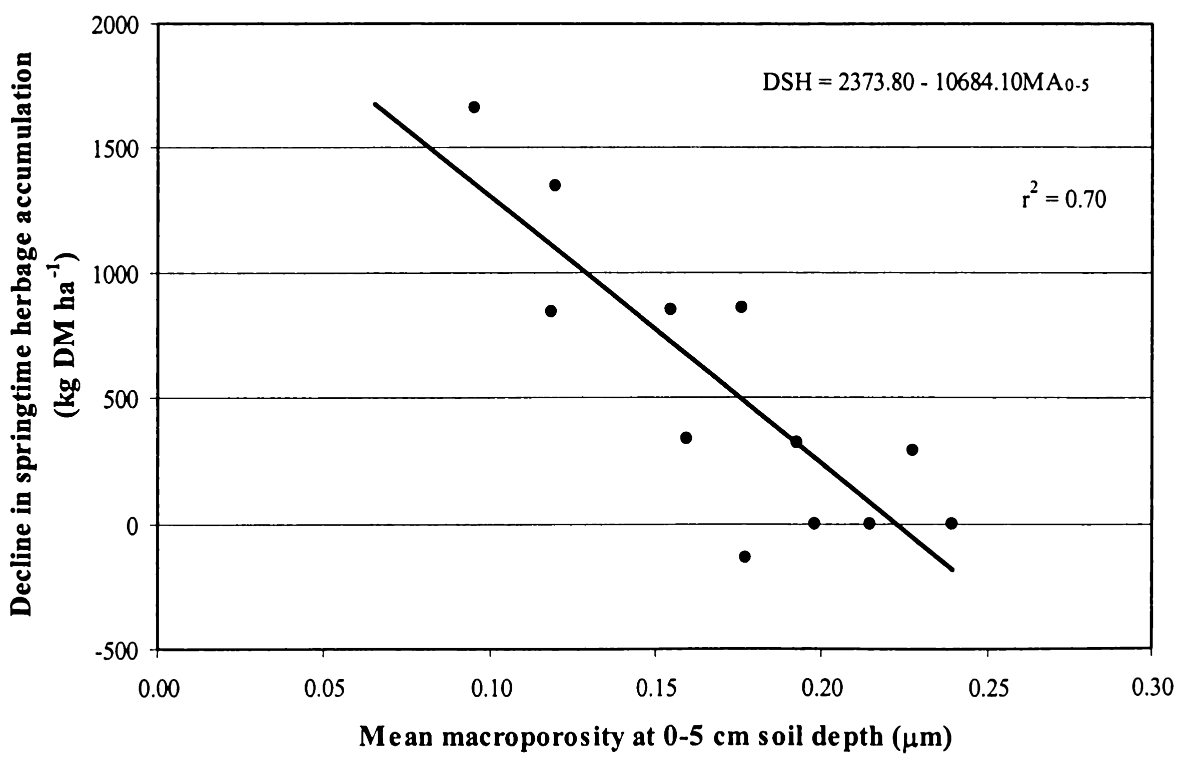


Figure 7.4 Correlation between macroporosity (treatment means) at 0-5 cm soil depth ($MA_{0\text{-}5}$) and the decline in spring herbage accumulation (DSH) compared to controls.

7.5.3 Comparison of Results to Soil Compaction Studies

Drewry *et al.* (2002; 2004a) reported that macroporosity at the 5-10 cm soil depth was more strongly correlated with spring growth than macroporosity at the 0-5 cm soil depth. However, in this thesis the correlation between macroporosity at the 0-5 cm soil depth and declines in spring herbage accumulation were stronger than for macroporosity at the 5-10 cm soil depth.

After pugging damage, K_{sat} at the 0-5 cm soil depth and, particularly, at the 5-10 cm soil depth strongly correlated with declines in spring herbage accumulation. Drewry and Paton (2000a) found averaging soil physical data from the 0-20 cm soil depth improved the reliability of the relationship with spring herbage accumulation. In this thesis, averaging data for the 0-5 cm and 5-10 cm soil depths improved the relationship between K_{sat} and decline in spring herbage accumulation, but not for macroporosity data.

In this thesis, the K_{-40} did not significantly correlate with declines in spring herbage accumulation. Drewry (2002; 2004a) found that K_{-10} did correlate with spring herbage accumulation while K_{-100} did not. Thus, decreases in the volume of large soil pores (>0.75 mm diameter), after soil compaction and pugging damage, may be more important for spring herbage accumulation than decreases in smaller soil pores (<0.75 mm diameter).

The compaction work by Drewry (2002; 2004a) showed that changes in soil physical properties due to cattle treading damage correlated with decreased in spring herbage accumulation. The work described in this thesis has shown that decreases in some soil physical properties (i.e. macroporosity and K_{sat}) in the context of pugging-dominated damage rather than compaction-dominated damage are also related to a decline in spring herbage accumulation. The correlations with declines in spring herbage accumulation was most reliable when macroporosities were used, similar to the findings from the compaction work by Drewry (2002; 2004a).

7.6 Relationship between Treading Damage Variables and Saturated Hydraulic Conductivity

7.6.1 Introduction

An important result of treading damage on soils is decreased hydraulic conductivity. Saturated hydraulic conductivity (K_{sat}) is an important indicator of the ability of the soil to rapidly drain water from the soil surface after heavy rainfall, which is also influences soil susceptibility to pugging damage (Wind & Schothorst, 1964; Horne & Singleton, 1997). Unfortunately, determination of K_{sat} is time consuming. From the data presented in this thesis it is possible to derive a regression model to estimate K_{sat} for treading-damaged soil using easily determined *in situ* treading damage variables. The data collected in this thesis can also be used to test the model reported by Tian *et al.* (1998), which aimed to estimate soil infiltration rates using soil physical properties and grazing management factors. The development of models that can estimate soil physical properties such as K_{sat} are useful for establishing large-scale mathematical models (e.g. whole-farm scale models) on which farm management pasture strategies can be based (Tian *et al.*, 1998).

7.6.2 Estimating Saturated Hydraulic Conductivity

Despite the importance of K_{sat} to soil management and soil condition, inherently high variability of K_{sat} data has been noted as a limitation to its use as a soil quality indicator (Schipper & Sparling, 2000) and as an indicator of pugging damage (Section 5.3). Therefore, to determine the relationship between treading damage and K_{sat}, treatment means (the mean of the three treatment replicates) were used, in preference to individual treatment plot means, to minimise variability.

The hours of treading was the best individual variable for estimating K_{sat} at the 0-5 cm soil depth after treading damage (Table 7.6), however, bare ground and soil surface roughness were also reliable indicators of K_{sat} after treading damage. There was a small curvature in the spread of the data, but by including the square of the hours (hours^2) the estimation of K_{sat} improved (Figure 7.5), however, the significance of the contribution of the square of the hours was P = 0.0546. As hours of treading, bare ground, and soil surface roughness are interrelated, using a multivariate regression did not significantly improve the explanation of variation in K_{sat} following treading damage.

As the decline in K_{sat} after treading damage was similar in all experiments (65%, 71%, and 81% GSM), addition of gravimetric soil moisture content did not significantly improve any of the regression models. The lack of sensitivity of the regression models to soil moisture content indicates that when gravimetric soil moisture content is 65% or higher, the decline in K_{sat} due to cattle treading is similar.

Table 7.6 Relationship between K_{sat} at the 0-5 cm soil depth and other treading damage variables.

Equation	r^2	r^2 (adj)	r.s.d.	*P*
$K_{sat} = 1313.36 - 50.58SR$	0.43	0.37	380.00	<0.05
$K_{sat} = 1545.24 - 15.96BG$	0.57	0.53	328.74	<0.01
$K_{sat} = 1144.18 - 38.86HR$	0.61	0.57	312.26	<0.01
$^a K_{sat} = 1327.78 - 116.40HR + 3.09HR^2$	0.75	0.69	265.07	<0.01

r^2 = coefficient of determination
r^2 (adj) = adjusted (corrected) coefficient of determination
r.s.d. = residual standard deviation
P = significance of the equation
K_{sat} = saturated hydraulic conductivity (mm hr^{-1}) at the 0-5 cm soil depth
SR = soil surface roughness index (%)
BG = proportion of bare ground (%)
HR = hours of treading
HR^2 = the square of the hours of treading
^{a} = the individual significance of HR^2 was P = 0.0546
Note The individual significance of each variable contribution to the multivariate regression was P <0.05

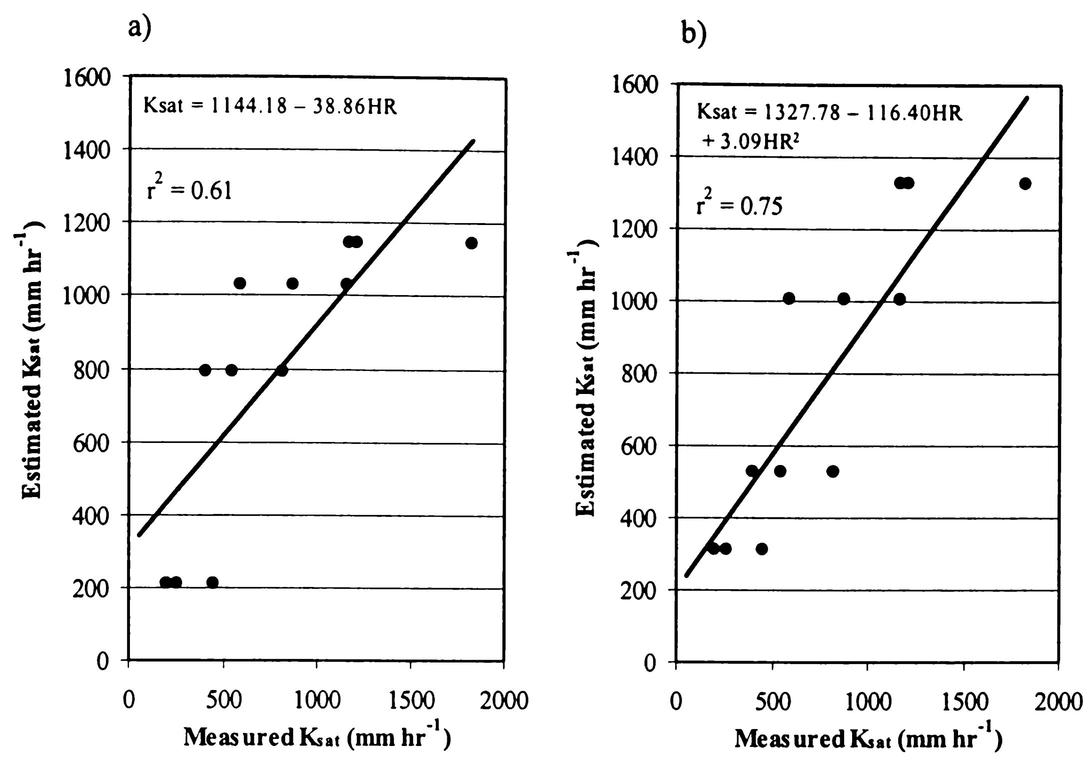


Figure 7.5 The relationship between a) saturated hydraulic conductivity (K_{sat}) and hours of treading (HR), and b) saturated hydraulic conductivity K_{sat} and the hours and hours^2 (HR^2) of treading.

7.6.3 Testing the Tian Infiltration Model

Tian *et al.* (1998) presented empirical models (statistical multivariate regression models) of infiltration rates for an 'ash hill-soil' (Dunmore silt loam; NZ soil classification, *Typic Orthic Allophanic*; USDA soil taxonomic classification, *Typic Hapludand*) and a 'clay hill-soil' (Hamilton clay loam; NZ soil classification, *Typic Orthic Granular*; USDA soil taxonomic classification, *Typic Haplohumult*). Infiltration rate is dependent on soil hydraulic conductivity (McLaren & Cameron, 1993). As Tian *et al.* (1998) simulated rainfall until steady state was obtained, it was assumed that saturated flow occurred. The Tian *et al.* (1998) clay hill-soil model had parameters that allowed for testing using the data obtained at the 0-5 cm soil depth from the 65%, 71%, and 81% GSM experiments. The Tian clay hill-soil model for estimating infiltration rates after treading damage is as follows:

$$F = -5.28 + 0.703OM - 0.147SM + 0.324HP - 0.539BG + 11.8TRT + 0.303ASC - 0.0208DAYS \quad (7.1)$$

r^2 adj. = 0.53; Tian *et al.* (1998)

Where:
F = infiltration rate (mm hr^{-1})
OM = soil organic matter
SM = soil moisture content
HP = the hoof print area of soil surface
BG = proportion of bare ground
TRT = number of grazing events
ASC = the soil anion storage capacity
DAYS = number of days after treading

To test the Tian model, inferences had to be made about soil organic matter, hoof print area, and anion storage capacity (ASC) values. Soil organic matter of 8.4% was obtained from a previous Te Kowhai soil study in nearby paddocks (Zegwaard, 1998), and typical ASC values for a Te Kowhai soil were low (20%) (Singleton, 1991). A range of hoof print areas of up to 95% was used after interpolation from photographs.

Predicted values obtained from the Tian model were lower (P <0.05) than measured K_{sat} at 0-5 cm soil depth from this thesis (Table 7.7). The possible causes of the lack of predictability from the Tian model may be two-fold. Firstly, the Tian model used infiltration data obtained from a hill-soil, whilst this thesis used lowland soils. Secondly, the Tian model was based on experiments carried out *in situ* using rainfall simulation and runoff from hill slope, whilst this thesis used undisturbed soil cores and laboratory measurements of K_{sat}.

Table 7.7 K_{sat} at the 0-5 cm soil depth as measured and estimated results using the model from Tian *et al.* (1998).

	65% GSM		71% GSM		81% GSM	
Hours of treading	Measured (mm hr^{-1})	Estimated (mm hr^{-1})	Measured (mm hr^{-1})	Estimated (mm hr^{-1})	Measured (mm hr^{-1})	Estimated (mm hr^{-1})
0 hours	1825.06	16.50	879.33	5.26	1104.94	10.63
3 hours	991.85	21.71	586.61	23.72	570.06	26.62
9 hours	401.34	15.91	281.54	8.12	486.86	12.12
24 hours	361.31	10.12	77.52	13.53	225.09	2.11

Note: Organic matter was assumed as 8.4%, anion storage capacity as 20%, hoof print area as a range from zero at the 0 hour to 95% at the 24 hour, number of treading events was one, days after treading was three, soil gravimetric moisture content as 65, 71, and 81%, and bare ground results were from Section 5.5.2.

Hill-soils are typically more variable and, as hydraulic conductivity data are already inherently variable (Rowell, 1994; Schipper & Sparling, 2000), reliable predictions are difficult to achieve. As hydraulic conductivity was determined on soils placed within a PVC core-holder, the water flow through a continuous soil pore (e.g. earthworm burrow) that extends from the top of the soil core to the bottom will be constant. However, *in situ* measurements of infiltration rates results in continuous soil pores eventually filling up with water due to obstruction lower in the soil profile, slowing the rate of infiltration. Therefore, conductivity values determined in the laboratory on soil cores tend to be faster than *in situ* infiltration rates. *In situ* measurements are also influenced by soil compaction layers further down the soil profile (e.g. at 15 cm soil depth), which would not be present in a 0-5 cm depth soil core.

7.6.4 Implications

The testing of the Tian model using K_{sat} data from this thesis identifies that when different soil types and methods of data collection were used, the derived models may not transfer well to new data. In order for statistical modelling to be useful for large-scale mathematical or simulated modelling, further development under a range of conditions is required to better understand the influence of different pastures, management practices, and soil properties (particularly soil physical properties). Therefore, the establishment of relationships between soil treading damage variables and K_{sat} for a Te Kowhai soil supporting a ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pasture in this thesis, will contribute to the greater understanding of the processes of change in soil hydraulic conductivity caused by cattle treading.

7.7 Summary and Conclusion

The use of pre-treading statistical models to estimate pasture productivity decline will help farm managers of Te Kowhai soils with ryegrass and white clover pastures make informed decisions on limiting grazing duration when the soil is susceptible to pugging damage. If treading damage has occurred, the post-treading statistical models will give estimations of the likely pasture productivity decline from the one-off severe treading event (assuming normal grazing rotation but avoidance of severe treading damage), and will allow for comparisons between the costs of soil and pasture amelioration (e.g. cost of mechanical loosing and re-sowing).

The pre-treading models developed in this thesis indicate that hours of treading was the main influence on pasture productivity decline when the soil had a gravimetric soil moisture content of 65% or greater. Often the square of the hours of treading was used in the models to allow for the curvature in the spread of the data, possibly caused by a decline in cattle activity during the night. The amount of plastic deformation (pugging) of soil was also dependent on soil moisture content, therefore, the gravimetric soil moisture content was an important variable relating pasture productivity decline due to treading. The AgResearch Penetrometer was found to be a suitable alternative to using gravimetric soil moisture content in the models, being easier to determine on-farm.

After treading damage had occurred, the soil surface roughness index gave the best estimations of the likely pasture productivity decline. Estimations of pasture productivity decline using the soil surface roughness index was strengthened by the inclusion of the hours of treading and depths of pugs.

Testing of the TREAD Ready Reckoner model by Betteridge *et al.* (2003) resulted in overestimation of likely pasture productivity declines. As the TREAD Ready Reckoner model was designed to be generic, it possibly overestimates the decline in herbage accumulation to account for soils that are more susceptible to pugging damage than the Te Kowhai soil. Therefore, it may be useful to derive soil specific models to estimate the effect of treading on soil and pasture. The models in this thesis further differ from the TREAD

Ready Reckoner model. The models from this thesis estimate the total herbage accumulation decline (kg DM ha^{-1}) from a severe treading event up to when pasture productivity has fully recovered, thus estimating the overall decline in farm productivity, rather than a proportional loss at one month after treading damage.

The time required for recovery of pasture productivity is important, as it indicates how long further treading should be avoided. Estimations of recovery time for a treading damaged Te Kowhai soil could be established using pre-treading and post-treading models, however, post-treading models of pasture productivity recovery were only marginally better than pre-treading models.

The models describing pasture productivity decline and recovery can potentially be used for other soil types with similar texture or within the same soil classification order (*Gley* soil). The models could also be utilised for other stocking densities by correcting the hours of treading coefficients (dividing the coefficient by 300 and multiplying by the actual stocking density used). However, as the statistical models have not been tested for other soil types or stocking densities, care should be taken when extrapolating beyond the conditions of this thesis. Using the models on soils with gravimetric soil moisture contents outside the range used in this thesis (65% to 81% GSM) is unlikely, as gravimetric soil moisture contents >81% GSM (89% saturation) are not likely to persist for long and, as pasture productivity declines at the 65% GSM experiment were small compared to the 71% and 81% GSM experiments, one-off treading events at <65% GSM are not likely to result in important pasture productivity declines.

Previous compaction research (e.g. Drewry & Paton, 2000a; Drewry *et al.*, 2001; Drewry *et al.*, 2002; Drewry *et al.*, 2004a) has shown that when soil compaction (not soil pugging) has occurred, soil macroporosity, K_{sat}, and K_{-10} correlate to subsequent spring herbage accumulation declines. Work from this thesis has shown that when soil pugging has occurred, without an increase in soil compaction, soil macroporosity and K_{sat} still correlate with a decline in spring herbage accumulation, however, K_{-40} does not. The best indicator of spring herbage accumulation decline was macroporosity at the 0-5 cm soil depth.

The estimation of K_{sat} using easily determined treading damage variables is important for farm-scale mathematical modelling. Previous work (e.g. Tian *et al.*, 1998) has attempted to use treading damage variables to estimate infiltration rates of soil after treading damage has occurred. Testing of the Tian model indicates that when different measurement techniques (i.e. laboratory k_{sat} measurements versus *in situ* k_{sat} measurements) and soil types are used, the models may not be applicable to different data sets. Therefore, a new regression model was determined using data from this thesis. The K_{sat} after treading damage occurs on a Te Kowhai soil was best estimated using the pre-treading variables, particularly proposed hours of treading and the square of the proposed hours of treading. Therefore, the impact of cattle treading on K_{sat} at the 0-5 cm soil depth can be determined before treading damage has taken place on Te Kowhai soils with gravimetric soil moisture contents of 65% or greater.

Chapter 8. Field Estimation of Treading Damage and Potential Benefits of Using Stand-off Pads

8. Field Estimation of Treading Damage and Potential Benefits of Using Stand-off Pads

8.1 General Introduction

This chapter describes field methods for determining susceptibility of soil to pugging damage and the potential pasture productivity losses if pugging damage occurs. The use of the AgResearch Penetrometer to determine when a conservative grazing approach (three hour grazing followed by stand-off pad use) was possible without a decline in pasture productivity is also discussed. A field guide, using visual cues such as photos, bare ground, and soil surface roughness provides a quick estimation of ensuing pasture productivity losses due to treading damage. Lastly, a cost-benefit analysis of treading damage avoidance is carried out, using outputs from the field guide and results from earlier chapters, and is compared with the cost of stand-off pad construction and maintenance.

8.2 The AgResearch Penetrometer

8.2.1 Background

The AgResearch Penetrometer was developed by Betteridge *et al.* (2003) to provide an indication of whether or not a soil would be susceptible to pugging damage. The device is a calibrated penetrometer (Figure 3.12) which applies a force of 350 kPa to a 3 cm diameter cone placed on the soil. After the force has been applied, the depth of the cone penetration into the soil is measured, and the number of soil penetrations of 2 cm or more is recorded. The underlying principle of the penetrometer is that the applied force per unit area is similar to that of a typical dairy cow hoof (Scholefield & Hall, 1986; Haynes, 1995). Therefore, the observed depth of penetration into the soil by the penetrometer is an indication of the potential depth of penetration by an individual cow hoof if the soil is trodden. The number of readings by the penetrometer that penetrate the soil by 2 cm or more is, therefore, an indication of soil susceptibility to pugging damage.

The penetrometer serves as an indicator of pugging susceptibility only at the time of measurement, as the ability of soil to resist deformation will change if soil structure has begun to fail or soil moisture has increased (i.e. rainfall has occurred) (Scholefield & Hall, 1985a, 1986). Betteridge *et al.* (2003) concluded that, over a broad range of soil types, if 30% or more of the penetrometer readings penetrate the soil by 2 cm or more, then the soil is susceptible to pugging damage. When the 30% threshold is exceeded, farm managers are directed to the TREAD Ready Reckoner model to obtain more accurate information of potential decline in pasture productivity (Betteridge *et al.*, 2003).

The purpose of the work presented here is to verify the AgResearch Penetrometer method on the Te Kowhai soil when it is susceptible to pugging damage and to further develop interpretations of the penetrometer for determining the grazing duration (followed by use of stand-off pads) that will minimise the likelihood of a decline in pasture productivity following the grazing.

8.2.2 Methods

The Eijkelkamp-Agrisearch Penetrometer (from Eijkelkamp, The Netherlands) was an early prototype of the AgResearch Penetrometer, and was used in the 65% and 71% GSM experiments. The final prototype of the AgResearch Penetrometer (Figure 3.11b) was used in the 81% GSM experiment. Before the treading treatment, 10 replicate penetrometer readings were taken at random from each treatment plot, as described in Section 3.8.

Rather than recording the number of penetrometer readings that penetrated the soil by 2 cm or more, the actual depths (in cm) of soil penetration were recorded for each treatment plot. By recording the depth of soil penetration, analyses could be carried out to determine if the '2 cm depth category' was the best to use under the conditions described in this thesis.

8.2.3 Verification of Current Method

In each of the three experiments, there were 12 plots (four treatments times three replicates) and from each plot a set of 10 penetrometer readings were obtained. Therefore, each experiment had 12 replications of penetrometer determination of soil susceptibility to pugging damage. The treading treatment with 300 cows ha^{-1}, resembling block/strip grazing management, resulted in pugging damage in each of the experiments, confirming the susceptibility of the soil to pugging damage at the time the penetrometer readings were taken.

Generally, the penetrometer readings confirmed that each of the experimental sites were susceptible to pugging damage (i.e. more than 30% of readings penetrated the soil by 2 cm or more), although readings from three of the 36 plots incorrectly indicated that they were not susceptible to pugging damage (Table 8.1, full data in Appendix XIV). The 95% confidence interval of the results was 10% (1 out of 10 readings), therefore, increasing the number of penetrometer readings per plot to 20 is recommended.

Table 8.1 AgResearch Penetrometer readings.

	65% GSM	71% GSM	81% GSM
Mean % of readings penetrating 2 cm or more	39.2	40.0	81.7
s.e. [a]	3.58	3.01	7.47
No. of correct indications [b]	10	11	12
No. of incorrect indications [b]	2	1	0

[a] s.e. is the standard error.
[b] a correct indication was 30% or more of the AgResearch Penetrometer readings penetrating soil by 2 cm or more; an incorrect indication was less than 30% of readings penetrating soil by 2 cm or more.

8.2.4 Analyses of Categories

The current AgResearch Penetrometer method uses the 'depth category' of soil penetration by 2 cm or more (the '2 cm depth category') to determine the soil susceptibility to pugging damage (Betteridge *et al.*, 2003). From the data collected in this thesis, analyses can be carried out on the consistency of these results using other depth categories (e.g. percent of readings penetrating soil by 3 cm or more) when soil was susceptible to pugging damage.

The current '2 cm depth category' correctly determined that soil was susceptible to pugging damage 92% of the time. However, increasing the depth category resulted in a higher rate of incorrect results. That is, when a deeper depth of soil penetration was used the penetrometer will more frequently incorrectly indicate that the soil was not susceptible to pugging damage compared with using the '2 cm depth category' (Figure 8.1). Using deeper soil penetration depth categories also biased the penetrometer readings towards one-off deep penetrations (skewness was up to 2.06).

The '1 cm depth category' was the only 'depth category' that gave a higher rate of correct indications of soil susceptibility to pugging damage compared with the '2 cm depth category'. However, if the '1 cm category' was used to determine soil susceptibility to pugging damage, the 30% threshold for penetrometer readings may need to be increased. Investigation of the penetrometer method on soils that are not susceptible to pugging damage would clarify the efficacy of the 30% threshold while using the 1 cm depth category.

The results indicated that the '2 cm depth category' was, generally, satisfactory as an indicator of susceptibility to pugging damage for soils used in this thesis.

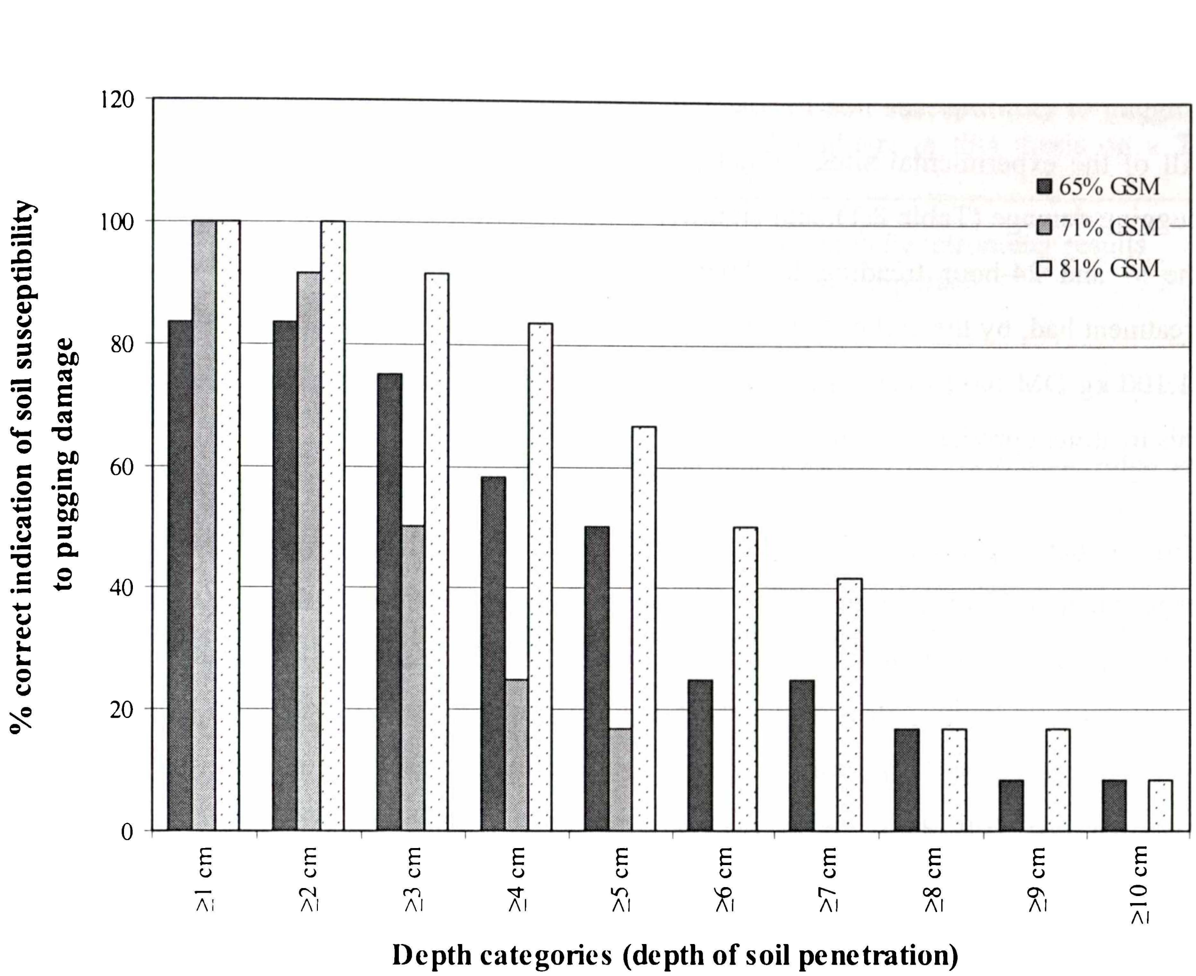


Figure 8.1 The percent of correct indications (30% or more readings exceeding the given 'depth category') of soil susceptibility to pugging damage by the AgResearch Penetrometer using a range of 'depth categories'. *Note*: in the 71% GSM experiment there were no correct readings for categories 6 cm or greater.

8.2.5 Further Development

The developers of the AgResearch Penetrometer (Betteridge *et al.*, 2003) suggested that if more than 30% of readings penetrated the soil by 2 cm or more then care should be taken with grazing as pugging damage was likely.

From the results of this thesis, it may be possible to refine the AgResearch Penetrometer method for the Te Kowhai soil by giving an indication of whether or not a conservative three hour grazing is likely to cause a significant decline in pasture productivity.

All of the experimental sites, as determined by the penetrometer, were susceptible to soil pugging damage (Table 8.1), and significant decline in pasture productivity occurred after all the 9- and 24-hour treading treatments (Sections 5.5 and 6.5). The 81% GSM 3-hour treatment had, by the end of the experiment, significantly (P <0.05) less herbage accumulated (1,100 kg DM ha^{-1}) than controls, in contrast to the 65% and 71% GSM experiments when this treatment produced a similar pasture yield to the controls.

The number of penetrometer readings exceeding 2 cm soil depth was 80% in the 81% GSM experiment and 40% in the 71% GSM experiment. Therefore, if 80% of penetrometer readings exceed 2 cm, and the soil was grazed for three hours, a significant decline in pasture productivity is likely. However, a three hour grazing on the soil with 40% of penetrometer readings exceeding 2 cm, may not result in a decline in pasture productivity. Thus, it was assumed that soil with >40% of the penetrometer readings exceeding 2 cm, even a conservative three hour grazing is likely to result in a decline in pasture productivity.

The method of Betteridge *et al.* (2003) recommends at least 10 readings per unit area to determine soil susceptibility to pugging damage, thus the next practically discernable step above the 40% threshold would be 50% (5 out of 10 readings). Therefore, the existing recommendations of Betteridge *et al.* (2003) have been combined with the findings from this thesis to provide further interpretations of results from the penetrometer on Te Kowhai soils (Table 8.2).

Despite the repeatability of the penetrometer (Section 8.2), the practical limitations are that only one penetrometer reading separates a three hour grazing that does result in pasture productivity decline from one that does not. Therefore, to gain greater certainty of the results, it is recommended that at least 20 readings per unit area be taken when deciding if a three hour grazing of a soil, that is susceptible to pugging, is desirable.

Table 8.2 Use of AgResearch Penetrometer as an indicator of soil susceptibility to pugging damage, based on method of Betteridge *et al.* (2003) and findings in this thesis on a Te Kowhai silt loam at typical grazing density (300 cows ha^{-1}).

% of AgResearch Penetrometer readings of 2 cm soil depth or more	Minimum number of readings	Interpretation of AgResearch Penetrometer results and suggested management approach
0%-29%	10	Normal grazing practices may be used (Betteridge *et al.*, 2003).
30%	10	Treading damage likely, care to be taken, refer to the TREAD Ready Reckoner model (Betteridge *et al.*, 2003).
30%-49%	20	Only conservative grazing to be used, for example maximum of three hours of grazing (at 300 cows ha^{-1}), after which cattle are to be removed from the paddock (e.g. placed on stand-off pads).
50% or greater	10	Any grazing at 300 cows ha^{-1} will result in a decline in pasture productivity, irrespective of grazing duration and, therefore, should be avoided.

8.3 Relationship between Bare ground, Soil Surface Roughness, and Treading Duration

8.3.1 Introduction

Treading damage, and subsequent pugging damage, have been shown previously to result in large open spaces within the sward (bare ground) and increased soil surface roughness (Warren *et al.*, 1986b; Ferrero, 1994; Nie *et al.*, 2001a; Russell *et al.*, 2001; Elliott *et al.*, 2002; Drewry *et al.*, 2003). The increase in soil surface roughness was attributed to the remoulding of soil caused by repetitive cattle treading which also buries herbage, thus increasing the proportion of bare ground. However, aside from the principle that longer treading duration should result in a greater amount of bare ground and soil surface roughness, the scientific literature has little information on how the duration of treading is related to increases in bare ground and soil surface roughness.

From the information in this thesis, the relationship between treading duration, bare ground, and soil surface roughness can be established and quantified for a soil susceptible to pugging damage. Bare ground and soil surface roughness are the clearest visible indicators to farm managers that damage to pasture has occurred and both variables are strongly correlated with decline in pasture productivity (Section 5.5 and 7.2). Therefore, it would be useful to have quantitative information to substantiate the relationship between bare ground or soil surface roughness with treading duration.

8.3.2 Interrelationships

There was a linear relationship between hours of treading and bare ground, and between hours of treading and soil surface roughness (Table 8.3). When gravimetric soil moisture content was included in the model a reliable relationship for bare ground and soil surface roughness was derived (Figure 8.2). Linear relationships between bare ground and treading damage have also been found for a hill-soil (Elliott *et al.*, 2002), where a multivariate regression model reliably (r^2 adj. = 0.69, P <0.05) estimated bare ground. However, in this thesis the rate of increase in bare ground and soil surface roughness was greater in the first 9-hours than for the 9th to the 24th hour of treading. The slower increase rate for the 9th to the 24th hour of treading can be attributed to cattle lie down behaviour during the night causing less treading activity (Krohn & Munksgaard, 1993) and also because by the 9th hour of treading soil surface roughness and bare ground had already increased and further treading may not increasing bare ground and soil surface roughness as readily. Allowing for the slower increase rate in bare ground and soil surface roughness for the 9th to the 24th hour of treading, a polynomial regression (2nd order) gave a better relationship between hours of treading and bare ground, and between hours of treading and soil surface roughness (Table 8.3). The polynomial effect of the increase rate in bare ground and soil surface roughness does not contradict the linear results of Elliot *et al.* (2002), as the variable Elliot used was 'soil damage', which presumably had slower rates of increase over time 'built into' the variable.

The significance of the relationship between hours of treading and bare ground and with soil surface roughness allows for the establishment of general hourly increase rates (Table 8.4). The increase rate of bare ground and soil surface roughness in the first three hours and from the 3rd to the 9th hour of treading (where the grazing began immediately after the morning milking) were similar, therefore, were grouped together. The 9th to the 24th hour of treading had a lower (P <0.05) increase rate compared to the first nine hour of treading, therefore, is presented separately.

Table 8.3 Relationship of hours of treading to bare ground and soil surface roughness.

Equation	r^2	r^2 (adj)	r.s.d.	*P*
Bare ground increase				
$BG = 8.45 + 2.02HR$	0.68	0.67	13.20	<0.001
$BG = -0.92 + 5.98HR - 0.16HR^2$	0.82	0.81	9.92	<0.001
$BG = -57.39 + 5.98HR + 0.16HR^2 + 0.78GSM$	0.88	0.86	8.47	<0.001
Roughness increase				
$SR = 2.03 + 0.41HR$	0.36	0.34	5.26	<0.001
$SR = -0.37 + 1.43HR - 0.04HR^2$	0.48	0.45	4.82	<0.001
$SR = -36.76 + 1.427HR - 0.04HR^2 + 0.50GSM$	0.75	0.73	3.39	<0.001

r^2 = coefficient of determination
r^2 (adj) = adjusted (corrected) coefficient of determination
r.s.d. = residual standard deviation
P = significance of the equation
BG = proportion of bare ground (%)
SR = soil surface roughness index (%)
HR = hours of treading
HR^2 = the square of the hours of treading
GSM = gravimetric soil moisture content (%)
Note The individual significance of each variable contribution to the multivariate regression was $P < 0.05$

Table 8.4 Hourly increase rates for bare ground and soil surface roughness in the first nine hours and from the 9th to the 24th hour of treading.

	First nine hours of treading (increase $hour^{-1}$)	From the 9th to the 24th hour of treading (increase $hour^{-1}$)
Bare ground	4.54%	0.72%
Soil surface roughness	1.06%	0.07%

Note: stocking density was 300 cows ha^{-1} on a Te Kowhai soil with treading commenced at about 7:00 am.

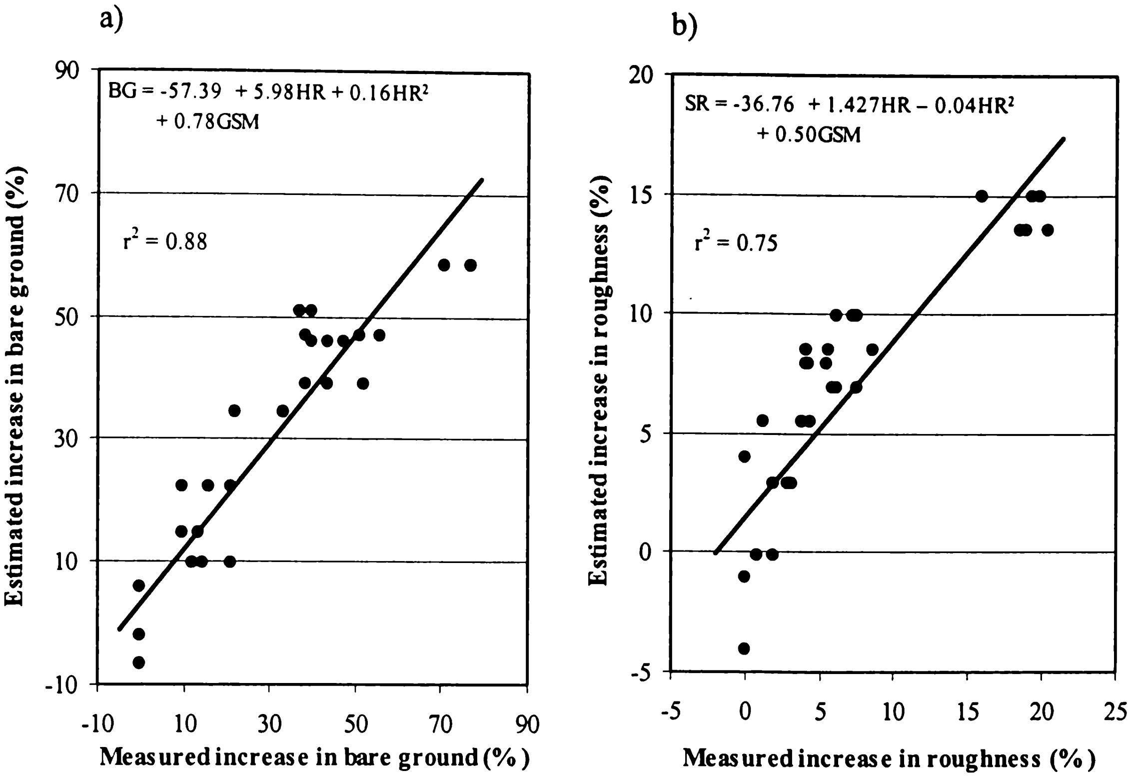


Figure 8.2 The relationship between estimated increases and actual increases for a) bare ground and b) soil surface roughness index, where BG is increase in bare ground (%), SR is increase in soil surface roughness index (%), HR is hours of treading, HR^2 is the square of the hours of treading, GSM is gravimetric soil moisture content (%).

8.4 A Visual Treading Field Guide

8.4.1 Introduction

A Treading Field Guide to categorise treading damage has been developed to simplify the practical application of results from this thesis. The Treading Field Guide is a compilation of several visual indicators, generalised findings of soil physical and sward changes, and photographs. The Treading Field Guide may be a simpler tool for on-farm use than the statistical models from Chapter 7, however, it is important to note that the Treading Field Guide is a generalisation of the thesis findings and so provides quick indications only. More accurate estimation of pasture productivity declines due to treading damage should be obtained from the statistical models (Section 7.2).

8.4.2 Treading Field Guide

The Treading Field Guide is divided into two parts: a pre-treading field guide (Table 8.5) based on a further development of the AgResearch Penetrometer data (Section 8.2), and a post-treading field guide (Table 8.6) based on visual cues such as photography and proportion of bare ground.

The pasture productivity decline as the proportion of the herbage accumulation in the controls at eight weeks after treading treatment was used because, generally, this was when proportional differences between treatments and controls were greatest.

The post-treading field guide also includes bare ground and soil surface roughness as visual indicators of pasture productivity decline, as both bare ground and soil surface roughness reliably estimated pasture productivity decline (Section 5.5 and 7.2). The damage category (Table 8.6) is an indicator used to determine the feasibility of using stand-off pads (Section 8.5).

The Treading Field Guides can potentially be used for soils that are similar to the Te Kowhai. As the post-treading Field Guide uses variables that are a direct measure of treading damage (unlike variables that estimate damage such as hours of treading), the post-treading Field Guide will not be as greatly affected by changes in stocking density than the statistical models (Section 7.4). However, as the Treading Field Guide has not been tested for other soil types, its use should be with care as further testing of the Treading Field Guide is needed.

Table 8.5 Field guide for estimating potential pugging damage and pasture productivity decline before a treading event.

% of AgResearch penetrometer readings ≥ 2cm [a]	Comment	Grazing duration (hours) [c]	Pasture productivity decline [d] (%)	Macropore volume decrease [e] (%)	Saturated hydraulic conductivity decrease [e] (%)
0-29%	Normal grazing practices may be used [b]				
30-49%	Only conservative grazing should be used, i.e. maximum of 3-hour at 300 cows ha^{-1}	3 9 24	Up to 20 20 - 30 30 – 40	Up to 10 10 - 15 15 – 40	Up to 40 40 - 80 80 – 90
>50%	Any grazing at 300 cows ha^{-1} will result in pasture productivity damage, irrespective of duration	3 9 24	Up to 20 20 - 35 35 - 65	Up to 25 25 - 40 40 - 50	Up to 50 50 - 60 60 - 80

[a] see Section 8.2 on details of the amended method of interpreting results from the AgResearch Penetrometer
[b] Betteridge *et al.* (2003)
[c] stocking density of 300 cows ha^{-1}
[d] pasture productivity decline is the proportion decrease in the herbage accumulation in the treatment plots compared to controls eight weeks after treading
[e] estimated decreases in macroporosity and saturated hydraulic conductivity immediately after the treading event

Table 8.6 Field Guide for estimating the potential pasture productivity decline following treading damage.

Damage category	Paddock condition	Close-up	Bare ground (%)	Roughness index (%) [a]	Mean pug depths (mm)	Pasture productivity decline [b] (%)
1			40	10	30	<20
2			50	10	40	20 – 30
3			60	20	60	30 – 40
4			65	10 [c]	40 [c]	40 – 60
5			85	25	80	>60

Note: values are mean of each category rounded to nearest 5^{th} percent or whole number

[a] roughness index determined by % chain length loss

[b] pasture productivity decline is the proportion decrease in the herbage accumulation in the treatment plots compared to controls eight weeks after treading

[c] is correct result; counter-intuitiveness attributed to inherent variability of using actual measurements

8.5 Cost-Benefit Modelling of Pugging Damage Avoidance

8.5.1 Introduction

When soils are susceptible to pugging damage, 'on/off' grazing is recommended, where the cows are removed from the paddock after a short grazing duration onto stand-off pads (also called holding pads) or farm raceways (Crook, 2002; Dexcel, 2003, 2004c, 2004d). The costs of construction and maintenance of stand-off pads have been discussed (Dexcel, 2004a, 2004b) but little is known of the economic benefits. The aim here is to present a mathematical model that gives a general estimation of the feasibility of using stand-off pads. The model only accounts for the avoidance of pugging damage, not compaction damage, and assume that the additional herbage mass (due to the prevention of pugging damage) is consumed by lactating dairy cattle. Estimation can be made on annual revenue loss from a one-off pugging event. The costs from a one-off pugging event can be more precisely estimated using the statistical models (Section 7.2). The cost-benefit models developed here take into account the number of pugging events per year based on simple visual cues from the Treading Field Guide and estimates the economic benefits of using stand-off pads for lactating cows.

8.5.2 Information Input

Data used in this cost-benefit analysis of pugging damage avoidance include pasture productivity decline (Section 6.5) and data on typical costs of stand-off pad construction and maintenance (Dexcel, 2004a, 2004b). The Treading Field Guide (Section 8.4) can be used as a point of reference for a mathematical model, using the annual occurrence of each visual category (level of treading damage) as an input variable to the model. Damage levels four and five of the Field Guide were combined.

Stand-off pads may be constructed with a woodchip surface (Figure 8.3.) or stone/lime surface (usually 'rotten rock' to prevent damage to cow hooves). Stand-off pads constructed with a stone surface are cheaper, but are not recommended for long term use (Dexcel, 2003).

However, 'soft surface' stand-off pads using woodchip or straw, are more favourable for animals lying down and resting (Krohn & Munksgaard, 1993; Fisher *et al.*, 2003; Vickers, 2003). Typical 2004 construction costs (assuming a 200 cow herd) are NZ$90 per cow for woodchip surface (NZ$18,000 total cost) (Dexcel, 2004a). Annual maintenance costs (replacing woodchip, rodent control, etc) have been estimated at NZ$15 per cow (Dexcel, 2004a). If stand-off pads are also used as feed pads, construction costs will increase to NZ$125 per cow, however, giving a dual purpose facility (Dexcel, 2004b). It is assumed that 15 kg of dry matter will, for an efficient dairy farming system, produce 1 kg of milksolids (Penno, 1999). Payout per kilogram of milksolids has varied from NZ$5.33 (2001/2002) to NZ$3.60 (2002/2003), with NZ$4.50 being projected for the 2005 (Fonterra, 2005).

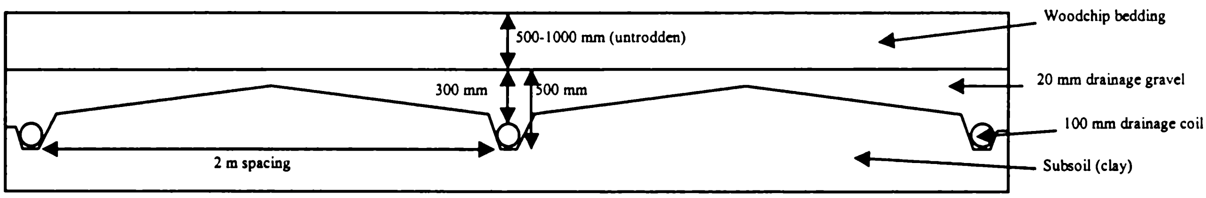


Figure 8.3 Stand-off pad design proposed by Dexcel, using woodchip, drainage gravel, clay subsoil, and drain piping (redrawn from Dexcel, 2004a).

8.5.3 Flexible Mathematical Model for Estimation of Annual Pugging Costs

An estimation of annual farm revenue loss due to pugging damage can be derived when the number of pugging events are put into the model. The 'pugging damage revenue loss' model can be used for various lactating herd sizes, however, the model assumes that pugging damage occurred at a stocking density of 300 cows per hectare on a Te Kowhai soil. The model also assumes that each pugging damage event took place at a site without previous pugging damage (e.g. not a 'sacrifice' paddocks), that full recovery such events had taken place, and had herbage accumulation not been declined the additional herbage would have been consumed by lactating dairy cattle. The model uses absolute values (kg DM ha^{-1}) for the decline in pasture productivity. The model requires input of the following data: number of observed pugging damage events at each damage level, herd size, and return per kilogram of milksolids ($ kg^{-1} MS).

The pugging damage revenue loss model is as follows:

$$C_a = \left(\frac{M_c H_n (T_1 P_1 + T_2 P_2 + T_3 P_3 + T_{4/5} P_{4/5})}{300 D_c} \right) \tag{8.1}$$

Where:

C_a = annual cost of pugging damage ($) if additional herbage was consumed by lactating dairy cattle
T_1 = number of pugging damage events at level one (see Treading Field Guide)
T_2 = number of pugging damage events at level two
T_3 = number of pugging damage events at level three
$T_{4/5}$ = number of pugging damage events at level four and five
P_1 = absolute pasture productivity loss at level one (202 kg DM ha^{-1})
P_2 = absolute pasture productivity loss at level two (1,174 kg DM ha^{-1})
P_3 = absolute pasture productivity loss at level three (2,029 kg DM ha^{-1})
$P_{4/5}$ = absolute pasture productivity loss at level four and five (2,399 kg DM ha^{-1})
D_c = dry matter weight conversion to milksolids (15 kg DM kg^{-1} MS)
M_c = payout per kilogram of milksolids ($ kg^{-1} MS)
H_n = number of cattle in herd used for grazing

8.5.4 Feasibility Models for Stand-off Pad Construction

The on-farm rationale for stand-off pad construction and usage depends on financial considerations. Two models give the financial feasibility of stand-off pad construction and estimation of revenue savings when pugging damage is avoided.

The 'stand-off pad economic feasibility' model estimates the number of years of usage required until the stand-off pad has become profitable (i.e. the number of years required until gains by avoiding pugging damage equals cost associated with the stand-off pad). The model takes into account the cost of construction, maintenance costs per year during the 'pay back' period, the typical number of observed pugging damage events per year at each treading damage level (determined from the Treading Field Guide), size of herd, and return per kilogram of milksolids. The model assumes that maintenance and construction cost per cow are constant (derived from construction and maintenance costs of a woodchip stand-off pad with a capacity for 200 cows). Stand-off pads with a larger capacity may have lower cost per cow.

The stand-off pad economic feasibility model is as follows:

$$Y_n = \left(\frac{H_n C_c}{\frac{H_n M_c (T_1 P_1 + T_2 P_2 + T_3 P_3 + T_{4/5} P_{4/5})}{300 D_c} - H_n C_m} \right) = \left(\frac{H_n C_c}{C_a - H_n C_m} \right) \qquad (8.2)$$

Where:

Y_n = the number of years of pugging avoidance required to cover stand-off pad construction and maintenance costs

C_m = annual cost per cow for pad maintenance (\$15 cow^{-1} year^{-1})

C_c = stand-off pad construction cost per cow (\$90 cow^{-1})

After the initial stage, where pugging avoidance savings are offsetting costs of stand-off pad construction, another mathematical model can be constructed to estimate annual savings by avoiding pugging damage. The 'pugging avoidance savings' model is as follows:

$$R_s = \left(\frac{M_c H_n (T_1 P_1 + T_2 P_2 + T_3 P_3 + T_{4/5} P_{4/5})}{300 D_c} - H_n C_m \right) = (C_a - H_n C_m) \qquad (8.3)$$

Where:

R_s = annual amount of revenue saved by pugging damage avoidance (\$) if additional herbage was consumed by lactating dairy cattle

8.5.5 Examples of Model Usage

The models presented above require input of variables based on the Treading Field Guide, as often visual assessment of treading damage is carried out by farm managers. The models give an estimation of the benefits of using stand-off pads to avoid pugging damage. However, more reliable estimations of pasture productivity decline (or potential pasture productivity decline if using the pre-treading models) from a one-off treading damage event are derived from the statistical models presented as Section 7.2.

Hypothetical examples (Table 8.7) give an indication of the model usage. Example one is based on average climate data obtained during the three experiments described in this thesis (Ruakura Climatological Station, Hamilton from June 1999 to January, 2003, Appendix II). The climate data indicate that there were, on average, five two-day 10-20 mm rainfall events, seven two-day 20-30 mm rainfall events, and six two-day >30 mm rainfall events (however, during the experiments there was lower rainfall than normal, Section 4.4.3). Therefore, in example one (Table 8.7), it is assumed that these rainfall events correspond to treading damage events at damage levels 2, 3, and 4/5, respectively. A nominal 10 treading damage events at level one are assumed. The examples apply to a woodchip surface stand-off pad, but does not take into account alternative treading avoidance techniques such as using raceways, sacrifice paddocks, farm dairy yards (milking shed yards), or grazing free draining soil types instead.

Table 8.7 Examples using the 'pugging damage revenue loss', 'stand-off pad economic feasibility', and 'pugging avoidance savings' models for a Te Kowhai soil.

	Example 1	Example 2	Example 3	Example 4	Example5
Inputs:					
No. level 1[a]	10	12	6	8	10
No. level 2	5	8	6	3	6
No. level 3	7	8	8	5	4
No. level 4&5	6	2	2	4	0
Herd size	300	300	400	400	300
Payout ($) per kg milksolids	3.60	3.60	5.33	4.50	4.15
Outputs: [b]					
Treading cost ($ yr^{-1}) [c]	8,757	7,883	13,874	11,787	4,753
No. of years to cover pad cost [d]	6.34	7.98	4.57	6.22	106.64
Revenue saved ($ yr^{-1}) after pad cost covered	4,257	3,383	7,874	5,787	253

[a] "No. level 1" is number of treading damage events corresponding to damage level one on Treading Field Guide in one year, "No. level 2" is number of treading damage events at damage level 2, etc.
[b] assumes that additional herbage available was consumed by lactating dairy cattle
[c] treading cost is total estimated annual revenue lost due to pugging damage
[d] costs assumed were NZ$15 cow^{-1} $year^{-1}$ for maintenance and NZ$90 cow^{-1} for construction

The examples (Table 8.7) show a range of situations (for a Te Kowhai soil trodden at 300 cows ha^{-1}), including different payout rates per kilogram of milksolids. The models were sensitive to the number of observed severe treading events (level 3 and 4/5). Example one, based on 1999-2001 Ruakura climate data, indicates that the gains from avoiding pugging damage outweighs the costs of stand-off pad construction and maintenance after six years. Example five indicates that if typically minor pugging damage events occur, the use of stand-off pads will not be economically viable. The models were also sensitive to projected payout per kilogram of milksolids. Example two had more pugging damage events than example three, however, as the payout per kilogram of milksolids was higher for the latter (using the 2001/2002 instead of the 2002/2003 payout), the cost-benefit of using stand-off pads became more financially advantageous.

These examples show that if soil is susceptible to severe treading damage during winter/spring, (and typically about 10 moderate to severe treading damage events occur), the investment in a stand-off pad is paid back within five to seven years, after which preventing pugging damage saves $3,000 to $8,000 per year. If soil is not susceptible to regular treading damage (i.e. free draining soils), using stand-off pads may not improve annual revenue. These examples also show that if payout per kilogram of milksolids decreases farm managers may not construct farm facilities favourable to soil and pasture (such as a stand-off pad) or they may use cheaper short-term alternatives such as raceways or metal surfaces rather than woodchip. However, the models do not include the potential benefits of avoiding compaction damage, only that of pugging damage. The potential savings from avoiding compaction damage, which occurs over a greater range of soil moisture contents then 65% to 81% GSM, will likely improve the feasibility of using stand-off pads.

8.6 Summary and Conclusion

The AgResearch Penetrometer method accurately indicated that the soils used in this thesis were susceptible to pugging damage. Further development of the interpretation of penetrometer data indicates when a conservative three hour grazing, after which cattle are removed from the paddock (e.g. placed on stand-off pads), can be used on pugging susceptible Te Kowhai soil without causing a significant decline in pasture productivity.

Soil surface roughness and bare ground were two treading damage variables that could be easily and visually determined. It was found that soil surface roughness and bare ground estimates were repeatable across replicates, providing reliable indications of treading damage and, therefore, can be used as visual indicators for the Treading Field Guide.

The use of the Treading Field Guide simplifies results from this thesis and allows for quick in-the-field indications of potential decline in pasture productivity on Te Kowhai soils. The use of photographs allows for visual comparisons of treading damage while soil surface roughness index and bare ground can be gauged either visually or measured.

The Treading Field Guide could potentially be used for other soils with similar texture or are within the same soil classification order as the Te Kowhai soil. As the post-treading Treading Guide uses variables that directly measure resultant treading damage, changes in stocking density should not greatly affect the pasture productivity decline estimations. However, as the Treading Field Guide has not been tested for other soil types, its use should be with care as further testing of the Treading Field Guide is needed.

Avoidance of pugging damage is the best management option to limit pasture productivity decline due to cattle treading. The practice of on/off grazing requires a stand-off area (e.g. stand-off pads). The economical benefits of using stand-off pads for lactating cows can be determined by using the treading damage levels from the Treading Field Guide and the costs associated with construction and maintenance of stand-off pads. Mathematical models can be used to determine the feasibility of using a stand-off pad rather than letting pugging damage events occur on the farm.

Hypothetical examples, used in the cost-benefit modelling of pugging damage avoidance, indicated that the models were sensitive to the severest form of treading damage (level 4/5) but if treading damage was slight (e.g. level 1 or 2) then the use of stand-off pads may not be economically feasible. The hypothetical examples also showed that the feasibility of stand-off pads was dependent on payout per kilogram of milksolids. If the payout for milksolids was low (e.g. \$3.60 kg^{-1} MS as in the 2001/2002 season) then the feasibility of using stand-off pads becomes marginal and farm managers may not invest in stand-off pads to protect the soil and pasture from treading damage.

Chapter 9. Summary and Recommendations

9. Summary and Recommendations

9.1 Experimental Background

Soils that have high clay content and slow drainage are susceptible to treading damage. Pugging causes soil plastic deformation, destroying soil pores, and burying herbage. Pugging damage causes unfavourable soil conditions (e.g. reduced soil aeration and water infiltration rates) contributing to a decline in pasture productivity. There has been some research of pugging damage effects on soil and pasture productivity, however, past work has largely been one-off investigations without systematic monitoring for sward response when subjected to varying severities of pugging damage. There has been little published research on recovery of soil and sward after a one-off severe treading damage event.

Three experiments were undertaken, using a similar experimental design, however, each experiment had a different gravimetric soil moisture (GSM) content (65%, 71%, and 81%). The experimental site was divided into treatment plots, which were trodden by lactating Holstein-Friesian cows, stocked at 300 cows ha^{-1}, for either zero (control), three, nine, or 24 hours (treading treatments). The treading treatments were replicated three times at each experimental site. After the treading treatments, the experimental sites were again included in the farm grazing rotation.

The experiments were carried out between 1999 and 2002 at the Ruakura Research Station, Hamilton, New Zealand (37° 47'S, 175° 19' E; altitude 40 m above sea level). The soil was the Te Kowhai silt loam (NZ soil classification, *Typic Orthic Gley*; USDA soil taxonomic classification, *Typic Endoaqualf*), a soil common in the Waikato region, New Zealand, that is used for dairy production and known for its susceptibility to pugging damage. The experimental sites had a well-established ryegrass (*Lolium perenne*) and white clover (*Trifolium repens* L.) swards and were used for Holstein-Friesian/Jersey dairy cow grazing.

Soil physical properties (macroporosity, microporosity, saturated hydraulic conductivity [K_{sat}], unsaturated hydraulic conductivity [K_{-40}], soil dry bulk density, and total porosity) at the 0-5 cm and 5-10 cm soil depths were determined before and immediately after the treading treatment. Soil physical properties were then monitored periodically for up to 26 weeks after the treading treatment to determine recovery (if any). Soil surface and sward characteristics (soil surface roughness, proportion of bare ground, botanical composition, tiller density, and herbage accumulation) were also determined before the treading treatment and periodically for up to 34 weeks after the treading treatment.

The experimental design allowed for the systematic determination of the effects of a one-off cattle treading event on soil physical properties and sward characteristics of soil with differing gravimetric soil moisture contents and varying treading durations. The experimental design also allowed for determination of soil and sward recovery after the occurrence of different severities of pugging damage. The results obtained from this thesis were used to estimate potential decline in pasture productivity before treading takes place, and to indicate the likely pasture productivity decline from a one-off pugging damage event.

9.2 Effects of Cattle Treading on Soil and Sward

The soil and sward analyses after a one-off severe treading event on a pugging susceptible Te Kowhai soil provided the following conclusions:

- The effects of the treading treatment on soil physical properties at the 0-5 cm soil depth were greater than at 5-10 cm. Generally, when treading duration was longer and the soil was wetter, the damage to soil physical properties and sward were greater.

- After the treading treatment, macroporosity had decreased (P <0.05) and microporosity increased (P <0.05) at the 0-5 cm soil depth by as much as 0.12 cm^3 cm^{-3}. Changes in macroporosity and microporosity at the 5-10 cm soil depth were only significant when the gravimetric soil moisture content at the time of the treading was 81%.

- When the gravimetric soil moisture content at the time of treading was ≥71%, soil dry bulk density and total porosity did not change after treading treatment (suggesting no soil compaction). However, when gravimetric soil moisture content was 65% and the soil was trodden for 24 hours, the dry bulk density increased (P <0.05) and total porosity decreased (P <0.05).

- The lack of change in soil dry bulk density and total porosity after treading was the result of increases in microporosity offsetting decreases in macroporosity. Soil saturation was up to 89% at the time of soil plastic deformation and there was an inverse correlation (r^2 = 0.63; P <0.001) between macroporosity and microporosity changes. Therefore, it is hypothesised that the increases in microporosity was caused by the redistribution of soil moisture, originally held in the soil macropores, resulting in the formation of new micropores and the destruction of macropores.

- Saturated hydraulic conductivity (K_{sat}) and unsaturated hydraulic conductivity (K_{-40}) were 90% slower (P <0.05) after soil treading in the 24-hour treatments compared with controls.

- The soil surface roughness index increased (P <0.05) from 4.5% to as much as 22% due to the treading of the soil. When gravimetric soil moisture content was 81% and soil was trodden for 24 hours, pug print depths as deep as 80 mm were recorded.

- The proportion of bare ground increased (P <0.05) from 25% to as much as 87% after the treading of the soil. Increases in the area of bare ground after treading were significant (P <0.05) compared to controls even for soils trodden for only three hours.

- At all experimental sites tiller density decreased (P <0.05), by as much as 66% compared with controls after treading.

- Sward botanical composition only changed in plots trodden for nine and 24 hours at 71% gravimetric soil moisture content, where the weed content increased in the large open spaces in the sward in spring. Therefore, the time of year that severe treading damage occurs is considered an important factor in sward botanical composition change.

- Herbage accumulation eight weeks after the treading of the soil was as much as 60% less ($P < 0.05$) at trodden sites than in controls. The proportional decrease in herbage accumulated compared with controls was strongly correlated with the amount of bare ground ($r^2 = 0.73$, $P < 0.001$).

- Macroporosity in individual cores, collected from soils which were trodden for nine to 24 hours at gravimetric soil moisture content of ≥ 71%, suggested that there were sporadic occurrences of soil anaerobic conditions restricting root growth.

- Treading caused a decrease in macroporosity, K_{sat}, and K_{-40}, and an increase in microporosity, which will result in the soil remaining wetter for longer after rainfall. Thus pugged soil becomes more susceptible to further pugging damage.

9.3 Recovery of Soil and Sward after Treading Damage

After treading treatment, the recovery of soil and sward were monitored, and the following conclusions were made:

- When soil and sward are retained within the grazing rotation after a one-off severe treading damage event soil macroporosity, microporosity, K_{sat}, K_{-40}, soil surface roughness, proportion of bare ground, tiller density, and rate of herbage accumulation do recover.

- The rate of recovery was different for each variable but, generally, recovery was complete 26 weeks after treading. When soil physical properties at the 5-10 cm soil depth were affected by treading, the time required for full recovery (compared with controls) was similar to the 0-5 cm soil depth.

- As soil susceptibility to further pugging damage is affected by water content, the recovery of macroporosity, microporosity, K_{sat}, and K_{-40} after treading indicates that soil was most susceptible to further pugging damage for up to 13 weeks after the initial pugging. However, the reduction in the proportion of bare ground indicated that the soil was most susceptible to direct damage by cattle hooves for up to 25 weeks after the initial treading.

- With the onset of summer soil dry bulk density decreased (P <0.05) and K_{-40} increased (P <0.05), however, these changes were inconsistent between experiments and conflict with some results reported in the literature.

- Herbage accumulation recovered after the treading treatment. However, the cumulative differences in herbage accumulation compared with controls were as much as 3,940 kg DM ha^{-1} by the time recovery of herbage accumulation was complete 22 weeks after treading.

- When gravimetric soil moisture was ≤71%, a three hour grazing did not result in a significant decline in herbage accumulation. However, when gravimetric soil moisture content was 81% a three hour grazing resulted in a 1,100 kg DM ha^{-1} decline (P <0.05) in herbage accumulation. Therefore, when gravimetric soil moisture content is >71%, a conservative three hour grazing, that is often used when soil is susceptible to pugging damage, should be avoided.

9.4 Statistical Modelling of Treading Damage and Recovery

Multivariate regression models were used to describe the relationship between the variables that were measured. The models can also describe pasture productivity declines, after a one-off severe treading damage event on a Te Kowhai soil with a GSM between 65% and 81% trodden at 300 cows ha^{-1}, and the following conclusions were made:

- The decline in herbage accumulation compared with controls can be estimated using pre-treading variables (i.e. gravimetric soil moisture content, AgResearch Penetrometer results, proposed hours of treading) and post-treading variables (i.e. soil surface roughness index, bare ground, pug print depths).

- The two most reliable pre-treading models for estimating likely pasture productivity decline if treading was to occur were:

$$DPP = -1770.98 + 196.35HR - 4.47HR^2 + 32.11AP \quad (r^2 = 0.72, P < 0.001) \qquad (9.1)$$

$$DPP = -7065.88 + 196.36HR - 4.47HR^2 + 97.00GSM \quad (r^2 = 0.73, P < 0.001) \qquad (9.2)$$

Where:
DPP = total decline in pasture productivity (kg DM ha^{-1}) compared to controls
HR = proposed hours of treading
HR^2 = the square of the proposed hours of treading
AP = AgResearch Penetrometer results (% of readings penetrating soil by ≥2 cm) immediately before treading
GSM = gravimetric soil moisture content (%) immediately before treading
Note: applies to soils with GSM between 65% and 81%

- The most reliable post-treading model for estimating total decline in pasture productivity was:

$$DPP = -701.16 - 155.89HR + 5.49HR^2 + 26.61PD + 122.68SR \quad (r^2 = 0.84, P < 0.001) \qquad (9.3)$$

Where:
DPP = total decline in pasture productivity (kg DM ha^{-1}) compared to controls
HR = actual hours of treading
HR^2 = the square of the actual hours of treading
SR = soil surface roughness index (%) after treading
Note: applies to soils with GSM between 65% and 81%

- The simplest model, however, less reliable than the models above, used only proposed or actual hours of treading:

$$DPP = 215.94 + 84.18HR \quad (r^2 = 0.41, P < 0.001) \qquad (9.4)$$

Where:
DPP = total decline in pasture productivity (kg DM ha^{-1}) compared to controls
HR = proposed or actual hours of treading
Note: applies to soils with GSM between 65% and 81%

- The time required for herbage accumulation recovery after treading damage can be estimated using the pre-treading and post-treading variables. The two most reliable models were:

$$RT = -6.94 + 1.35HR - 0.0032HR^2 + 0.16AP \quad (r^2 = 0.78, P < 0.001) \qquad (9.5)$$

$$RT = -6.10 + 0.36HR + 0.10AP + 0.58SR \quad (r^2 = 0.80, P < 0.001) \qquad (9.6)$$

Where:
RT = time (weeks) required before recovery (i.e. no significant difference compared to controls) of herbage accumulation was complete (recovery time)
HR = proposed or actual hours of treading
SR = soil surface roughness index (%) after treading
AP = AgResearch Penetrometer results (% of readings penetrating soil by ≥2 cm) immediately before treading
Note: applies to soils with GSM between 65% and 81%

- The decline in spring (eight weeks of regrowth) herbage accumulation were most reliably estimated using macroporosity at the 0-5 cm soil depth and averaged K_{sat} at the 0-5 cm and 5-10 cm soil depths:

$$DSH = 1352.46 - 0.63K_{sat0-10} \quad (r^2 = 0.61, P < 0.01) \qquad (9.7)$$

$$DSH = 2373.80 - 10684.10MA_{0-5} \quad (r^2 = 0.70, P < 0.001) \qquad (9.8)$$

Where:
DSH = decline in spring herbage accumulation (kg DM ha^{-1})
$K_{sat0-10}$ = mean saturated hydraulic conductivity (mm hr^{-1}) from the 0-5 cm and 5-10 soil depths
MA_{0-5} = soil macroporosity (cm^3 cm^{-3}) at the 0-5 cm soil depth
Note: applies to soils with GSM between 65% and 81%

- Saturated hydraulic conductivity is an important soil physical property that can be detrimentally affected by treading. Results from this thesis show that K_{sat} at the 0-5 cm soil depth declined at a steady rate with increasing hours of treading, therefore, K_{sat} after the proposed grazing duration can be estimated as follows:

$$K_{sat0\text{-}5} = 1327.78 - 116.40HR + 3.09HR^2 \quad (r^2 = 0.75, P < 0.01) \tag{9.9}$$

Where:
$K_{sat0\text{-}5}$ = saturated hydraulic conductivity (mm hr^{-1}) at the 0-5 cm soil depth
HR = proposed hours of treading.
HR^2 = the square of the proposed hours of treading
Note: applies to soils with GSM between 65% and 81%

- Bare ground and soil surface roughness index were strongly correlated with herbage accumulation decline. Bare ground and soil surface roughness index are visible indicators of treading damage and are, therefore, useful for field estimations of the likely decline in pasture productivity. A Treading Field Guide, including photography of treading damage, has been developed (Section 8.4) and can be used for quick in-the-field estimations of the likely loss in pasture productivity due to treading damage.

- The AgResearch Penetrometer accurately indicated that soils used in this thesis were susceptible to pugging damage. Interpretation of penetrometer data has been extended by this thesis to indicate when (30-49% of penetrometer readings are ≥ 2 cm) a three hour grazing on a pugging-susceptible Te Kowhai soil could be undertaken without causing a significant (P <0.05) decline in pasture productivity.

- The herbage accumulation decline after treading damage has been combined with estimated costs of constructing and maintaining stand-off pads. The cost-benefit models (Section 8.5) can be used to determine potential benefits of using a stand-off pad for lactating cows.

9.5 Potential Applications of the Models and Field Guides

The potential application of the results, models, and Field Guides presented in this thesis are restrained by the parameters of the research: a ryegrass and white clover sward, trodden at a stocking rate of 300 cows ha^{-1}, commencing in the morning (about 7:00am) for no longer than 24 hours on a Te Kowhai soil with a GSM between 65% and 81%.

The Te Kowhai soil moisture contents during the winter/spring period are likely to be ≥65% GSM, therefore, there could be considerable potential for applying the models from this thesis to Te Kowhai soils. There is, however, potential for applying the models and field guides to soils with similar textures as the Te Kowhai soil or to soils within the same Gley Soil classification order. The statistical models using the 'hours of treading' (pre-treading models and some post-treading models) are sensitive to changes in stocking density. However, by making a proportional adjustment to the model coefficient for the 'hours of treading' (Section 7.4), the models could potentially be used to estimate treading effects at different stocking densities. Post-treading variables and the post-treading Field Guide are not as sensitive to changes in stocking density as the 'hours of treading' variable, as they directly measure the resultant treading damage and, therefore, may potentially be easier to use in conditions outside the parameters of this thesis. It is unlikely that there will be a need for applying the field guides and statistical models beyond the soil moisture content ranges used in this thesis, as moisture contents of >81% GSM (89% saturation) do not persist for long periods and moisture contents of <65% GSM are not likely to result in marked declines in pasture productivity.

Nevertheless, extrapolation of the models and Field Guides beyond the thesis parameters should be carried out with care. Experimental testing of these models and Field Guides for treading at different stocking densities and for other soils is recommended.

9.6 Recommendations for Further Research

To further the research achievements made in this thesis, there is a need to carry out experimentation to validate the statistical models and Field Guides on other soil types or soil/pasture conditions.

Published research of soil recovery after treading damage was limited to a few investigations of soils with predominately compaction damage. No published research was found that investigated the recovery of one-off severely pugged soil. Whilst this thesis has established recovery rates for severely pugged Te Kowhai soils, further research is required to establish recovery trends of other soils types subjected to severe pugging damage.

The hydraulic conductivity of soil is an important soil property that influences the duration of soil susceptibility to pugging damage, however, measuring soil hydraulic conductivity is time consuming. To date there have been few attempts to establish models to estimate change in K_{sat} after treading damage using easily determined soil properties (such as bare ground and soil surface roughness). Even though some progress has been made here by the determination of a reliable model, the high inherent variability of K_{sat} causes some uncertainty and further research is needed to determine a variable that best accounts for the K_{sat} variability, thus allowing the establishment of more reliable models.

Greater emphasis needs to be placed on soil macroporosity (>30 μm) when investigating changes in soil structure due to farm management (e.g. excessive cattle treading, farm vehicle compaction). This thesis has shown that when severe soil damage occurs as plastic deformation, the loss of macropore volume was offset by the gain in micropore volume, resulting in no change in soil dry bulk density. Therefore, investigations of soil treading damage and recovery need to include the monitoring of macroporosity, as soil dry bulk density and total porosity are not reliable indicators of soil physical damage.

Changes in soil physical properties were observed with the onset of summer during the experiments, however, the changes were not consistent between experiments or variables. Changes in soil physical properties from season to season have been observed in some other investigations, however, the mechanisms causing the changes are not understood. Seasonal changes in soil structure could be important for soil recovery (or perceived recovery) after treading damage. Thus, further investigation is needed to explain the mechanisms causing seasonal changes in soil physical properties.

It has been suggested in the literature and this thesis that recovery of treading damaged soils could be partly attributed to earthworm activity; however, neither the literature nor this thesis has data to support such claims. Nevertheless, as earthworm activity is important for soil structure formation, investigations are needed to determine the role of earthworms in recovery of soils damaged by treading.

As mathematical models are being designed to simulate farm activities and their effects, more systemic research needs to be carried out under a range of different soil, pasture, and management conditions with the view of incorporating the results into farm-scale models. However, as shown by the comparison of models from this thesis to the more generic model of Betteridge *et al.* (2003), farm-scale models may still have to retain some specificities such as soil type and stocking densities.

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Appendix I

Rising Plate and Pasture Cuts Comparison

Appendix I Comparison of Rising Plate and Pasture Cuts methods for Estimating Herbage Mass

I.1 Experimental Description

I.1.1 Background

The rising plate meter was developed as a quick and simple method of non-destructively estimating herbage mass. At the commencement of the research some debate existed regarding the validity of the rising plate method (e.g. Stockdale, 1984). Since, however, the rising plate method has been used in some agricultural research (e.g. Gourley & James, 1997; Johnson & Morrison, 1997; Bluett *et al.*, 1998; Mosimann & Troxler, 1999; Freckleton *et al.*, 2000; Garcia *et al.*, 2000; Lile *et al.*, 2001; Tharmaraj *et al.*, 2003). To determine the reliability of the rising plate method for estimating herbage mass compared to pasture cuts (cutting by mower and weighing green herbage), a comparison between the rising plate and pasture cuts methods was carried out.

I.1.2 Methods

Within each treatment plot at the 65% GSM experiment, a strip 9 m by 0.46 m (mower width) was set aside for pasture cuts. Prior to pasture cuts by mower, 23 to 26 rising plate measurements were taken along the length of the strip (essentially covering the entire strip) and repeated after the pasture cuts. The difference between the two rising plate results was the amount of herbage removed (cut) by the mower, as determined by the rising plate method. Rising plate measurements and pasture cuts were carried out in two separates times; the 30th of September, 1999 (Data collection one), and the 30th of October, 1999 (Data collection two).

The rising plate results were converted to herbage mass (kg DM ha^{-1}) as outlined in Section 3.12. The herbage was cut to 30 mm height (determined at a previous grazing event as the grazing height) using a rotary lawnmower and catcher (Masport Mars model, Briggs and Stratton Quantum XE50 engine). For each strip, all cut herbage was weighed (bulk green weight), from which three sub-samples of about 150 g were taken and weighed (sub-sample green weight). The sub-samples were oven-dried for 48 hours at 80 °C and re-weighed (sub-sample oven dry weight). The herbage dry matter content (%), as determined using pasture cuts, was then calculated as follows:

$$D_{Ms} = \left(1 - \frac{W_{Gs} - W_{Ds}}{W_{Gs}}\right)100$$

Where:
D_{Ms} = proportion of green sub-sample that was dry-matter (%)
W_{Gs} = green (wet) weight of sub-sample (g)
W_{Ds} = oven-dry weight of sub-sample (g)

$$D_{MT} = \left(\frac{W_{Gb} D_{Ms\bar{x}}}{U_c}\right)$$

Where:
D_{MT} = total dry matter (kg DM ha^{-1})
W_{Gb} = green (wet) weight of bulk sample
$D_{Ms\bar{x}}$ = average proportional dry matter content (D_{ms}) from the 3 replicate sub-samples per mow strip
U_c = unit conversion from mow strip area to hectare area (0.000414)

I.1.3 Results and Discussion

Herbage dry matter masses ranged from 1,295 to 3,603 kg DM ha^{-1} (Table I.1). There was a reliable correlation between results from the rising plate meter and pasture cuts for each data collection set (r^2 = 0.81 to r^2 = 0.82, P <0.001). The variability of the correlation decreased when the two data sets were combined (r^2 = 0.95, P <0.001) (Table I.2, Figure I.1 & I.2). The difference between the combined-data means from both methods was 5%. There was a tendency (17 out of 24 readings) for rising plate estimates to be 6.94% lower than pasture cuts estimates, however, the difference between the means were not significant.

The results of the experiment suggest that estimating herbage mass using the rising plate was as reliable as (i.e. not significantly different from) the pasture cuts methods. Therefore, as the rising plate was a non-destructive method of estimating herbage mass and allowed the experimental plots to be rotationally grazed, it was preferred for the series of experiments carried out in thesis. It can also be concluded that, given its ease and reliability, the use of rising plates by farm managers would give reliable knowledge on herbage mass and aid decision-making on grazing timing and rotation frequency.

Table I.1 Comparison of the pasture cuts method and the rising plate method.

Plot #	Data collection one		Data collection two	
	Pasture cuts herbage mass (kg DM ha^{-1})	Rising plate herbage mass (kg DM ha^{-1})	Pasture cuts herbage mass (kg DM ha^{-1})	Rising plate herbage mass (kg DM ha^{-1})
1	2699	2750	1999	1880
2	3084	2951	1853	2025
3	2871	2696	2353	2315
4	2833	2647	1560	1750
5	2822	2729	2365	2305
6	3033	3185	1684	1585
7	2767	2506	1497	1390
8	2887	2924	1710	1510
9	3239	3310	1768	1455
10	3521	3603	1693	1575
11	3095	2908	1542	1490
12	2900	2598	1527	1295
mean	2979.25	2900.55	1795.92	1714.58
stdev	230.501	323.548	300.269	345.283
s.e.	66.540	93.400	86.680	99.675
r^2	0.813 [a]		0.822 [a]	
P	<0.001 [a]		<0.001 [a]	

[a] The correlation and significance of the correlation between data from the rising plate method and pasture cuts method for each data collection set

Table I.2 Results of the pooled data from both data collections.

Combined data from both data collections sets	Pasture cuts	Rising plate
Grand mean [a]	2387.58	2307.57
stdev	658.651	688.480
s.e.	190.136	198.747
r^2	0.954 [b]	
P	<0.001 [b]	

[a] grand mean was the mean from the pooled data of both data sets
[b] the correlation and significance of the correlation between the two methods from the pooled data

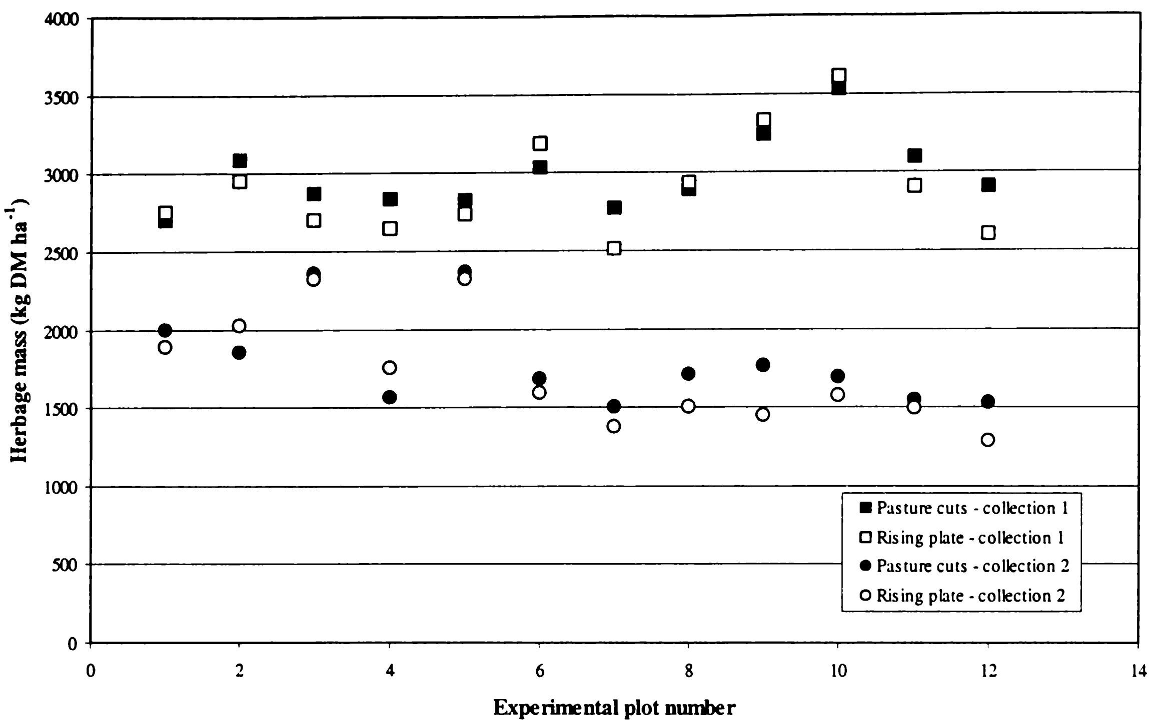


Figure I.1 Herbage mass (kg DM ha^{-1}) at each experimental plot determined by pasture cuts and rising plate for both data sets.

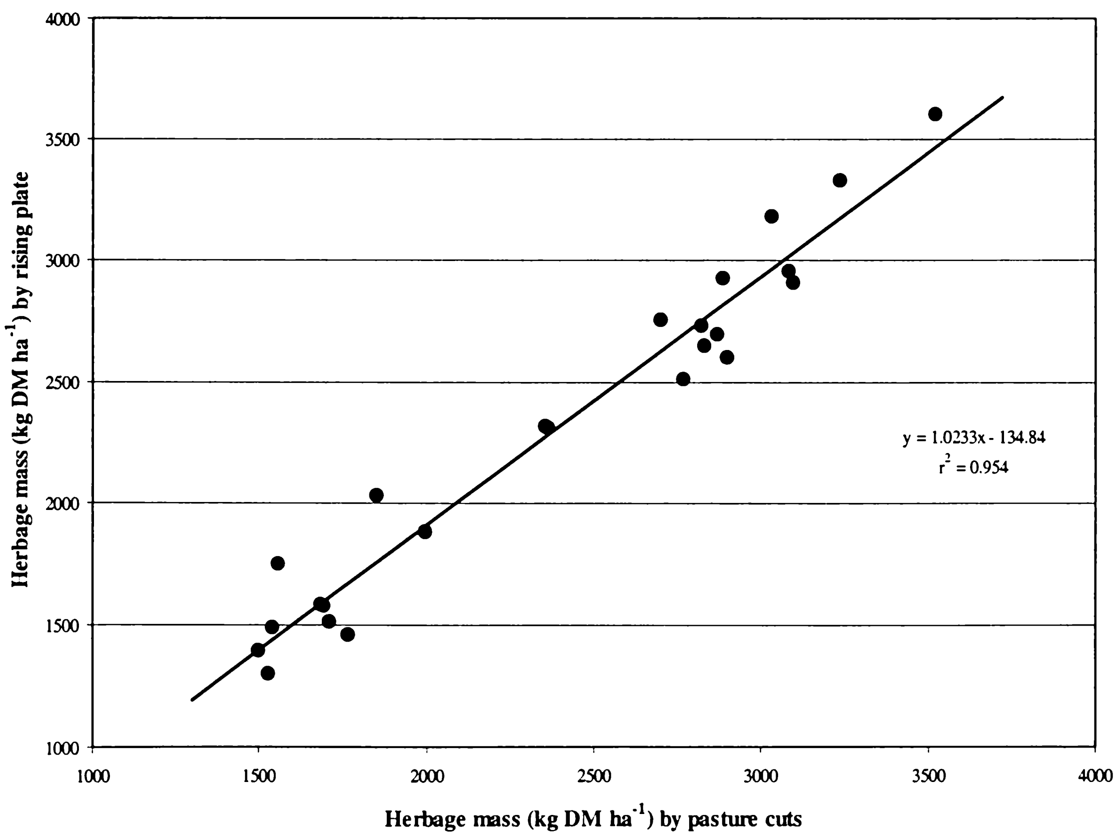


Figure I.2 Regression, using results from both data sets, of herbage mass estimating by pasture cuts and rising plate methods.

I.2 Raw Data

I.2.1 Raw Data from First Data Collection

30-9-1999	Pasture Cuts								Rising Plate (125CMR+640, n = 23)						
									Before pasture cut		After pasture cut				
Plot #	Bulk green weight (kg)	Green Sub-sample reps	Tin weight (g)	Wet weight (g)	Oven dry weight (g)	Net dry weight (g)	Herbage mass (kg DM ha^{-1})	Mean per mow strip (kg DM ha$_{.1}$) cut	Start reading	End Reading	Start reading	End reading	Herbage Mass (kg DM ha^{-1}) before	Herbage Mass (kg DM ha^{-1}) after	Herbage Mass (kg DM ha^{-1}) cut
1	5.68	a	460.8	752.7	517.4	56.6	2660								
		b	460.9	783.5	524.9	64.0	2722								
		c	460.6	743.7	516.6	56.0	2714	2699	752	1447	93125	93314	4417	1667	2750
2	6.36	a	460.6	761.4	521.3	60.7	3100								
		b	461.0	703.9	512.8	51.8	3276								
		c	460.4	783.0	520.8	60.4	2876	3084	1447	2164	93314	93488	4537	1586	2951
3	6.38	a	460.4	805.5	524.6	64.2	2867								
		b	460.5	744.5	513.0	52.5	2849								
		c	460.6	782.9	521.2	60.6	2898	2871	2169	2850	93488	93673	4341	1645	2696
4	6.28	a	460.6	859.3	530.9	70.3	2675								
		b	460.4	773.2	519.7	59.3	2876								
		c	460.6	793.0	525.2	64.6	2948	2833	2850	3529	93673	93865	4330	1683	2647
5	6.38	a	460.9	795.2	518.0	57.1	2632								
		b	460.5	802.0	525.4	64.9	2929								
		c	460.6	736.0	512.5	51.9	2904	2822	3529	4200	93865	94034	4287	1558	2729
6	6.76	a	461.0	849.7	532.2	71.2	2991								
		b	460.8	783.6	521.6	60.8	3076								
		c	460.7	859.5	534.8	74.1	3034	3033	4201	4979	94034	94226	4868	1683	3185
7	5.72	a	460.7	751.7	517.9	57.2	2716								
		b	460.7	805.2	532.8	72.1	2892								
		c	460.9	758.3	518.9	58.0	2695	2767	4979	5650	94226	94436	4287	1781	2506
8	6.22	a	460.9	897.7	540.0	79.1	2721								
		b	460.6	749.5	518.1	57.5	2990								
		c	460.7	764.6	520.4	59.7	2951	2887	5652	6348	94436	94594	4423	1499	2924
9	6.58	a	460.7	754.0	520.8	60.1	3257								
		b	461.6	744.8	518.7	57.1	3205								
		c	460.6	732.5	516.3	55.7	3256	3239	6348	7104	94594	94741	4749	1439	3310
10	8.19	a	461.1	758.6	513.6	52.5	3491								
		b	460.9	838.4	530.0	69.1	3621								
		c	460.8	791.7	518.5	57.7	3450	3521	7107	7913	94742	94885	5020	1417	3603
11	6.40	a	460.3	759.7	521.0	60.7	3134								
		b	460.7	713.5	512.0	51.3	3137								
		c	460.5	790.3	524.8	64.3	3014	3095	7914	8629	94886	95066	4526	1618	2908
12	5.92	a	460.5	779.5	529.2	68.7	3080								
		b	460.6	857.0	539.2	78.6	2835								
		c	460.6	830.9	532.7	72.1	2784	2900	8629	9307	95066	95266	4325	1727	2598

I.2.2 Raw Data from Second Data Collection

30-10-1999	Pasture Cuts								Rising Plate (130CMR+990, n = 26)						
									Before pasture cut		After pasture cut				
Plot #	Bulk green weight (kg)	Green Sub-sample reps	Tin weight (g)	Wet weight (g)	Oven dry weight (g)	Net dry weight (g)	Herbage mass (kg DM ha^{-1})	Mean per mow strip (kg DM ha_{-1}) cut	Start reading	End Reading	Start reading	End reading	Herbage Mass (kg DM ha^{-1}) before	Herbage Mass (kg DM ha^{-1}) after	Herbage Mass (kg DM ha^{-1}) cut
1	3.42	a	460.9	636.2	502.6	41.7	1965								
		b	460.7	637.2	505.4	44.7	2092								
		c	460.8	620.9	498.4	37.6	1940	1999	30460	31001	36555	36720	3695	1815	1880
2	3.70	a	460.7	576.1	484.6	23.9	1851								
		b	460.8	590.3	488.3	27.5	1898								
		c	460.7	594.4	487.8	27.1	1812	1853	31001	31534	36720	36848	3655	1630	2025
3	4.64	a	460.8	599.8	487.3	26.5	2137								
		b	460.6	600.5	491.1	30.5	2443								
		c	460.9	661.1	505.2	44.3	2480	2353	31534	32127	36848	36978	3955	1640	2315
4	2.79	a	460.9	590.8	495.0	34.1	1769								
		b	460.5	602.3	491.0	30.5	1450								
		c	460.6	606.8	492.3	31.7	1461	1560	32127	32623	36978	37124	3470	1720	1750
5	4.98	a	460.8	636.9	495.1	34.3	2343								
		b	460.7	610.3	490.3	29.6	2380								
		c	460.8	608.3	489.9	29.1	2373	2365	32623	33223	37125	37264	3990	1685	2305
6	3.29	a	460.9	623.9	494.1	33.2	1619								
		b	461.0	583.1	486.0	25.0	1627								
		c	460.8	595.0	491.3	30.5	1806	1684	33223	33693	37266	37419	3340	1755	1585
7	2.79	a	460.8	601.1	490.3	29.5	1417								
		b	460.6	584.8	487.7	27.1	1470								
		c	460.5	613.4	496.9	36.4	1604	1497	33696	34103	37419	37548	3020	1635	1390
8	3.20	a	460.6	597.7	490.8	30.2	1703								
		b	460.6	620.4	496.4	35.8	1732								
		c	461.6	589.2	489.6	28.0	1696	1710	34103	34524	37548	37667	3095	1585	1510
9	3.37	a	460.8	600.0	493.0	32.2	1883								
		b	460.6	588.4	488.1	27.5	1752								
		c	460.7	602.2	489.7	29.0	1668	1768	34524	34954	37669	37808	3140	1685	1455
10	3.54	a	460.7	619.8	490.4	29.7	1596								
		b	460.7	599.1	490.5	29.8	1841								
		c	460.8	606.1	488.7	27.9	1642	1693	34955	35399	37815	37944	3210	1635	1575
11	2.60	a	460.7	607.5	496.5	35.8	1532								
		b	460.9	588.7	493.2	32.3	1587								
		c	460.9	572.1	487.6	26.7	1508	1542	35399	35839	37944	38086	3190	1700	1490
12	2.98	a	460.9	585.4	485.9	25.0	1445								
		b	460.8	604.0	491.7	30.9	1553								
		c	460.6	601.5	491.6	31.0	1584	1527	35840	36230	38086	38217	2940	1645	1295

Appendix II

Climate Data

Appendix II Climate Data

II.1 Monthly Climate Data

II.1.1 Mean Monthly Climate Data

	Mean rainfall (mm)	Mean max temp	Mean min temp	Mean grass min temp	Mean 10 cm soil depth temp	Mean humidity	Mean soil moisture	Mean no. of rainy days	Mean no. of frosty days
June	119	14.1	4.7	2.4	8.7	na	na	13	11
July	126	13.6	3.9	1.1	7.5	na	na	14	14
August	117	14.6	5.1	1.1	8.5	na	na	14	11
September	102	16.2	6.7	3.5	10.4	na	na	14	7
October	96	17.9	8.3	4.9	12.9	na	na	12	3
November	93	20.0	10.0	6.7	15.2	na	na	11	1
December	95	22.0	11.6	9.7	17.3	na	na	9	0
January	85	23.8	12.8	9.8	18.6	na	na	8	0
February	71	24.3	13.0	10.3	18.6	na	na	6	0

Note: climate data were obtained from the NIWA Ruakura climate station and is mean results from 1971 to 1995, na = no mean annual results available, soil moisture data collection began in September 2000

II.1.2 The 65% GSM Experiment (1999/2000)

	Rainfall (mm)	Mean max temp	Mean min temp	Mean grass min temp	Mean 10 cm soil depth temp	Mean humidity	Mean soil moisture	No. of rainy days	No. of frosty days
June	90	14.7	4.0	0.7	10.4	97.93	na	14	11
July	138	14.7	3.3	-0.4	9.2	97.48	na	13	13
August	117	14.9	3.7	-0.7	9.4	93.10	na	18	25
September	101	17.1	5.7	1.8	12.5	89.70	na	12	11
October	30	19.3	8.7	4.5	15.8	86.29	na	11	11
November	170	20.7	10.8	8.1	18.0	80.97	na	14	0
December	60	20.6	10.6	8.5	19.9	75.55	na	10	0
January	68	22.5	11.5	9.5	21.3	82.13	na	13	0
February	6	23.2	11.2	9.0	21.9	82.07	na	8	0

II.1.3 The 71% GSM Experiment (2000/2001)

	Rainfall (mm)	Mean max temp	Mean min temp	Mean grass min temp	Mean 10 cm soil depth temp	Mean humidity	Mean soil moisture	No. of rainy days	No. of frosty days
June	88	13.7	4.3	0.8	10.4	90.00	na	12	11
July	110	14.5	6.5	3.6	10.7	84.52	na	13	5
August	83	14.3	2.9	0.1	10.2	91.75	na	17	16
September	95	16.2	5.7	2.9	12.1	83.07	38.79	15	11
October	65	18.5	8.3	4.4	15.5	83.26	38.58	14	7
November	69	18.6	8.7	5.2	16.8	78.13	36.64	11	5
December	89	22.5	13.2	11.0	20.5	81.29	31.77	10	0
January	28	23.3	12.2	9.3	21.0	80.74	29.63	19	1
February	158	24.9	15.1	12.6	22.1	87.86	27.75	11	0

II.1.4 The 81% GSM Experiment (2001/2002)

	Rainfall (mm)	Mean max temp	Mean min temp	Mean grass min temp	Mean 10 cm soil depth temp	Mean humidity	Mean soil moisture	No. of rainy days	No. of frosty days
June	40	14.5	3.4	0.3	9.8	95.27	38.85	11	16
July	90	13.4	2.7	-0.6	8.0	91.77	39.35	9	18
August	56	15.1	5.4	2.3	10.4	92.74	39.05	19	11
September	38	17.1	6.9	2.9	13.4	83.23	37.99	12	6
October	66	19.9	10.4	7.5	16.4	86.94	33.78	16	2
November	134	20.4	11.3	8.7	17.8	82.13	37.61	15	0
December	208	22.3	14.4	12.5	20.2	85.87	35.35	18	0
January	94	23.9	13.6	10.1	21.5	86.03	33.50	18	0
February	22	23.6	12.1	9.1	21.5	86.28	27.58	8	0

II.2 Daily Climate Data

II.2.1 The 65% GSM Experiment (1999/2000)

Date	Max temp	Rain fall (mm)	Min temp	Grass min temp	10 cm soil depth temp	Humidity	Soil moisture
31/05/1999	18.2	4.60	8.6	4.4	15.1	100	na
1/06/1999	17.7	0.00	12.6	12.3	13.9	100	na
2/06/1999	17.2	8.40	7.6	2.5	14.6	100	na
3/06/1999	16.9	2.40	6.1	1.9	13.6	100	na
4/06/1999	14.5	0.20	1.6	-0.8	12.8	100	na
5/06/1999	13.8	15.60	7.4	4.7	11.3	100	na
6/06/1999	18.3	0.00	1.8	-0.9	10.8	85	na
7/06/1999	16	0.00	4.3	-0.7	10.9	100	na
8/06/1999	16.9	0.00	7.7	5.5	10.4	100	na
9/06/1999	16	6.40	-0.1	-3.1	11.3	100	na
10/06/1999	14.8	0.80	2.4	1.2	10.4	100	na
11/06/1999	15.1	0.00	7.5	3	10.2	100	na
12/06/1999	15.9	0.00	10	10.1	11.1	100	na
13/06/1999	16.6	14.60	8.1	3.4	12.3	97	na
14/06/1999	17.6	0.80	10.2	6.1	12.6	100	na
15/06/1999	18.1	1.20	11.4	5.1	12.9	88	na
16/06/1999	17.6	19.20	5.9	-3.3	13.5	91	na
17/06/1999	15.1	16.40	2.1	-1	12.4	100	na
18/06/1999	14.6	0.60	6	1.5	10.4	100	na
19/06/1999	9.3	3.40	4.9	5.6	10.2	100	na
20/06/1999	12.1	0.00	4.2	0.8	10.1	100	na
21/06/1999	13.5	0.00	4	0.2	9.6	95	na
22/06/1999	13.1	0.00	-2.4	-6.1	9	89	na
23/06/1999	13.7	0.00	-1.6	-4.4	7.4	100	na
24/06/1999	14	0.00	0.3	-1.7	6.8	100	na
25/06/1999	10.5	0.00	3.6	0.2	6.7	100	na
26/06/1999	10.7	0.00	1.5	-3.1	8.1	98	na
27/06/1999	13	0.00	-2.2	-5.9	8.7	95	na
28/06/1999	13.6	0.00	-3.3	-7.8	6.7	100	na
29/06/1999	14.1	0.00	-1.5	-4.5	6.3	100	na
30/06/1999	9.7	0.00	0.7	-0.3	5.9	100	na
1/07/1999	15.5	0.00	0.7	-2	6.3	100	na
2/07/1999	16.6	0.00	1.9	2.9	8	100	na
3/07/1999	16.7	1.40	1.7	-1.2	9.6	85	na
4/07/1999	12.8	9.40	-0.2	-2.7	10.2	100	na
5/07/1999	14.8	1.20	0.2	-3.7	7.8	100	na
6/07/1999	14.4	0.00	5.2	1.3	7.6	100	na
7/07/1999	17.2	0.00	4	0.1	8.8	100	na
8/07/1999	17.3	0.00	4.7	1.8	9.3	100	na
9/07/1999	12.4	1.00	-0.3	-5.3	9.4	80	na
10/07/1999	13.9	0.00	-2.3	-5.9	7.5	94	na
11/07/1999	11.5	0.00	-0.6	-2.1	6.4	100	na
12/07/1999	10.9	0.00	4.5	3.3	6.6	100	na
13/07/1999	14.7	0.00	5.2	1.3	8.7	100	na
14/07/1999	15.6	0.20	0.8	-2.9	9	100	na
15/07/1999	15.6	0.00	4.9	5.7	9	100	na
16/07/1999	15.4	9.00	12.1	8.5	9.9	97	na
17/07/1999	18.3	14.80	13.3	9.2	12.3	100	na
18/07/1999	17.7	11.60	12.6	6.9	13.8	97	na
19/07/1999	17.2	29.40	9.9	4.8	13.7	98	na
20/07/1999	17	7.40	6.5	1.1	12.8	100	na
21/07/1999	14.7	9.80	7.4	1.9	11.6	100	na
22/07/1999	16.3	3.80	3.6	-1.2	11.2	100	na
23/07/1999	9.6	0.00	6.4	0.4	10.5	100	na
24/07/1999	14.9	24.60	-0.2	-4.7	9	86	na
25/07/1999	15.5	0.00	4.5	3.2	8.5	100	na
26/07/1999	14.8	6.40	2.6	-3.6	9.8	100	na
27/07/1999	11.8	7.60	-0.9	-5.8	9.3	100	na
28/07/1999	13.8	0.00	-1.7	-6.1	7	90	na
29/07/1999	11.6	0.00	-0.3	-4.6	6.8	100	na
30/07/1999	13.6	0.00	-0.6	-5.5	7.3	95	na
31/07/1999	13.2	0.00	-3.4	-7.3	7.6	100	na
1/08/1999	14.3	0.00	-2.5	-6.6	6.6	97	na
2/08/1999	13.6	0.00	2.6	5.8	6.3	100	na
3/08/1999	15.8	24.80	2.2	-3.1	8.2	100	na
4/08/1999	13.7	0.40	6.7	2.2	9.9	100	na
5/08/1999	12.4	23.40	5.1	-0.5	9.4	100	na

6/08/1999	14.8	5.80	-0.7	-4.5	9.6	100	na
7/08/1999	13.9	0.20	-1.3	-6.5	8.8	99	na
8/08/1999	14.4	0.00	0.2	-4.9	7.1	99	na
9/08/1999	16.2	0.00	0	-4.1	7.3	97	na
10/08/1999	16.4	0.00	1.9	-2.9	7.7	100	na
11/08/1999	15.6	0.00	6.6	0.6	8.4	100	na
12/08/1999	15.9	6.80	7.1	0.9	9.4	97	na
13/08/1999	15.1	9.00	2.3	-1.1	9.8	100	na
14/08/1999	15.1	3.60	7.8	4.6	9.1	100	na
15/08/1999	15.1	0.00	10.8	9.9	10.9	95	na
16/08/1999	13.8	22.00	4.7	0.7	11.5	100	na
17/08/1999	14.4	5.60	2.6	-1.5	11.1	100	na
18/08/1999	12.3	3.20	-2.9	-7.2	9.7	77	na
19/08/1999	14.2	0.00	3.2	-1.1	7.5	100	na
20/08/1999	14.2	0.00	9.6	7.9	8.5	80	na
21/08/1999	13	1.40	5.7	-0.9	10.1	92	na
22/08/1999	14.9	6.40	5.9	0.3	9.3	82	na
23/08/1999	13.8	3.00	7.5	-0.2	10	73	na
24/08/1999	15.5	0.80	10.7	3.9	9.8	82	na
25/08/1999	15.9	0.20	4.7	-2	10.6	75	na
26/08/1999	17.5	0.00	1.4	-3.8	11.3	82	na
27/08/1999	16.8	0.00	0.3	-4.5	10.8	100	na
28/08/1999	14.9	0.00	3.6	-1.5	9.8	100	na
29/08/1999	16.8	0.00	0.7	-3.2	10.1	88	na
30/08/1999	16	0.00	6.6	3.9	10.4	100	na
31/08/1999	16.4	0.00	1.7	-3.2	11.1	71	na
1/09/1999	15.1	0.00	6.8	2.5	11.4	69	na
2/09/1999	17.5	0.40	4.1	-0.5	11.4	100	na
3/09/1999	18.5	0.00	3.2	-1	11.9	100	na
4/09/1999	18.6	0.00	5.2	-0.6	11.8	100	na
5/09/1999	18.1	0.00	4.2	-1.6	12.3	100	na
6/09/1999	18.7	0.00	10.8	5.8	11.9	98	na
7/09/1999	18.1	0.00	11.5	9.9	12.7	96	na
8/09/1999	17.8	16.00	8.2	5.6	13.7	93	na
9/09/1999	14.9	1.20	4.2	0.1	14	73	na
10/09/1999	15.6	0.00	0	-3.8	12.2	74	na
11/09/1999	15.4	0.00	5.2	2.9	11.2	100	na
12/09/1999	17.4	0.00	12.6	10.1	11.5	78	na
13/09/1999	16.3	0.80	11.9	9.4	12.3	91	na
14/09/1999	18.6	33.60	9.7	6.2	13.5	98	na
15/09/1999	19.4	0.80	7.7	2.7	14.7	93	na
16/09/1999	15.1	4.20	7.3	0.9	13.8	100	na

17/09/1999	19.9	19.40	2.7	-0.8	12.4	88	na
18/09/1999	17.2	0.00	7.3	3.1	13.6	100	na
19/09/1999	14.7	0.00	9.6	6.2	12.4	97	na
20/09/1999	16.8	11.40	4.8	1	12.4	78	na
21/09/1999	14.6	7.80	4.3	-2	12.8	90	na
22/09/1999	16.8	0.40	1.3	-2.9	10.9	68	na
23/09/1999	17.6	0.00	1.3	-2.6	10.4	93	na
24/09/1999	17.7	0.20	2.1	-1.4	11.3	97	na
25/09/1999	17.7	0.00	5.6	1.2	12.9	100	na
26/09/1999	18	0.00	10.7	9.4	13	91	na
27/09/1999	16.5	4.80	-0.7	-4.2	14.9	80	na
28/09/1999	16.7	0.40	1	-1.6	12.3	72	na
29/09/1999	16.9	0.00	4.4	-0.7	12.3	95	na
30/09/1999	17.6	0.00	3.3	-0.4	12.4	79	na
1/10/1999	19.3	0.00	8.6	4.5	13.3	100	na
2/10/1999	17	0.00	11.1	6.3	14.2	84	na
3/10/1999	17.4	0.00	4.3	-1.6	13.4	72	na
4/10/1999	18.7	0.00	4.9	0.6	14.4	92	na
5/10/1999	20.9	0.00	6.3	1.4	14.9	100	na
6/10/1999	21.6	0.00	9.9	5.4	15	100	na
7/10/1999	20	0.00	14.9	14	17.2	91	na
8/10/1999	16.9	0.20	14	12.3	16.4	97	na
9/10/1999	21.9	13.00	8.6	4.3	15.8	85	na
10/10/1999	19.9	0.00	12.7	8.3	16.8	88	na
11/10/1999	21.8	0.00	10.9	8	16	81	na
12/10/1999	19.6	0.00	10.4	6.1	18.8	94	na
13/10/1999	19.8	1.00	7.3	2.4	16.8	97	na
14/10/1999	18	0.00	4.1	-0.7	16.4	84	na
15/10/1999	15.9	1.60	0.3	-4.8	14.7	69	na
16/10/1999	17.4	0.00	1.8	-2.5	13.7	83	na
17/10/1999	19.1	0.00	4	-0.8	14.4	80	na
18/10/1999	18.9	0.00	9.4	5.6	16.1	97	na
19/10/1999	19.5	0.00	4.9	-1.8	16.3	81	na
20/10/1999	20.5	0.00	10.5	5.8	16.3	79	na
21/10/1999	17.5	0.20	10.1	4.9	17.2	89	na
22/10/1999	18.5	3.60	5.4	0.1	14.9	76	na
23/10/1999	19.1	0.00	7	1.8	15.6	72	na
24/10/1999	20.2	0.00	4.6	-0.3	16.5	89	na
25/10/1999	18.3	0.40	10.2	6	15.7	76	na
26/10/1999	18.8	0.00	12.2	10.1	16.3	88	na
27/10/1999	18	0.00	14.5	12.8	15.9	79	na
28/10/1999	17.2	1.60	14.2	12.1	16.1	96	na

29/10/1999	20.9	8.00	10.2	5.2	16.3	84	na
30/10/1999	23.4	0.00	10.3	6.2	16.9	84	na
31/10/1999	23.3	0.00	11.5	7.9	17.8	88	na
1/11/1999	22.5	0.00	10.5	6.2	19.7	81	na
2/11/1999	22.1	0.00	14.1	11.8	19.1	82	na
3/11/1999	21.5	0.00	15.3	12.1	19.7	89	na
4/11/1999	19.4	0.00	15.8	13.2	18.7	85	na
5/11/1999	21.4	15.60	14	9.6	17.4	85	na
6/11/1999	23.1	3.60	16.1	15.2	17.9	89	na
7/11/1999	21.7	11.60	14.3	11.6	18.4	88	na
8/11/1999	22.3	9.00	13.9	10.6	18.2	83	na
9/11/1999	22.8	22.40	15.6	13.3	18.9	92	na
10/11/1999	22	0.80	16.3	15.3	18.6	93	na
11/11/1999	22.4	33.20	12.3	10	18.5	89	na
12/11/1999	18.9	2.80	6.6	1.2	18.5	81	na
13/11/1999	18.8	2.40	6.1	2.8	16.5	60	na
14/11/1999	20.9	0.00	6.5	2.9	16.7	78	na
15/11/1999	22.1	0.00	7.7	3.7	17.1	83	na
16/11/1999	23.1	0.00	10.8	6.2	17.7	83	na
17/11/1999	23.1	0.00	11.8	8.4	19	75	na
18/11/1999	17.7	0.00	11.2	7.7	19.5	82	na
19/11/1999	19.3	8.00	11	10.4	17.4	66	na
20/11/1999	18.1	0.00	5.5	2.6	18.5	71	na
21/11/1999	17.2	0.00	3.8	1.2	17.4	80	na
22/11/1999	19.1	1.00	5.1	0.9	16.2	66	na
23/11/1999	20.9	0.00	5.4	1.9	16.8	67	na
24/11/1999	18.7	0.00	11.7	9.5	18.2	80	na
25/11/1999	24.1	2.00	12.9	13.5	17.6	80	na
26/11/1999	21.4	10.80	10.9	7.8	20	86	na
27/11/1999	22.1	0.00	12.3	12.6	18.5	82	na
28/11/1999	16.5	35.80	10.5	10.3	18.3	96	na
29/11/1999	18.3	10.00	8.3	5.4	16.1	93	na
30/11/1999	20.4	0.60	7.2	5	15.9	64	na
1/12/1999	20.5	0.00	14.5	14.4	17.6	79	na
2/12/1999	21.2	0.00	12.7	10.2	18.4	77	na
3/12/1999	20.4	0.00	15.1	13.1	18.6	73	na
4/12/1999	22.4	0.00	7.8	4.3	19.4	76	na
5/12/1999	23.8	0.00	14.2	12	19.8	77	na
6/12/1999	22.7	0.00	11.1	7.7	21.5	81	na
7/12/1999	21.8	0.00	10.3	7.3	21.5	75	na
8/12/1999	19.9	7.20	9.1	5.2	20.7	72	na
9/12/1999	21.4	0.00	7.3	3.9	20.8	64	na

10/12/1999	20	0.00	7.2	4.4	20.9	81	na
11/12/1999	21.3	0.00	14.4	13.3	20.8	85	na
12/12/1999	21.5	6.00	14.6	13.2	20.4	97	na
13/12/1999	20.5	14.00	10.8	9.2	20.3	83	na
14/12/1999	16.5	3.80	6.2	2.8	18.8	58	na
15/12/1999	19.3	0.80	7.2	4	16.8	69	na
16/12/1999	18.9	0.00	7.1	4.2	18.9	73	na
17/12/1999	20.8	0.00	9.5	6.5	19.1	83	na
18/12/1999	21.6	0.00	13.5	11.9	20.6	78	na
19/12/1999	20.8	0.00	12.4	10.4	21	84	na
20/12/1999	20.3	10.80	10.4	9.6	19.8	66	na
21/12/1999	17.1	0.00	11.6	10.7	20.1	80	na
22/12/1999	20.1	3.40	5.3	3.3	17.2	66	na
23/12/1999	22.5	0.00	9.7	5.8	19.5	73	na
24/12/1999	20.5	0.00	5.5	2.2	21.1	78	na
25/12/1999	19.9	0.00	8.9	7.7	21	74	na
26/12/1999	21.1	13.40	9.1	6.6	19	74	na
27/12/1999	20.6	0.20	11.8	10.9	19.1	60	na
28/12/1999	20.4	0.00	12.5	11.5	20.7	64	na
29/12/1999	20.8	0.00	12.8	12	21.1	85	na
30/12/1999	20.6	0.00	13.3	11.4	21.8	83	na
31/12/1999	19.5	0.00	13.8	14	21.6	74	na
1/01/2000	24.7	4.20	13.9	11.1	19.4	92	na
2/01/2000	22.8	2.40	13.9	12.4	21.4	84	na
3/01/2000	18.8	2.00	7.5	4.4	21	93	na
4/01/2000	18.2	0.40	6.1	3.2	19.6	86	na
5/01/2000	21.8	5.60	11.4	9	18	76	na
6/01/2000	21.6	0.00	7.5	4.8	20.3	83	na
7/01/2000	23.2	0.00	12.8	11.1	20.2	94	na
8/01/2000	21.2	0.00	11.1	7.3	21.6	83	na
9/01/2000	21.2	0.00	11.5	9.4	22.2	75	na
10/01/2000	22.3	0.80	11	9.6	20.4	76	na
11/01/2000	20.4	17.00	10.5	8.7	20.3	64	na
12/01/2000	20.8	0.00	11.5	9.4	19.1	64	na
13/01/2000	22.6	0.00	8.8	7.1	20.5	68	na
14/01/2000	25.1	0.00	11.8	10.7	21.7	81	na
15/01/2000	23.5	0.00	12.7	11.8	23.9	81	na
16/01/2000	21.1	0.00	14.6	12.9	23	85	na
17/01/2000	24	0.00	9.2	7.9	21.7	80	na
18/01/2000	24	0.00	11.2	9.8	23.1	93	na
19/01/2000	23.2	0.00	14	13.8	22.9	83	na
20/01/2000	23.7	5.20	11.8	10.6	21.3	84	na

21/01/2000	24.4	0.00	9.9	6.3	21.6	78	na
22/01/2000	25.1	0.00	14.8	11.8	22.9	86	na
23/01/2000	24.1	0.00	15.5	12.6	24	80	na
24/01/2000	26.6	0.00	17.2	16.2	22.8	74	na
25/01/2000	19.6	4.20	7.6	4.1	23.3	92	na
26/01/2000	22.5	16.20	11.3	12.2	19.2	81	na
27/01/2000	21.7	0.20	7.7	4.1	20.7	83	na
28/01/2000	22.8	0.00	10	6.6	20.8	88	na
29/01/2000	23.7	0.00	15.3	15.2	21	84	na
30/01/2000	24	2.20	12.4	9.9	21.3	93	na
31/01/2000	19.9	7.40	12.7	10.4	20.7	82	na
1/02/2000	19	0.80	11.4	10.3	19.8	62	na
2/02/2000	20.4	0.00	6.8	2.9	19.2	67	na
3/02/2000	20.3	0.00	5.4	1.8	20.1	66	na
4/02/2000	19.8	0.00	13.1	9.9	20.5	78	na
5/02/2000	24.7	0.00	9.8	5.7	20.8	81	na
6/02/2000	22.5	0.00	15.7	13.5	22.4	85	na
7/02/2000	21.9	0.00	10.4	7.3	22.8	76	na
8/02/2000	21.9	0.00	8.7	6.8	23	67	na
9/02/2000	23.7	0.00	8.8	4.7	22.6	98	na
10/02/2000	24.7	0.00	11.7	8.7	22.2	81	na
11/02/2000	25.8	0.00	15.8	14.1	22.9	96	na
12/02/2000	23.8	0.00	13.3	9.6	23.2	79	na
13/02/2000	25.3	0.00	13.4	11	23	78	na

14/02/2000	22.7	0.60	16.8	15.7	23	90	na
15/02/2000	22.4	2.00	16.1	14.4	21.4	84	na
16/02/2000	20.5	0.40	12.5	10.5	20.9	90	na
17/02/2000	23.8	2.00	8.4	6.5	20.4	92	na
18/02/2000	24.3	0.00	14.4	13.6	21.6	78	na
19/02/2000	24.3	0.20	8.3	5.9	21.9	72	na
20/02/2000	25.3	0.00	7.8	6.6	22	81	na
21/02/2000	22.2	0.00	10.6	9.3	22.4	96	na
22/02/2000	25.7	0.00	14	12.3	21.4	88	na
23/02/2000	24.4	0.20	7.3	5	22.8	68	na
24/02/2000	24.9	0.00	9.5	7.9	22.4	79	na
25/02/2000	22.9	0.00	13.2	15.4	22.4	96	na
26/02/2000	24.6	0.00	9.8	7.9	22.8	82	na
27/02/2000	24	0.00	12.9	8.9	23	95	na
28/02/2000	24.1	0.00	8.3	6.6	22.6	84	na
29/02/2000	na	0.00	na	na	22.3	91	na
1/03/2000	na	0.00	na	na	22.5	86	na

II.2.2 The 71% GSM Experiment (2000/2001)

Date	Max temp	Rainfall (mm)	Min temp	Grass min temp	10 cm soil depth temp	Humidity	Soil moisture
31/05/2000	15.8	16.80	9	5.1	13	98	na
1/06/2000	16.4	7.20	7	2.3	13.4	93	na
2/06/2000	14.5	6.80	7.1	3.7	13.3	86	na
3/06/2000	14.4	5.20	8.3	5.8	12.5	98	na
4/06/2000	12.5	21.80	8.5	3.7	12.4	92	na
5/06/2000	15.1	16.60	8.2	3.4	11.2	68	na
6/06/2000	14.8	0.00	5.7	2.3	11	66	na
7/06/2000	10.5	3.80	4.4	0.9	11.3	97	na
8/06/2000	13.7	5.40	-1.5	-4.7	10.7	84	na
9/06/2000	12.7	0.00	1.4	-2.8	9.5	98	na
10/06/2000	13.8	0.00	4.9	0.1	9.1	97	na
11/06/2000	14.9	3.40	3.5	0.8	9.9	89	na
12/06/2000	11.1	2.20	-3.4	-7	10.3	95	na
13/06/2000	9	0.40	-4.3	-10.4	8.8	82	na
14/06/2000	9.4	0.00	-3.1	-8	6.7	95	na
15/06/2000	11.6	0.00	-1.6	-3.9	6.4	98	na
16/06/2000	9.9	0.00	2.5	3.9	7	98	na
17/06/2000	14.2	0.00	6.4	3	8.2	93	na
18/06/2000	16.2	0.20	5.6	-0.4	10	88	na
19/06/2000	13.4	0.00	2.9	-1.2	11.2	81	na
20/06/2000	12.5	0.00	6.2	1.7	10.5	96	na
21/06/2000	11.8	0.00	-0.3	-3.2	10.6	94	na
22/06/2000	14.3	0.00	-0.1	-3.5	9.9	98	na
23/06/2000	14.7	0.00	2.8	-2.6	8.9	97	na
24/06/2000	15.6	0.00	5.3	0.8	9.1	98	na
25/06/2000	17	0.00	9.3	6.1	10	84	na
26/06/2000	16.1	0.00	10.2	8.3	11.6	90	na
27/06/2000	14.1	0.00	11.3	10.9	12	78	na
28/06/2000	14.2	3.00	12.1	11.3	12.1	77	na
29/06/2000	14.2	11.40	6.4	3.1	12.5	91	na
30/06/2000	17.2	1.00	4.3	0.7	12.8	99	na
1/07/2000	15.7	0.00	6.2	8.8	12	99	na
2/07/2000	14.7	2.00	11.1	10	11.7	83	na
3/07/2000	15.7	1.80	10.9	9	12.1	89	na
4/07/2000	16.2	1.40	7.5	2.6	12.1	67	na
5/07/2000	15.1	0.00	9.2	5.8	11.5	72	na
6/07/2000	16	0.20	7	2.6	11.1	71	na
7/07/2000	16	0.00	4.9	1	11.3	68	na
8/07/2000	14	0.00	1.4	-3.4	10.3	71	na
9/07/2000	14.3	0.00	1.1	-3.3	9.3	85	na
10/07/2000	14.7	0.00	-0.7	-6.6	8.5	89	na
11/07/2000	14.1	0.00	0.2	-4.2	7.9	96	na
12/07/2000	13.1	0.00	3.6	0.2	7.4	87	na
13/07/2000	13.6	0.00	5.4	1.4	7.5	77	na
14/07/2000	14.5	0.00	10.4	9.2	8.4	78	na
15/07/2000	13.6	0.00	10.2	9.6	9.8	74	na
16/07/2000	13.6	0.00	7.2	4.2	10.6	69	na
17/07/2000	15	0.00	7.2	4.1	10.6	70	na
18/07/2000	13	0.00	8.9	8.9	10	76	na
19/07/2000	15.3	0.60	11.8	10.9	10.6	92	na
20/07/2000	15.6	8.60	12.1	10.8	12.5	94	na
21/07/2000	17.2	8.40	6.6	3.8	13.1	94	na
22/07/2000	15.3	0.40	7.4	3.1	12.8	98	na
23/07/2000	14	11.60	2	-2.3	11.8	80	na
24/07/2000	14.1	0.40	6.1	1.7	10.6	97	na
25/07/2000	14.5	0.00	9.7	6.9	10.1	84	na
26/07/2000	15.6	21.80	7.3	4.5	11.1	95	na
27/07/2000	17	16.20	11.2	9.1	12.4	90	na
28/07/2000	11.9	25.80	6.6	3.5	12.9	95	na
29/07/2000	11.2	10.40	1.5	-1.7	12.1	95	na
30/07/2000	12.2	0.20	5.1	3	10.4	98	na
31/07/2000	13.9	0.00	2.3	-2.8	10.2	87	na
1/08/2000	14.1	0.00	-1.2	-5.6	10.3	98	na
2/08/2000	13.7	0.00	-0.4	-6.6	9.2	98	na
3/08/2000	13.3	0.00	3.9	4.9	8.7	91	na
4/08/2000	12.9	7.40	1.7	-3.8	9.2	97	na
5/08/2000	12.6	0.80	-1.1	-8.4	9.9	98	na
6/08/2000	14.7	0.00	-2.2	-6	9.4	90	na
7/08/2000	14.3	0.00	-0.6	-3.5	8.3	98	na

8/08/2000	11.5	0.00	4.5	1.9	8.3	98	na
9/08/2000	13.8	0.00	5.4	2	9.3	70	na
10/08/2000	16.2	0.00	8.1	8.4	10.6	90	na
11/08/2000	15.4	14.60	5.5	0.1	11.4	85	na
12/08/2000	12.5	7.40	-2.1	-6.2	11.5	78	na
13/08/2000	13.6	0.00	1.6	-3.3	9.9	96	na
14/08/2000	14.6	0.00	-1.5	-5.3	9.3	91	na
15/08/2000	14.2	0.00	-1.6	-5.7	9.3	92	na
16/08/2000	13	0.00	3.2	3	8.6	98	na
17/08/2000	13.4	0.00	9.2	9.4	7.9	na	na
18/08/2000	16.4	14.40	7.2	7.7	11	na	na
19/08/2000	13.5	7.40	8	5	11.9	na	na
20/08/2000	15.6	0.80	2	-0.2	11.7	na	na
21/08/2000	15.6	0.00	2.8	0.9	11	na	na
22/08/2000	14	0.00	3.3	0.3	10.8	na	na
23/08/2000	12.8	0.40	-2	-6.5	10.7	na	na
24/08/2000	13.8	0.00	-1	-4.9	9.7	na	na
25/08/2000	12.8	0.00	4.4	7.9	8.8	na	na
26/08/2000	15.2	2.80	5	2.4	9.8	na	na
27/08/2000	16.5	4.40	5.2	2.8	11.2	na	na
28/08/2000	15.6	1.20	2.2	0	11.8	na	na
29/08/2000	17	0.20	7.7	5.2	11.5	na	na
30/08/2000	13.5	1.60	8	5.1	12	na	na
31/08/2000	16	19.60	5	3.5	11.8	na	na
1/09/2000	14.4	4.80	2.1	-0.1	12.2	na	na
2/09/2000	15.2	0.80	1.4	-0.9	11.1	na	na
3/09/2000	14.1	0.40	-0.1	-2.1	10.2	na	na
4/09/2000	15.7	0.00	4.8	1.6	10.4	na	na
5/09/2000	12.5	4.20	7.8	6.7	11	na	na
6/09/2000	16.8	19.00	10.4	10	10.7	na	na
7/09/2000	14.9	10.40	10.9	10.5	12.7	na	na
8/09/2000	17.1	19.20	10	8.1	12.9	na	na
9/09/2000	17.3	0.00	10.1	9	13.3	na	na
10/09/2000	15.1	7.20	3	-0.1	13.5	na	na
11/09/2000	15.1	1.40	1	-2.1	12.7	na	na
12/09/2000	15.1	0.00	4.9	2	11.4	na	na
13/09/2000	13.2	0.00	4	0.8	11.5	na	na
14/09/2000	17	7.00	4	-	10.9	na	na
15/09/2000	15.6	0.00	0.7	-3	5.7	na	na
16/09/2000	16.6	0.00	3.8	-1.3	11.3	93	na
17/09/2000	17.1	0.00	1.8	-2.1	12.5	86	39.6
18/09/2000	16.6	0.00	5.8	-0.7	12.4	98	39.3

19/09/2000	17.3	0.00	13.3	12.9	12.5	84	39.2
20/09/2000	17.6	1.00	14.1	12.2	13.4	88	39
21/09/2000	20.8	1.20	6.4	1.9	14.2	81	38.8
22/09/2000	17.5	0.00	5.3	0.7	15.3	97	38.6
23/09/2000	18.6	0.00	8.9	4.4	13.9	83	38.5
24/09/2000	18.3	0.00	4.6	0.8	14.4	79	38.3
25/09/2000	15.2	0.00	4.3	3.7	14.5	90	38.1
26/09/2000	13.7	8.80	-1.6	-6.8	11.8	60	39
27/09/2000	16.2	0.00	0	-5	10.8	70	39.1
28/09/2000	16.6	0.00	2	-2.8	11.3	76	38.7
29/09/2000	17.4	0.00	11.9	11.8	12	77	38.3
30/09/2000	17.7	9.40	14.5	14.2	13.2	84	38.5
1/10/2000	17.2	2.40	14.5	13.8	14.4	91	39.4
2/10/2000	16.6	10.00	10.1	5.4	14.7	91	41.7
3/10/2000	17.5	12.40	10.3	7	14.3	84	42.8
4/10/2000	17.5	1.00	8.9	5.1	14.5	77	42.5
5/10/2000	16.8	1.80	11.6	10	13.8	70	41.8
6/10/2000	18.1	0.00	12.9	9.8	14.3	68	41.4
7/10/2000	19	0.00	13.4	11.7	15.5	78	40.9
8/10/2000	19.7	0.00	13.7	10.6	15.9	92	40.4
9/10/2000	17.8	0.00	6.3	2.9	16.1	81	40.1
10/10/2000	17	3.00	6.7	2	14.2	80	39.9
11/10/2000	14.1	2.60	6.5	3.5	14.3	95	39.8
12/10/2000	15.2	22.80	5.2	0.1	12.9	88	43.3
13/10/2000	17.9	3.00	2	-2.3	12.8	73	42
14/10/2000	18.7	0.20	6.3	1.7	13.2	81	41.7
15/10/2000	16.8	0.00	7	2.8	14.3	90	41.3
16/10/2000	19.2	0.40	2.6	-0.8	14.3	90	40.6
17/10/2000	18.7	0.00	6	1	15.1	97	39.9
18/10/2000	16.9	0.00	2.4	-3	15.5	63	39.1
19/10/2000	17	0.00	3	-1.8	15.2	72	38.4
20/10/2000	17.9	0.00	4.2	-0.7	15.4	65	38
21/10/2000	20.7	0.00	6.4	1.6	16	83	37.5
22/10/2000	21.7	0.00	6.5	3.2	16.7	86	36.7
23/10/2000	20.2	0.00	6.3	2.2	17.5	97	35.9
24/10/2000	18.1	0.00	12.8	9.6	17	78	35.2
25/10/2000	19.9	0.00	11.5	9.4	16.9	85	34.7
26/10/2000	20.9	0.00	11.7	8.7	17.7	81	34.3
27/10/2000	21	0.00	7.5	2.2	17.7	93	33.7
28/10/2000	20.5	0.00	9.9	4.7	18	85	33.4
29/10/2000	21.5	0.00	12.4	7.5	17.7	88	33.5
30/10/2000	21.2	3.20	7.7	3.2	17.8	90	33.2

31/10/2000	18.4	2.60	9.7	5	18	89	33
1/11/2000	20.4	0.60	10.4	6.6	16.7	77	32.6
2/11/2000	20.4	0.00	5.8	-0.7	17.6	81	32.6
3/11/2000	19.5	0.00	8.9	6.6	16.6	61	32.6
4/11/2000	13.3	0.00	9.7	9.3	17.1	70	32.9
5/11/2000	19.6	32.20	11	11.8	14	94	39.2
6/11/2000	17.5	7.80	8.8	4.7	15.6	91	41.5
7/11/2000	18.2	0.00	11.6	10.4	15.7	80	39.5
8/11/2000	14.1	1.80	8.9	6.8	15.8	91	39
9/11/2000	17.6	7.80	5.1	-1.1	14.2	63	39.5
10/11/2000	18.9	0.00	5.9	0.2	14.8	67	39.4
11/11/2000	18.3	0.00	5.8	1	15.3	64	39.9
12/11/2000	20.2	0.00	7.9	4.1	15.6	67	39.7
13/11/2000	19.8	0.00	8.2	2	17.7	85	39.1
14/11/2000	19.8	0.00	12.4	9.7	18.4	75	38.2
15/11/2000	18.4	0.00	3.6	-1.1	18.5	81	37.4
16/11/2000	18.2	0.00	12.7	10.7	17.4	77	36.9
17/11/2000	18.2	0.00	11.7	8.6	18.1	68	36.8
18/11/2000	16.5	0.00	10.6	8.5	18.1	64	36.4
19/11/2000	16.7	0.80	3.2	-1.1	17.6	69	36
20/11/2000	16.2	1.20	10.2	8.5	16.4	90	35.8
21/11/2000	18.2	0.80	12.8	12.5	16.2	89	35.8
22/11/2000	19.7	6.60	9	3.9	16.6	95	35.9
23/11/2000	19.6	1.60	3.4	-1.4	16.6	73	36.3
24/11/2000	20.7	0.00	6.5	2.2	17.5	83	36.1
25/11/2000	20.2	0.00	10.3	5.8	17.9	87	35.6
26/11/2000	20.5	1.20	8.1	4	17.3	87	35.3
27/11/2000	18.1	0.00	9.8	8	18.4	69	35.1
28/11/2000	16.6	0.00	9.6	6.3	18.2	84	34.7
29/11/2000	19.2	6.80	8.3	3.9	16.6	87	34.6
30/11/2000	22.9	0.00	10.2	4.8	17.7	75	34.9
1/12/2000	19.8	0.00	7.9	4.7	18.8	68	34.4
2/12/2000	21.6	0.00	12.2	8.1	18.7	76	33.8
3/12/2000	23.2	0.00	14.8	14.1	19.9	78	33.3
4/12/2000	19.4	5.20	14.9	14.3	20	94	32.7
5/12/2000	22.4	0.80	11.6	8.4	18.9	76	32.6
6/12/2000	22.6	0.00	10.5	6.7	19.9	77	32.6
7/12/2000	23.3	0.00	9.1	5.2	20.7	78	32
8/12/2000	23.7	12.40	7.7	4.3	20.3	85	33
9/12/2000	24.9	0.00	10.2	5.5	20.1	78	32.7
10/12/2000	21.7	1.20	15	14.3	20.5	78	32.2
11/12/2000	22.1	0.60	11.3	7.6	19.8	81	31.8

12/12/2000	18.8	10.40	8.7	4.3	19	84	32.1
13/12/2000	25.6	10.60	14.1	11.9	18.1	88	34.1
14/12/2000	23.5	0.00	16.6	16.3	20.5	77	33.8
15/12/2000	20.9	0.00	15.8	15.6	20.8	82	33.2
16/12/2000	23.4	0.00	12	9.4	20.1	77	32.8
17/12/2000	26.1	0.00	15.3	13.8	20.9	81	32.5
18/12/2000	25.6	0.00	14.2	11.5	22.2	87	32.2
19/12/2000	23.3	0.00	13.5	10.7	22.6	68	31.6
20/12/2000	23.6	0.00	13.3	10	21.9	81	31.1
21/12/2000	23.3	0.00	14.2	11	21.9	73	30.7
22/12/2000	21.6	0.00	7.4	5.5	21.9	54	30.4
23/12/2000	21.2	0.00	13.3	10.9	21.4	71	29.7
24/12/2000	20.5	0.00	18.4	18.1	21.5	84	28.8
25/12/2000	22.5	3.80	15.8	13.9	20.2	88	28.8
26/12/2000	22.9	0.20	19.1	18.8	20.4	90	28.9
27/12/2000	24.1	2.60	16.2	15.1	20.8	96	28.9
28/12/2000	25.2	0.00	19.2	19.2	21	86	28.9
29/12/2000	22	18.80	14.7	15.1	21.4	96	29.1
30/12/2000	20.7	12.20	13.1	12	20.5	95	32.5
31/12/2000	19.5	9.80	8.5	5.8	19.4	93	33.7
1/01/2001	19.5	3.40	12.3	8.9	18.4	67	33.4
2/01/2001	21.1	0.60	11.2	9	18.4	85	33.5
3/01/2001	23	0.60	8.3	5.3	19.4	60	33.1
4/01/2001	25.1	0.00	9	6.7	20.2	81	32.7
5/01/2001	25	0.00	9.3	6.6	20.8	78	32.2
6/01/2001	26.2	0.00	11.1	9.4	21.1	83	31.8
7/01/2001	26.1	0.00	14.6	12.7	21.6	87	31.3
8/01/2001	25.8	6.00	15.5	14.1	21.9	82	31.2
9/01/2001	26.3	2.20	16	14.1	22.4	85	30.6
10/01/2001	23.2	0.00	16	15.2	23.6	90	30.2
11/01/2001	24	1.60	14.6	14	22	86	29.8
12/01/2001	26.5	5.40	15.4	12.6	20.6	90	29.8
13/01/2001	22.1	0.60	14.6	13.8	20.8	71	30.3
14/01/2001	22.1	0.60	10.6	7.2	21.6	79	30.2
15/01/2001	21.2	0.20	13.3	10.7	21.6	58	30
16/01/2001	21.9	0.60	8.8	3.6	21.1	75	29.8
17/01/2001	20.9	1.00	10.6	6.6	19.5	74	29.9
18/01/2001	21.4	0.00	8.2	4.3	20.1	83	29.9
19/01/2001	24.7	0.00	14.5	13	20.3	89	29.7
20/01/2001	20.9	0.00	11.1	6.8	21.8	72	29.4
21/01/2001	21.5	0.00	16.1	13.5	21.1	78	28.9
22/01/2001	23.4	0.00	5.8	1.8	21	94	28.4

23/01/2001	25.4	0.00	7.5	2.4	21.3	90	27.7
24/01/2001	24.2	0.00	16.1	19	21.8	90	26.7
25/01/2001	23.3	0.20	18.5	17.7	21.9	90	25.9
26/01/2001	20.9	0.20	9.1	4.2	22.9	89	29.4
27/01/2001	19.9	4.80	6.2	-0.2	19.9	64	27.2
28/01/2001	24.1	0.00	12	7.6	19.4	76	25.8
29/01/2001	24.7	0.00	13.4	9.1	21	88	29.9
30/01/2001	26.7	0.00	14.2	10.4	21.7	84	26.2
31/01/2001	21.3	0.00	13.1	7.9	22.1	85	23.7
1/02/2001	25.9	0.00	6.5	1.7	20.4	78	23.4
2/02/2001	24.9	0.00	11	7.9	21.8	84	22.5
3/02/2001	24.5	0.00	10	4.5	22.3	88	21.5
4/02/2001	22.2	0.00	14.9	9.6	22.2	70	20.4
5/02/2001	23.1	0.00	16.8	14	21.6	76	19.5
6/02/2001	22.7	0.00	6.2	0.7	21.7	88	18.9
7/02/2001	18.1	0.00	13.5	14.2	21.6	83	18.3
8/02/2001	24	9.00	9	3.3	19.3	97	18.8
9/02/2001	27	0.20	10.3	5.3	19.7	93	22.1
10/02/2001	27.4	0.00	15.8	16.9	21.4	85	21.5
11/02/2001	21.3	0.20	19.4	19	22.6	90	21
12/02/2001	23.2	45.00	18.1	15.6	21	95	29.6
13/02/2001	25.7	17.00	19.6	17.5	20.6	86	33.7

14/02/2001	28.8	0.00	18.1	14.4	21.6	88	30.8
15/02/2001	29.5	0.00	19.3	16.5	22.8	95	30.1
16/02/2001	25.9	5.40	19	19.1	23.5	93	30.4
17/02/2001	21.9	8.00	17.5	16.5	23	96	30.5
18/02/2001	25.8	23.40	16	13.8	21.8	92	34.7
19/02/2001	26.2	0.00	18.3	20.1	22.5	92	32.6
20/02/2001	23.3	0.00	18.9	17.9	22.8	88	31.9
21/02/2001	28.3	0.20	17.3	14.7	22.5	86	31.6
22/02/2001	27.5	0.00	16.5	16.4	24.6	90	31
23/02/2001	19.2	36.80	12	9.1	24.7	95	33
24/02/2001	26.1	12.60	13.7	10.1	20.6	77	36.6
25/02/2001	27.4	0.00	17.1	14	22	89	33.3
26/02/2001	27.2	0.00	18.2	15.5	23.3	88	32.6
27/02/2001	26.1	0.00	14.9	11.6	24.1	84	31.9
28/02/2001	na	0.00	na	na	23.4	93	31.4
1/03/2001	na	0.00	na	na	22.8	89	31.1

II.2.3 The 81% GSM Experiment (2002/2003)

Date	Max temp	Rainfall (mm)	Min temp	Grass min temp	10 cm soil depth temp	Humidity	Soil moisture
31/05/2001	14.2	9.60	-1.9	-6.1	9.1	89	42.4
1/06/2001	12.7	0.00	0.8	-0.8	9.3	98	39.9
2/06/2001	11.7	1.40	-2.5	-5.4	8.7	99	39.2
3/06/2001	12.9	0.00	-1.3	-2.9	8.7	99	39
4/06/2001	12.3	0.00	0.1	-3.4	8.1	99	38.8
5/06/2001	11.5	0.00	0.3	-1.6	8.3	99	38.6
6/06/2001	13.9	0.00	2.3	1.1	8.4	99	38.4
7/06/2001	14.1	0.00	4.9	2.5	9.1	99	38.3
8/06/2001	15.8	3.00	2.2	-0.8	9.7	99	38.3
9/06/2001	16.1	0.00	5.3	6.6	10.1	99	38.3
10/06/2001	16.1	3.80	2.6	-1.2	10.7	87	38.4
11/06/2001	11.4	8.40	-0.5	-3.7	11.5	73	40.1
12/06/2001	12.7	0.00	-0.7	-5.7	9	93	39.6
13/06/2001	13.8	0.00	3.1	-1.1	7.8	96	39.2
14/06/2001	16.2	0.00	7.9	8.6	8.2	94	39
15/06/2001	18.1	0.00	10.4	6.6	9.9	95	38.7
16/06/2001	18.9	0.00	11.6	8.5	11.5	95	38.4
17/06/2001	16.3	5.00	8.5	6.5	12.6	99	38.6
18/06/2001	14.5	3.60	3.9	-0.7	12.3	98	39
19/06/2001	12.4	0.40	-1.2	-5.5	11.1	88	39
20/06/2001	10.9	0.00	3.2	-0.7	9.4	98	38.9
21/06/2001	12.9	0.00	2	-1.5	8.7	98	38.8
22/06/2001	15.8	0.00	4.8	0.3	9.3	99	38.6
23/06/2001	17.3	0.00	6	4.1	9.8	98	38.4
24/06/2001	14.9	0.20	5.9	0.8	10.3	99	38.2
25/06/2001	14.1	3.80	6.2	1.7	10.2	75	38.5
26/06/2001	15.7	4.80	1.5	-1.2	10	92	38.8
27/06/2001	17.5	0.00	7	2.5	9.6	98	39.1
28/06/2001	14.5	4.00	2	-0.8	10	98	39
29/06/2001	15.3	1.40	5.1	-0.5	10.6	99	39.3
30/06/2001	13.4	0.00	0.4	-4.5	10	96	39.1
1/07/2001	12.1	0.00	0.3	-5.8	9.3	88	38.9
2/07/2001	13.1	0.00	-1.1	-6.1	7.7	85	38.7
3/07/2001	12.6	0.00	-0.8	-5.4	7	89	38.6
4/07/2001	13.4	0.00	1.8	-3.1	6.7	97	38.5
5/07/2001	13.6	0.00	6.6	3.6	6.8	78	38.4
6/07/2001	15.2	0.00	5.7	1.9	7.6	78	38.2
7/07/2001	13.9	0.00	5.7	2.5	8.3	78	38
8/07/2001	14	0.00	1.1	-4	8.3	81	37.8
9/07/2001	14.6	0.00	0.3	-4.3	7.9	90	37.7
10/07/2001	12.5	0.00	-3.4	-7.2	7.6	96	37.5
11/07/2001	12.3	0.00	-4.3	-8.3	7.1	98	37.4
12/07/2001	11.7	0.00	-2	-4.7	6.3	98	37.3
13/07/2001	12.2	0.00	-1	-3	5.9	99	37.3
14/07/2001	11.2	0.00	3.8	1.3	6.8	97	37.1
15/07/2001	11.5	5.80	8	8.5	7.7	99	37.1
16/07/2001	14.9	18.80	9.4	8.1	8.8	98	39.2
17/07/2001	14.1	22.40	8.2	5.3	9.9	97	43.5
18/07/2001	14.7	14.00	5.7	1.7	10	84	44.3
19/07/2001	11.1	12.80	5	1	10.1	84	43.3
20/07/2001	11.5	11.00	5.3	-1.8	8.7	92	43.3
21/07/2001	14.7	0.00	4.8	2.6	8	99	41.9
22/07/2001	14.6	0.20	3.2	-1.5	8.2	85	40.8
23/07/2001	14.6	0.00	-1.5	-5.3	8.2	92	40.4
24/07/2001	13.2	0.00	-4.8	-4.8	7.8	98	39.9
25/07/2001	13.6	0.00	0	-3.8	7.3	98	39.8
26/07/2001	14.3	0.00	2.6	-0.8	7.2	96	39.4
27/07/2001	14.8	0.00	1	-2.7	8	98	39.3
28/07/2001	10.3	0.00	3.3	2.4	8.1	99	39.1
29/07/2001	14.3	0.00	6.6	7.4	7.9	99	39
30/07/2001	16.2	4.00	7.1	5.7	9.4	98	38.9
31/07/2001	14.6	0.80	6.6	2.4	10.6	77	39.3
1/08/2001	15.3	0.20	3.4	-0.3	10.6	96	39.2
2/08/2001	14.5	0.00	7.8	5.3	10.2	96	38.9
3/08/2001	15.5	0.00	-0.7	-5	10.3	95	38.7
4/08/2001	15	0.00	3	-0.5	9.9	99	38.6
5/08/2001	15.1	0.00	4.3	1.4	9.5	98	38.4
6/08/2001	14.3	0.40	5.1	0.8	10	99	38.3
7/08/2001	15	0.00	6.6	8.1	10.1	99	38.2
8/08/2001	18.3	3.40	8.6	4.5	10.9	97	38.1
9/08/2001	19.5	1.60	10.4	7.2	12	92	38.2
10/08/2001	17.1	0.00	7.6	3.4	12.6	97	38.3
11/08/2001	15.4	1.20	4.7	0.6	12	92	38.1
12/08/2001	15.1	3.80	-0.1	-5.3	11.2	88	38.4

13/08/2001	14.8	0.00	4.6	1.9	10.3	94	38.6
14/08/2001	12.8	2.00	4.9	0.3	9.9	95	38.5
15/08/2001	10.9	0.40	4.8	1.6	9.7	67	38.5
16/08/2001	12	0.00	-1.2	-4.9	8.8	70	38.4
17/08/2001	13.8	0.00	1.3	-2.1	8.7	96	38.4
18/08/2001	12.9	0.00	3.8	1.5	8.8	98	38.2
19/08/2001	15.3	4.60	7.2	4	8.8	98	38.3
20/08/2001	14.1	5.00	7	3.5	9.5	86	38.6
21/08/2001	16.4	4.80	7.4	2.5	9.8	96	39.8
22/08/2001	17.8	8.40	8.8	5.7	10.1	98	40.8
23/08/2001	17.5	3.60	10.7	8.6	11.2	98	41
24/08/2001	14.1	0.40	8	6.2	11.8	82	40.1
25/08/2001	16.2	5.80	4.5	0.6	11.2	93	40.2
26/08/2001	14.4	3.20	1.5	-2	11.2	98	40.2
27/08/2001	15.9	6.40	0.2	-3	10.8	99	40.8
28/08/2001	16.5	0.00	3.9	-0.4	10.5	98	40.4
29/08/2001	16.2	0.00	9.3	7.1	10.5	91	39.8
30/08/2001	13.8	0.20	10.6	9.8	10.9	90	39.5
31/08/2001	14	0.40	9.8	8.7	11.3	80	39.2
1/09/2001	12.8	2.40	9.1	7.7	11.2	79	39
2/09/2001	17.5	0.40	7.9	6	11	72	39
3/09/2001	16	0.00	7.3	2.5	12.3	71	38.9
4/09/2001	14.5	0.00	8.8	7.4	12.2	83	38.6
5/09/2001	14.5	21.80	8.8	3.5	11.6	97	40.7
6/09/2001	18.4	0.00	10.5	8.7	12.9	97	41.7
7/09/2001	13.8	0.20	6.9	1.8	13.2	93	40.4
8/09/2001	18.6	9.60	4.6	-0.8	12.4	88	41.4
9/09/2001	17	0.00	4.5	-0.6	13.1	84	40.8
10/09/2001	16.7	0.00	4.6	0.2	12.5	76	40.1
11/09/2001	15.7	0.00	6.2	1.1	12.5	73	39.6
12/09/2001	16.6	0.00	6.4	2.1	12.7	83	39.1
13/09/2001	18	0.00	8.4	4.5	13.1	85	38.8
14/09/2001	17.6	0.00	10.8	8.9	14.1	79	38.5
15/09/2001	16.7	0.00	10.8	7.8	14.1	83	38
16/09/2001	19.6	0.20	10.7	6.9	13.8	96	37.8
17/09/2001	16.7	3.00	9.7	4.9	14.9	81	37.9
18/09/2001	17.8	0.00	4.3	0	14.3	74	37.7
19/09/2001	17.2	0.00	7.9	2	14.3	77	37.4
20/09/2001	15.6	0.00	10.2	8.2	13.9	76	37.1
21/09/2001	16.3	0.00	6.9	2.8	13.9	77	36.9
22/09/2001	17.9	0.20	6.6	1.2	14.1	97	36.6
23/09/2001	17.7	0.20	6.1	0.9	14.1	76	36.5

24/09/2001	15.8	0.00	1.9	-3.4	14.6	77	36.1
25/09/2001	16.8	0.20	0.9	-3.4	13.3	69	35.9
26/09/2001	18.2	0.00	3.1	-1.7	13.5	87	35.7
27/09/2001	18.8	0.00	6.9	3.3	14.2	85	35.3
28/09/2001	19.1	0.00	3.8	0	14.5	86	35
29/09/2001	20.3	0.00	5.8	2.2	14.5	98	34.7
30/09/2001	20	0.00	5.7	2.3	14.9	98	34.5
1/10/2001	21.5	0.00	7.8	3.2	15.6	93	34.1
2/10/2001	20.2	0.00	8.2	3	16.7	93	33.7
3/10/2001	21.2	0.00	6.9	1.6	16.1	88	33.6
4/10/2001	20	0.00	10.8	6.8	15.9	84	33.2
5/10/2001	21.2	0.00	14.4	13.1	16.3	81	32.8
6/10/2001	19.6	0.00	14.7	15	17.1	91	32.4
7/10/2001	18.2	5.00	6.4	3.1	16.5	92	32.5
8/10/2001	18.7	0.00	12.9	10.8	16	96	32.7
9/10/2001	18.5	0.20	9.7	5.2	15.8	87	32.6
10/10/2001	19	1.40	10.2	7	15.1	97	32.3
11/10/2001	19.6	8.80	9.2	6.7	15.3	77	34.1
12/10/2001	20	0.00	4.8	0.1	15.3	80	33.8
13/10/2001	20.4	0.00	9.3	6.8	15.7	97	33.3
14/10/2001	19.1	0.00	7.1	4.1	16.2	94	32.9
15/10/2001	20.7	4.40	12.8	12.7	16	98	33.4
16/10/2001	18.5	7.80	10.7	7	16.5	87	33.6
17/10/2001	19.1	0.40	9.7	7.3	15.9	65	34.7
18/10/2001	20.7	0.00	10.6	7.9	16.9	89	34
19/10/2001	22.2	0.00	14.6	14	17.4	96	33.5
20/10/2001	22	2.00	8.9	4.8	18.3	93	33
21/10/2001	21.2	0.60	12.1	9.3	17.6	94	32.8
22/10/2001	19.5	10.20	11.1	8.1	17.6	86	34.3
23/10/2001	20.7	2.60	11.1	6.8	16.3	74	34.8
24/10/2001	18.4	0.00	0	-6	16.4	85	34.4
25/10/2001	17.2	0.20	7.8	3.4	15.1	70	34
26/10/2001	18.1	0.00	11.8	7.7	16.1	82	33.6
27/10/2001	22.6	2.00	14.4	13.5	16.1	91	33.5
28/10/2001	18.6	1.40	13.5	11.7	17.9	89	33.2
29/10/2001	18.2	18.80	13.3	10.6	16.3	83	37.1
30/10/2001	21.1	0.60	16.4	15.7	16.1	77	36.9
31/10/2001	22.4	0.00	11.8	11.1	17.2	86	36.3
1/11/2001	19.9	11.60	11.6	10.4	17.8	84	36.6
2/11/2001	18.2	10.60	8.7	4.7	16.8	84	38
3/11/2001	16.1	0.00	6.5	2.6	16.4	89	38.2
4/11/2001	17.5	7.20	6.7	2.7	14.5	90	38.6

5/11/2001	18.7	18.40	6.8	2.6	13.8	68	41.8
6/11/2001	21.8	0.00	12.1	9.8	15	66	40.4
7/11/2001	18.5	0.40	14.1	13.5	16.4	83	39.4
8/11/2001	19.9	9.80	11.9	9.5	16.3	92	39.9
9/11/2001	20.8	0.20	8.9	4.8	17.3	62	39.6
10/11/2001	22.1	0.00	10.7	7.3	17.8	85	38.6
11/11/2001	20.5	13.00	12.2	10.7	18	88	39.2
12/11/2001	21.3	0.00	11.3	7.2	18.1	88	38.5
13/11/2001	18.3	0.60	14	12.9	18.2	97	37.5
14/11/2001	20.7	14.00	11.8	10.1	17.3	79	38.3
15/11/2001	21.2	4.80	7.7	2.7	17.5	74	37.9
16/11/2001	20.9	0.00	12.2	9.5	17.8	83	38
17/11/2001	18.9	0.00	7.1	3	18.7	87	37.4
18/11/2001	20.3	0.00	8.1	3.6	18.3	80	36.7
19/11/2001	21.2	0.00	9.5	5.3	18.4	80	36.3
20/11/2001	23.9	0.00	13.7	10.4	18.7	97	36.1
21/11/2001	21.4	0.00	15.2	15	20.3	83	35.5
22/11/2001	22	3.80	12.4	8.6	19.3	89	35
23/11/2001	22	27.20	13.3	13.7	18	96	38.6
24/11/2001	20.8	6.40	10.1	9.7	18.6	86	37.7
25/11/2001	20.9	6.40	9.6	6.4	19	68	36.8
26/11/2001	19.5	0.00	11	6.8	18.9	65	36.4
27/11/2001	18.3	0.00	13.2	12.7	19.5	82	35.7
28/11/2001	20.8	0.00	13.2	10.7	18.2	80	35.4
29/11/2001	22.9	0.00	17.6	16.3	18.9	76	35.1
30/11/2001	21.9	0.00	17.5	17.3	19.6	83	35
1/12/2001	21.5	4.40	17.4	17.3	19.7	93	34.6
2/12/2001	20	17.00	17.4	17	19.4	95	34.7
3/12/2001	20.7	3.20	15.3	13	19.1	88	36.5
4/12/2001	24.7	4.00	16	14.6	19.1	83	35.8
5/12/2001	23.9	0.00	14.9	12.3	20.4	85	35.1
6/12/2001	24.2	21.40	18.7	18.1	20.6	83	36.8
7/12/2001	23.3	2.60	13.9	11.8	20.9	93	35.3
8/12/2001	19.5	9.80	14.9	15.2	20.1	97	36
9/12/2001	22.5	28.40	13.5	10.6	18.9	97	37.2
10/12/2001	21.7	0.00	13.8	11.8	20.5	84	36.6
11/12/2001	20.6	5.80	14.8	14.6	19.8	83	35.6
12/12/2001	23.8	4.60	11.9	9.1	19.1	85	35.4
13/12/2001	20.2	3.60	10.7	5.7	19.5	78	35.7
14/12/2001	22.1	0.00	13.9	12.7	19.5	74	35
15/12/2001	22	0.00	16	17	20	85	34.5
16/12/2001	24.9	2.80	15.7	12.6	19.6	87	34.3

17/12/2001	23.6	0.00	16.9	15.5	20.9	90	34.1
18/12/2001	21.7	11.20	16.1	15.2	20.8	96	33.8
19/12/2001	19.7	8.40	15.4	14.9	20	86	35.9
20/12/2001	24.9	10.80	15.7	14	19.3	83	36
21/12/2001	24.7	16.20	11.3	7.8	20.8	86	37.2
22/12/2001	22.3	0.00	15.6	13.1	21.2	72	35.3
23/12/2001	22.9	0.00	15.7	15.7	21.4	85	34.5
24/12/2001	23.1	8.40	13.9	10.6	21.7	96	34.2
25/12/2001	22.8	4.80	11.2	7.6	20.6	83	35.1
26/12/2001	25.7	0.00	16.3	13.4	21	84	34.4
27/12/2001	20.7	0.40	14.6	12.8	22.5	96	33.8
28/12/2001	21.2	23.00	11.1	8.9	20.6	86	35.3
29/12/2001	20.8	11.00	13.4	11.4	19.5	81	36.1
30/12/2001	20.5	6.00	9.2	5.6	19.3	81	35.6
31/12/2001	22.2	0.00	11.2	8	19	67	35.3
1/01/2002	26.3	0.00	11.3	7.5	20.2	90	34.6
2/01/2002	26.4	0.00	12	9.2	22.1	85	34
3/01/2002	27.1	0.00	17.3	15.8	23	88	33.3
4/01/2002	23	0.00	11.5	8.6	23.5	85	32.8
5/01/2002	21.2	4.20	10.7	6.4	22.4	70	32.5
6/01/2002	18.9	0.60	9.9	5.8	20.9	77	32.5
7/01/2002	21.6	9.80	7.8	3.2	19.1	75	33.5
8/01/2002	21.1	0.00	12.9	9.6	19.7	88	33.2
9/01/2002	18.4	0.20	14.9	14	20.5	92	32.9
10/01/2002	24.2	14.00	12.9	10.3	18.9	95	34.1
11/01/2002	22.6	2.00	12.3	9.6	20.9	89	34.2
12/01/2002	22.7	7.60	12.8	10.1	20	88	34.1
13/01/2002	24.7	7.80	14.7	12.7	19.6	98	35.6
14/01/2002	24.2	1.00	15.6	12.6	21	95	34.7
15/01/2002	23.4	8.20	14.9	12.1	19.8	94	34.6
16/01/2002	23.1	1.60	13.2	9.9	20.1	81	34.8
17/01/2002	25.5	0.40	16.2	13.2	20.4	94	34.3
18/01/2002	22.1	0.00	15.2	13.8	21.3	89	33.9
19/01/2002	22.9	30.80	22.9	9.4	20.6	84	36.3
20/01/2002	21.9	0.00	9.8	5.7	21.4	82	35.3
21/01/2002	23.6	6.00	10.6	7	20.3	78	34.9
22/01/2002	25.2	0.00	10.6	7	20.9	98	34.4
23/01/2002	25.9	0.00	17.4	14.6	21.8	88	33.8
24/01/2002	25.1	0.00	13.1	9.7	23.2	84	33.3
25/01/2002	25.4	0.00	12.8	9.2	23	85	32.8
26/01/2002	24.8	0.00	14.9	12	23.6	92	32.4
27/01/2002	24.3	0.00	13.7	10.9	23.2	83	32.1

28/01/2002	26.4	0.00	14.9	10.7	22.8	86	31.6
29/01/2002	25.7	0.00	14.1	11	24.3	80	31.2
30/01/2002	26.4	0.00	14.6	10.6	24.2	73	30.7
31/01/2002	26.4	0.00	14.9	12.4	24.6	81	30.2
1/02/2002	26.6	0.00	12.3	8.5	23.9	83	29.9
2/02/2002	22.9	0.40	9	4.6	24.4	63	29.5
3/02/2002	25.6	0.00	11.2	7.4	23.4	76	29
4/02/2002	25.1	0.00	13.8	11.4	23.5	79	28.7
5/02/2002	22.5	0.00	12.8	8.9	23.6	97	28.3
6/02/2002	22.2	9.00	7.5	3.7	20.7	73	29.8
7/02/2002	22.3	0.00	11.8	7.7	20.5	87	29.6
8/02/2002	19.8	0.00	13.7	13.2	20.9	87	29.1
9/02/2002	23.1	0.00	13.6	9.1	20.2	75	28.9
10/02/2002	23.6	0.00	18.4	19.1	21.8	81	28.4
11/02/2002	24.8	0.00	19.7	19.7	21.5	89	28
12/02/2002	23.9	1.40	14.9	11.8	22	93	27.8
13/02/2002	24.1	6.20	12.6	11.4	21.3	93	28.4
14/02/2002	22.1	0.00	6.8	1.6	21	78	28.4
15/02/2002	22.9	0.00	11.1	8.8	20.5	81	28

16/02/2002	23	0.00	11	7.4	20.5	77	27.8
17/02/2002	23.9	0.00	9.9	5.7	21.2	74	27.5
18/02/2002	24.7	0.00	8.5	4.4	21.6	92	27.1
19/02/2002	23.7	0.00	11.3	8.5	21.6	98	26.8
20/02/2002	25.9	0.00	13.1	12	21.6	98	26.4
21/02/2002	19.8	0.80	13.2	9.1	22.4	89	26
22/02/2002	23.2	0.00	16.7	16.4	20.5	89	25.9
23/02/2002	24.5	2.40	12.8	9.8	20.6	95	26.1
24/02/2002	23.1	1.20	8.8	4.9	20.3	93	26.1
25/02/2002	22.7	0.20	7.4	3.1	20.2	93	26.1
26/02/2002	24.6	0.00	11.3	6.6	20.1	98	26.2
27/02/2002	25.7	0.00	13.3	10.2	21	93	26
28/02/2002	na	0.00	na	na	21.9	90	25.7
1/03/2002	na	0.00	na	na	22.1	88	24.4

Appendix III

Soil Particle Density and Size Distribution

Appendix III Soil Particle Density and Size Distribution

III.1 Experimental Means

III.1.1 Particle Density

	0-5 cm soil depth			5-10 cm soil depth		
	Density ($Mg\ m^{-3}$)	st.dev.	s.e.	Density ($Mg\ m^{-3}$)	st.dev.	s.e.
65% GSM	2.32	0.019	0.009	2.35	0.014	0.006
71% GSM	2.31	0.035	0.016	2.36	0.020	0.009
81% GSM	2.30	0.015	0.007	2.36	0.013	0.006

III.1.2 Particle Size Distribution

		0-5 cm soil depth			5-10 cm soil depth		
		% particles	st.dev.	s.e.	% particles	st.dev.	s.e.
65% GSM							
	Clay	22.2	0.743	0.429	23.9	1.0733	0.620
	Silt	60.6	0.685	0.397	63.5	1.639	0.946
	Sand	17.2	0.923	0.5328	12.6	2.645	1.527
	Class	*Silt loam*			*Silt loam*		
71% GSM							
	Clay	22.4	0.332	0.1917	24.6	0.978	0.565
	Silt	64.4	1.180	0.681	64.0	2.174	1.255
	Sand	13.2	1.513	0.874	11.4	1.881	1.086
	Class	*Silt loam*			*Silt loam*		
81% GSM							
	Clay	21.4	0.866	0.500	24.2	7.301	4.215
	Silt	63.3	1.444	0.833	65.0	0.398	0.230
	Sand	15.2	1.396	0.806	10.5	0.914	0.528
	Class	*Silt loam*			*Silt loam*		

III.2 Individual Results for Soil Particle Density

Experiment	Soil depth (cm)	Rep #	Flask weight (g)	Flask and soil (g)	Flask, soil and water (g)	Volume of water (mm^3)	Volume of soil (mm^3)	Particle density ($Mg\ m^{-3}$)
65% GSM	0-5	1	49.95	75.65	163.68	88.81	0.21	2.30
		2	50.70	77.84	165.49	88.43	0.20	2.34
		3	53.60	78.14	166.80	89.44	0.22	2.32
		4	39.62	64.53	153.05	89.30	0.22	2.33
		5	52.56	77.96	166.16	88.98	0.21	2.30
	5-10	1	57.49	80.79	170.07	90.07	0.24	2.35
		2	51.54	76.88	165.20	89.10	0.21	2.33
		3	57.93	85.89	173.28	88.16	0.20	2.36
		4	58.44	84.50	172.66	88.94	0.21	2.36
		5	52.45	78.48	166.61	88.91	0.21	2.35
71% GSM	0-5	1	44.34	74.07	160.42	87.11	0.18	2.31
		2	57.59	80.85	170.10	90.04	0.23	2.34
		3	58.99	81.41	171.05	90.43	0.24	2.34
		4	45.78	67.74	157.21	90.26	0.23	2.25
		5	60.73	84.72	173.59	89.66	0.22	2.32
	5-10	1	49.40	77.15	164.62	88.24	0.20	2.36
		2	58.36	84.13	172.30	88.95	0.21	2.33
		3	63.16	91.67	178.86	87.96	0.20	2.37
		4	54.04	81.04	168.95	88.69	0.21	2.39
		5	56.48	84.12	171.58	88.23	0.20	2.35
81% GSM	0-5	1	57.94	84.25	172.14	88.67	0.20	2.32
		2	58.44	76.41	167.74	92.14	0.29	2.29
		3	59.79	84.00	172.66	89.44	0.22	2.29
		4	42.51	65.24	154.51	90.06	0.23	2.29
		5	58.99	85.16	173.02	88.64	0.20	2.30
	5-10	1	56.49	82.34	170.55	88.99	0.21	2.35
		2	54.50	82.72	169.91	87.96	0.19	2.34
		3	57.61	83.99	171.98	88.77	0.21	2.35
		4	55.97	86.50	172.80	87.06	0.18	2.36
		5	43.78	72.66	159.74	87.85	0.20	2.38
								Water density
Blanks		1	49.25		148.44	99.19		0.992
		2	53.78		152.87	99.09		0.991
		3	57.84		156.93	99.09		0.991

III.3 Individual Results for Soil Particle Size Distribution

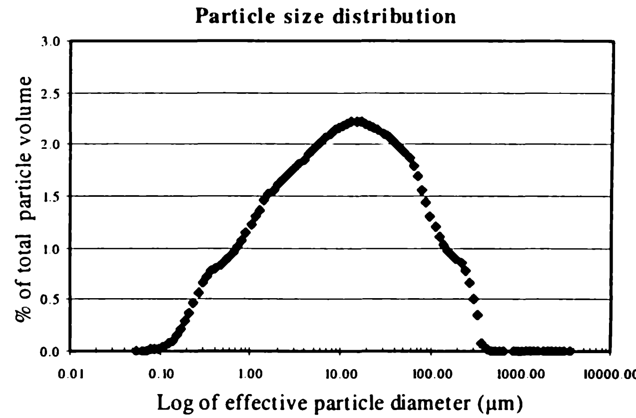
III.3.1 Soil Particle Size Distribution for 65% GSM 0-5 cm Soil Depth

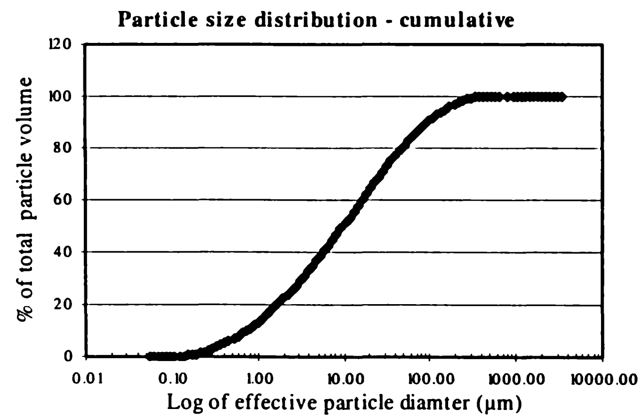
	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
0.050	na	na	na	na	na
0.056	0.00	0.00	0.00	0.00	0.00
0.063	0.00	0.00	0.00	0.00	0.00
0.070	0.00	0.00	0.01	0.00	0.00
0.078	0.04	0.01	0.01	0.02	0.02
0.087	0.04	0.01	0.02	0.02	0.05
0.098	0.02	0.02	0.04	0.03	0.07
0.109	0.04	0.04	0.06	0.05	0.12
0.122	0.07	0.06	0.09	0.07	0.19
0.137	0.10	0.08	0.13	0.10	0.30
0.153	0.15	0.13	0.18	0.15	0.45
0.171	0.21	0.18	0.25	0.21	0.66
0.191	0.29	0.25	0.32	0.29	0.95
0.213	0.38	0.34	0.41	0.38	1.33
0.238	0.49	0.43	0.51	0.48	1.80
0.266	0.59	0.52	0.60	0.57	2.37
0.298	0.69	0.61	0.68	0.66	3.03
0.333	0.76	0.68	0.74	0.73	3.76
0.373	0.81	0.73	0.78	0.77	4.53
0.416	0.84	0.76	0.81	0.80	5.34
0.466	0.88	0.80	0.84	0.84	6.18
0.521	0.91	0.84	0.88	0.88	7.05
0.582	0.95	0.89	0.92	0.92	7.97
0.651	0.98	0.92	0.95	0.95	8.92
0.727	1.03	0.97	1.01	1.00	9.93
0.813	1.09	1.04	1.07	1.07	10.99
0.909	1.16	1.12	1.15	1.14	12.14
1.02	1.24	1.20	1.23	1.22	13.36
1.14	1.32	1.28	1.31	1.30	14.66
1.27	1.39	1.35	1.38	1.37	16.04
1.42	1.47	1.43	1.46	1.45	17.49
1.59	1.53	1.50	1.52	1.52	19.01
1.78	1.58	1.55	1.57	1.57	20.57
1.99	1.63	1.59	1.61	1.61	22.18
2.22	1.67	1.64	1.66	1.66	23.84
2.48	1.71	1.68	1.70	1.70	25.54
2.77	1.75	1.72	1.73	1.73	27.27
3.10	1.79	1.77	1.77	1.78	29.05
3.47	1.83	1.81	1.81	1.82	30.86
3.88	1.88	1.85	1.85	1.86	32.72
4.34	1.92	1.90	1.89	1.90	34.63
4.85	1.96	1.94	1.93	1.94	36.57
5.42	2.01	1.98	1.97	1.99	38.56
6.06	2.05	2.02	2.01	2.03	40.58
6.77	2.09	2.06	2.05	2.07	42.65
7.57	2.13	2.09	2.09	2.10	44.75
8.47	2.16	2.13	2.12	2.14	46.89
9.47	2.19	2.15	2.15	2.16	49.05
10.58	2.21	2.18	2.17	2.19	51.24
11.83	2.23	2.20	2.19	2.21	53.45

	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
13.23	2.24	2.21	2.20	2.22	55.66
14.79	2.24	2.21	2.20	2.22	57.88
16.54	2.23	2.21	2.20	2.21	60.09
18.49	2.22	2.20	2.18	2.20	62.29
20.67	2.20	2.19	2.16	2.18	64.48
23.11	2.18	2.18	2.13	2.16	66.64
25.84	2.15	2.16	2.10	2.14	68.78
28.89	2.12	2.13	2.07	2.11	70.88
32.29	2.09	2.11	2.03	2.08	72.96
36.11	2.06	2.08	1.99	2.04	75.00
40.37	2.04	2.05	1.95	2.01	77.02
45.13	2.00	2.02	1.91	1.98	78.99
50.46	1.96	1.98	1.86	1.93	80.93
56.41	1.89	1.93	1.79	1.87	82.80
63.07	1.80	1.86	1.71	1.79	84.59
70.52	1.69	1.76	1.61	1.69	86.27
78.84	1.55	1.65	1.50	1.57	87.84
88.14	1.41	1.53	1.38	1.44	89.28
98.55	1.27	1.41	1.26	1.31	90.59
110.2	1.14	1.30	1.16	1.20	91.79
123.2	1.04	1.20	1.08	1.11	92.90
137.7	0.96	1.12	1.02	1.03	93.93
154.0	0.90	1.05	0.98	0.98	94.91
172.1	0.85	0.99	0.96	0.93	95.84
192.5	0.81	0.93	0.95	0.90	96.74
215.2	0.76	0.86	0.94	0.85	97.59
240.6	0.69	0.77	0.89	0.78	98.38
269.0	0.55	0.62	0.80	0.66	99.03
300.7	0.41	0.46	0.65	0.51	99.54
336.2	0.28	0.32	0.45	0.35	99.89
375.9	0.04	0.04	0.18	0.09	99.98
420.2	0.00	0.00	0.07	0.02	100.00
469.8	0.00	0.00	0.00	0.00	100.00
525.3	0.00	0.00	0.00	0.00	100.00
587.3	0.00	0.00	0.00	0.00	100.00
656.6	0.00	0.00	0.00	0.00	100.00
820.7	0.00	0.00	0.00	0.00	100.00
917.6	0.00	0.00	0.00	0.00	100.00
1025.9	0.00	0.00	0.00	0.00	100.00
1147.0	0.00	0.00	0.00	0.00	100.00
1282.4	0.00	0.00	0.00	0.00	100.00
1433.7	0.00	0.00	0.00	0.00	100.00
1602.9	0.00	0.00	0.00	0.00	100.00
1792.1	0.00	0.00	0.00	0.00	100.00
2003.6	0.00	0.00	0.00	0.00	100.00
2240.1	0.00	0.00	0.00	0.00	100.00
2504.5	0.00	0.00	0.00	0.00	100.00
2800.1	0.00	0.00	0.00	0.00	100.00
3130.5	0.00	0.00	0.00	0.00	100.00
3500.0	0.00	0.00	0.00	0.00	100.00

Particle size distribution per texture class

	Rep 1	Rep 2	Rep 3	**Mean**
Clay	22.68	21.33	22.54	**22.18**
Silt	61.20	60.78	59.86	**60.61**
Sand	16.15	17.87	17.59	**17.20**





III.3.2 Soil Particle Size Distribution for 65% GSM 5-10 cm Soil Depth

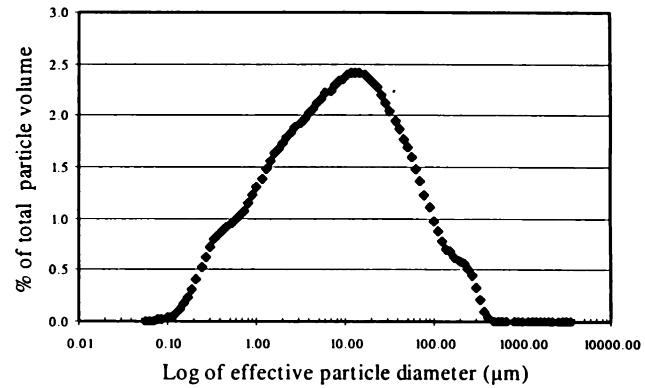
	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
0.050	na	na	na	na	
0.056	0.00	0.00	0.00	0.00	0.00
0.063	0.00	0.00	0.00	0.00	0.00
0.070	0.01	0.00	0.00	0.00	0.00
0.078	0.01	0.01	0.01	0.01	0.01
0.087	0.02	0.02	0.01	0.02	0.03
0.098	0.04	0.03	0.02	0.03	0.06
0.109	0.06	0.04	0.04	0.05	0.11
0.122	0.09	0.07	0.07	0.08	0.18
0.137	0.14	0.10	0.10	0.11	0.30
0.153	0.19	0.16	0.16	0.17	0.47
0.171	0.26	0.22	0.22	0.23	0.70
0.191	0.34	0.30	0.31	0.32	1.02
0.213	0.43	0.39	0.41	0.41	1.43
0.238	0.53	0.50	0.52	0.52	1.94
0.266	0.63	0.61	0.64	0.63	2.57
0.298	0.72	0.71	0.74	0.72	3.29
0.333	0.78	0.77	0.82	0.79	4.08
0.373	0.82	0.82	0.88	0.84	4.92
0.416	0.85	0.85	0.91	0.87	5.79
0.466	0.89	0.89	0.96	0.91	6.71
0.521	0.92	0.93	1.01	0.95	7.66
0.582	0.96	0.97	1.05	0.99	8.65
0.651	1.00	0.99	1.09	1.03	9.68
0.727	1.05	1.04	1.15	1.08	10.76
0.813	1.12	1.11	1.23	1.15	11.91
0.909	1.19	1.18	1.31	1.23	13.14
1.02	1.28	1.26	1.40	1.31	14.45
1.14	1.36	1.32	1.48	1.39	15.84
1.27	1.44	1.42	1.57	1.48	17.32
1.42	1.52	1.50	1.66	1.56	18.88
1.59	1.59	1.57	1.73	1.63	20.51
1.78	1.64	1.62	1.79	1.68	22.19
1.99	1.69	1.67	1.84	1.73	23.92
2.22	1.74	1.72	1.89	1.78	25.71
2.48	1.79	1.77	1.94	1.83	27.54
2.77	1.83	1.82	1.99	1.88	29.42
3.10	1.87	1.87	2.04	1.93	31.35
3.47	1.92	1.92	2.09	1.98	33.32
3.88	1.96	1.97	2.14	2.02	35.35
4.34	2.01	2.01	2.19	2.07	37.42
4.85	2.05	2.06	2.24	2.12	39.53
5.42	2.09	2.11	2.29	2.16	41.70
6.06	2.14	2.16	2.34	2.21	43.91
6.77	2.17	2.20	2.38	2.25	46.16
7.57	2.21	2.24	2.43	2.29	48.45
8.47	2.25	2.28	2.47	2.33	50.79
9.47	2.28	2.31	2.51	2.37	53.15
10.58	2.30	2.33	2.54	2.39	55.54
11.83	2.32	2.35	2.55	2.41	57.95

	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
13.23	2.33	2.36	2.56	2.42	60.37
14.79	2.33	2.35	2.55	2.41	62.78
16.54	2.32	2.34	2.52	2.39	65.17
18.49	2.29	2.32	2.48	2.36	67.53
20.67	2.26	2.28	2.43	2.32	69.86
23.11	2.21	2.24	2.36	2.27	72.13
25.84	2.16	2.20	2.24	2.20	74.33
28.89	2.11	2.15	2.11	2.12	76.45
32.29	2.04	2.09	1.98	2.04	78.49
36.11	1.97	2.03	1.85	1.95	80.44
40.37	1.91	1.97	1.72	1.87	82.30
45.13	1.84	1.90	1.60	1.78	84.08
50.46	1.76	1.83	1.49	1.69	85.78
56.41	1.68	1.75	1.37	1.60	87.38
63.07	1.57	1.63	1.26	1.49	88.86
70.52	1.46	1.51	1.14	1.37	90.23
78.84	1.32	1.37	1.02	1.24	91.47
88.14	1.18	1.23	0.91	1.11	92.58
98.55	1.04	1.09	0.80	0.98	93.55
110.2	0.92	0.98	0.71	0.87	94.42
123.2	0.81	0.88	0.63	0.77	95.20
137.7	0.73	0.81	0.57	0.70	95.90
154.0	0.68	0.86	0.52	0.69	96.59
172.1	0.66	0.73	0.47	0.62	97.21
192.5	0.66	0.70	0.42	0.59	97.80
215.2	0.66	0.66	0.37	0.56	98.36
240.6	0.65	0.59	0.29	0.51	98.87
269.0	0.62	0.47	0.23	0.44	99.31
300.7	0.53	0.33	0.15	0.34	99.65
336.2	0.39	0.21	0.07	0.22	99.87
375.9	0.27	0.03	0.02	0.11	99.98
420.2	0.09	0.00	0.00	0.03	100.01
469.8	0.00	0.00	0.00	0.00	100.01
525.3	0.00	0.00	0.00	0.00	100.01
587.3	0.00	0.00	0.00	0.00	100.01
656.6	0.00	0.00	0.00	0.00	100.01
820.7	0.00	0.00	0.00	0.00	100.01
917.6	0.00	0.00	0.00	0.00	100.01
1025.9	0.00	0.00	0.00	0.00	100.01
1147.0	0.00	0.00	0.00	0.00	100.01
1282.4	0.00	0.00	0.00	0.00	100.01
1433.7	0.00	0.00	0.00	0.00	100.01
1602.9	0.00	0.00	0.00	0.00	100.01
1792.1	0.00	0.00	0.00	0.00	100.01
2003.6	0.00	0.00	0.00	0.00	100.01
2240.1	0.00	0.00	0.00	0.00	100.01
2504.5	0.00	0.00	0.00	0.00	100.01
2800.1	0.00	0.00	0.00	0.00	100.01
3130.5	0.00	0.00	0.00	0.00	100.01
3500.0	0.00	0.00	0.00	0.00	100.01

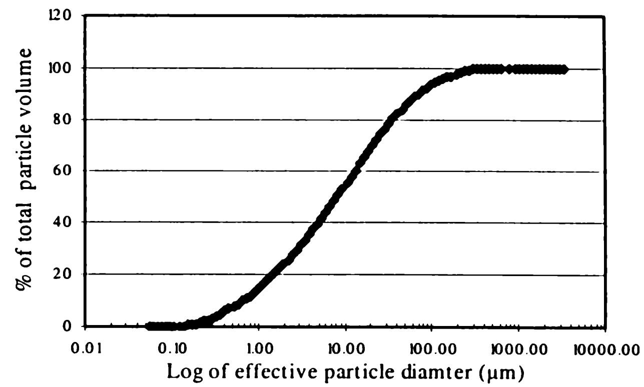
Particle size distribution per texture class

	Rep 1	Rep 2	Rep 3	**Mean**
Clay	23.57	23.07	25.13	23.92
Silt	62.14	62.93	65.29	63.45
Sand	14.24	14.08	9.58	12.63

Particle size distribution



Particle size distribution - cumulative



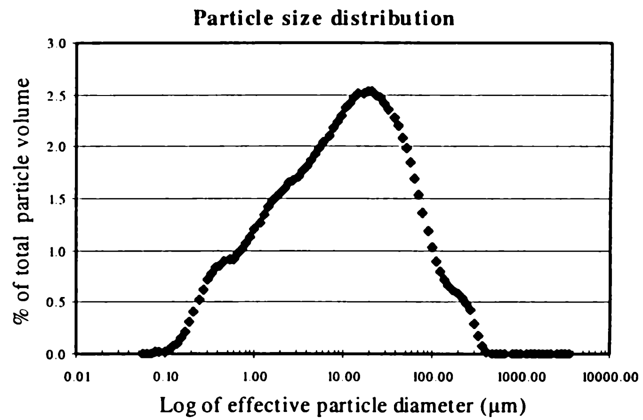
III.3.3 Soil Particle Size Distribution for 71% GSM 0-5 cm Soil Depth

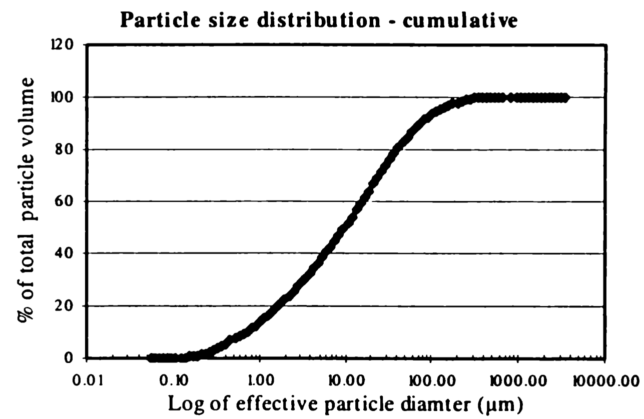
	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
0.050	na	na	na	na	
0.056	0.00	0.00	0.00	0.00	0.00
0.063	0.00	0.00	0.00	0.00	0.00
0.070	0.00	0.00	0.00	0.00	0.00
0.078	0.01	0.01	0.01	0.01	0.01
0.087	0.01	0.01	0.02	0.01	0.02
0.098	0.02	0.02	0.03	0.02	0.05
0.109	0.04	0.04	0.04	0.04	0.09
0.122	0.07	0.07	0.07	0.07	0.16
0.137	0.10	0.10	0.11	0.10	0.26
0.153	0.16	0.15	0.16	0.16	0.42
0.171	0.22	0.22	0.23	0.22	0.64
0.191	0.30	0.30	0.32	0.31	0.95
0.213	0.40	0.40	0.42	0.41	1.35
0.238	0.51	0.51	0.53	0.52	1.87
0.266	0.61	0.61	0.64	0.62	2.49
0.298	0.71	0.71	0.74	0.72	3.21
0.333	0.78	0.78	0.80	0.79	4.00
0.373	0.82	0.83	0.84	0.83	4.83
0.416	0.84	0.86	0.86	0.85	5.68
0.466	0.87	0.90	0.89	0.89	6.57
0.521	0.90	0.93	0.92	0.92	7.48
0.582	0.93	0.90	0.94	0.92	8.41
0.651	0.95	0.99	0.96	0.97	9.37
0.727	0.99	1.04	0.99	1.01	10.38
0.813	1.05	1.10	1.05	1.07	11.45
0.909	1.12	1.17	1.11	1.13	12.58
1.02	1.19	1.25	1.18	1.21	13.79
1.14	1.22	1.32	1.25	1.26	15.05
1.27	1.34	1.39	1.32	1.35	16.40
1.42	1.42	1.47	1.39	1.43	17.83
1.59	1.48	1.53	1.45	1.49	19.31
1.78	1.52	1.57	1.49	1.53	20.84
1.99	1.57	1.60	1.53	1.57	22.41
2.22	1.61	1.64	1.57	1.61	24.01
2.48	1.65	1.67	1.62	1.65	25.66
2.77	1.69	1.70	1.66	1.68	27.34
3.10	1.73	1.74	1.70	1.72	29.07
3.47	1.77	1.78	1.75	1.77	30.83
3.88	1.82	1.82	1.80	1.81	32.65
4.34	1.87	1.87	1.85	1.86	34.51
4.85	1.92	1.93	1.91	1.92	36.43
5.42	1.98	1.99	1.97	1.98	38.41
6.06	2.01	2.09	2.04	2.05	40.46
6.77	2.10	2.13	2.10	2.11	42.57
7.57	2.16	2.20	2.16	2.17	44.74
8.47	2.23	2.28	2.22	2.24	46.98
9.47	2.29	2.35	2.28	2.31	49.29
10.58	2.35	2.42	2.34	2.37	51.66
11.83	2.40	2.48	2.38	2.42	54.08

	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
13.23	2.45	2.54	2.42	2.47	56.55
14.79	2.48	2.58	2.45	2.50	59.05
16.54	2.50	2.60	2.46	2.52	61.57
18.49	2.51	2.61	2.46	2.53	64.10
20.67	2.50	2.60	2.50	2.53	66.63
23.11	2.48	2.58	2.43	2.50	69.13
25.84	2.45	2.55	2.40	2.47	71.60
28.89	2.40	2.51	2.36	2.42	74.02
32.29	2.35	2.44	2.31	2.37	76.39
36.11	2.28	2.35	2.23	2.29	78.67
40.37	2.19	2.25	2.15	2.20	80.87
45.13	2.09	2.13	2.06	2.09	82.96
50.46	1.98	2.01	1.97	1.99	84.95
56.41	1.85	1.86	1.85	1.85	86.80
63.07	1.70	1.69	1.72	1.70	88.51
70.52	1.55	1.51	1.57	1.54	90.05
78.84	1.38	1.31	1.41	1.37	91.42
88.14	1.22	1.12	1.24	1.19	92.61
98.55	1.08	0.95	1.09	1.04	93.65
110.2	0.96	0.80	0.95	0.90	94.55
123.2	0.87	0.68	0.84	0.80	95.35
137.7	0.80	0.59	0.75	0.71	96.06
154.0	0.75	0.53	0.69	0.66	96.72
172.1	0.71	0.49	0.66	0.62	97.34
192.5	0.67	0.45	0.64	0.59	97.93
215.2	0.61	0.41	0.63	0.55	98.48
240.6	0.53	0.36	0.60	0.50	98.97
269.0	0.42	0.29	0.55	0.42	99.39
300.7	0.26	0.18	0.46	0.30	99.69
336.2	0.12	0.08	0.33	0.18	99.87
375.9	0.03	0.02	0.16	0.07	99.94
420.2	0.00	0.00	0.07	0.02	99.96
469.8	0.00	0.00	0.00	0.00	99.96
525.3	0.00	0.00	0.00	0.00	99.96
587.3	0.00	0.00	0.00	0.00	99.96
656.6	0.00	0.00	0.00	0.00	99.96
820.7	0.00	0.00	0.00	0.00	99.96
917.6	0.00	0.00	0.00	0.00	99.96
1025.9	0.00	0.00	0.00	0.00	99.96
1147.0	0.00	0.00	0.00	0.00	99.96
1282.4	0.00	0.00	0.00	0.00	99.96
1433.7	0.00	0.00	0.00	0.00	99.96
1602.9	0.00	0.00	0.00	0.00	99.96
1792.1	0.00	0.00	0.00	0.00	99.96
2003.6	0.00	0.00	0.00	0.00	99.96
2240.1	0.00	0.00	0.00	0.00	99.96
2504.5	0.00	0.00	0.00	0.00	99.96
2800.1	0.00	0.00	0.00	0.00	99.96
3130.5	0.00	0.00	0.00	0.00	99.96
3500.0	0.00	0.00	0.00	0.00	99.96

Particle size distribution per texture class

	Rep 1	Rep 2	Rep 3	**Mean**
Clay	22.15	22.78	22.29	22.41
Silt	64.09	65.70	63.40	64.40
Sand	13.66	11.46	14.36	13.16





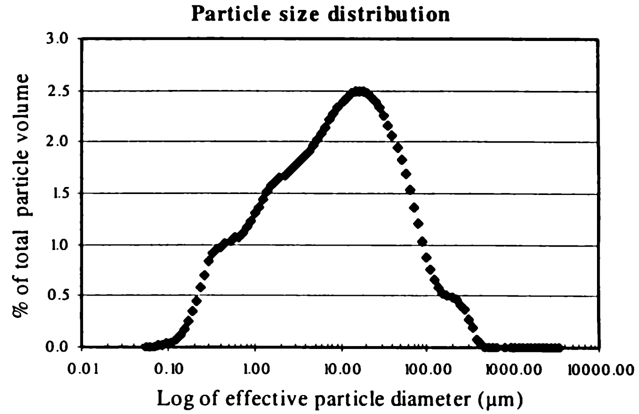
III.3.4 Soil Particle Size Distribution for 71% GSM 5-10 cm Soil Depth

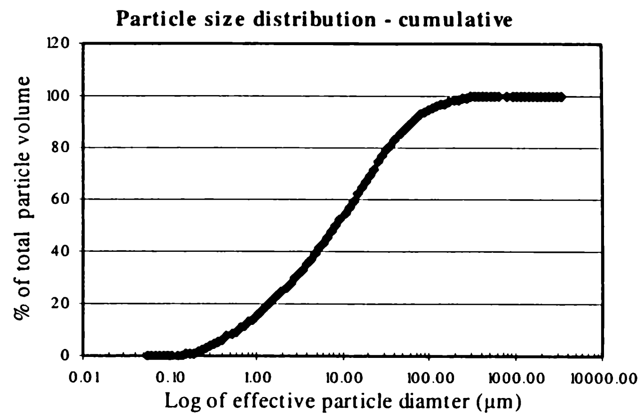
	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
0.050	na	na	na	na	
0.056	0.00	0.00	0.00	0.00	0.00
0.063	0.00	0.00	0.00	0.00	0.00
0.070	0.00	0.00	0.01	0.00	0.00
0.078	0.01	0.01	0.01	0.01	0.01
0.087	0.02	0.01	0.02	0.02	0.03
0.098	0.03	0.02	0.04	0.03	0.06
0.109	0.04	0.03	0.05	0.04	0.10
0.122	0.07	0.06	0.09	0.07	0.17
0.137	0.11	0.09	0.14	0.11	0.29
0.153	0.17	0.15	0.20	0.17	0.46
0.171	0.23	0.23	0.28	0.25	0.71
0.191	0.32	0.33	0.38	0.34	1.05
0.213	0.42	0.44	0.50	0.45	1.50
0.238	0.54	0.58	0.63	0.58	2.09
0.266	0.65	0.72	0.76	0.71	2.80
0.298	0.76	0.85	0.88	0.83	3.63
0.333	0.83	0.94	0.95	0.91	4.53
0.373	0.88	0.99	1.00	0.96	5.49
0.416	0.91	1.02	1.02	0.98	6.47
0.466	0.94	1.05	1.04	1.01	7.48
0.521	0.97	1.08	1.07	1.04	8.52
0.582	1.00	1.10	1.09	1.06	9.59
0.651	1.02	1.11	1.10	1.08	10.66
0.727	1.06	1.15	1.13	1.11	11.78
0.813	1.12	1.20	1.18	1.17	12.94
0.909	1.19	1.26	1.24	1.23	14.17
1.02	1.26	1.33	1.31	1.30	15.47
1.14	1.33	1.40	1.38	1.37	16.84
1.27	1.41	1.48	1.45	1.45	18.29
1.42	1.48	1.55	1.52	1.52	19.81
1.59	1.54	1.61	1.57	1.57	21.38
1.78	1.58	1.65	1.60	1.61	22.99
1.99	1.62	1.69	1.63	1.65	24.64
2.22	1.66	1.72	1.67	1.68	26.32
2.48	1.70	1.76	1.70	1.72	28.04
2.77	1.73	1.79	1.73	1.75	29.79
3.10	1.77	1.83	1.76	1.79	31.58
3.47	1.81	1.87	1.80	1.83	33.40
3.88	1.85	1.92	1.84	1.87	35.27
4.34	1.90	1.97	1.88	1.92	37.19
4.85	1.96	2.03	1.93	1.97	39.16
5.42	2.01	2.08	1.99	2.03	41.19
6.06	2.08	2.14	2.05	2.09	43.28
6.77	2.14	2.20	2.11	2.15	45.43
7.57	2.21	2.26	2.17	2.21	47.64
8.47	2.28	2.32	2.22	2.27	49.92
9.47	2.34	2.38	2.28	2.33	52.25
10.58	2.40	2.43	2.33	2.39	54.64
11.83	2.46	2.47	2.37	2.43	57.07

	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
13.23	2.50	2.50	2.40	2.47	59.54
14.79	2.53	2.52	2.42	2.49	62.03
16.54	2.54	2.52	2.42	2.49	64.52
18.49	2.54	2.51	2.42	2.49	67.01
20.67	2.53	2.48	2.40	2.47	69.48
23.11	2.50	2.45	2.37	2.44	71.92
25.84	2.46	2.41	2.34	2.40	74.32
28.89	2.41	2.33	2.27	2.34	76.66
32.29	2.34	2.24	2.19	2.26	78.92
36.11	2.24	2.14	2.11	2.16	81.08
40.37	2.14	2.04	2.02	2.07	83.15
45.13	2.02	1.92	1.92	1.95	85.10
50.46	1.89	1.80	1.81	1.83	86.93
56.41	1.74	1.66	1.68	1.69	88.63
63.07	1.58	1.50	1.54	1.54	90.17
70.52	1.41	1.32	1.39	1.37	91.54
78.84	1.23	1.16	1.22	1.20	92.74
88.14	1.06	0.99	1.06	1.04	93.78
98.55	0.91	0.83	0.91	0.88	94.66
110.2	0.79	0.70	0.78	0.76	95.42
123.2	0.70	0.59	0.67	0.65	96.07
137.7	0.64	0.52	0.59	0.58	96.66
154.0	0.61	0.46	0.53	0.53	97.19
172.1	0.58	0.42	0.50	0.50	97.69
192.5	0.56	0.39	0.50	0.48	98.17
215.2	0.53	0.35	0.50	0.46	98.63
240.6	0.46	0.29	0.50	0.42	99.05
269.0	0.38	0.24	0.47	0.36	99.41
300.7	0.25	0.18	0.41	0.28	99.69
336.2	0.13	0.12	0.31	0.19	99.88
375.9	0.03	0.03	0.19	0.08	99.96
420.2	0.00	0.00	0.10	0.03	100.00
469.8	0.00	0.00	0.00	0.00	100.00
525.3	0.00	0.00	0.00	0.00	100.00
587.3	0.00	0.00	0.00	0.00	100.00
656.6	0.00	0.00	0.00	0.00	100.00
820.7	0.00	0.00	0.00	0.00	100.00
917.6	0.00	0.00	0.00	0.00	100.00
1025.9	0.00	0.00	0.00	0.00	100.00
1147.0	0.00	0.00	0.00	0.00	100.00
1282.4	0.00	0.00	0.00	0.00	100.00
1433.7	0.00	0.00	0.00	0.00	100.00
1602.9	0.00	0.00	0.00	0.00	100.00
1792.1	0.00	0.00	0.00	0.00	100.00
2003.6	0.00	0.00	0.00	0.00	100.00
2240.1	0.00	0.00	0.00	0.00	100.00
2504.5	0.00	0.00	0.00	0.00	100.00
2800.1	0.00	0.00	0.00	0.00	100.00
3130.5	0.00	0.00	0.00	0.00	100.00
3500.0	0.00	0.00	0.00	0.00	100.00

Particle size distribution per texture class

	Rep 1	Rep 2	Rep 3	Mean
Clay	23.51	25.13	25.27	24.64
Silt	64.68	64.69	62.60	63.99
Sand	11.85	10.09	12.17	11.37





III.3.5 Soil Particle Size Distribution for 81% GSM 0-5 cm Soil Depth

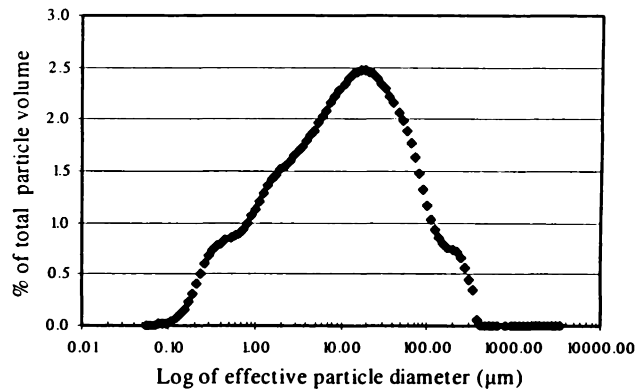
	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
0.050	na	na	na	na	
0.056	0.00	0.00	0.00	0.00	0.00
0.063	0.00	0.00	0.00	0.00	0.00
0.070	0.00	0.01	0.00	0.00	0.00
0.078	0.01	0.02	0.01	0.01	0.02
0.087	0.01	0.03	0.01	0.02	0.03
0.098	0.02	0.04	0.02	0.03	0.06
0.109	0.04	0.06	0.04	0.05	0.11
0.122	0.06	0.10	0.07	0.08	0.18
0.137	0.09	0.14	0.11	0.11	0.30
0.153	0.14	0.19	0.16	0.16	0.46
0.171	0.20	0.26	0.23	0.23	0.69
0.191	0.27	0.34	0.32	0.31	1.00
0.213	0.36	0.42	0.42	0.40	1.40
0.238	0.46	0.52	0.53	0.50	1.90
0.266	0.55	0.60	0.64	0.60	2.50
0.298	0.64	0.68	0.74	0.69	3.19
0.333	0.70	0.73	0.81	0.75	3.93
0.373	0.74	0.77	0.85	0.79	4.72
0.416	0.77	0.78	0.87	0.81	5.53
0.466	0.80	0.81	0.89	0.83	6.36
0.521	0.83	0.83	0.92	0.86	7.22
0.582	0.86	0.85	0.94	0.88	8.10
0.651	0.88	0.87	0.95	0.90	9.00
0.727	0.93	0.91	0.99	0.94	9.95
0.813	0.99	0.96	1.05	1.00	10.95
0.909	1.06	1.03	1.11	1.07	12.01
1.02	1.13	1.10	1.18	1.14	13.15
1.14	1.21	1.17	1.26	1.21	14.36
1.27	1.28	1.24	1.33	1.28	15.65
1.42	1.35	1.32	1.41	1.36	17.01
1.59	1.41	1.38	1.47	1.42	18.43
1.78	1.46	1.44	1.51	1.47	19.90
1.99	1.50	1.49	1.55	1.51	21.41
2.22	1.55	1.54	1.59	1.56	22.97
2.48	1.59	1.59	1.63	1.60	24.57
2.77	1.63	1.64	1.67	1.65	26.22
3.10	1.67	1.69	1.71	1.69	27.91
3.47	1.71	1.74	1.75	1.73	29.64
3.88	1.76	1.80	1.80	1.79	31.43
4.34	1.82	1.86	1.85	1.84	33.27
4.85	1.87	1.92	1.90	1.90	35.17
5.42	1.94	1.99	1.96	1.96	37.13
6.06	2.00	2.05	2.02	2.02	39.16
6.77	2.07	2.12	2.08	2.09	41.25
7.57	2.14	2.18	2.15	2.16	43.40
8.47	2.21	2.24	2.21	2.22	45.62
9.47	2.28	2.30	2.27	2.28	47.91
10.58	2.35	2.35	2.33	2.34	50.25
11.83	2.41	2.39	2.38	2.39	52.64

	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
13.23	2.46	2.41	2.42	2.43	55.07
14.79	2.51	2.43	2.45	2.46	57.54
16.54	2.54	2.43	2.46	2.48	60.01
18.49	2.56	2.41	2.46	2.48	62.49
20.67	2.56	2.38	2.44	2.46	64.95
23.11	2.55	2.33	2.42	2.43	67.38
25.84	2.53	2.28	2.38	2.40	69.78
28.89	2.50	2.22	2.32	2.35	72.13
32.29	2.46	2.15	2.27	2.29	74.42
36.11	2.41	2.08	2.20	2.23	76.65
40.37	2.34	2.00	2.12	2.15	78.80
45.13	2.26	1.93	2.03	2.07	80.88
50.46	2.17	1.85	1.94	1.99	82.86
56.41	2.06	1.77	1.83	1.89	84.75
63.07	1.92	1.68	1.70	1.77	86.52
70.52	1.76	1.57	1.55	1.63	88.14
78.84	1.57	1.46	1.39	1.47	89.62
88.14	1.38	1.34	1.23	1.32	90.93
98.55	1.19	1.23	1.08	1.17	92.10
110.2	1.01	1.13	0.95	1.03	93.13
123.2	0.87	1.06	0.85	0.93	94.06
137.7	0.75	1.01	0.79	0.85	94.91
154.0	0.67	0.97	0.74	0.79	95.70
172.1	0.61	0.95	0.73	0.76	96.46
192.5	0.57	0.92	0.72	0.74	97.20
215.2	0.54	0.89	0.71	0.71	97.91
240.6	0.50	0.83	0.67	0.67	98.58
269.0	0.41	0.70	0.56	0.56	99.14
300.7	0.31	0.56	0.45	0.44	99.58
336.2	0.23	0.47	0.36	0.35	99.93
375.9	0.03	0.07	0.06	0.05	99.98
420.2	0.00	0.00	0.00	0.00	99.98
469.8	0.00	0.00	0.00	0.00	99.98
525.3	0.00	0.00	0.00	0.00	99.98
587.3	0.00	0.00	0.00	0.00	99.98
656.6	0.00	0.00	0.00	0.00	99.98
820.7	0.00	0.00	0.00	0.00	99.98
917.6	0.00	0.00	0.00	0.00	99.98
1025.9	0.00	0.00	0.00	0.00	99.98
1147.0	0.00	0.00	0.00	0.00	99.98
1282.4	0.00	0.00	0.00	0.00	99.98
1433.7	0.00	0.00	0.00	0.00	99.98
1602.9	0.00	0.00	0.00	0.00	99.98
1792.1	0.00	0.00	0.00	0.00	99.98
2003.6	0.00	0.00	0.00	0.00	99.98
2240.1	0.00	0.00	0.00	0.00	99.98
2504.5	0.00	0.00	0.00	0.00	99.98
2800.1	0.00	0.00	0.00	0.00	99.98
3130.5	0.00	0.00	0.00	0.00	99.98
3500.0	0.00	0.00	0.00	0.00	99.98

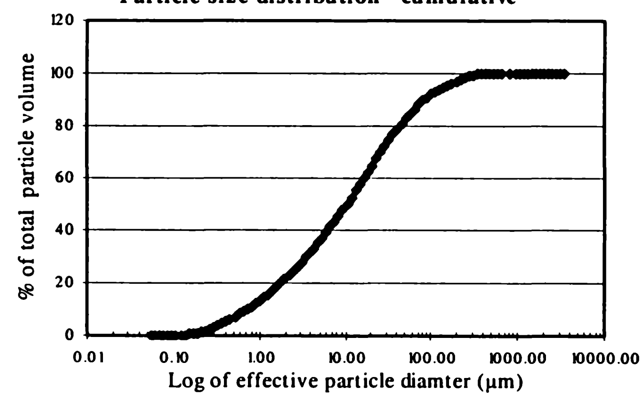
Particle size distribution per texture class

	Rep 1	Rep 2	Rep 3	**Mean**
Clay	20.75	21.09	22.39	21.41
Silt	64.91	62.07	63.04	63.34
Sand	14.32	16.84	14.54	15.23

Particle size distribution



Particle size distribution - cumulative

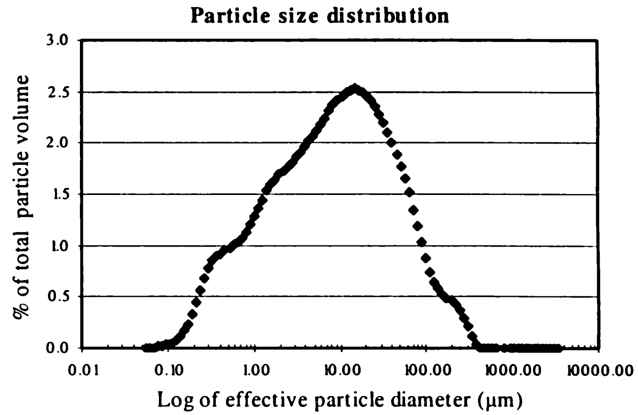


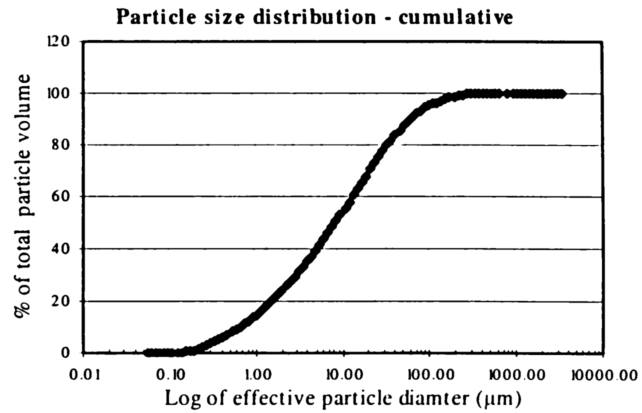
III.3.6 Soil Particle Size Distribution for 81% GSM 5-10 cm Soil Depth

	% volume of total sample				
Size (µm)	Rep 1	Rep 2	Rep 3	Mean	Cum
0.050	na	na	na	na	
0.056	0.00	0.00	0.00	0.00	0.00
0.063	0.00	0.00	0.00	0.00	0.00
0.070	0.01	0.00	0.01	0.01	0.01
0.078	0.01	0.01	0.01	0.01	0.02
0.087	0.02	0.02	0.02	0.02	0.04
0.098	0.03	0.03	0.03	0.03	0.07
0.109	0.04	0.05	0.04	0.04	0.11
0.122	0.07	0.07	0.08	0.07	0.18
0.137	0.12	0.11	0.12	0.12	0.30
0.153	0.17	0.17	0.17	0.17	0.47
0.171	0.24	0.24	0.25	0.24	0.71
0.191	0.33	0.33	0.34	0.33	1.05
0.213	0.44	0.44	0.45	0.44	1.49
0.238	0.55	0.56	0.57	0.56	2.05
0.266	0.66	0.68	0.69	0.68	2.73
0.298	0.77	0.78	0.80	0.78	3.51
0.333	0.83	0.86	0.88	0.86	4.37
0.373	0.87	0.90	0.93	0.90	5.27
0.416	0.89	0.93	0.95	0.92	6.19
0.466	0.92	0.96	0.98	0.95	7.14
0.521	0.94	0.99	1.01	0.98	8.12
0.582	0.96	1.02	1.04	1.01	9.13
0.651	0.98	1.05	1.06	1.03	10.16
0.727	1.02	1.09	1.11	1.07	11.23
0.813	1.08	1.16	1.17	1.14	12.37
0.909	1.15	1.23	1.24	1.21	13.58
1.02	1.23	1.32	1.32	1.29	14.87
1.14	1.31	1.40	1.40	1.37	16.24
1.27	1.39	1.48	1.48	1.45	17.69
1.42	1.47	1.57	1.56	1.53	19.22
1.59	1.54	1.63	1.62	1.60	20.82
1.78	1.59	1.68	1.66	1.64	22.46
1.99	1.64	1.73	1.71	1.69	24.15
2.22	1.69	1.78	1.75	1.74	25.89
2.48	1.73	1.82	1.79	1.78	27.67
2.77	1.78	1.86	1.82	1.82	29.49
3.10	1.83	1.91	1.86	1.87	31.36
3.47	1.88	1.95	1.91	1.91	33.27
3.88	1.93	2.00	1.95	1.96	35.23
4.34	1.99	2.06	2.00	2.02	37.25
4.85	2.04	2.11	2.05	2.07	39.32
5.42	2.11	2.17	2.11	2.13	41.45
6.06	2.17	2.23	2.17	2.19	43.64
6.77	2.23	2.29	2.22	2.25	45.88
7.57	2.30	2.35	2.28	2.31	48.19
8.47	2.36	2.40	2.36	2.37	50.57
9.47	2.41	2.45	2.38	2.41	52.98
10.58	2.46	2.50	2.43	2.46	55.44
13.23	2.52	2.55	2.49	2.52	60.46
14.79	2.53	2.55	2.50	2.53	62.99
16.54	2.52	2.54	2.50	2.52	65.51
18.49	2.50	2.52	2.48	2.50	68.01
20.67	2.46	2.47	2.45	2.46	70.47
23.11	2.41	2.43	2.42	2.42	72.89
25.84	2.35	2.37	2.38	2.37	75.25
28.89	2.28	2.27	2.30	2.28	77.54
32.29	2.20	2.17	2.22	2.20	79.73
36.11	2.11	2.07	2.12	2.10	81.83
40.37	2.03	1.96	2.01	2.00	83.83
45.13	1.94	1.84	1.90	1.89	85.73
50.46	1.85	1.72	1.77	1.78	87.51
56.41	1.74	1.59	1.63	1.65	89.16
63.07	1.62	1.44	1.47	1.51	90.67
70.52	1.48	1.28	1.30	1.35	92.02
78.84	1.32	1.11	1.13	1.19	93.21
88.14	1.16	0.95	0.96	1.02	94.24
98.55	1.01	0.80	0.82	0.88	95.11
110.2	0.87	0.68	0.70	0.75	95.86
123.2	0.75	0.58	0.61	0.65	96.51
137.7	0.66	0.51	0.56	0.58	97.09
154.0	0.58	0.46	0.52	0.52	97.61
172.1	0.52	0.44	0.50	0.49	98.09
192.5	0.47	0.42	0.49	0.46	98.55
215.2	0.42	0.40	0.46	0.43	98.98
240.6	0.35	0.36	0.41	0.37	99.35
269.0	0.28	0.29	0.33	0.30	99.65
300.7	0.20	0.20	0.22	0.21	99.86
336.2	0.13	0.11	0.11	0.12	99.98
375.9	0.03	0.03	0.03	0.03	100.01
420.2	0.00	0.00	0.00	0.00	100.01
469.8	0.00	0.00	0.00	0.00	100.01
525.3	0.00	0.00	0.00	0.00	100.01
587.3	0.00	0.00	0.00	0.00	100.01
656.6	0.00	0.00	0.00	0.00	100.01
820.7	0.00	0.00	0.00	0.00	100.01
917.6	0.00	0.00	0.00	0.00	100.01
1025.9	0.00	0.00	0.00	0.00	100.01
1147.0	0.00	0.00	0.00	0.00	100.01
1282.4	0.00	0.00	0.00	0.00	100.01
1433.7	0.00	0.00	0.00	0.00	100.01
1602.9	0.00	0.00	0.00	0.00	100.01
1792.1	0.00	0.00	0.00	0.00	100.01
2003.6	0.00	0.00	0.00	0.00	100.01
2240.1	0.00	0.00	0.00	0.00	100.01
2504.5	0.00	0.00	0.00	0.00	100.01
2800.1	0.00	0.00	0.00	0.00	100.01
3130.5	0.00	0.00	0.00	0.00	100.01

Particle size distribution per texture class

	Rep 1	Rep 2	Rep 3	**Mean**
Clay	23.27	24.49	24.70	24.15
Silt	64.85	65.46	64.71	65.01
Sand	11.85	10.06	10.62	10.84





Appendix IV

Soil Plastic and Liquid Limits

Appendix IV Soil Plastic and Liquid Limits

IV.1 Experimental Means

	Plastic Limits			Liquid Limits		
	soil moisture ($g\ g^{-1}$)	st.dev.	s.e.	soil moisture ($g\ g^{-1}$)	st.dev.	s.e.
65% GSM						
0-5 cm	0.50	0.525	0.303	0.81	0.717	0.366
5-10 cm	0.46	0.588	0.340	0.76	0.518	0.204
71% GSM						
0-5 cm	0.54	0.849	0.490	0.99	0.460	0.124
5-10 cm	0.48	0.953	0.550	0.85	0.417	0.119
81% GSM						
0-5 cm	0.55	0.889	0.513	0.95	0.610	0.226
5-10 cm	0.49	0.949	0.548	0.89	0.555	0.201

IV.2 Individual Results

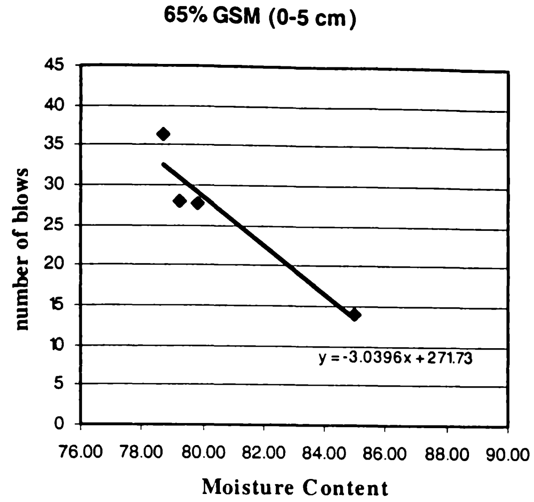
IV.2.1 Plastic limits

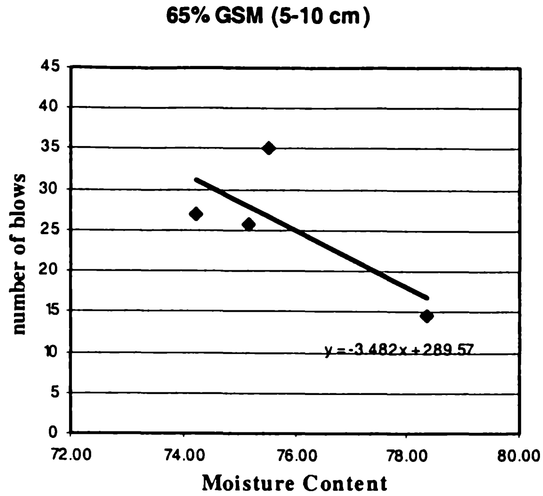
Experiment	Soil depth (cm)	Rep #	Container weight (g)	Wet soil (g)	Over dry soil (g)	Moisture content (% gravimetric)
65% GSM	0-5	1	7.18	19.45	15.36	50.00
		2	8.77	22.68	18.01	50.54
		3	7.04	20.27	15.89	49.49
65% GSM	5-10	1	7.32	20.46	16.32	46.00
		2	11.8	23.63	19.95	45.15
		3	6.93	22.48	17.56	46.28
71% GSM	0-5	1	7.15	15.02	12.23	54.92
		2	8.69	15.19	12.92	53.66
		3	7.09	17.53	13.9	53.30
71% GSM	5-10	1	8.72	16.00	13.68	46.77
		2	6.93	19.17	15.17	48.54
		3	6.92	16.78	13.57	48.27
81% GSM	0-5	1	6.93	9.07	8.3	56.20
		2	6.91	11.59	9.93	54.97
		3	11.79	18.34	16.03	54.48
81% GSM	5-10	1	7.11	22.88	17.77	47.94
		2	11.57	21.76	18.45	48.11
		3	8.72	19.75	16.09	49.66

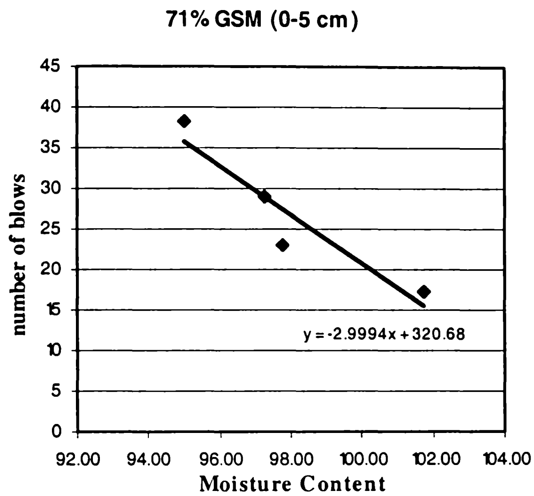
IV.2.2 Liquid Limits

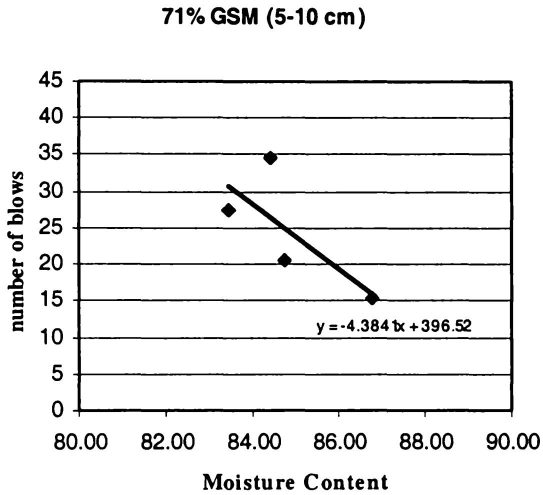
Experiment	Soil depth (cm)	Set #	# of casagrande blows			Container weight (g)	Wet soil (g)	Oven dry soil (g)	Moisture content (% gravimetric)	Mean number of blows[a]
			Rep 1	Rep 2	Rep 3					
65% GSM	0-5	1	13	14	15	7.09	18.89	13.47	84.95	14
		2	25	30	28	6.96	20.77	14.64	79.82	28
		3	33	36	40	12.43	25.28	19.62	78.72	36
		4	26	27	31	11.54	24.48	18.76	79.22	28
65% GSM	5-10	1	14	15	15	11.33	23.76	18.30	78.34	15
		2	36	32	37	7.12	19.74	14.31	75.52	35
		3	24	28	29	7.02	19.60	14.24	74.24	27
		4	24	26	27	10.89	21.75	17.09	75.16	26
71% GSM	0-5	1	17	18	17	11.87	24.62	18.19	101.74	17
		2	22	23	24	6.75	20.87	13.89	97.76	23
		3	30	28	29	7.16	20.83	14.09	97.26	29
		4	35	40	40	11.81	26.26	19.22	95.01	38
71% GSM	5-10	1	14	16	16	7.08	22.92	15.56	86.79	15
		2	32	35	37	6.91	20.63	14.35	84.41	35
		3	28	27	27	7.14	21.23	14.82	83.46	27
		4	20	21	21	6.99	19.11	13.55	84.76	21
81% GSM	0-5	1	17	14	14	7.01	20.11	13.59	99.09	15
		2	26	28	29	7.04	17.63	12.54	92.55	28
		3	27	26	29	7.05	17.75	12.55	94.55	27
		4	33	32	34	11.81	23.44	17.85	92.55	33
81% GSM	5-10	1	17	18	18	7.32	18.13	12.97	91.33	18
		2	24	28	26	6.95	18.74	13.24	87.44	26
		3	30	36	31	7.12	19.55	13.81	85.80	32
		4	37	35	38	6.83	17.97	12.84	85.36	37

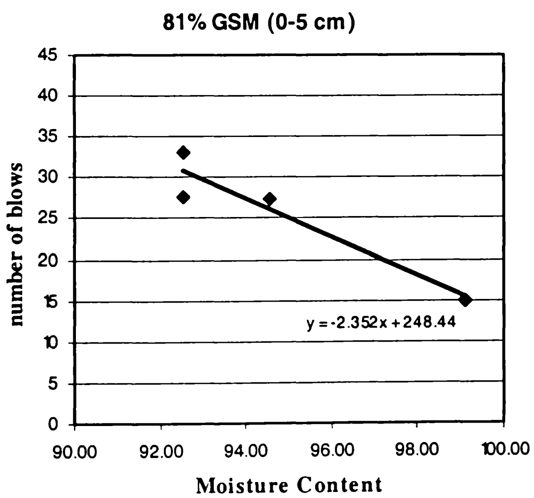
[a] Liquid limit was determined by plotting the moisture content with the number of casagrande blows, where 25 blows was the liquid limit (see graphs over page).

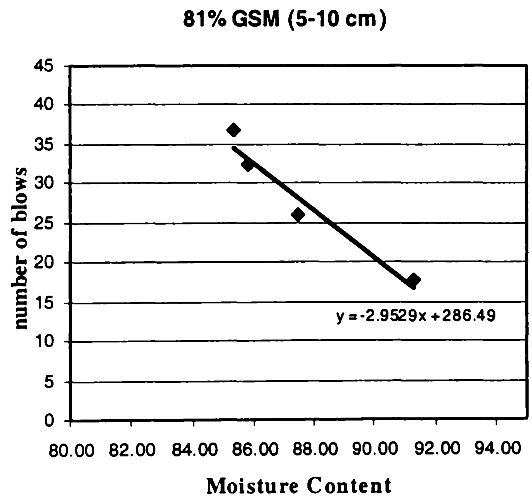












Graphs for each experimental site and soil depth, showing soil moisture content with the number of casagrande blows to determine liquid limits (25 blows).

Appendix V

Soil Porosity and Density

Appendix V Soil Porosity and Dry Bulk Density

V.1 Treatment Means

V.1.1 Soil Dry Bulk Density

65% GSM					
	Soil Dry Bulk Density (Mg m^{-3})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.80	0.76	0.68	0.68	0.76
3 hour	0.77	0.76	0.77	0.69	0.74
9 hour	0.80	0.82	0.76	0.74	0.87
24 hour	0.82	0.85	0.78	0.77	0.83
F.pr	0.149	0.072	0.017	0.045	0.008
e.s.e	0.0138	0.0242	0.01890	0.0189	0.02018
s.e.d	0.0296	0.0342	0.02673	0.0267	0.02854
l.s.d	0.0451	0.0788	0.06164	0.0615	0.06581

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

65% GSM					
	Soil Dry Bulk Density (Mg m^{-3})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.97	0.95	0.97	0.96	0.96
3 hour	0.94	0.96	0.95	0.92	0.95
9 hour	1.00	1.03	0.99	0.96	1.03
24 hour	1.04	1.03	1.03	1.03	1.03
F.pr	0.147	0.199	0.422	0.084	0.328
e.s.e	0.02771	0.03422	0.03606	0.02391	0.03860
s.e.d	0.03919	0.04840	0.05100	0.03381	0.05458
l.s.d	0.09038	0.11160	0.11760	0.07798	0.12587

71% GSM					
	Soil Dry Bulk Density (Mg m^{-3})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.71	0.64	0.71	0.79	0.78
3 hour	0.70	0.69	0.74	0.83	0.84
9 hour	0.69	0.70	0.78	0.86	0.83
24 hour	0.75	0.75	0.81	0.92	0.86
F.pr	0.724	0.529	0.579	0.373	0.748
e.s.e	0.0356	0.0510	0.05451	0.05125	0.04869
s.e.d	0.0503	0.0721	0.07708	0.07247	0.06887
l.s.d	0.116	0.1663	0.17776	0.16713	0.15880

	71% GSM				
	Soil Dry Bulk Density (Mg m^{-3})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.88	0.88	0.89	0.94	0.91
3 hour	0.89	0.89	0.91	0.96	0.94
9 hour	0.89	0.89	0.92	0.98	0.94
24 hour	0.92	0.94	0.97	1.01	0.97
F.pr	0.946	0.869	0.820	0.903	0.922
e.s.e	0.05293	0.05942	0.06297	0.06455	0.05745
s.e.d	0.07485	0.08403	0.08906	0.09128	0.08125
l.s.d	0.17261	0.19377	0.20537	0.21049	0.18736

	81% GSM				
	Soil Dry Bulk Density (Mg m^{-3})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.73	0.74	0.76	0.76	0.87
3 hour	0.73	0.73	0.67	0.80	0.84
9 hour	0.73	0.73	0.71	0.79	0.93
24 hour	0.77	0.71	0.68	0.85	0.89
F.pr	0.307	0.900	0.040	0.301	0.239
e.s.e	0.0176	0.0264	0.01802	0.0311	0.0303
s.e.d	0.0250	0.0373	0.02548	0.0440	0.0428
l.s.d	0.0576	0.0859	0.05875	0.1014	0.0987

	81% GSM				
	Soil Dry Bulk Density (Mg m^{-3})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.95	0.92	0.95	0.93	1.02
3 hour	0.92	0.89	0.90	0.93	0.95
9 hour	0.99	0.93	0.93	1.03	1.08
24 hour	0.95	0.92	0.93	0.97	1.00
F.pr	0.126	0.642	0.340	0.019	0.021
e.s.e	0.01908	0.02448	0.01932	0.01853	0.02238
s.e.d	0.02698	0.03461	0.02732	0.02621	0.03166
l.s.d	0.06222	0.07982	0.06299	0.06044	0.07300

V.1.2 Soil Total Porosity

65% GSM					
	Soil Total Porosity (cm^3 cm^{-3})		0-5 cm soil depth		
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.66	0.67	0.71	0.71	0.67
3 hour	0.67	0.67	0.67	0.70	0.68
9 hour	0.66	0.65	0.67	0.68	0.63
24 hour	0.65	0.63	0.66	0.67	0.64
F.pr	0.149	0.072	0.017	0.045	0.008
e.s.e	0.00596	0.01042	0.00815	0.00813	0.00870
s.e.d	0.00844	0.01474	0.01152	0.01149	0.01230
l.s.d	0.019545	0.03399	0.02657	0.02650	0.02837

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

65% GSM					
	Soil Total Porosity (cm^3 cm^{-3})		5-10 cm soil depth		
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.59	0.60	0.59	0.59	0.59
3 hour	0.60	0.59	0.60	0.61	0.59
9 hour	0.57	0.56	0.58	0.59	0.56
24 hour	0.56	0.56	0.56	0.56	0.56
F.pr	0.147	0.199	0.422	0.084	0.328
e.s.e	0.01181	0.01458	0.01536	0.01019	0.01644
s.e.d	0.01670	0.02062	0.02172	0.01441	0.02325
l.s.d	0.03850	0.04754	0.05010	0.03322	0.05362

71% GSM					
	Soil Total Porosity (cm^3 cm^{-3})		0-5 cm soil depth		
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.69	0.72	0.69	0.66	0.66
3 hour	0.70	0.70	0.68	0.64	0.64
9 hour	0.70	0.70	0.66	0.63	0.64
24 hour	0.68	0.67	0.65	0.60	0.63
F.pr	0.724	0.529	0.579	0.373	0.748
e.s.e	0.01539	0.02205	0.02358	0.02217	0.02106
s.e.d	0.02176	0.03119	0.03334	0.03135	0.02979
l.s.d	0.05018	0.07191	0.07689	0.07229	0.06869

	71% GSM				
	Soil Total Porosity (cm^3 cm^{-3})			5-10 cm soil depth	
	Before	After	4 weeks	13 weeks	26 weeks
Control	0.63	0.63	0.62	0.60	0.61
3 hour	0.62	0.62	0.62	0.59	0.60
9 hour	0.62	0.62	0.61	0.59	0.60
24 hour	0.61	0.60	0.59	0.57	0.59
F.pr	0.946	0.869	0.820	0.903	0.922
e.s.e	0.02243	0.02518	0.02669	0.02736	0.02435
s.e.d	0.03173	0.03562	0.03775	0.03869	0.03444
l.s.d	0.07316	0.08213	0.08705	0.08922	0.07941

	81% GSM				
	Soil Total Porosity (cm^3 cm^{-3})			0-5 cm soil depth	
	Before	After	4 weeks	13 weeks	26 weeks
Control	0.68	0.68	0.67	0.67	0.62
3 hour	0.68	0.68	0.71	0.65	0.63
9 hour	0.68	0.68	0.69	0.66	0.59
24 hour	0.66	0.69	0.71	0.63	0.61
F.pr	0.307	0.900	0.040	0.301	0.239
e.s.e	0.00768	0.01147	0.00784	0.01353	0.01317
s.e.d	0.01086	0.01622	0.01109	0.01913	0.01862
l.s.d	0.02505	0.03740	0.02556	0.04412	0.04294

	81% GSM				
	Soil Total Porosity (cm^3 cm^{-3})			5-10 cm soil depth	
	Before	After	4 weeks	13 weeks	26 weeks
Control	0.60	0.61	0.60	0.61	0.56
3 hour	0.61	0.62	0.62	0.61	0.59
9 hour	0.58	0.61	0.60	0.56	0.54
24 hour	0.60	0.61	0.60	0.59	0.57
F.pr	0.126	0.642	0.340	0.019	0.021
e.s.e	0.00810	0.01039	0.00820	0.00787	0.00950
s.e.d	0.001146	0.01469	0.01160	0.01113	0.01344
l.s.d	0.02642	0.03389	0.02674	0.02566	0.03099

V.1.3 Soil Macroporosity

65% GSM Soil Macroporosity (cm^3 cm^{-3}) 0-5 cm soil depth	Before	After	4 weeks	13 weeks	26 weeks
Control	0.20	0.24	0.24	0.24	0.25
3 hour	0.23	0.23	0.19	0.24	0.25
9 hour	0.21	0.19	0.21	0.20	0.18
24 hour	0.20	0.18	0.18	0.20	0.22
F.pr	0.042	0.027	0.314	0.015	0.035
e.s.e	0.0074	0.01292	0.2122	0.00956	0.01613
s.e.d	0.01046	0.01828	0.03001	0.01353	0.02281
l.s.d	0.02412	0.04215	0.06921	0.03119	0.05261

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

65% GSM Soil Macroporosity (cm^3 cm^{-3}) 5-10 cm soil depth	Before	After	4 weeks	13 weeks	26 weeks
Control	0.17	0.20	0.16	0.16	0.17
3 hour	0.19	0.19	0.16	0.17	0.18
9 hour	0.17	0.17	0.17	0.16	0.15
24 hour	0.15	0.16	0.14	0.14	0.14
F.pr	0.066	0.262	0.245	0.140	0.228
e.s.e	0.00787	0.01246	0.01007	0.00821	0.01351
s.e.d	0.01113	0.01762	0.01424	0.01162	0.01911
l.s.d	0.02567	0.04064	0.03283	0.02679	0.04407

71% GSM Soil Macroporosity (cm^3 cm^{-3}) 0-5 cm soil depth	Before	After	4 weeks	13 weeks	26 weeks
Control	0.19	0.21	0.17	0.18	0.19
3 hour	0.18	0.18	0.16	0.15	0.17
9 hour	0.17	0.15	0.10	0.13	0.17
24 hour	0.18	0.12	0.11	0.10	0.16
F.pr	0.792	0.014	0.091	0.109	0.612
e.s.e	0.01252	0.01525	0.01990	0.01916	0.01496
s.e.d	0.01770	0.02157	0.02814	0.02709	0.02116
l.s.d	0.04082	0.04974	0.06488	0.06247	0.04880

	71% GSM				
	Soil Macroporosity (cm^3 cm^{-3}) 5-10 cm soil depth				
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.15	0.16	0.14	0.14	0.17
3 hour	0.14	0.14	0.13	0.11	0.15
9 hour	0.14	0.14	0.13	0.12	0.15
24 hour	0.14	0.12	0.11	0.12	0.15
F.pr	0.863	0.225	0.280	0.828	0.402
e.s.e	0.00890	0.01208	0.01268	0.01659	0.00886
s.e.d	0.01258	0.01708	0.01793	0.02346	0.01253
l.s.d	0.02901	0.03938	0.04136	0.05409	0.02889

	81% GSM				
	Soil Macroporosity (cm^3 cm^{-3}) 0-5 cm soil depth				
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.23	0.20	0.20	0.19	0.14
3 hour	0.21	0.16	0.20	0.18	0.16
9 hour	0.21	0.12	0.18	0.18	0.11
24 hour	0.21	0.10	0.14	0.15	0.12
F.pr	0.196	0.008	0.197	0.184	0.388
e.s.e	0.00835	0.01575	0.01998	0.01400	0.02257
s.e.d	0.01181	0.02227	0.02825	0.01980	0.03191
l.s.d	0.02724	0.05137	0.06515	0.04566	0.07359

	81% GSM				
	Soil Macroporosity (cm^3 cm^{-3}) 5-10 cm soil depth				
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.16	0.16	0.13	0.15	0.11
3 hour	0.17	0.15	0.15	0.14	0.13
9 hour	0.14	0.13	0.14	0.13	0.08
24 hour	0.16	0.13	0.11	0.13	0.09
F.pr	0.398	0.071	0.073	0.055	0.111
e.s.e	0.00949	0.00646	0.00826	0.00552	0.01264
s.e.d	0.01343	0.00914	0.01168	0.00781	0.01788
l.s.d	0.03096	0.02108	0.02694	0.01800	0.04124

V.1.4 Soil Microporosity

	65% GSM				
	Soil Microporosity (cm^3 cm^{-3})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.46	0.43	0.47	0.47	0.42
3 hour	0.44	0.44	0.48	0.46	0.43
9 hour	0.45	0.46	0.47	0.48	0.45
24 hour	0.45	0.46	0.48	0.47	0.42
F.pr	0.437	0.073	0.787	0.126	0.450
e.s.e	0.00754	0.00584	0.01385	0.00565	0.01233
s.e.d	0.01067	0.00827	0.01959	0.00799	0.01744
l.s.d	0.02460	0.01906	0.04517	0.01843	0.04022

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	65% GSM				
	Soil Microporosity (cm^3 cm^{-3})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.41	0.40	0.43	0.43	0.42
3 hour	0.41	0.41	0.43	0.44	0.41
9 hour	0.40	0.39	0.40	0.43	0.41
24 hour	0.41	0.40	0.42	0.42	0.42
F.pr	0.642	0.199	0.208	0.511	0.867
e.s.e	0.00746	0.01458	0.1034	0.00665	0.00831
s.e.d	0.01055	0.02062	0.01463	0.00940	0.01176
l.s.d	0.02434	0.03189	0.03373	0.02167	0.02711

	71% GSM				
	Soil Microporosity (cm^3 cm^{-3})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.50	0.51	0.52	0.48	0.47
3 hour	0.52	0.52	0.52	0.49	0.47
9 hour	0.53	0.54	0.56	0.50	0.47
24 hour	0.50	0.55	0.54	0.50	0.47
F.pr	0.454	0.133	0.369	0.580	0.996
e.s.e	0.01389	0.01316	0.01627	0.01246	0.01484
s.e.d	0.01965	0.01861	0.02301	0.01763	0.02099
l.s.d	0.04531	0.04292	0.05306	0.04064	0.04840

	71% GSM				
	Soil Microporosity (cm^3 cm^{-3})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.48	0.47	0.48	0.47	0.45
3 hour	0.49	0.48	0.48	0.48	0.46
9 hour	0.48	0.49	0.49	0.46	0.45
24 hour	0.47	0.48	0.48	0.45	0.44
F.pr	0.940	0.859	0.996	0.747	0.982
e.s.e	0.01571	0.01614	0.01982	0.01662	0.02218
s.e.d	0.02222	0.02282	0.02803	0.02350	0.03137
l.s.d	0.05124	0.05263	0.06464	0.05419	0.07233

	81% GSM				
	Soil Microporosity (cm^3 cm^{-3})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.45	0.48	0.47	0.48	0.48
3 hour	0.47	0.52	0.51	0.47	0.47
9 hour	0.47	0.56	0.51	0.47	0.48
24 hour	0.46	0.60	0.57	0.48	0.49
F.pr	0.401	0.018	0.047	0.616	0.801
e.s.e	0.01077	0.02003	0.01928	0.00613	0.01600
s.e.d	0.01523	0.02832	0.02726	0.00866	0.02263
l.s.d	0.03512	0.06531	0.06287	0.01998	0.05219

	81% GSM				
	Soil Microporosity (cm^3 cm^{-3})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	0.44	0.45	0.46	0.46	0.45
3 hour	0.45	0.48	0.47	0.46	0.47
9 hour	0.44	0.48	0.47	0.44	0.46
24 hour	0.44	0.47	0.49	0.46	0.49
F.pr	0.918	0.033	0.029	0.277	0.124
e.s.e	0.01108	0.00554	0.00582	0.00809	0.00959
s.e.d	0.01567	0.00783	0.00823	0.01145	0.01356
l.s.d	0.03613	0.01806	0.01897	0.02639	0.03127

V.2 Individual Results for 65% GSM Experiment

V.2.1 Before Treading Treatment

Date sampled: 17/6/99

Treat-ment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
control	1	0-5	2	425.70	80.91	27.0	599.36	333.56	0.84	0.64	0.46	0.18
			3	424.03	81.12	4.5	567.44	318.28	0.76	0.67	0.40	0.27
			5	421.60	81.00	6.5	609.62	332.60	0.80	0.65	0.47	0.18
			7	426.53	80.85	19.0	570.12	302.95	0.74	0.68	0.46	0.22
			9	425.70	80.57	27.5	635.28	370.17	0.93	0.60	0.46	0.14
control	1	5-10	1	424.85	81.09	5.0	633.02	368.07	0.88	0.63	0.44	0.19
			4	424.85	81.25	3.0	635.12	371.79	0.88	0.62	0.43	0.19
			6	425.69	81.59	1.0	640.38	379.72	0.89	0.62	0.42	0.20
			8	425.71	80.97	1.0	617.04	352.54	0.83	0.65	0.43	0.21
			10	424.48	80.65	4.5	643.96	392.32	0.93	0.60	0.41	0.19
3 hour	2	0-5	11	426.79	80.19	73.0	488.64	260.34	0.74	0.68	0.42	0.26
			13	428.20	80.72	61.0	443.60	206.06	0.56	0.76	0.43	0.33
			15	424.62	80.65	23.0	566.74	305.49	0.76	0.67	0.45	0.22
			17	423.60	80.75	22.5	589.60	330.85	0.82	0.64	0.44	0.20
			19	421.39	80.52	26.0	577.76	326.26	0.83	0.64	0.43	0.21
3 hour	2	5-10	12	428.11	80.26	4.0	652.80	396.21	0.93	0.60	0.42	0.19
			14	423.43	80.26	5.0	617.26	360.82	0.86	0.63	0.42	0.21
			16	424.56	80.92	6.0	667.26	406.70	0.97	0.59	0.43	0.16
			18	427.78	80.37	32.0	609.94	380.25	0.96	0.59	0.38	0.21
			20	425.28	81.30	2.0	659.40	418.76	0.99	0.58	0.38	0.20
24 hour	3	0-5	21	422.33	80.32	44.0	539.52	292.82	0.77	0.67	0.44	0.23
			23	427.34	80.47	12.5	592.04	331.40	0.80	0.66	0.43	0.22
			25	424.42	80.66	17.0	608.18	348.18	0.85	0.63	0.44	0.19
			27	426.98	80.28	7.5	680.04	408.78	0.97	0.58	0.46	0.12
			29	421.00	81.33	47.5	552.36	318.23	0.85	0.63	0.41	0.22
24 hour	3	5-10	22	425.70	80.63	2.5	688.16	443.50	1.05	0.55	0.39	0.17
			24	424.87	80.79	7.0	675.16	427.62	1.02	0.56	0.40	0.16
			26	423.81	81.34	9.0	738.96	501.46	1.21	0.48	0.38	0.11
			28	426.38	80.60	9.0	667.26	432.61	1.04	0.56	0.37	0.19
			30	425.14	80.56	3.5	714.82	462.06	1.10	0.53	0.41	0.12
3 hour	4	0-5	31	432.17	81.65	30.0	553.28	302.54	0.75	0.68	0.42	0.26
			33	425.84	80.43	13.0	605.74	342.19	0.83	0.64	0.44	0.20
			35	427.45	81.13	12.0	607.86	333.59	0.80	0.65	0.46	0.19
			37	422.80	80.98	10.0	601.66	330.02	0.80	0.66	0.46	0.19
			39	425.65	80.22	34.0	556.86	298.73	0.76	0.67	0.45	0.22
3 hour	4	5-10	32	424.22	81.06	1.0	651.92	397.98	0.94	0.60	0.41	0.19
			34	427.71	80.66	0.5	659.94	402.28	0.94	0.60	0.41	0.18
			36	426.15	80.69	2.0	643.22	387.14	0.91	0.61	0.41	0.20
			38	424.98	80.35	2.0	638.78	374.57	0.89	0.62	0.43	0.19
			40	424.78	80.86	2.5	667.68	403.19	0.95	0.59	0.43	0.16
9 hour	5	0-5	41	425.73	79.89	47.0	524.74	274.07	0.72	0.69	0.45	0.24
			43	424.55	80.34	34.0	564.04	312.32	0.80	0.66	0.44	0.22
			45	427.97	80.54	49.5	542.40	286.45	0.76	0.67	0.46	0.21
			47	426.51	80.26	23.0	609.02	360.57	0.89	0.61	0.42	0.20
			49	425.20	81.17	43.0	605.68	347.26	0.91	0.61	0.46	0.14
9 hour	5	5-10	42	429.22	80.70	53.5	537.28	326.06	0.87	0.63	0.35	0.28
			44	426.55	80.00	0.5	714.34	456.53	1.07	0.54	0.42	0.13
			46	424.73	80.07	2.5	681.70	430.49	1.02	0.57	0.41	0.16
			48	425.08	80.72	2.5	698.30	451.72	1.07	0.54	0.39	0.15
			50	424.62	80.97	1.5	687.76	436.79	1.03	0.56	0.40	0.16
control	6	0-5	51	423.81	80.60	42.5	595.60	351.07	0.92	0.60	0.43	0.17
			53	427.54	80.48	55.5	549.86	285.19	0.77	0.67	0.50	0.17
			55	426.55	80.54	32.0	566.50	311.28	0.79	0.66	0.44	0.22
			57	425.84	79.88	69.0	494.78	250.94	0.70	0.70	0.46	0.24
			59	427.71	81.56	49.0	548.80	286.68	0.76	0.67	0.48	0.20
control	6	5-10	52	425.57	80.64	2.5	703.96	448.56	1.06	0.55	0.41	0.14
			54	423.64	80.92	7.0	673.66	433.09	1.04	0.56	0.38	0.17
			56	425.67	80.44	5.0	693.66	443.98	1.06	0.55	0.40	0.15
			58	426.79	80.71	0.5	703.40	457.35	1.07	0.54	0.39	0.16
			60	428.87	81.30	3.5	684.76	434.46	1.02	0.56	0.40	0.17

9 hour	7	0-5	61	423.78	79.99	24.5	597.12	346.32	0.87	0.63	0.43	0.20
			63	422.50	80.30	11.0	604.72	346.79	0.84	0.64	0.43	0.21
			65	429.54	80.16	33.0	497.70	256.35	0.65	0.72	0.41	0.31
			67	428.55	80.37	15.5	589.84	329.64	0.80	0.66	0.44	0.22
			69	432.16	80.99	24.0	621.96	364.88	0.89	0.61	0.43	0.18
9 hour	7	5-10	62	423.70	80.60	2.0	680.08	425.83	1.01	0.57	0.41	0.16
			64	425.63	80.07	0.5	669.22	418.21	0.98	0.58	0.40	0.18
			66	426.13	80.55	11.0	658.98	414.30	1.00	0.57	0.40	0.18
			68	425.30	80.80	1.0	649.78	406.38	0.96	0.59	0.38	0.21
			70	429.01	80.43	2.0	655.52	404.75	0.95	0.60	0.40	0.20
3 hour	8	0-5	71	477.15	80.45	23.0	558.56	305.82	0.67	0.71	0.38	0.33
			73	425.34	80.00	7.0	627.22	353.67	0.85	0.64	0.46	0.17
			75	430.22	80.61	38.5	538.38	292.82	0.75	0.68	0.42	0.26
			77	425.62	80.99	30.5	531.74	287.04	0.73	0.69	0.41	0.27
			79	424.49	80.68	2.0	636.48	355.28	0.84	0.64	0.47	0.16
3 hour	8	5-10	72	425.96	81.05	48.0	569.66	336.10	0.89	0.62	0.40	0.22
			74	425.96	79.89	1.0	640.68	362.91	0.85	0.64	0.47	0.17
			76	426.16	80.90	24.5	619.22	391.13	0.97	0.59	0.37	0.22
			78	422.95	80.87	21.5	653.02	408.91	1.02	0.57	0.41	0.16
			80	424.89	80.11	2.0	658.60	405.53	0.96	0.59	0.41	0.18
24 hour	9	0-5	82	425.70	81.12	51.5	507.08	260.94	0.70	0.70	0.44	0.26
			83	424.85	80.18	48.0	526.04	283.94	0.75	0.68	0.43	0.25
			85	428.19	80.51	91.5	476.76	249.56	0.74	0.68	0.44	0.24
			87	423.95	80.84	7.0	654.32	372.01	0.89	0.62	0.48	0.13
			89	424.20	80.73	4.0	638.28	360.68	0.86	0.63	0.47	0.16
24 hour	9	5-10	81	425.67	80.31	3.0	677.00	413.61	0.98	0.58	0.43	0.15
			84	426.52	80.83	2.5	692.20	432.54	1.02	0.57	0.42	0.14
			86	428.65	81.21	35.0	644.42	401.72	1.02	0.57	0.41	0.16
			88	423.59	80.66	0.5	702.10	452.95	1.07	0.54	0.40	0.15
			90	425.23	80.77	0.5	691.36	435.75	1.03	0.56	0.41	0.15
24 hour	10	0-5	91	426.12	80.27	9.0	606.50	328.66	0.79	0.66	0.47	0.19
			93	428.97	80.70	9.5	624.08	349.48	0.83	0.64	0.46	0.18
			95	425.72	80.74	26.0	576.38	312.16	0.78	0.66	0.46	0.20
			97	426.52	80.94	45.5	594.22	334.74	0.88	0.62	0.47	0.15
			99	426.55	81.30	22.5	576.94	312.01	0.77	0.67	0.45	0.21
24 hour	10	5-10	92	420.67	80.38	0.5	687.64	428.23	1.02	0.57	0.43	0.14
			94	430.71	80.92	5.5	692.30	427.76	1.01	0.57	0.43	0.14
			96	425.26	80.69	10.5	657.80	404.08	0.97	0.58	0.42	0.17
			98	428.17	80.80	17.0	645.28	403.82	0.98	0.58	0.39	0.19
			100	427.78	80.66	1.0	689.60	433.57	1.02	0.57	0.41	0.16
control	11	0-5	101	426.48	80.58	17.0	606.54	353.55	0.86	0.63	0.42	0.21
			103	423.18	80.79	23.5	586.62	320.26	0.80	0.65	0.46	0.19
			105	427.75	80.18	16.5	499.76	231.88	0.56	0.76	0.46	0.30
			107	426.39	80.99	2.0	632.90	352.67	0.83	0.64	0.47	0.17
			109	425.81	81.21	10.0	641.84	366.85	0.88	0.62	0.47	0.15
control	11	5-10	102	427.32	79.79	1.5	668.60	411.74	0.97	0.59	0.42	0.17
			104	425.70	80.65	1.5	677.26	427.38	1.01	0.57	0.40	0.17
			106	427.12	81.21	15.5	615.36	357.92	0.87	0.63	0.43	0.20
			108	424.48	80.90	4.0	661.68	399.84	0.95	0.59	0.43	0.16
			110	425.13	80.58	1.5	703.66	443.21	1.05	0.55	0.42	0.13
9 hour	12	0-5	111	427.77	80.98	29.5	577.62	309.45	0.78	0.67	0.47	0.20
			113	427.53	80.79	72.0	556.66	310.67	0.87	0.62	0.46	0.16
			115	424.31	80.24	41.5	523.60	269.82	0.70	0.70	0.45	0.24
			117	426.94	80.61	97.5	448.00	216.97	0.66	0.72	0.46	0.26
			119	424.25	80.52	11.5	633.32	354.61	0.86	0.63	0.48	0.15
9 hour	12	5-10	112	425.45	80.32	3.0	698.38	442.08	1.05	0.55	0.42	0.14
			114	428.12	80.07	1.5	701.76	445.51	1.04	0.56	0.41	0.14
			116	428.18	80.41	29.0	628.76	387.06	0.97	0.59	0.40	0.18
			118	426.55	80.21	5.0	676.34	409.53	0.97	0.59	0.44	0.14
			120	423.22	80.70	5.0	677.26	433.56	1.04	0.56	0.39	0.17

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.2.2 After Treading Treatment (1-week)

Date sampled: 29/6/99

Treat-ment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
control	1	0-5	121	422.69	79.74	72.5	423.66	196.22	0.56	0.76	0.42	0.34
			123	426.73	81.49	59.0	551.92	303.39	0.83	0.64	0.45	0.19
			125	425.31	80.70	60.0	492.22	251.10	0.69	0.70	0.44	0.26
			127	426.52	80.12	1.5	639.14	377.29	0.89	0.62	0.43	0.19
			129	426.52	80.59	13.5	592.72	321.67	0.78	0.66	0.46	0.20
control	1	5-10	122	426.85	80.56	0.0	626.78	369.47	0.87	0.63	0.41	0.22
			124	424.22	80.04	2.5	619.80	366.75	0.87	0.63	0.41	0.22
			126	426.52	80.64	0.5	666.28	409.46	0.96	0.59	0.41	0.18
			128	423.19	80.25	2.0	639.52	380.76	0.90	0.61	0.42	0.19
			130	428.17	80.46	79.0	422.90	209.49	0.60	0.74	0.38	0.36
3 hour	2	0-5	131	428.17	80.59	30.5	552.76	293.23	0.74	0.68	0.45	0.23
			133	428.58	81.03	55.5	523.90	276.08	0.74	0.68	0.45	0.23
			135	428.19	80.38	42.0	571.58	317.57	0.82	0.65	0.45	0.20
			137	425.85	80.24	78.0	493.82	264.29	0.76	0.67	0.43	0.24
			139	426.44	80.44	65.5	531.24	288.33	0.80	0.66	0.45	0.21
3 hour	2	5-10	132	425.67	81.09	2.0	651.44	396.89	0.94	0.60	0.41	0.19
			134	424.03	81.12	3.5	641.64	387.53	0.92	0.61	0.41	0.20
			136	430.64	80.68	2.0	659.76	407.81	0.95	0.59	0.40	0.20
			138	424.34	80.18	5.5	699.62	450.23	1.07	0.54	0.40	0.14
			140	425.80	81.00	0.5	710.00	467.84	1.10	0.53	0.38	0.15
24 hour	3	0-5	141	428.59	80.60	36.0	620.96	357.66	0.91	0.61	0.47	0.14
			143	424.98	80.93	41.5	558.64	299.23	0.78	0.66	0.47	0.20
			145	426.88	80.60	69.5	530.12	287.21	0.80	0.65	0.45	0.20
			147	424.88	81.04	31.0	617.44	353.90	0.90	0.61	0.46	0.15
			149	426.50	80.55	35.0	637.38	381.31	0.97	0.58	0.45	0.13
24 hour	3	5-10	142	424.81	80.27	0.5	693.10	457.10	1.08	0.54	0.37	0.17
			144	426.61	80.42	0.5	701.32	459.78	1.08	0.54	0.38	0.16
			146	425.65	80.56	1.5	742.50	499.47	1.18	0.50	0.38	0.12
			148	425.67	80.67	3.5	695.86	446.31	1.06	0.55	0.40	0.15
			150	425.70	80.84	2.5	702.02	466.88	1.10	0.53	0.36	0.17
3 hour	4	0-5	151	427.62	80.24	95.5	478.80	248.93	0.75	0.68	0.45	0.23
			153	427.36	80.86	92.0	511.24	278.09	0.83	0.64	0.45	0.19
			155	425.42	80.58	57.0	560.20	308.99	0.84	0.64	0.46	0.18
			157	425.70	80.00	61.0	547.74	297.68	0.82	0.65	0.47	0.18
			159	424.06	80.86	66.5	516.96	269.46	0.75	0.68	0.47	0.21
3 hour	4	5-10	152	428.56	80.36	3.0	642.46	387.58	0.91	0.61	0.41	0.20
			154	428.03	80.38	3.0	668.48	418.30	0.98	0.58	0.40	0.18
			156	422.38	80.40	1.0	649.96	388.08	0.92	0.61	0.43	0.18
			158	424.03	80.47	2.0	637.46	379.94	0.90	0.62	0.42	0.20
			160	428.19	80.62	4.5	654.16	396.18	0.94	0.60	0.42	0.18
9 hour	5	0-5	161	423.24	80.47	54.0	516.32	268.33	0.73	0.69	0.45	0.23
			163	427.96	80.28	90.0	469.70	244.77	0.72	0.69	0.43	0.26
			165	426.80	80.46	73.0	512.14	266.36	0.75	0.68	0.47	0.21
			167	429.35	80.06	53.0	576.72	325.63	0.87	0.63	0.45	0.17
			169	427.53	80.00	46.0	580.00	324.26	0.85	0.63	0.46	0.17
9 hour	5	5-10	162	425.31	80.19	0.5	677.94	432.40	1.02	0.57	0.39	0.18
			164	425.55	81.04	0.5	678.62	436.03	1.03	0.56	0.38	0.18
			166	425.32	79.78	3.0	659.86	435.02	1.03	0.56	0.34	0.22
			168	426.24	81.92	2.0	678.60	454.42	1.07	0.54	0.34	0.21
			170	425.12	80.85	1.5	695.66	455.91	1.08	0.54	0.38	0.17
control	6	0-5	171	426.60	80.40	75.0	509.08	277.45	0.79	0.66	0.43	0.23
			173	425.46	80.76	83.5	473.00	250.45	0.73	0.68	0.41	0.27
			175	424.98	80.60	44.0	510.78	271.43	0.71	0.69	0.42	0.28
			177	430.11	80.52	79.5	508.82	282.36	0.81	0.65	0.42	0.24
			179	426.84	80.57	115.5	441.30	218.99	0.70	0.70	0.46	0.24
control	6	5-10	172	425.62	80.83	3.5	640.82	424.14	1.00	0.57	0.32	0.25
			174	424.57	80.45	2.5	680.56	427.59	1.01	0.57	0.41	0.16
			176	425.80	80.59	5.0	683.30	442.56	1.05	0.55	0.38	0.17
			178	427.28	80.26	7.5	693.06	460.38	1.10	0.53	0.36	0.17
			180	426.50	80.43	3.0	672.66	400.49	0.95	0.60	0.45	0.14
9 hour	7	0-5	181	425.96	80.60	78.0	515.24	281.75	0.81	0.65	0.44	0.21
			184	427.72	80.13	17.5	683.40	421.52	1.03	0.56	0.44	0.11
			185	429.46	80.05	12.0	623.48	341.62	0.82	0.65	0.48	0.16
			187	423.57	80.72	90.0	500.98	266.96	0.80	0.66	0.46	0.20
			189	427.86	80.38	45.5	588.18	334.69	0.88	0.62	0.45	0.17

9 hour	7	5-10	182	422.19	80.17	2.5	707.50	490.81	1.17	0.50	0.33	0.18
			183	426.05	80.63	4.0	623.46	350.33	0.83	0.65	0.46	0.19
			186	423.58	80.30	1.5	702.30	446.53	1.06	0.55	0.42	0.13
			188	426.10	80.81	6.0	667.52	427.13	1.02	0.57	0.38	0.19
			190	426.75	80.92	2.5	666.12	411.14	0.97	0.59	0.41	0.18
3 hour	8	0-5	201	420.48	85.45	69.0	522.78	280.05	0.80	0.66	0.45	0.21
			203	425.65	84.80	61.5	473.20	237.21	0.65	0.72	0.42	0.30
			205	422.66	84.71	61.5	499.42	264.12	0.73	0.68	0.42	0.27
			207	430.95	84.85	39.0	578.66	319.46	0.82	0.65	0.44	0.20
			209	423.99	84.31	83.5	426.68	204.17	0.60	0.74	0.41	0.34
3 hour	8	5-10	202	422.75	85.04	4.5	655.28	397.38	0.95	0.60	0.41	0.18
			204	424.86	86.48	2.5	628.56	357.27	0.85	0.64	0.44	0.20
			206	424.70	87.27	3.0	663.62	423.13	1.00	0.57	0.36	0.21
			208	421.39	85.09	4.0	646.80	395.13	0.95	0.60	0.40	0.20
			210	423.33	84.24	3.5	655.88	402.68	0.96	0.59	0.40	0.19
24 hour	9	0-5	211	421.19	84.80	65.0	641.20	425.61	1.19	0.48	0.37	0.12
			213	422.69	85.06	55.0	560.82	311.39	0.85	0.63	0.45	0.19
			215	424.68	84.54	67.5	561.96	307.51	0.86	0.63	0.48	0.15
			217	424.85	84.67	81.5	511.00	263.20	0.77	0.67	0.48	0.19
			219	426.76	83.91	58.0	552.60	290.81	0.79	0.66	0.48	0.18
24 hour	9	5-10	212	423.40	83.44	43.0	568.82	324.84	0.85	0.64	0.42	0.21
			214	419.81	84.43	1.0	718.70	458.12	1.09	0.53	0.42	0.11
			216	425.75	84.34	0.5	686.48	421.97	0.99	0.58	0.42	0.15
			218	422.38	83.97	5.5	661.32	414.55	0.99	0.58	0.39	0.19
			220	420.87	85.28	1.5	691.94	430.63	1.03	0.56	0.42	0.14
24 hour	10	0-5	221	425.02	85.68	39.5	566.88	301.43	0.78	0.66	0.47	0.20
			223	424.86	87.20	57.5	543.06	281.85	0.77	0.67	0.47	0.20
			225	425.92	84.18	169.5	403.98	199.18	0.78	0.67	0.47	0.19
			227	421.90	83.95	32.0	551.26	292.29	0.75	0.68	0.45	0.23
			229	426.41	84.92	56.5	568.58	312.10	0.84	0.64	0.46	0.17
24 hour	10	5-10	222	420.68	85.19	2.0	638.56	408.32	0.98	0.58	0.35	0.24
			224	425.35	84.64	1.0	689.88	433.53	1.02	0.56	0.40	0.16
			226	427.24	83.14	4.5	684.86	424.41	1.00	0.57	0.42	0.15
			228	425.18	84.74	5.5	676.22	428.10	1.02	0.57	0.39	0.18
			230	426.43	84.30	2.0	697.00	436.99	1.03	0.56	0.41	0.15
control	11	0-5	231	424.34	84.82	32.5	579.84	333.41	0.85	0.63	0.41	0.22
			233	419.81	84.30	57.5	518.16	278.16	0.77	0.67	0.43	0.24
			235	419.55	85.14	27.0	578.50	321.10	0.82	0.65	0.44	0.21
			237	421.54	83.91	41.5	512.46	254.33	0.67	0.71	0.46	0.25
			239	422.29	85.06	59.0	516.58	270.28	0.74	0.68	0.44	0.24
control	11	5-10	232	423.17	84.53	0.5	665.76	417.16	0.99	0.58	0.39	0.19
			234	428.03	85.17	3.0	679.26	429.18	1.01	0.57	0.39	0.18
			236	426.84	85.51	7.0	651.84	387.99	0.92	0.61	0.42	0.18
			238	420.77	85.19	1.0	661.80	404.42	0.96	0.59	0.41	0.18
			240	422.44	84.84	1.5	679.50	421.55	1.00	0.57	0.41	0.16
9 hour	12	0-5	241	425.73	83.52	36.5	595.38	333.49	0.86	0.63	0.46	0.17
			243	423.10	84.59	54.5	573.02	318.70	0.86	0.63	0.46	0.17
			245	422.51	85.63	83.5	497.06	250.37	0.74	0.68	0.48	0.21
			247	424.37	86.04	75.0	535.24	287.21	0.82	0.65	0.46	0.18
			249	426.75	83.91	64.5	500.08	258.70	0.71	0.69	0.43	0.26
9 hour	12	5-10	242	421.38	85.02	2.5	699.16	446.29	1.07	0.55	0.40	0.15
			244	426.26	83.82	1.0	704.72	447.53	1.05	0.55	0.41	0.14
			246	423.34	84.72	1.5	680.42	422.85	1.00	0.57	0.41	0.16
			248	419.31	84.77	0.5	713.44	451.91	1.08	0.54	0.42	0.12
			250	422.43	84.81	5.0	698.56	438.25	1.05	0.55	0.42	0.13

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.2.3 After Treading Treatment (4-weeks)

Date sampled: 22/7/99

Treat-ment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
control	1	0-5	1	424.85	81.09	31.5	565.76	289.72	0.74	0.68	0.50	0.19
			3	424.03	81.12	113.0	430.92	197.14	0.63	0.73	0.49	0.24
			5	421.60	81.00	53.0	549.67	246.50	0.67	0.71	0.60	0.11
			7	426.53	80.85	49.0	553.29	279.99	0.74	0.68	0.51	0.17
			9	425.70	80.57	84.5	538.70	290.93	0.85	0.63	0.49	0.14
control	1	5-10	2	425.70	80.91	0.5	656.32	382.25	0.90	0.62	0.45	0.16
			4	424.85	81.25	1.5	646.06	373.84	0.88	0.62	0.45	0.17
			6	425.69	81.59	0.5	655.34	378.63	0.89	0.62	0.46	0.16
			8	425.71	80.97	0.5	673.80	387.28	0.91	0.61	0.48	0.13
			10	424.48	80.65	0.5	650.72	370.88	0.87	0.63	0.47	0.16
3 hour	2	0-5	11	426.79	80.19	34.5	579.32	303.20	0.77	0.67	0.50	0.17
			13	428.20	80.72	22.5	593.74	302.85	0.75	0.68	0.52	0.16
			15	424.62	80.65	28.0	593.38	321.21	0.81	0.65	0.48	0.17
			17	423.60	80.75	60.5	527.44	274.15	0.76	0.67	0.48	0.20
			19	421.39	80.52	31.5	577.30	319.88	0.82	0.65	0.45	0.19
3 hour	2	5-10	12	428.11	80.26	1.5	663.68	402.21	0.94	0.60	0.42	0.17
			14	423.43	80.26	20.5	609.70	358.54	0.89	0.62	0.42	0.20
			16	424.56	80.92	2.0	673.38	411.63	0.97	0.59	0.43	0.16
			18	427.78	80.37	25.0	681.08	433.13	1.08	0.54	0.42	0.13
			20	425.28	81.30	0.5	723.34	474.84	1.12	0.52	0.39	0.13
24 hour	3	0-5	21	422.33	80.32	65.0	503.66	247.23	0.69	0.70	0.49	0.21
			23	427.34	80.47	17.0	624.26	340.60	0.83	0.64	0.50	0.15
			25	424.42	80.66	121.0	457.74	226.65	0.75	0.68	0.50	0.18
			27	426.98	80.28	72.5	539.65	282.17	0.80	0.66	0.50	0.16
			29	421.00	81.33	42.0	584.64	312.17	0.82	0.64	0.50	0.14
24 hour	3	5-10	22	425.70	80.63	2.5	719.06	462.92	1.09	0.53	0.41	0.12
			24	424.87	80.79	3.0	708.18	445.11	1.06	0.55	0.43	0.12
			26	423.81	81.34	9.0	721.68	468.29	1.13	0.52	0.41	0.10
			28	426.38	80.60	18.0	673.80	431.61	1.06	0.55	0.40	0.15
			30	425.14	80.56	6.5	717.38	465.81	1.11	0.53	0.41	0.12
3 hour	4	0-5	31	432.17	81.65	54.0	548.98	286.29	0.76	0.67	0.48	0.19
			33	425.84	80.43	83.0	500.57	259.53	0.76	0.67	0.47	0.21
			35	427.45	81.13	17.0	627.78	347.56	0.85	0.63	0.49	0.15
			37	422.80	80.98	29.0	633.66	339.58	0.86	0.63	0.54	0.09
			39	425.65	80.22	59.0	558.11	288.41	0.79	0.66	0.52	0.14
3 hour	4	5-10	32	424.22	81.06	0.5	666.88	389.74	0.92	0.61	0.46	0.15
			34	427.71	80.66	1.5	699.46	431.08	1.01	0.57	0.44	0.13
			36	426.15	80.69	4.0	630.46	358.34	0.85	0.64	0.45	0.18
			38	424.98	80.35	2.5	635.14	359.90	0.85	0.64	0.46	0.18
			40	424.78	80.86	2.5	647.72	379.77	0.90	0.62	0.44	0.17
9 hour	5	0-5	41	425.73	79.89	67.0	532.80	276.72	0.77	0.67	0.49	0.18
			43	424.55	80.34	55.0	550.78	301.37	0.82	0.65	0.46	0.19
			45	427.97	80.54	34.0	577.06	317.21	0.81	0.65	0.46	0.20
			47	426.51	80.26	23.0	612.10	349.74	0.87	0.63	0.45	0.18
			49	425.20	81.17	87.0	469.16	231.11	0.68	0.71	0.46	0.24
9 hour	5	5-10	42	429.22	80.70	3.0	672.62	418.54	0.98	0.58	0.41	0.17
			44	426.55	80.00	4.0	673.88	429.22	1.02	0.57	0.39	0.18
			46	424.73	80.07	2.0	690.80	451.66	1.07	0.54	0.38	0.17
			48	425.08	80.72	2.5	691.74	444.13	1.05	0.55	0.39	0.16
			50	424.62	80.97	1.5	712.62	454.10	1.07	0.54	0.42	0.12
control	6	0-5	51	423.81	80.60	56.0	457.44	211.20	0.57	0.75	0.45	0.30
			53	427.54	80.48	12.0	617.52	340.88	0.82	0.65	0.47	0.17
			55	426.55	80.54	145.0	371.23	163.61	0.58	0.75	0.45	0.30
			57	425.84	79.88	100.0	438.88	212.73	0.65	0.72	0.45	0.27
			59	427.71	81.56	62.5	487.70	242.58	0.66	0.71	0.45	0.27
control	6	5-10	52	425.57	80.64	2.0	717.60	456.94	1.08	0.54	0.43	0.12
			54	423.64	80.92	3.5	708.42	447.19	1.06	0.55	0.43	0.12
			56	425.67	80.44	0.5	696.64	452.21	1.06	0.55	0.39	0.16
			58	426.79	80.71	3.0	697.82	451.54	1.07	0.55	0.39	0.16
			60	428.87	81.30	2.0	717.02	463.53	1.09	0.54	0.40	0.13
9 hour	7	0-5	61	423.78	79.99	56.0	554.06	297.52	0.81	0.65	0.48	0.17
			63	422.50	80.30	59.5	484.66	237.59	0.65	0.72	0.46	0.26
			65	429.54	80.16	64.0	538.72	284.27	0.78	0.66	0.48	0.19
			67	428.55	80.37	66.5	537.32	289.30	0.80	0.66	0.46	0.19
			69	432.16	80.99	35.5	536.28	276.96	0.70	0.70	0.45	0.25

9 hour	7	5-10	62	423.70	80.60	13.0	619.32	391.93	0.95	0.59	0.36	0.24
			64	425.63	80.07	2.0	640.20	386.57	0.91	0.61	0.41	0.20
			66	426.13	80.55	2.5	663.72	412.29	0.97	0.59	0.40	0.18
			68	425.30	80.80	2.5	668.74	413.36	0.98	0.58	0.41	0.17
			70	429.01	80.43	1.0	642.16	388.32	0.91	0.61	0.41	0.21
3 hour	8	0-5	71	477.15	80.45	30.0	543.54	284.07	0.64	0.73	0.40	0.33
			73	425.34	80.00	31.0	575.76	311.56	0.79	0.66	0.47	0.19
			75	430.22	80.61	73.0	517.96	270.77	0.76	0.67	0.47	0.21
			77	425.62	80.99	47.0	530.94	273.92	0.72	0.69	0.46	0.22
			79	424.49	80.68	40.5	534.78	270.80	0.71	0.70	0.48	0.22
3 hour	8	5-10	72	425.96	81.05	3.0	656.74	400.18	0.95	0.60	0.41	0.18
			74	425.96	79.89	5.0	621.10	354.83	0.84	0.64	0.44	0.20
			76	426.16	80.90	15.0	632.88	376.13	0.91	0.61	0.43	0.18
			78	422.95	80.87	3.5	697.30	435.58	1.04	0.56	0.43	0.13
			80	424.89	80.11	3.5	647.94	382.49	0.91	0.61	0.44	0.17
24 hour	9	0-5	81	425.70	81.12	58.0	519.98	267.48	0.73	0.69	0.47	0.22
			83	424.85	80.18	40.0	556.94	296.12	0.77	0.67	0.47	0.20
			85	428.19	80.51	54.0	539.44	290.67	0.78	0.67	0.45	0.22
			87	423.95	80.84	48.0	539.38	277.81	0.74	0.68	0.48	0.20
			89	424.20	80.73	68.5	548.77	297.10	0.84	0.64	0.48	0.16
24 hour	9	5-10	82	425.67	80.31	15.5	697.10	449.72	1.10	0.53	0.41	0.13
			84	426.52	80.83	6.0	688.92	430.01	1.02	0.56	0.42	0.14
			86	428.65	81.21	7.0	656.16	402.34	0.95	0.59	0.41	0.18
			90	425.23	80.77	11.5	663.74	414.65	1.00	0.57	0.41	0.17
			88	423.59	80.66	6.5	683.20	425.40	1.02	0.57	0.42	0.14
24 hour	10	0-5	91	426.12	80.27	9.5	638.80	363.69	0.87	0.62	0.47	0.16
			93	428.97	80.70	43.0	538.82	274.53	0.71	0.69	0.48	0.22
			95	425.72	80.74	59.5	556.26	290.94	0.79	0.66	0.50	0.15
			97	426.52	80.94	85.0	507.88	262.36	0.77	0.67	0.48	0.19
			99	426.55	81.30	35.0	608.18	333.07	0.85	0.63	0.49	0.14
24 hour	10	5-10	92	420.67	80.38	9.0	667.74	408.75	0.99	0.58	0.43	0.14
			94	430.71	80.92	8.0	668.50	410.18	0.97	0.59	0.42	0.17
			96	425.26	80.69	4.5	685.58	428.32	1.02	0.57	0.42	0.15
			98	428.17	80.80	9.0	657.10	402.70	0.96	0.59	0.41	0.18
			100	427.78	80.66	2.5	691.80	427.40	1.00	0.57	0.43	0.14
control	11	0-5	101	426.48	80.58	35.0	514.88	254.79	0.65	0.72	0.46	0.26
			103	423.18	80.79	38.0	468.30	215.36	0.56	0.76	0.45	0.31
			106	427.12	81.21	36.5	555.83	299.88	0.77	0.67	0.45	0.22
			107	426.39	80.99	133.5	362.59	151.03	0.52	0.78	0.45	0.33
			109	425.81	81.21	30.5	540.64	293.65	0.74	0.68	0.42	0.26
control	11	5-10	102	427.32	79.79	5.0	668.30	414.59	0.98	0.58	0.41	0.17
			104	425.70	80.65	1.0	688.18	421.86	0.99	0.58	0.44	0.14
			105	427.75	80.18	2.0	641.88	383.93	0.90	0.62	0.42	0.20
			108	424.48	80.90	2.5	642.66	378.25	0.90	0.62	0.43	0.18
			110	425.13	80.58	3.5	666.20	416.27	0.99	0.58	0.40	0.18
9 hour	12	0-5	111	427.77	80.98	46.0	524.06	262.30	0.69	0.70	0.47	0.23
			113	427.53	80.79	43.5	528.64	277.40	0.72	0.69	0.44	0.24
			115	424.31	80.24	85.0	496.62	258.38	0.76	0.67	0.47	0.21
			117	426.94	80.61	29.0	584.68	312.91	0.79	0.66	0.48	0.18
			119	424.25	80.52	37.5	572.42	310.41	0.80	0.65	0.47	0.18
9 hour	12	5-10	112	425.45	80.32	3.5	696.66	431.49	1.02	0.56	0.44	0.13
			114	428.12	80.07	13.0	675.46	420.92	1.01	0.57	0.42	0.15
			116	428.18	80.41	6.0	625.42	393.35	0.93	0.60	0.36	0.24
			118	426.55	80.21	1.5	690.60	434.49	1.02	0.56	0.41	0.15
			120	423.22	80.70	2.5	686.40	426.00	1.01	0.57	0.43	0.14

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
c over-dry weight was exclusive the weight of the PVC core-holder

V.2.4 After Treading Treatment (13-weeks)

Date sampled: 23/9/99

Treat-ment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
control	1	0-5	1	424.85	81.09	91.0	468.04	231.42	0.69	0.70	0.47	0.24
			3	424.03	81.12	30.0	566.88	295.69	0.75	0.68	0.48	0.19
			5	421.60	81.00	25.0	509.85	242.46	0.61	0.74	0.47	0.27
			7	426.53	80.85	66.0	526.13	271.02	0.75	0.68	0.48	0.19
			9	425.70	80.57	52.0	550.32	292.39	0.78	0.66	0.47	0.19
control	1	5-10	2	425.70	80.91	1.5	676.94	413.70	0.98	0.58	0.43	0.15
			4	424.85	81.25	0.5	653.80	379.06	0.89	0.62	0.46	0.16
			6	425.69	81.59	0.5	653.40	370.21	0.87	0.63	0.47	0.15
			8	425.71	80.97	3.0	655.99	390.34	0.92	0.61	0.44	0.17
			10	424.48	80.65	20.5	599.90	340.91	0.84	0.64	0.44	0.20
3 hour	2	0-5	11	426.79	80.19	37.5	564.66	309.59	0.80	0.66	0.45	0.21
			13	428.20	80.72	82.0	458.89	218.97	0.63	0.73	0.46	0.27
			15	424.62	80.65	107.0	405.93	185.42	0.58	0.75	0.44	0.31
			17	423.60	80.75	69.0	515.79	265.85	0.75	0.68	0.48	0.20
			19	421.39	80.52	59.5	516.55	261.80	0.72	0.69	0.48	0.21
3 hour	2	5-10	12	428.11	80.26	1.0	671.30	400.55	0.94	0.60	0.45	0.15
			14	423.43	80.26	4.5	657.94	398.15	0.95	0.60	0.43	0.17
			16	424.56	80.92	0.5	687.00	416.11	0.98	0.58	0.45	0.13
			18	427.78	80.37	37.5	623.24	375.50	0.96	0.59	0.43	0.16
			20	425.28	81.30	3.5	685.30	428.06	1.01	0.57	0.42	0.15
24 hour	3	0-5	21	422.33	80.32	49.5	559.71	302.03	0.81	0.65	0.48	0.18
			23	427.34	80.47	57.0	504.21	245.97	0.66	0.71	0.48	0.23
			25	424.42	80.66	81.0	522.21	280.26	0.82	0.65	0.47	0.18
			27	426.98	80.28	62.0	543.61	297.84	0.82	0.65	0.45	0.19
			29	421.00	81.33	34.0	589.31	337.37	0.87	0.62	0.44	0.18
24 hour	3	5-10	22	425.70	80.63	3.5	742.64	489.85	1.16	0.51	0.41	0.10
			24	424.87	80.79	6.0	694.66	439.67	1.05	0.55	0.42	0.14
			26	423.81	81.34	0.5	727.46	461.44	1.09	0.54	0.44	0.10
			28	426.38	80.60	17.5	633.32	387.02	0.95	0.60	0.41	0.19
			30	425.14	80.56	5.5	694.22	438.08	1.04	0.56	0.42	0.14
3 hour	4	0-5	31	432.17	81.65	52.0	560.90	310.45	0.82	0.65	0.44	0.20
			33	425.84	80.43	62.0	534.29	283.08	0.78	0.66	0.47	0.20
			35	427.45	81.13	101.0	429.68	196.39	0.60	0.74	0.47	0.27
			37	422.80	80.98	125.0	361.67	155.63	0.52	0.77	0.42	0.35
			39	425.65	80.22	60.5	517.46	256.70	0.70	0.70	0.49	0.20
3 hour	4	5-10	32	424.22	81.06	4.0	659.32	392.95	0.94	0.60	0.44	0.16
			34	427.71	80.66	2.0	652.96	384.19	0.90	0.62	0.44	0.17
			36	426.15	80.69	2.0	624.12	360.87	0.85	0.64	0.43	0.21
			38	424.98	80.35	0.5	638.90	366.22	0.86	0.63	0.45	0.18
			40	424.78	80.86	0.5	634.56	358.51	0.84	0.64	0.46	0.18
9 hour	5	0-5	41	425.73	79.89	159.0	403.18	196.28	0.74	0.68	0.48	0.21
			43	424.55	80.34	26.0	564.44	290.14	0.73	0.69	0.49	0.20
			45	427.97	80.54	141.0	405.14	195.67	0.68	0.71	0.45	0.26
			47	426.51	80.26	77.0	510.50	263.06	0.75	0.68	0.48	0.20
			49	425.20	81.17	37.5	570.89	309.00	0.80	0.66	0.47	0.19
9 hour	5	5-10	42	429.22	80.70	4.0	641.74	385.25	0.91	0.61	0.41	0.20
			44	426.55	80.00	0.5	678.90	408.58	0.96	0.59	0.45	0.14
			46	424.73	80.07	5.0	624.74	365.25	0.87	0.63	0.43	0.20
			48	425.08	80.72	0.5	676.50	417.05	0.98	0.58	0.42	0.16
			50	424.62	80.97	2.0	682.82	433.18	1.02	0.56	0.40	0.16
control	6	0-5	51	423.81	80.60	147.5	383.46	180.88	0.65	0.72	0.44	0.28
			53	427.54	80.48	66.5	557.94	316.86	0.88	0.62	0.44	0.18
			55	426.55	80.54	110.5	441.99	215.42	0.68	0.71	0.46	0.24
			57	425.84	79.88	39.0	541.23	284.98	0.74	0.68	0.46	0.23
			59	427.71	81.56	87.0	462.58	209.22	0.61	0.74	0.50	0.23
control	6	5-10	52	425.57	80.64	2.5	716.52	455.50	1.08	0.54	0.43	0.11
			54	423.64	80.92	3.0	702.02	448.53	1.07	0.55	0.41	0.14
			56	425.67	80.44	4.5	695.02	434.88	1.03	0.56	0.43	0.13
			58	426.79	80.71	3.0	663.14	422.56	1.00	0.58	0.38	0.20
			60	428.87	81.30	4.5	651.26	377.11	0.89	0.62	0.45	0.17
9 hour	7	0-5	61	423.78	79.99	60.0	507.35	250.07	0.69	0.70	0.49	0.22
			63	422.50	80.30	24.5	617.74	331.13	0.83	0.64	0.52	0.12
			65	429.54	80.16	37.0	589.65	321.12	0.82	0.65	0.48	0.17
			67	428.55	80.37	93.5	432.64	204.08	0.61	0.74	0.44	0.30
			69	432.16	80.99	87.0	461.33	226.96	0.66	0.72	0.44	0.27

9 hour	7	5-10	62	423.70	80.60	3.0	687.86	429.90	1.02	0.56	0.42	0.14
			64	425.63	80.07	2.5	662.70	410.53	0.97	0.59	0.41	0.18
			66	426.13	80.55	8.0	678.08	425.36	1.02	0.57	0.41	0.15
			68	425.30	80.80	1.5	642.10	381.45	0.90	0.62	0.42	0.19
			70	429.01	80.43	3.0	642.42	385.74	0.91	0.61	0.41	0.20
3 hour	8	0-5	71	477.15	80.45	80.0	537.57	281.12	0.71	0.69	0.44	0.25
			73	425.34	80.00	128.0	386.13	182.99	0.62	0.73	0.41	0.32
			75	430.22	80.61	35.0	575.44	310.08	0.78	0.66	0.47	0.19
			77	425.62	80.99	50.0	527.15	254.42	0.68	0.71	0.51	0.20
			79	424.49	80.68	64.5	481.13	247.28	0.69	0.70	0.43	0.28
3 hour	8	5-10	72	425.96	81.05	13.5	631.48	380.96	0.92	0.61	0.41	0.20
			74	425.96	79.89	3.0	618.64	368.44	0.87	0.63	0.40	0.23
			76	426.16	80.90	7.0	652.64	396.84	0.95	0.60	0.42	0.18
			78	422.95	80.87	2.5	647.66	372.53	0.89	0.62	0.46	0.16
			80	424.89	80.11	0.5	675.76	407.47	0.96	0.59	0.44	0.15
24 hour	9	0-5	81	425.70	81.12	130.0	422.76	190.91	0.65	0.72	0.51	0.21
			83	424.85	80.18	5.0	649.44	362.87	0.86	0.63	0.49	0.14
			85	428.19	80.51	93.0	487.37	245.88	0.73	0.68	0.48	0.20
			87	423.95	80.84	72.5	502.60	253.16	0.72	0.69	0.48	0.21
			89	424.20	80.73	34.0	539.33	268.41	0.69	0.70	0.49	0.22
24 hour	9	5-10	82	425.67	80.31	2.0	697.28	432.79	1.02	0.56	0.43	0.13
			84	426.52	80.83	1.0	704.64	448.27	1.05	0.55	0.41	0.14
			86	428.65	81.21	5.0	701.88	456.41	1.08	0.54	0.39	0.15
			88	423.59	80.66	1.5	687.50	425.12	1.01	0.57	0.43	0.14
			90	425.23	80.77	3.5	696.74	429.44	1.02	0.57	0.44	0.12
24 hour	10	0-5	91	426.12	80.27	96.0	465.25	228.75	0.69	0.70	0.47	0.23
			93	428.97	80.70	49.0	510.04	253.87	0.67	0.71	0.46	0.25
			95	425.72	80.74	35.5	600.28	329.70	0.84	0.64	0.49	0.15
			97	426.52	80.94	75.0	567.40	316.64	0.90	0.61	0.48	0.13
			99	426.55	81.30	61.5	519.29	281.60	0.77	0.67	0.43	0.24
24 hour	10	5-10	92	420.67	80.38	1.5	680.60	424.74	1.01	0.57	0.42	0.15
			94	430.71	80.92	2.0	665.24	406.74	0.95	0.60	0.41	0.18
			96	425.26	80.69	0.0	682.28	407.05	0.96	0.59	0.46	0.13
			98	428.17	80.80	0.5	689.48	426.78	1.00	0.57	0.43	0.15
			100	427.78	80.66	2.5	680.28	421.10	0.99	0.58	0.42	0.16
control	11	0-5	101	426.48	80.58	62.0	483.19	232.83	0.64	0.72	0.47	0.26
			103	423.18	80.79	69.0	444.47	209.94	0.59	0.74	0.43	0.31
			105	427.75	80.18	50.0	491.92	231.66	0.61	0.74	0.48	0.26
			107	426.39	80.99	67.5	446.97	205.82	0.57	0.75	0.45	0.31
			109	425.81	81.21	64.0	503.42	250.37	0.69	0.70	0.47	0.23
control	11	5-10	102	427.32	79.79	0.5	662.40	395.24	0.93	0.61	0.44	0.17
			104	425.70	80.65	1.0	682.98	417.37	0.98	0.58	0.44	0.15
			106	427.12	81.21	3.0	659.72	394.32	0.93	0.60	0.43	0.17
			108	424.48	80.90	2.5	679.26	427.55	1.01	0.57	0.40	0.16
			110	425.13	80.58	10.0	678.50	414.35	1.00	0.57	0.44	0.13
9 hour	12	0-5	111	427.77	80.98	78.0	469.62	222.40	0.64	0.73	0.48	0.25
			113	427.53	80.79	85.5	469.59	224.19	0.66	0.72	0.48	0.24
			115	424.31	80.24	35.5	588.22	316.95	0.82	0.65	0.49	0.16
			117	426.94	80.61	48.5	575.92	298.45	0.79	0.66	0.52	0.14
			119	424.25	80.52	30.0	601.30	333.27	0.85	0.64	0.48	0.16
9 hour	12	5-10	112	425.45	80.32	1.5	685.50	424.07	1.00	0.57	0.43	0.15
			114	428.12	80.07	2.0	651.84	383.56	0.90	0.62	0.44	0.17
			116	428.18	80.41	4.0	683.54	416.02	0.98	0.58	0.44	0.14
			118	426.55	80.21	2.0	693.30	413.64	0.97	0.58	0.47	0.12
			120	423.22	80.70	2.0	685.90	421.22	1.00	0.57	0.44	0.14

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
c over-dry weight was exclusive the weight of the PVC core-holder

V.2.5 After Treading Treatment (26-weeks)

Date sampled: 17/12/99

Treat-ment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
control	1	0-5	1	424.85	81.09	27.00	599.36	333.56	0.84	0.64	0.46	0.18
			3	424.03	81.12	4.50	567.44	318.28	0.76	0.67	0.40	0.27
			5	421.60	81.00	6.50	609.62	332.60	0.80	0.65	0.47	0.18
			7	426.53	80.85	19.00	570.12	302.95	0.74	0.68	0.46	0.22
			9	425.70	80.57	27.50	635.28	370.17	0.93	0.60	0.46	0.14
control	1	5-10	2	425.70	80.91	5.00	633.02	368.07	0.88	0.63	0.44	0.19
			4	424.85	81.25	3.00	635.12	371.79	0.88	0.62	0.43	0.19
			6	425.69	81.59	1.00	640.38	379.72	0.89	0.62	0.42	0.20
			8	425.71	80.97	1.00	617.04	352.54	0.83	0.65	0.43	0.21
			10	424.48	80.65	4.50	643.96	392.32	0.93	0.60	0.41	0.19
3 hour	2	0-5	11	426.79	80.19	73.00	488.64	260.34	0.74	0.68	0.42	0.26
			13	428.20	80.72	61.00	443.60	206.06	0.56	0.76	0.43	0.33
			15	424.62	80.65	23.00	566.74	305.49	0.76	0.67	0.45	0.22
			17	423.60	80.75	22.50	589.60	330.85	0.82	0.64	0.44	0.20
			19	421.39	80.52	26.00	577.76	326.26	0.83	0.64	0.43	0.21
3 hour	2	5-10	12	428.11	80.26	4.00	652.80	396.21	0.93	0.60	0.42	0.19
			14	423.43	80.26	5.00	617.26	360.82	0.86	0.63	0.42	0.21
			16	424.56	80.92	6.00	667.26	406.70	0.97	0.59	0.43	0.16
			18	427.78	80.37	32.00	609.94	380.25	0.96	0.59	0.38	0.21
			20	425.28	81.30	2.00	659.40	418.76	0.99	0.58	0.38	0.20
24 hour	3	0-5	21	422.33	80.32	44.00	539.52	292.82	0.77	0.67	0.44	0.23
			23	427.34	80.47	12.50	592.04	331.40	0.80	0.66	0.43	0.22
			25	424.42	80.66	17.00	608.18	348.18	0.85	0.63	0.44	0.19
			27	426.98	80.28	7.50	680.04	408.78	0.97	0.58	0.46	0.12
			29	421.00	81.33	47.50	552.36	318.23	0.85	0.63	0.41	0.22
24 hour	3	5-10	22	425.70	80.63	2.50	688.16	443.50	1.05	0.55	0.39	0.17
			24	424.87	80.79	7.00	675.16	427.62	1.02	0.56	0.40	0.16
			26	423.81	81.34	9.00	738.96	501.46	1.21	0.48	0.38	0.11
			28	426.38	80.60	9.00	667.26	432.61	1.04	0.56	0.37	0.19
			30	425.14	80.56	3.50	714.82	462.06	1.10	0.53	0.41	0.12
3 hour	4	0-5	31	432.17	81.65	30.00	553.28	302.54	0.75	0.68	0.42	0.26
			33	425.84	80.43	13.00	605.74	342.19	0.83	0.64	0.44	0.20
			35	427.45	81.13	12.00	607.86	333.59	0.80	0.65	0.46	0.19
			37	422.80	80.98	10.00	601.66	330.02	0.80	0.66	0.46	0.19
			39	425.65	80.22	34.00	556.86	298.73	0.76	0.67	0.45	0.22
3 hour	4	5-10	32	424.22	81.06	1.00	651.92	397.98	0.94	0.60	0.41	0.19
			34	427.71	80.66	0.50	659.94	402.28	0.94	0.60	0.41	0.18
			36	426.15	80.69	2.00	643.22	387.14	0.91	0.61	0.41	0.20
			38	424.98	80.35	2.00	638.78	374.57	0.89	0.62	0.43	0.19
			40	424.78	80.86	2.50	667.68	403.19	0.95	0.59	0.43	0.16
9 hour	5	0-5	41	425.73	79.89	47.00	524.74	274.07	0.72	0.69	0.45	0.24
			43	424.55	80.34	34.00	564.04	312.32	0.80	0.66	0.44	0.22
			45	427.97	80.54	49.50	542.40	286.45	0.76	0.67	0.46	0.21
			47	426.51	80.26	23.00	609.02	360.57	0.89	0.61	0.42	0.20
			49	425.20	81.17	43.00	605.68	347.26	0.91	0.61	0.46	0.14
9 hour	5	5-10	42	429.22	80.70	53.50	537.28	326.06	0.87	0.63	0.35	0.28
			44	426.55	80.00	0.50	714.34	456.53	1.07	0.54	0.42	0.13
			46	424.73	80.07	2.50	681.70	430.49	1.02	0.57	0.41	0.16
			48	425.08	80.72	2.50	698.30	451.72	1.07	0.54	0.39	0.15
			50	424.62	80.97	1.50	687.76	436.79	1.03	0.56	0.40	0.16
control	6	0-5	51	423.81	80.60	42.50	595.60	351.07	0.92	0.60	0.43	0.17
			53	427.54	80.48	55.50	549.86	285.19	0.77	0.67	0.50	0.17
			55	426.55	80.54	32.00	566.50	311.28	0.79	0.66	0.44	0.22
			57	425.84	79.88	69.00	494.78	250.94	0.70	0.70	0.46	0.24
			59	427.71	81.56	49.00	548.80	286.68	0.76	0.67	0.48	0.20
control	6	5-10	52	425.57	80.64	2.50	703.96	448.56	1.06	0.55	0.41	0.14
			54	423.64	80.92	7.00	673.66	433.09	1.04	0.56	0.38	0.17
			56	425.67	80.44	5.00	693.66	443.98	1.06	0.55	0.40	0.15
			58	426.79	80.71	0.50	703.40	457.35	1.07	0.54	0.39	0.16
			60	428.87	81.30	3.50	684.76	434.46	1.02	0.56	0.40	0.17
9 hour	7	0-5	61	423.78	79.99	24.50	597.12	346.32	0.87	0.63	0.43	0.20
			63	422.50	80.30	11.00	604.72	346.79	0.84	0.64	0.43	0.21
			65	429.54	80.16	33.00	497.70	256.35	0.65	0.72	0.41	0.31
			67	428.55	80.37	15.50	589.84	329.64	0.80	0.66	0.44	0.22
			69	432.16	80.99	24.00	621.96	364.88	0.89	0.61	0.43	0.18

9 hour	7	5-10	62	423.70	80.60	2.00	680.08	425.83	1.01	0.57	0.41	0.16
			64	425.63	80.07	0.50	669.22	418.21	0.98	0.58	0.40	0.18
			66	426.13	80.55	11.00	658.98	414.30	1.00	0.57	0.40	0.18
			68	425.30	80.80	1.00	649.78	406.38	0.96	0.59	0.38	0.21
			70	429.01	80.43	2.00	655.52	404.75	0.95	0.60	0.40	0.20
3 hour	8	0-5	71	477.15	80.45	23.00	558.56	305.82	0.67	0.71	0.38	0.33
			73	425.34	80.00	7.00	627.22	353.67	0.85	0.64	0.46	0.17
			75	430.22	80.61	38.50	538.38	292.82	0.75	0.68	0.42	0.26
			77	425.62	80.99	30.50	531.74	287.04	0.73	0.69	0.41	0.27
			79	424.49	80.68	2.00	636.48	355.28	0.84	0.64	0.47	0.16
3 hour	8	5-10	72	425.96	81.05	48.00	569.66	336.10	0.89	0.62	0.40	0.22
			74	425.96	79.89	1.00	640.68	362.91	0.85	0.64	0.47	0.17
			76	426.16	80.90	24.50	619.22	391.13	0.97	0.59	0.37	0.22
			78	422.95	80.87	21.50	653.02	408.91	1.02	0.57	0.41	0.16
			80	424.89	80.11	2.00	658.60	405.53	0.96	0.59	0.41	0.18
24 hour	9	0-5	81	425.70	81.12	51.50	507.08	260.94	0.70	0.70	0.44	0.26
			83	424.85	80.18	48.00	526.04	283.94	0.75	0.68	0.43	0.25
			85	428.19	80.51	91.50	476.76	249.56	0.74	0.68	0.44	0.24
			87	423.95	80.84	7.00	654.32	372.01	0.89	0.62	0.48	0.13
			89	424.20	80.73	4.00	638.28	360.68	0.86	0.63	0.47	0.16
24 hour	9	5-10	82	425.67	80.31	3.00	677.00	413.61	0.98	0.58	0.43	0.15
			84	426.52	80.83	2.50	692.20	432.54	1.02	0.57	0.42	0.14
			86	428.65	81.21	35.00	644.42	401.72	1.02	0.57	0.41	0.16
			88	423.59	80.66	0.50	702.10	452.95	1.07	0.54	0.40	0.15
			90	425.23	80.77	0.50	691.36	435.75	1.03	0.56	0.41	0.15
24 hour	10	0-5	91	426.12	80.27	9.00	606.50	328.66	0.79	0.66	0.47	0.19
			93	428.97	80.70	9.50	624.08	349.48	0.83	0.64	0.46	0.18
			95	425.72	80.74	26.00	576.38	312.16	0.78	0.66	0.46	0.20
			97	426.52	80.94	45.50	594.22	334.74	0.88	0.62	0.47	0.15
			99	426.55	81.30	22.50	576.94	312.01	0.77	0.67	0.45	0.21
24 hour	10	5-10	92	420.67	80.38	0.50	687.64	428.23	1.02	0.57	0.43	0.14
			94	430.71	80.92	5.50	692.30	427.76	1.01	0.57	0.43	0.14
			96	425.26	80.69	10.50	657.80	404.08	0.97	0.58	0.42	0.17
			98	428.17	80.80	17.00	645.28	403.82	0.98	0.58	0.39	0.19
			100	427.78	80.66	1.00	689.60	433.57	1.02	0.57	0.41	0.16
control	11	0-5	101	426.48	80.58	17.00	606.54	353.55	0.86	0.63	0.42	0.21
			103	423.18	80.79	23.50	586.62	320.26	0.80	0.65	0.46	0.19
			105	427.75	80.18	16.50	499.76	231.88	0.56	0.76	0.46	0.30
			107	426.39	80.99	2.00	632.90	352.67	0.83	0.64	0.47	0.17
			109	425.81	81.21	10.00	641.84	366.85	0.88	0.62	0.47	0.15
control	11	5-10	102	427.32	79.79	1.50	668.60	411.74	0.97	0.59	0.42	0.17
			104	425.70	80.65	1.50	677.26	427.38	1.01	0.57	0.40	0.17
			106	427.12	81.21	15.50	615.36	357.92	0.87	0.63	0.43	0.20
			108	424.48	80.90	4.00	661.68	399.84	0.95	0.59	0.43	0.16
			110	425.13	80.58	1.50	703.66	443.21	1.05	0.55	0.42	0.13
9 hour	12	0-5	111	427.77	80.98	29.50	577.62	309.45	0.78	0.67	0.47	0.20
			113	427.53	80.79	72.00	556.66	310.67	0.87	0.62	0.46	0.16
			115	424.31	80.24	41.50	523.60	269.82	0.70	0.70	0.45	0.24
			117	426.94	80.61	97.50	448.00	216.97	0.66	0.72	0.46	0.26
			119	424.25	80.52	11.50	633.32	354.61	0.86	0.63	0.48	0.15
9 hour	12	5-10	112	425.45	80.32	3.00	698.38	442.08	1.05	0.55	0.42	0.14
			114	428.12	80.07	1.50	701.76	445.51	1.04	0.56	0.41	0.14
			116	428.18	80.41	29.00	628.76	387.06	0.97	0.59	0.40	0.18
			118	426.55	80.21	5.00	676.34	409.53	0.97	0.59	0.44	0.14
			120	423.22	80.70	5.00	677.26	433.56	1.04	0.56	0.39	0.17

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
c over-dry weight was exclusive the weight of the PVC core-holder

V.3 Individual Results for 71% GSM Experiment

V.3.1 Before Treading Treatment

Date sampled: 22/8/00

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
9 hour	1	0-5	1	424.85	81.09	5.5	591.03	305.54	0.73	0.68	0.49	0.20
			3	424.03	81.12	30.5	551.32	251.51	0.64	0.72	0.56	0.17
			5	421.60	81.00	6.5	571.46	264.11	0.64	0.72	0.55	0.18
			7	426.53	80.85	80.0	480.99	206.26	0.60	0.74	0.56	0.18
			9	425.70	80.57	5.0	595.87	278.24	0.66	0.71	0.56	0.15
9 hour	1	5-10	2	425.70	80.91	3.0	648.10	367.00	0.87	0.63	0.47	0.16
			4	424.85	81.25	2.0	669.12	372.83	0.88	0.63	0.51	0.12
			6	425.69	81.59	1.0	610.72	321.15	0.76	0.68	0.49	0.19
			8	425.71	80.97	6.5	647.60	366.85	0.88	0.63	0.48	0.15
			10	424.48	80.65	4.0	615.50	322.56	0.77	0.67	0.50	0.17
control	2	0-5	11	426.79	80.19	9.5	535.48	248.71	0.60	0.74	0.50	0.25
			13	428.20	80.72	49.0	491.32	207.72	0.55	0.76	0.54	0.23
			15	424.62	80.65	58.0	486.73	216.09	0.59	0.75	0.52	0.23
			17	423.60	80.75	41.5	500.24	233.87	0.61	0.74	0.49	0.25
			19	421.39	80.52	63.0	505.03	244.02	0.68	0.71	0.50	0.20
control	2	5-10	12	428.11	80.26	1.0	617.92	325.84	0.76	0.68	0.50	0.18
			14	423.43	80.26	4.5	616.48	321.24	0.77	0.67	0.51	0.16
			16	424.56	80.92	3.0	630.42	335.82	0.80	0.66	0.51	0.16
			18	427.78	80.37	5.0	644.92	363.55	0.86	0.64	0.48	0.16
			20	425.28	81.30	2.0	652.96	380.06	0.90	0.62	0.45	0.17
24 hour	3	0-5	21	422.33	80.32	62.5	500.17	235.79	0.66	0.72	0.51	0.21
			23	427.34	80.47	64.5	463.04	186.12	0.51	0.78	0.54	0.24
			25	424.42	80.66	3.5	609.18	300.33	0.71	0.69	0.54	0.15
			27	426.98	80.28	16.5	570.31	280.58	0.68	0.70	0.51	0.19
			29	421.00	81.33	105.0	518.54	289.45	0.92	0.60	0.47	0.14
24 hour	3	5-10	22	425.70	80.63	0.5	656.56	369.16	0.87	0.63	0.49	0.15
			24	424.87	80.79	3.0	623.30	330.46	0.78	0.67	0.50	0.17
			26	423.81	81.34	0.5	647.80	364.09	0.86	0.64	0.48	0.16
			28	426.38	80.60	2.0	642.46	363.67	0.86	0.64	0.47	0.17
			30	425.14	80.56	0.5	632.14	329.49	0.78	0.67	0.52	0.15
3 hour	4	0-5	31	432.17	81.65	16.0	584.34	295.03	0.71	0.69	0.50	0.19
			33	425.84	80.43	35.0	585.51	308.83	0.79	0.66	0.50	0.16
			35	427.45	81.13	25.0	554.85	257.97	0.64	0.72	0.54	0.19
			37	422.80	80.98	77.0	466.35	217.02	0.63	0.73	0.49	0.24
			39	425.65	80.22	54.5	530.99	262.71	0.71	0.69	0.51	0.19
3 hour	4	5-10	32	424.22	81.06	1.0	660.40	371.55	0.88	0.63	0.49	0.14
			34	427.71	80.66	2.0	676.12	392.31	0.92	0.61	0.48	0.13
			36	426.15	80.69	2.0	631.02	343.67	0.81	0.66	0.49	0.17
			38	424.98	80.35	4.0	672.84	394.33	0.94	0.60	0.47	0.13
			40	424.78	80.86	1.5	655.00	367.66	0.87	0.63	0.49	0.14
9 hour	5	0-5	41	425.73	79.89	18.5	575.11	279.38	0.69	0.70	0.53	0.17
			43	424.55	80.34	101.0	445.43	205.89	0.64	0.72	0.49	0.23
			45	427.97	80.54	42.0	557.34	244.59	0.63	0.73	0.60	0.12
			47	426.51	80.26	59.5	541.45	273.30	0.74	0.68	0.51	0.17
			49	425.20	81.17	57.0	567.77	303.14	0.82	0.64	0.50	0.15
9 hour	5	5-10	42	429.22	80.70	3.0	682.90	396.47	0.93	0.61	0.48	0.12
			44	426.55	80.00	3.0	677.96	417.35	0.99	0.58	0.43	0.16
			46	424.73	80.07	1.5	670.58	382.98	0.90	0.62	0.49	0.13
			48	425.08	80.72	1.0	662.04	359.90	0.85	0.64	0.52	0.12
			50	424.62	80.97	3.0	672.80	385.62	0.91	0.61	0.49	0.12
3 hour	6	0-5	51	423.81	80.60	40.0	534.64	256.30	0.67	0.71	0.52	0.20
			53	427.54	80.48	15.5	534.33	260.81	0.63	0.73	0.47	0.26
			55	426.55	80.54	80.0	516.37	258.15	0.74	0.68	0.51	0.17
			57	425.84	79.88	31.5	599.97	317.56	0.81	0.65	0.51	0.14
			59	427.71	81.56	91.0	491.79	239.11	0.71	0.69	0.51	0.18
3 hour	6	5-10	52	425.57	80.64	1.0	652.78	358.78	0.85	0.64	0.50	0.14
			54	423.64	80.92	1.0	660.90	382.06	0.90	0.62	0.47	0.15
			56	425.67	80.44	1.0	686.40	404.42	0.95	0.60	0.47	0.12
			58	426.79	80.71	0.5	676.78	399.85	0.94	0.60	0.46	0.14
			60	428.87	81.30	0.5	713.58	437.92	1.02	0.57	0.45	0.11
24 hour	7	0-5	61	423.78	79.99	31.0	617.54	348.99	0.89	0.62	0.48	0.14
			63	422.50	80.30	62.0	483.13	235.10	0.65	0.72	0.47	0.25

			65	429.54	80.16	47.0	589.46	332.21	0.87	0.62	0.46	0.16
			67	428.55	80.37	41.0	622.00	355.49	0.92	0.60	0.48	0.12
			69	432.16	80.99	30.0	550.34	297.89	0.74	0.68	0.43	0.25
24 hour	7	5-10	62	423.70	80.60	4.0	693.80	435.45	1.04	0.56	0.42	0.14
			64	425.63	80.07	3.0	723.62	463.73	1.10	0.53	0.43	0.11
			66	426.13	80.55	4.0	704.50	426.32	1.01	0.57	0.47	0.10
			68	425.30	80.80	16.0	710.78	456.56	1.12	0.53	0.42	0.10
			70	429.01	80.43	4.0	740.40	495.43	1.17	0.51	0.39	0.12
control	8	0-5	71	477.15	80.45	55.0	588.48	328.73	0.78	0.66	0.42	0.24
			73	425.34	80.00	80.0	528.86	278.59	0.81	0.65	0.49	0.16
			75	430.22	80.61	13.5	617.40	328.62	0.79	0.66	0.50	0.16
			77	425.62	80.99	10.0	664.34	382.02	0.92	0.60	0.48	0.12
			79	424.49	80.68	36.5	553.85	287.61	0.74	0.68	0.48	0.20
control	8	5-10	72	425.96	81.05	5.0	678.94	410.36	0.97	0.59	0.45	0.14
			74	425.96	79.89	2.5	694.82	434.12	1.03	0.57	0.43	0.14
			76	426.16	80.90	14.0	674.50	410.27	1.00	0.58	0.44	0.13
			78	422.95	80.87	2.0	681.98	413.17	0.98	0.58	0.45	0.14
			80	424.89	80.11	1.0	673.88	392.17	0.93	0.61	0.48	0.13
9 hour	9	0-5	81	425.67	80.31	70.0	507.27	251.34	0.71	0.69	0.49	0.20
			83	424.85	80.18	58.0	502.86	238.85	0.65	0.72	0.50	0.22
			85	428.19	80.51	52.5	540.85	260.71	0.69	0.70	0.53	0.17
			87	423.95	80.84	61.5	565.80	290.87	0.80	0.65	0.54	0.12
			89	424.20	80.73	18.5	583.99	293.46	0.72	0.69	0.52	0.17
9 hour	9	5-10	82	425.70	81.12	1.0	680.40	393.92	0.93	0.61	0.48	0.12
			84	426.52	80.83	1.0	669.20	386.78	0.91	0.61	0.47	0.14
			86	428.65	81.21	0.5	672.46	390.42	0.91	0.61	0.47	0.14
			88	423.59	80.66	1.5	640.64	362.85	0.86	0.64	0.47	0.17
			90	425.23	80.77	2.0	693.18	406.91	0.96	0.59	0.49	0.11
24 hour	10	0-5	91	426.12	80.27	85.0	466.71	210.33	0.62	0.73	0.52	0.22
			93	428.97	80.70	3.0	648.46	352.16	0.83	0.64	0.51	0.14
			95	425.72	80.74	27.0	589.10	297.86	0.75	0.68	0.53	0.15
			97	426.52	80.94	73.0	487.72	231.75	0.66	0.72	0.50	0.22
			99	426.55	81.30	21.0	630.50	321.14	0.79	0.66	0.56	0.10
24 hour	10	5-10	92	420.67	80.38	6.0	629.70	338.40	0.82	0.65	0.51	0.15
			94	430.71	80.92	3.0	655.62	360.58	0.84	0.64	0.50	0.14
			96	425.26	80.69	2.5	647.38	353.71	0.84	0.65	0.50	0.14
			98	428.17	80.80	1.5	644.50	345.33	0.81	0.66	0.51	0.15
			100	427.78	80.66	5.0	664.04	378.80	0.90	0.62	0.48	0.14
3 hour	11	0-5	101	426.48	80.58	50.0	504.56	216.57	0.58	0.75	0.55	0.20
			103	423.18	80.79	52.0	575.95	307.59	0.83	0.64	0.51	0.14
			105	427.75	80.18	9.0	635.82	315.41	0.75	0.67	0.57	0.10
			107	426.39	80.99	25.0	550.37	258.26	0.64	0.72	0.53	0.20
			109	425.81	81.21	3.0	609.32	285.93	0.68	0.71	0.57	0.13
3 hour	11	5-10	102	427.32	79.79	2.0	642.18	356.74	0.84	0.64	0.48	0.16
			104	425.70	80.65	3.0	669.24	394.52	0.93	0.60	0.46	0.15
			106	427.12	81.21	0.5	657.10	344.55	0.81	0.66	0.54	0.12
			108	424.48	80.90	0.5	671.36	367.65	0.87	0.63	0.53	0.11
			110	425.13	80.58	3.0	622.50	327.34	0.78	0.67	0.51	0.16
control	12	0-5	111	427.77	80.98	35.5	585.28	293.68	0.75	0.68	0.54	0.14
			113	427.53	80.79	3.0	629.14	321.45	0.76	0.67	0.53	0.14
			115	424.31	80.24	68.0	532.88	271.16	0.76	0.67	0.51	0.16
			117	426.94	80.61	27.0	526.01	249.40	0.62	0.73	0.49	0.24
			119	424.25	80.52	75.0	521.83	252.60	0.72	0.69	0.54	0.15
control	12	5-10	112	425.45	80.32	4.0	631.22	342.94	0.81	0.66	0.49	0.16
			114	428.12	80.07	2.0	659.02	357.19	0.84	0.64	0.52	0.12
			116	428.18	80.41	1.5	663.92	367.50	0.86	0.63	0.51	0.13
			118	426.55	80.21	3.0	636.84	340.66	0.80	0.66	0.51	0.15
			120	423.22	80.70	23.0	617.36	332.93	0.83	0.65	0.51	0.14

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
c over-dry weight was exclusive the weight of the PVC core-holder

V.3.2 After Treading Treatment (1-week)

Date sampled: 1/9/00

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm⁻³)	Core-holder weight (g)	Seed volume (cm³) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density (Mg m⁻³)	Total porosity (cm³ cm⁻³)	Micro-porosity (cm³ cm⁻³)	Macro-porosity (cm³ cm⁻³)
9 hour	1	0-5	121	422.69	79.74	132.0	466.26	215.64	0.74	0.68	0.59	0.09
			123	426.73	81.49	100.0	475.37	214.46	0.66	0.72	0.55	0.17
			125	425.31	80.70	53.0	496.87	210.93	0.57	0.75	0.55	0.20
			127	426.52	80.12	62.0	538.65	253.41	0.70	0.70	0.56	0.14
			129	426.52	80.59	35.0	455.36	176.02	0.45	0.81	0.51	0.30
9 hour	1	5-10	122	426.85	80.56	1.0	637.24	352.08	0.83	0.65	0.48	0.17
			124	424.22	80.04	0.5	663.66	376.65	0.89	0.62	0.49	0.13
			126	426.52	80.64	1.0	631.82	330.28	0.78	0.67	0.52	0.15
			128	423.19	80.25	0.5	662.06	370.44	0.88	0.63	0.50	0.13
			130	428.17	80.46	3.0	621.34	330.71	0.78	0.67	0.49	0.18
control	2	0-5	131	428.17	80.59	31.0	450.04	175.23	0.44	0.81	0.49	0.32
			133	428.58	81.03	33.5	535.08	240.77	0.61	0.74	0.54	0.20
			135	428.19	80.38	43.5	492.58	215.83	0.56	0.76	0.51	0.25
			137	425.85	80.24	21.5	492.94	216.74	0.54	0.77	0.48	0.28
			139	426.44	80.44	62.0	481.75	219.16	0.60	0.74	0.50	0.24
control	2	5-10	132	425.67	81.09	1.0	605.40	306.90	0.72	0.69	0.51	0.18
			134	424.03	81.12	3.0	617.36	326.37	0.78	0.67	0.50	0.17
			136	430.64	80.68	3.0	615.76	326.64	0.76	0.68	0.49	0.19
			138	424.34	80.18	1.5	632.40	353.04	0.83	0.65	0.47	0.18
			140	425.80	81.00	0.5	645.08	374.65	0.88	0.63	0.45	0.18
24 hour	3	0-5	141	428.59	80.60	65.5	554.86	262.55	0.72	0.69	0.58	0.10
			143	424.98	80.93	61.0	548.05	251.98	0.69	0.70	0.59	0.11
			145	426.88	80.60	104.0	490.14	217.94	0.67	0.71	0.59	0.11
			147	424.88	81.04	100.0	481.51	216.17	0.67	0.71	0.57	0.14
			149	426.50	80.55	90.5	479.35	206.80	0.62	0.73	0.57	0.16
24 hour	3	5-10	142	424.81	80.27	1.5	644.00	364.72	0.86	0.63	0.47	0.16
			144	426.61	80.42	2.0	645.50	364.55	0.86	0.64	0.47	0.16
			146	425.65	80.56	1.0	646.70	357.74	0.84	0.64	0.49	0.15
			148	425.67	80.67	0.0	662.80	362.68	0.85	0.64	0.52	0.12
			150	425.70	80.84	2.0	644.16	337.24	0.80	0.66	0.53	0.13
3 hour	4	0-5	151	427.62	80.24	26.0	571.62	299.40	0.75	0.68	0.48	0.20
			153	427.36	80.86	27.0	570.67	286.08	0.71	0.69	0.51	0.18
			155	425.42	80.58	7.5	627.26	325.04	0.78	0.66	0.53	0.13
			157	425.70	80.00	19.0	543.09	255.04	0.63	0.73	0.51	0.22
			159	424.06	80.86	60.5	539.96	267.29	0.74	0.68	0.53	0.15
3 hour	4	5-10	152	428.56	80.36	1.5	662.12	369.74	0.87	0.63	0.50	0.14
			154	428.03	80.38	3.0	656.72	385.66	0.91	0.62	0.45	0.17
			156	422.38	80.40	1.5	628.74	342.03	0.81	0.66	0.49	0.17
			158	424.03	80.47	1.0	684.18	401.44	0.95	0.60	0.48	0.12
			160	428.19	80.62	1.0	650.46	364.47	0.85	0.64	0.48	0.16
9 hour	5	0-5	161	423.24	80.47	115.5	455.50	204.13	0.66	0.71	0.56	0.16
			163	427.96	80.28	73.0	515.58	257.59	0.73	0.69	0.50	0.19
			165	426.80	80.46	18.5	605.46	313.37	0.77	0.67	0.52	0.15
			167	429.35	80.06	51.0	558.87	276.28	0.73	0.68	0.54	0.15
			169	427.53	80.00	12.0	617.28	316.88	0.76	0.67	0.53	0.14
9 hour	5	5-10	162	425.31	80.19	0.5	652.22	376.70	0.89	0.62	0.46	0.16
			164	425.55	81.04	3.0	675.36	403.19	0.95	0.60	0.45	0.14
			166	425.32	79.78	4.0	672.12	397.93	0.94	0.60	0.46	0.14
			168	426.24	81.92	0.5	695.32	395.63	0.93	0.61	0.51	0.09
			170	425.12	80.85	3.0	655.08	381.85	0.90	0.62	0.46	0.16
3 hour	6	0-5	171	426.60	80.40	42.0	571.62	284.38	0.74	0.68	0.54	0.14
			173	425.46	80.76	65.0	485.26	230.58	0.64	0.72	0.48	0.24
			175	424.98	80.60	46.0	556.71	277.07	0.73	0.68	0.53	0.16
			177	430.11	80.52	44.0	558.70	274.66	0.71	0.69	0.53	0.17
			179	426.84	80.57	21.0	614.08	323.52	0.80	0.66	0.52	0.14
3 hour	6	5-10	172	425.62	80.83	3.0	638.72	351.53	0.83	0.65	0.49	0.16
			174	424.57	80.45	1.0	683.88	406.62	0.96	0.59	0.46	0.13
			176	425.80	80.59	2.0	697.10	430.29	1.02	0.57	0.44	0.13
			178	427.28	80.26	1.5	684.32	409.68	0.96	0.59	0.46	0.14
			180	426.50	80.43	0.5	717.40	437.37	1.03	0.56	0.47	0.10
24 hour	7	0-5	182	422.19	80.17	38.5	621.72	343.57	0.90	0.61	0.52	0.10
			183	427.72	80.13	40.0	638.98	364.99	0.94	0.59	0.50	0.09
			185	429.46	80.05	59.0	556.05	279.51	0.75	0.67	0.53	0.14
			187	423.57	80.72	54.5	612.34	347.64	0.94	0.59	0.50	0.09
			189	427.86	80.38	52.0	602.24	336.23	0.89	0.61	0.49	0.12

24 hour	7	5-10	181	425.96	80.60	3.0	728.16	459.44	1.09	0.54	0.44	0.09
			184	426.05	80.63	1.0	756.42	487.30	1.15	0.51	0.44	0.07
			186	423.58	80.30	3.0	729.80	455.22	1.08	0.54	0.46	0.08
			188	426.10	80.81	25.0	698.12	448.60	1.12	0.53	0.42	0.11
			190	426.75	80.92	1.5	749.10	495.87	1.17	0.51	0.41	0.10
control	8	0-5	201	420.48	85.45	75.0	505.67	248.96	0.72	0.69	0.50	0.19
			203	425.65	84.80	40.0	646.70	381.73	0.99	0.57	0.47	0.10
			205	422.66	84.71	49.0	524.69	248.75	0.67	0.71	0.51	0.20
			207	430.95	84.85	64.0	545.79	283.90	0.77	0.67	0.48	0.18
			209	423.99	84.31	100.0	474.60	208.31	0.64	0.72	0.56	0.16
control	8	5-10	202	422.75	85.04	5.5	715.08	462.02	1.11	0.53	0.40	0.13
			204	424.86	86.48	2.0	706.42	430.37	1.02	0.57	0.45	0.12
			206	424.70	87.27	1.5	711.62	451.96	1.07	0.55	0.41	0.14
			208	421.39	85.09	8.0	667.24	390.78	0.95	0.60	0.46	0.14
			210	423.33	84.24	1.0	661.48	386.80	0.92	0.61	0.45	0.16
9 hour	9	0-5	211	423.40	83.44	51.0	574.20	281.90	0.76	0.67	0.56	0.11
			213	422.69	85.06	135.0	465.74	217.80	0.76	0.67	0.57	0.11
			215	424.68	84.54	88.0	554.59	280.81	0.83	0.64	0.56	0.08
			217	424.85	84.67	17.0	578.15	278.50	0.68	0.70	0.53	0.18
			219	426.76	83.91	55.0	532.10	246.84	0.66	0.71	0.54	0.17
9 hour	9	5-10	212	421.19	84.80	3.0	675.00	375.54	0.90	0.62	0.51	0.11
			214	419.81	84.43	1.0	676.94	373.39	0.89	0.62	0.52	0.10
			216	425.75	84.34	4.0	690.26	396.77	0.94	0.60	0.50	0.11
			218	422.38	83.97	2.0	664.22	361.32	0.86	0.64	0.52	0.11
			220	420.87	85.28	2.0	667.84	393.93	0.94	0.60	0.45	0.15
24 hour	10	0-5	221	425.02	85.68	94.0	450.21	180.06	0.54	0.76	0.56	0.21
			223	424.86	87.20	62.0	598.86	298.83	0.82	0.64	0.59	0.06
			225	425.92	84.18	89.0	529.49	251.60	0.75	0.68	0.57	0.10
			227	421.90	83.95	75.0	523.71	239.52	0.69	0.70	0.58	0.12
			229	426.41	84.92	85.0	519.65	238.91	0.70	0.70	0.57	0.12
24 hour	10	5-10	222	420.68	85.19	0.5	661.42	364.73	0.87	0.63	0.50	0.13
			224	425.35	84.64	0.5	664.18	354.10	0.83	0.65	0.53	0.12
			226	427.24	83.14	1.0	665.88	368.35	0.86	0.63	0.50	0.13
			228	425.18	84.74	2.5	682.94	374.11	0.89	0.62	0.53	0.09
			230	426.43	84.30	0.5	682.16	385.10	0.90	0.62	0.50	0.12
3 hour	11	0-5	231	424.34	84.82	22.0	575.37	273.50	0.68	0.71	0.54	0.17
			233	419.81	84.30	69.5	518.28	245.20	0.70	0.70	0.54	0.16
			235	419.55	85.14	35.5	525.27	223.52	0.58	0.75	0.56	0.18
			237	421.54	83.91	35.0	514.58	243.76	0.63	0.73	0.48	0.24
			239	422.29	85.06	58.0	509.54	216.72	0.59	0.74	0.57	0.17
3 hour	11	5-10	232	423.17	84.53	0.5	643.48	360.79	0.85	0.64	0.47	0.17
			234	428.03	85.17	0.5	692.38	401.35	0.94	0.60	0.48	0.12
			236	426.84	85.51	0.5	620.88	318.69	0.75	0.68	0.51	0.17
			238	420.77	85.19	1.0	651.56	363.01	0.86	0.63	0.48	0.15
			240	422.44	84.84	1.0	643.10	339.03	0.80	0.66	0.52	0.14
control	12	0-5	241	425.73	83.52	29.5	526.82	240.53	0.61	0.74	0.51	0.23
			243	423.10	84.59	73.0	498.16	239.52	0.68	0.70	0.50	0.21
			245	422.51	85.63	53.0	488.96	208.68	0.56	0.76	0.53	0.23
			247	424.37	86.04	105.0	472.74	224.21	0.70	0.70	0.51	0.19
			249	426.75	83.91	35.0	500.86	208.71	0.53	0.77	0.53	0.24
control	12	5-10	242	421.38	85.02	0.5	666.70	374.85	0.89	0.62	0.49	0.13
			244	426.26	83.82	0.5	655.40	359.49	0.84	0.64	0.50	0.14
			246	423.34	84.72	1.0	650.84	355.79	0.84	0.64	0.50	0.14
			248	419.31	84.77	1.0	633.42	338.63	0.81	0.66	0.50	0.15
			250	422.43	84.81	0.5	623.44	344.87	0.82	0.65	0.46	0.19

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.3.3 After Treading Treatment (4-weeks)

Date sampled: 28/9/00

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density (Mg m^{-3})	Total porosity (cm^3 cm^{-3})	Micro-porosity (cm^3 cm^{-3})	Macro-porosity (cm^3 cm^{-3})
9 hour	1	0-5	1	424.85	81.09	120.0	463.66	216.44	0.71	0.69	0.54	0.15
			3	424.03	81.12	70.0	548.02	264.12	0.75	0.68	0.57	0.10
			5	421.60	81.00	68.0	484.16	197.61	0.56	0.76	0.58	0.18
			7	426.53	80.85	48.5	574.70	280.20	0.74	0.68	0.57	0.11
			9	425.70	80.57	52.0	535.14	246.64	0.66	0.71	0.56	0.16
9 hour	1	5-10	2	425.70	80.91	13.0	649.72	379.93	0.92	0.61	0.46	0.15
			4	424.85	81.25	1.0	671.88	377.59	0.89	0.62	0.50	0.12
			6	425.69	81.59	1.0	639.16	350.54	0.83	0.65	0.49	0.16
			8	425.71	80.97	0.5	657.00	383.68	0.90	0.62	0.45	0.17
			10	424.48	80.65	0.5	612.90	324.88	0.77	0.68	0.49	0.19
control	2	0-5	11	426.79	80.19	82.0	436.42	181.40	0.53	0.77	0.51	0.27
			13	428.20	80.72	77.0	506.60	228.43	0.65	0.72	0.56	0.16
			15	424.62	80.65	62.5	495.76	223.04	0.62	0.73	0.53	0.20
			17	423.60	80.75	32.0	571.74	281.13	0.72	0.69	0.54	0.15
			19	421.39	80.52	74.5	472.56	217.54	0.63	0.73	0.50	0.23
control	2	5-10	12	428.11	80.26	1.0	627.28	325.75	0.76	0.68	0.52	0.16
			14	423.43	80.26	0.5	610.88	325.50	0.77	0.67	0.48	0.19
			16	424.56	80.92	3.0	607.24	308.21	0.73	0.69	0.52	0.17
			18	427.78	80.37	4.0	638.72	357.78	0.84	0.64	0.47	0.17
			20	425.28	81.30	1.5	659.90	379.58	0.90	0.62	0.47	0.15
24 hour	3	0-5	21	422.33	80.32	81.0	519.00	246.02	0.72	0.69	0.56	0.12
			23	427.34	80.47	95.0	495.34	232.02	0.70	0.70	0.55	0.15
			25	424.42	80.66	66.0	559.46	272.21	0.76	0.67	0.58	0.10
			27	426.98	80.28	82.0	520.68	255.69	0.74	0.68	0.54	0.14
			29	421.00	81.33	82.5	491.46	222.02	0.66	0.72	0.56	0.16
24 hour	3	5-10	22	425.70	80.63	1.0	669.54	370.78	0.87	0.63	0.51	0.12
			24	424.87	80.79	5.5	641.86	354.99	0.85	0.64	0.49	0.15
			26	423.81	81.34	1.5	666.16	366.56	0.87	0.63	0.52	0.12
			28	426.38	80.60	11.0	662.10	374.96	0.90	0.62	0.50	0.12
			30	425.14	80.56	1.5	638.68	327.48	0.77	0.67	0.54	0.13
3 hour	4	0-5	31	432.17	81.65	116.0	432.92	195.58	0.62	0.73	0.49	0.24
			33	425.84	80.43	117.5	456.04	220.76	0.72	0.69	0.50	0.19
			35	427.45	81.13	129.0	380.12	168.39	0.56	0.76	0.44	0.32
			37	422.80	80.98	69.0	543.44	275.13	0.78	0.66	0.53	0.13
			39	425.65	80.22	78.0	493.90	230.66	0.66	0.71	0.53	0.19
3 hour	4	5-10	32	424.22	81.06	10.0	647.84	355.62	0.86	0.64	0.51	0.13
			34	427.71	80.66	7.5	666.90	379.53	0.90	0.62	0.49	0.13
			36	426.15	80.69	0.5	634.98	347.25	0.82	0.65	0.49	0.17
			38	424.98	80.35	0.5	654.80	400.67	0.94	0.60	0.41	0.19
			40	424.78	80.86	2.0	644.44	361.67	0.86	0.64	0.48	0.16
9 hour	5	0-5	41	425.73	79.89	125.0	459.38	216.19	0.72	0.69	0.54	0.15
			43	424.55	80.34	80.5	573.22	300.08	0.87	0.62	0.56	0.06
			45	427.97	80.54	36.5	649.70	356.44	0.91	0.61	0.54	0.06
			47	426.51	80.26	53.0	600.30	314.06	0.84	0.64	0.55	0.08
			49	425.20	81.17	50.0	617.40	327.66	0.87	0.62	0.56	0.07
9 hour	5	5-10	42	429.22	80.70	2.0	674.98	397.05	0.93	0.61	0.46	0.14
			44	426.55	80.00	1.5	698.50	422.95	1.00	0.58	0.46	0.12
			46	424.73	80.07	2.5	697.62	416.31	0.99	0.58	0.48	0.11
			48	425.08	80.72	5.0	682.48	396.60	0.94	0.60	0.49	0.11
			50	424.62	80.97	4.5	684.58	386.67	0.92	0.61	0.52	0.09
3 hour	6	0-5	51	423.81	80.60	83.0	506.84	250.44	0.73	0.68	0.52	0.17
			53	427.54	80.48	85.0	521.66	259.92	0.76	0.67	0.53	0.14
			55	426.55	80.54	38.0	606.04	336.67	0.87	0.63	0.49	0.14
			57	425.84	79.88	45.0	641.64	360.21	0.95	0.59	0.53	0.06
			59	427.71	81.56	58.0	569.58	310.01	0.84	0.64	0.48	0.16
3 hour	6	5-10	52	425.57	80.64	3.5	644.40	368.16	0.87	0.63	0.46	0.17
			54	423.64	80.92	1.5	697.84	421.91	1.00	0.58	0.46	0.11
			56	425.67	80.44	1.0	707.60	447.22	1.05	0.55	0.42	0.13
			58	426.79	80.71	3.0	701.82	421.25	0.99	0.58	0.47	0.11
			60	428.87	81.30	2.0	723.42	448.80	1.05	0.55	0.45	0.10
24 hour	7	0-5	61	423.78	79.99	79.0	609.24	356.16	1.03	0.55	0.50	0.05
			63	422.50	80.30	74.0	569.84	323.83	0.93	0.60	0.48	0.12
			65	429.54	80.16	101.0	497.32	255.55	0.78	0.66	0.49	0.17
			67	428.55	80.37	67.0	641.94	375.24	1.04	0.55	0.52	0.04
			69	432.16	80.99	62.0	606.50	350.38	0.95	0.59	0.47	0.12

24 hour	7	5-10	62	423.70	80.60	0.5	741.56	477.65	1.13	0.52	0.43	0.09
			64	425.63	80.07	13.5	747.04	492.03	1.19	0.49	0.42	0.07
			66	426.13	80.55	8.0	741.28	477.12	1.14	0.52	0.44	0.08
			68	425.30	80.80	5.5	754.12	508.10	1.21	0.49	0.39	0.09
			70	429.01	80.43	25.0	721.08	476.43	1.18	0.50	0.41	0.09
control	8	0-5	71	477.15	80.45	6.0	690.06	404.00	0.86	0.63	0.44	0.19
			73	425.34	80.00	76.0	546.26	299.41	0.86	0.63	0.48	0.15
			75	430.22	80.61	43.0	604.22	328.48	0.85	0.63	0.50	0.13
			77	425.62	80.99	55.0	536.98	253.15	0.68	0.70	0.55	0.16
			79	424.49	80.68	20.0	606.50	298.69	0.74	0.68	0.56	0.12
control	8	5-10	72	425.96	81.05	17.0	665.38	421.58	1.03	0.56	0.40	0.17
			74	425.96	79.89	3.0	700.90	435.30	1.03	0.56	0.44	0.12
			76	426.16	80.90	14.5	673.62	416.47	1.01	0.57	0.43	0.14
			78	422.95	80.87	3.0	675.98	392.99	0.94	0.60	0.48	0.12
			80	424.89	80.11	2.0	673.08	392.89	0.93	0.61	0.47	0.13
9 hour	9	0-5	81	425.70	81.12	35.0	628.16	326.24	0.84	0.64	0.57	0.07
			83	424.85	80.18	49.0	618.00	318.48	0.85	0.63	0.58	0.05
			85	428.19	80.51	49.0	599.88	309.57	0.82	0.65	0.55	0.09
			87	423.95	80.84	63.0	537.10	258.89	0.72	0.69	0.55	0.14
			89	424.20	80.73	18.0	685.56	376.02	0.93	0.60	0.56	0.04
9 hour	9	5-10	82	425.67	80.31	1.0	693.30	405.54	0.95	0.60	0.49	0.11
			84	426.52	80.83	0.5	702.46	403.44	0.95	0.60	0.51	0.09
			86	428.65	81.21	1.5	698.94	403.30	0.94	0.60	0.50	0.10
			88	423.59	80.66	3.0	679.80	384.79	0.91	0.61	0.51	0.10
			90	425.23	80.77	3.0	676.70	395.89	0.94	0.60	0.47	0.13
24 hour	10	0-5	91	426.12	80.27	36.0	576.52	271.09	0.69	0.70	0.58	0.12
			93	428.97	80.70	91.0	532.62	259.43	0.77	0.67	0.57	0.10
			95	425.72	80.74	38.5	632.02	325.13	0.84	0.64	0.58	0.05
			97	426.52	80.94	27.0	619.34	315.59	0.79	0.66	0.56	0.10
			99	426.55	81.30	62.0	582.94	294.70	0.81	0.65	0.57	0.08
24 hour	10	5-10	92	420.67	80.38	1.0	663.32	361.69	0.86	0.63	0.53	0.11
			94	430.71	80.92	3.0	681.90	383.08	0.90	0.62	0.51	0.11
			96	425.26	80.69	2.0	686.40	380.79	0.90	0.62	0.53	0.09
			98	428.17	80.80	1.0	666.16	374.02	0.88	0.63	0.49	0.13
			100	427.78	80.66	2.5	671.12	381.16	0.90	0.62	0.49	0.13
3 hour	11	0-5	101	426.48	80.58	23.0	617.62	316.27	0.78	0.66	0.55	0.11
			103	423.18	80.79	88.5	533.12	267.68	0.80	0.65	0.55	0.10
			105	427.75	80.18	41.0	554.84	254.27	0.66	0.72	0.57	0.15
			107	426.39	80.99	27.0	578.74	280.35	0.70	0.70	0.54	0.15
			109	425.81	81.21	4.0	621.36	291.13	0.69	0.70	0.59	0.11
3 hour	11	5-10	102	427.32	79.79	13.0	660.54	377.92	0.91	0.61	0.49	0.12
			104	425.70	80.65	3.5	686.06	396.30	0.94	0.60	0.50	0.11
			106	427.12	81.21	6.5	641.56	338.75	0.81	0.66	0.53	0.13
			108	424.48	80.90	2.0	629.82	333.36	0.79	0.67	0.51	0.16
			110	425.13	80.58	2.0	656.98	349.95	0.83	0.65	0.54	0.11
control	12	0-5	111	427.77	80.98	64.0	488.56	216.90	0.60	0.74	0.52	0.22
			113	427.53	80.79	42.0	570.24	285.31	0.74	0.68	0.53	0.15
			115	424.31	80.24	82.0	472.98	218.97	0.64	0.72	0.51	0.22
			117	426.94	80.61	50.0	572.44	287.20	0.76	0.67	0.54	0.13
			119	424.25	80.52	48.0	588.46	301.39	0.80	0.65	0.55	0.10
control	12	5-10	112	425.45	80.32	3.0	685.88	382.84	0.91	0.62	0.53	0.09
			114	428.12	80.07	2.5	684.96	392.33	0.92	0.61	0.50	0.11
			116	428.18	80.41	3.0	675.18	385.17	0.91	0.62	0.49	0.12
			118	426.55	80.21	4.5	638.16	342.65	0.81	0.66	0.51	0.15
			120	423.22	80.70	6.0	623.48	346.74	0.83	0.65	0.47	0.18

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.3.4 After Treading Treatment (13-weeks)

Date sampled: 23/11/00

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
9 hour	1	0-5	1	424.85	81.09	92.0	518.95	274.33	0.82	0.64	0.49	0.15
			3	424.03	81.12	149.0	497.90	276.21	1.00	0.57	0.51	0.05
			6	425.69	81.59	69.0	524.06	251.64	0.71	0.69	0.54	0.16
			7	426.53	80.85	81.0	498.06	248.57	0.72	0.69	0.49	0.20
			9	425.70	80.57	55.0	523.57	249.84	0.67	0.71	0.52	0.19
9 hour	1	5-10	2	425.70	80.91	7.0	659.12	394.29	0.94	0.60	0.44	0.16
			4	424.85	81.25	4.0	684.26	405.92	0.96	0.59	0.47	0.12
			5	421.60	81.00	9.0	609.96	347.42	0.84	0.64	0.44	0.20
			8	425.71	80.97	4.0	647.12	366.33	0.87	0.63	0.47	0.16
			10	424.48	80.65	1.0	640.88	354.96	0.84	0.64	0.48	0.16
control	2	0-5	11	426.79	80.19	6.0	542.74	265.97	0.63	0.73	0.47	0.26
			13	428.20	80.72	25.0	569.28	277.05	0.69	0.70	0.52	0.18
			15	424.62	80.65	70.0	461.41	209.40	0.59	0.74	0.48	0.26
			17	423.60	80.75	41.0	519.88	260.45	0.68	0.71	0.47	0.24
			19	421.39	80.52	32.0	581.95	316.65	0.81	0.65	0.47	0.17
control	2	5-10	12	428.11	80.26	8.0	598.20	316.66	0.75	0.68	0.48	0.20
			14	423.43	80.26	4.5	623.96	328.36	0.78	0.67	0.51	0.15
			16	424.56	80.92	4.0	648.86	361.70	0.86	0.64	0.49	0.15
			18	427.78	80.37	4.0	640.54	351.01	0.83	0.65	0.49	0.16
			20	425.28	81.30	13.0	638.80	371.59	0.90	0.62	0.45	0.17
24 hour	3	0-5	21	422.33	80.32	27.0	607.36	325.73	0.82	0.64	0.51	0.13
			23	427.34	80.47	33.0	635.10	356.01	0.90	0.61	0.50	0.11
			25	424.42	80.66	28.0	574.17	302.28	0.76	0.67	0.48	0.19
			27	426.98	80.28	53.5	567.21	314.07	0.84	0.64	0.46	0.17
			29	421.00	81.33	104.5	474.93	235.39	0.74	0.68	0.50	0.18
24 hour	3	5-10	22	425.70	80.63	17.0	651.64	370.15	0.91	0.62	0.49	0.12
			24	424.87	80.79	3.0	634.20	376.62	0.89	0.62	0.42	0.20
			26	423.81	81.34	7.0	657.34	384.74	0.92	0.61	0.46	0.15
			28	426.38	80.60	9.0	665.34	389.11	0.93	0.60	0.47	0.14
			30	425.14	80.56	7.0	634.00	362.93	0.87	0.63	0.46	0.18
3 hour	4	0-5	31	432.17	81.65	78.0	580.95	315.12	0.89	0.62	0.52	0.10
			33	425.84	80.43	17.0	648.52	367.44	0.90	0.61	0.49	0.12
			35	427.45	81.13	81.0	484.05	238.19	0.69	0.70	0.48	0.23
			37	422.80	80.98	36.0	611.02	334.93	0.87	0.63	0.50	0.12
			39	425.65	80.22	64.0	539.92	284.00	0.79	0.66	0.49	0.17
3 hour	4	5-10	32	424.22	81.06	20.0	649.06	374.59	0.93	0.61	0.48	0.13
			34	427.71	80.66	9.0	697.36	414.55	0.99	0.58	0.48	0.10
			36	426.15	80.69	5.0	655.38	359.58	0.85	0.64	0.51	0.13
			38	424.98	80.35	4.0	688.82	417.72	0.99	0.58	0.45	0.13
			40	424.78	80.86	4.0	636.94	358.84	0.85	0.64	0.47	0.17
9 hour	5	0-5	41	425.73	79.89	60.0	598.23	336.67	0.92	0.60	0.50	0.11
			43	424.55	80.34	59.0	591.72	332.23	0.91	0.61	0.49	0.12
			45	427.97	80.54	71.0	577.42	313.33	0.88	0.62	0.51	0.11
			47	426.51	80.26	25.0	701.56	404.82	1.01	0.56	0.54	0.02
			49	425.20	81.17	89.0	546.73	297.93	0.89	0.62	0.50	0.12
9 hour	5	5-10	42	429.22	80.70	8.0	705.70	418.12	0.99	0.58	0.49	0.09
			44	426.55	80.00	3.0	708.64	436.21	1.03	0.56	0.45	0.11
			46	424.73	80.07	5.0	711.68	440.26	1.05	0.56	0.46	0.10
			48	425.08	80.72	6.0	694.06	419.85	1.00	0.58	0.46	0.11
			50	424.62	80.97	7.0	671.60	400.68	0.96	0.59	0.45	0.14
3 hour	6	0-5	51	423.81	80.60	62.0	577.15	306.69	0.85	0.63	0.52	0.11
			53	427.54	80.48	83.0	522.57	278.61	0.81	0.65	0.47	0.18
			55	426.55	80.54	114.0	464.21	243.50	0.78	0.66	0.45	0.21
			57	425.84	79.88	25.0	641.84	370.78	0.93	0.60	0.48	0.12
			59	427.71	81.56	13.0	656.66	376.23	0.91	0.61	0.48	0.13
3 hour	6	5-10	52	425.57	80.64	19.0	658.44	383.95	0.94	0.60	0.48	0.12
			54	423.64	80.92	28.0	663.56	402.69	1.02	0.57	0.45	0.11
			56	425.67	80.44	4.0	720.14	448.27	1.06	0.55	0.45	0.10
			58	426.79	80.71	4.0	734.08	457.76	1.08	0.54	0.46	0.08
			60	428.87	81.30	5.5	727.58	455.42	1.08	0.54	0.45	0.09
24 hour	7	0-5	61	423.78	79.99	45.0	663.58	405.82	1.07	0.54	0.47	0.07
			63	422.50	80.30	52.0	654.96	395.38	1.07	0.54	0.48	0.05
			65	429.54	80.16	52.0	667.70	416.85	1.10	0.52	0.45	0.07
			67	428.55	80.37	48.0	649.30	399.19	1.05	0.55	0.45	0.10
			69	432.16	80.99	6.0	727.04	450.80	1.06	0.54	0.46	0.08

24 hour	7	5-10	62	423.70	80.60	2.0	768.04	500.57	1.19	0.50	0.44	0.05
			64	425.63	80.07	24.0	722.76	478.46	1.19	0.50	0.41	0.09
			66	426.13	80.55	3.0	754.66	496.52	1.17	0.50	0.42	0.08
			68	425.30	80.80	30.5	717.86	478.95	1.21	0.49	0.40	0.09
			70	429.01	80.43	13.0	713.48	484.82	1.17	0.51	0.36	0.15
control	8	0-5	71	477.15	80.45	95.0	526.75	293.01	0.77	0.67	0.40	0.27
			73	425.34	80.00	75.0	557.79	314.05	0.90	0.61	0.47	0.14
			75	430.22	80.61	53.0	572.56	315.74	0.84	0.64	0.47	0.17
			77	425.62	80.99	14.0	645.06	368.69	0.90	0.61	0.47	0.14
			80	424.89	80.11	35.5	633.48	350.77	0.90	0.61	0.52	0.09
control	8	5-10	72	425.96	81.05	12.5	732.74	474.04	1.15	0.51	0.43	0.08
			74	425.96	79.89	57.0	637.10	413.94	1.12	0.52	0.39	0.14
			76	426.16	80.90	24.5	709.80	465.01	1.16	0.51	0.41	0.10
			78	422.95	80.87	3.0	675.42	413.49	0.98	0.58	0.43	0.15
			79	424.49	80.68	4.0	683.56	404.34	0.96	0.59	0.47	0.12
9 hour	9	0-5	81	425.70	81.12	40.0	579.91	307.08	0.80	0.66	0.50	0.16
			83	424.85	80.18	113.0	511.17	285.61	0.92	0.60	0.47	0.14
			85	428.19	80.51	113.5	478.18	248.25	0.79	0.66	0.47	0.18
			87	423.95	80.84	78.0	554.38	292.46	0.85	0.63	0.52	0.11
			89	424.20	80.73	68.0	598.63	339.57	0.95	0.59	0.50	0.09
9 hour	9	5-10	82	425.67	80.31	8.0	734.68	458.03	1.10	0.54	0.47	0.07
			84	426.52	80.83	12.5	697.88	413.24	1.00	0.58	0.49	0.08
			86	428.65	81.21	5.5	729.64	448.52	1.06	0.55	0.47	0.08
			88	423.59	80.66	25.0	663.10	408.98	1.03	0.57	0.44	0.13
			90	425.23	80.77	7.0	701.14	421.03	1.01	0.57	0.48	0.10
24 hour	10	0-5	91	426.12	80.27	41.5	629.10	338.30	0.88	0.62	0.55	0.07
			93	428.97	80.70	43.0	619.10	331.23	0.86	0.63	0.54	0.09
			95	425.72	80.74	77.0	601.24	337.53	0.97	0.58	0.52	0.06
			97	426.52	80.94	44.0	627.46	336.40	0.88	0.62	0.55	0.07
			99	426.55	81.30	28.0	633.18	340.46	0.85	0.63	0.53	0.10
24 hour	10	5-10	92	420.67	80.38	10.5	661.04	375.62	0.92	0.61	0.50	0.11
			94	430.71	80.92	13.0	672.56	382.31	0.92	0.61	0.50	0.11
			96	425.26	80.69	4.0	679.88	387.07	0.92	0.61	0.50	0.11
			98	428.17	80.80	20.0	664.02	390.99	0.96	0.59	0.47	0.12
			100	427.78	80.66	3.0	682.58	401.20	0.94	0.60	0.47	0.13
3 hour	11	0-5	101	426.48	80.58	45.0	660.06	371.92	0.97	0.58	0.54	0.03
			103	423.18	80.79	111.0	488.70	263.80	0.85	0.63	0.46	0.17
			105	427.75	80.18	59.0	534.61	267.92	0.73	0.69	0.51	0.18
			107	426.39	80.99	77.0	526.28	270.86	0.78	0.66	0.50	0.17
			109	425.81	81.21	15.5	606.16	306.52	0.75	0.68	0.53	0.14
3 hour	11	5-10	102	427.32	79.79	13.0	677.30	389.59	0.94	0.60	0.50	0.10
			104	425.70	80.65	8.0	715.34	428.93	1.03	0.56	0.49	0.07
			106	427.12	81.21	12.0	648.48	360.60	0.87	0.63	0.50	0.13
			108	424.48	80.90	4.0	689.80	407.26	0.97	0.59	0.48	0.11
			110	425.13	80.58	8.0	642.86	354.51	0.85	0.64	0.50	0.14
control	12	0-5	111	427.77	80.98	31.0	631.76	340.14	0.86	0.63	0.53	0.10
			113	427.53	80.79	42.5	621.48	353.09	0.92	0.60	0.49	0.12
			115	424.31	80.24	93.0	488.32	256.03	0.77	0.67	0.46	0.21
			117	426.94	80.61	35.0	569.39	303.80	0.78	0.66	0.47	0.19
			119	424.25	80.52	20.0	616.66	339.68	0.84	0.64	0.49	0.15
control	12	5-10	112	425.45	80.32	20.0	656.10	382.42	0.94	0.60	0.48	0.12
			114	428.12	80.07	6.0	709.62	413.22	0.98	0.59	0.51	0.07
			116	428.18	80.41	6.0	660.16	378.85	0.90	0.62	0.48	0.14
			118	426.55	80.21	20.0	632.76	360.75	0.89	0.62	0.47	0.15
			120	423.22	80.70	6.0	662.52	375.74	0.90	0.62	0.49	0.12

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.3.5 After Treading Treatment (26-weeks)

Date sampled: 19/2/01

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm-3)	Core-holder weight (g)	Seed volume (cm3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density (Mg m-3)	Total porosity (cm3 cm-3)	Micro-porosity (cm3 cm-3)	Macro-porosity (cm3 cm-3)
9 hour	1	0-5	1	424.85	81.09	7.5	612.06	334.60	0.80	0.65	0.47	0.18
			3	424.03	81.12	63.5	512.01	248.75	0.69	0.70	0.51	0.20
			5	421.60	81.00	38.0	581.94	308.26	0.80	0.65	0.50	0.15
			7	426.53	80.85	12.0	611.70	314.64	0.76	0.67	0.52	0.15
			9	425.70	80.57	70.0	485.02	235.08	0.66	0.71	0.48	0.24
9 hour	1	5-10	2	425.70	80.91	4.0	651.34	377.30	0.89	0.62	0.46	0.16
			4	424.85	81.25	5.5	668.28	389.75	0.93	0.61	0.47	0.14
			6	425.69	81.59	3.0	641.10	352.14	0.83	0.65	0.49	0.16
			8	425.71	80.97	4.0	617.14	343.43	0.81	0.65	0.46	0.20
			10	424.48	80.65	2.5	632.30	348.46	0.83	0.65	0.48	0.17
control	2	0-5	11	426.79	80.19	15.0	548.86	264.29	0.64	0.72	0.50	0.23
			13	428.20	80.72	40.0	517.56	249.34	0.64	0.72	0.48	0.24
			15	424.62	80.65	95.0	488.63	247.75	0.75	0.67	0.49	0.19
			17	423.60	80.75	41.0	512.91	252.44	0.66	0.71	0.47	0.24
			19	421.39	80.52	68.0	511.08	266.11	0.75	0.67	0.47	0.21
control	2	5-10	12	428.11	80.26	3.0	618.62	332.43	0.78	0.67	0.48	0.18
			14	423.43	80.26	1.0	620.36	333.42	0.79	0.67	0.49	0.18
			16	424.56	80.92	4.5	633.78	365.27	0.87	0.63	0.45	0.18
			18	427.78	80.37	2.0	614.50	354.08	0.83	0.65	0.42	0.22
			20	425.28	81.30	13.0	630.70	361.27	0.88	0.63	0.46	0.17
24 hour	3	0-5	21	422.33	80.32	63.0	538.45	279.55	0.78	0.66	0.50	0.17
			23	427.34	80.47	52.0	550.99	296.80	0.79	0.66	0.46	0.20
			25	424.42	80.66	41.5	593.57	312.29	0.82	0.65	0.52	0.12
			27	426.98	80.28	60.5	576.14	316.58	0.86	0.63	0.49	0.14
			29	421.00	81.33	54.5	511.94	255.43	0.70	0.70	0.48	0.22
24 hour	3	5-10	22	425.70	80.63	2.0	652.08	378.90	0.89	0.62	0.45	0.17
			24	424.87	80.79	5.0	674.82	391.66	0.93	0.60	0.48	0.12
			26	423.81	81.34	2.0	643.54	355.06	0.84	0.64	0.49	0.15
			28	426.38	80.60	8.0	629.62	358.21	0.86	0.64	0.46	0.18
			30	425.14	80.56	2.0	605.14	313.34	0.74	0.69	0.50	0.19
3 hour	4	0-5	31	432.17	81.65	77.0	573.41	314.60	0.89	0.62	0.50	0.12
			33	425.84	80.43	41.0	618.06	348.05	0.90	0.61	0.49	0.12
			35	427.45	81.13	50.0	519.93	266.44	0.71	0.69	0.46	0.24
			37	422.80	80.98	40.5	608.96	350.95	0.92	0.60	0.46	0.14
			39	425.65	80.22	99.5	527.81	289.30	0.89	0.62	0.49	0.13
3 hour	4	5-10	32	424.22	81.06	3.5	669.16	389.46	0.93	0.61	0.47	0.14
			34	427.71	80.66	3.0	653.58	384.46	0.91	0.62	0.44	0.17
			36	426.15	80.69	2.0	646.52	361.49	0.85	0.64	0.48	0.16
			38	424.98	80.35	3.0	661.82	392.29	0.93	0.61	0.45	0.16
			40	424.78	80.86	2.5	653.00	399.27	0.95	0.60	0.41	0.19
9 hour	5	0-5	41	425.73	79.89	76.0	542.50	314.78	0.90	0.61	0.42	0.19
			43	424.55	80.34	65.0	542.10	315.04	0.88	0.62	0.41	0.21
			45	427.97	80.54	29.0	634.92	362.77	0.91	0.61	0.48	0.13
			47	426.51	80.26	17.0	624.36	351.42	0.86	0.63	0.47	0.16
			49	425.20	81.17	102.0	502.53	261.36	0.81	0.65	0.50	0.16
9 hour	5	5-10	42	429.22	80.70	3.5	685.44	412.07	0.97	0.59	0.45	0.14
			44	426.55	80.00	5.0	671.62	410.53	0.97	0.59	0.43	0.16
			46	424.73	80.07	4.0	677.90	418.13	0.99	0.58	0.43	0.15
			48	425.08	80.72	2.0	688.28	413.26	0.98	0.59	0.46	0.13
			50	424.62	80.97	8.0	672.66	396.67	0.95	0.60	0.47	0.13
3 hour	6	0-5	51	423.81	80.60	80.0	483.92	250.32	0.73	0.69	0.45	0.24
			53	427.54	80.48	52.0	537.86	305.03	0.81	0.65	0.41	0.24
			55	426.55	80.54	45.0	597.20	342.80	0.90	0.61	0.46	0.16
			57	425.84	79.88	75.0	550.02	311.98	0.89	0.62	0.45	0.16
			59	427.71	81.56	38.0	629.98	363.39	0.93	0.60	0.47	0.12
3 hour	6	5-10	52	425.57	80.64	15.0	630.10	352.64	0.86	0.64	0.48	0.16
			54	423.64	80.92	3.0	689.04	427.25	1.02	0.57	0.43	0.14
			56	425.67	80.44	2.5	709.80	461.70	1.09	0.54	0.40	0.14
			58	426.79	80.71	5.0	680.76	421.77	1.00	0.58	0.42	0.15
			60	428.87	81.30	6.5	700.22	432.02	1.02	0.57	0.44	0.12
24 hour	7	0-5	61	423.78	79.99	153.0	436.09	237.60	0.88	0.62	0.44	0.18
			63	422.50	80.30	59.0	608.32	372.44	1.02	0.56	0.43	0.13
			65	429.54	80.16	13.0	686.02	419.50	1.01	0.56	0.45	0.12
			67	428.55	80.37	53.0	623.10	387.10	1.03	0.55	0.41	0.14
			69	432.16	80.99	64.0	630.76	388.58	1.06	0.54	0.44	0.11

24 hour	7	5-10	62	423.70	80.60	6.5	651.14	427.17	1.02	0.57	0.34	0.22
			64	425.63	80.07	3.0	724.00	472.87	1.12	0.53	0.40	0.12
			66	426.13	80.55	3.0	731.84	471.94	1.12	0.53	0.42	0.10
			68	425.30	80.80	13.5	738.20	509.12	1.24	0.48	0.36	0.12
			70	429.01	80.43	15.0	706.52	486.11	1.17	0.50	0.34	0.16
control	8	0-5	71	477.15	80.45	49.0	620.52	366.11	0.86	0.63	0.41	0.22
			73	425.34	80.00	13.5	626.34	360.68	0.88	0.62	0.45	0.17
			75	430.22	80.61	75.0	494.36	255.66	0.72	0.69	0.45	0.24
			77	425.62	80.99	28.0	627.46	366.47	0.92	0.60	0.45	0.15
			79	424.49	80.68	55.5	533.51	277.15	0.75	0.68	0.48	0.20
control	8	5-10	72	425.96	81.05	4.5	695.42	446.20	1.06	0.55	0.40	0.15
			74	425.96	79.89	43.0	642.14	414.72	1.08	0.54	0.39	0.16
			76	426.16	80.90	70.0	583.05	372.13	1.04	0.56	0.37	0.19
			78	422.95	80.87	9.0	667.50	411.29	0.99	0.58	0.42	0.16
			80	424.89	80.11	3.0	679.14	402.13	0.95	0.60	0.47	0.13
9 hour	9	0-5	81	425.70	81.12	61.5	550.85	302.51	0.83	0.64	0.46	0.18
			83	424.85	80.18	38.0	617.42	349.34	0.90	0.61	0.49	0.12
			85	428.19	80.51	37.5	631.28	360.88	0.92	0.60	0.49	0.11
			87	423.95	80.84	67.0	578.24	326.97	0.92	0.60	0.48	0.13
			89	424.20	80.73	134.0	440.39	231.08	0.80	0.66	0.44	0.21
9 hour	9	5-10	82	425.67	80.31	5.0	677.64	404.24	0.96	0.59	0.46	0.13
			84	426.52	80.83	4.0	642.58	413.82	0.98	0.58	0.35	0.23
			86	428.65	81.21	5.0	698.70	424.34	1.00	0.58	0.46	0.12
			88	423.59	80.66	3.5	666.64	406.89	0.97	0.59	0.43	0.16
			90	425.23	80.77	4.0	682.82	412.97	0.98	0.58	0.45	0.14
24 hour	10	0-5	91	426.12	80.27	119.0	467.79	240.11	0.78	0.66	0.48	0.18
			93	428.97	80.70	85.0	504.78	252.29	0.73	0.68	0.50	0.18
			95	425.72	80.74	33.5	601.92	326.76	0.83	0.64	0.50	0.14
			97	426.52	80.94	55.0	552.33	292.56	0.79	0.66	0.48	0.18
			99	426.55	81.30	105.5	483.02	249.94	0.78	0.66	0.47	0.19
24 hour	10	5-10	92	420.67	80.38	5.5	649.60	363.82	0.88	0.63	0.49	0.13
			94	430.71	80.92	4.5	668.66	384.59	0.90	0.62	0.48	0.14
			96	425.26	80.69	5.0	676.02	394.48	0.94	0.60	0.48	0.12
			98	428.17	80.80	5.0	662.58	373.50	0.88	0.63	0.49	0.13
			100	427.78	80.66	4.0	676.84	404.67	0.95	0.60	0.45	0.14
3 hour	11	0-5	101	426.48	80.58	61.0	567.41	302.28	0.83	0.64	0.50	0.14
			103	423.18	80.79	50.0	588.92	325.35	0.87	0.62	0.49	0.13
			105	427.75	80.18	52.5	548.26	282.74	0.75	0.67	0.49	0.18
			107	426.39	80.99	36.5	593.98	321.24	0.82	0.64	0.49	0.15
			109	425.81	81.21	83.0	488.44	241.45	0.70	0.70	0.48	0.21
3 hour	11	5-10	102	427.32	79.79	6.0	671.14	394.58	0.94	0.60	0.47	0.14
			104	425.70	80.65	6.5	665.90	388.94	0.93	0.61	0.47	0.14
			106	427.12	81.21	11.0	672.22	379.79	0.91	0.61	0.51	0.11
			108	424.48	80.90	7.0	687.82	403.44	0.97	0.59	0.49	0.10
			110	425.13	80.58	6.0	621.44	339.56	0.81	0.66	0.48	0.18
control	12	0-5	111	427.77	80.98	100.0	504.28	261.15	0.80	0.66	0.49	0.16
			113	427.53	80.79	28.0	625.32	346.43	0.87	0.62	0.50	0.13
			115	424.31	80.24	50.0	624.58	352.47	0.94	0.59	0.51	0.08
			117	426.94	80.61	52.0	565.85	296.87	0.79	0.66	0.50	0.16
			119	424.25	80.52	70.0	523.15	273.81	0.77	0.67	0.48	0.19
control	12	5-10	112	425.45	80.32	3.0	661.78	393.90	0.93	0.60	0.44	0.16
			114	428.12	80.07	2.5	697.26	404.99	0.95	0.60	0.50	0.10
			116	428.18	80.41	19.0	659.92	374.74	0.92	0.61	0.50	0.11
			118	426.55	80.21	10.0	598.44	324.61	0.78	0.67	0.46	0.20
			120	423.22	80.70	2.0	612.78	333.43	0.79	0.66	0.47	0.19

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.4 Individual Results for 81% GSM Experiment

V.4.1 Before Treading Treatment

Date sampled: 28/7/01

Treat-ment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density (Mg m^{-3})	Total porosity (cm^3 cm^{-3})	Micro-porosity (cm^3 cm^{-3})	Macro-porosity (cm^3 cm^{-3})
9 hour	1	0-5	1	424.85	81.09	18.0	571.90	297.46	0.73	0.68	0.48	0.21
			3	424.03	81.12	25.0	517.54	241.37	0.60	0.74	0.49	0.25
			5	421.60	81.00	25.0	538.04	265.53	0.67	0.71	0.48	0.23
			7	426.53	80.85	41.0	557.76	297.46	0.77	0.66	0.47	0.20
			9	425.70	80.57	38.0	582.64	313.88	0.81	0.65	0.49	0.16
9 hour	1	5-10	2	425.70	80.91	2.0	680.08	402.45	0.95	0.60	0.46	0.13
			4	424.85	81.25	3.0	691.82	417.05	0.99	0.58	0.46	0.12
			6	425.69	81.59	3.0	723.78	450.07	1.06	0.55	0.45	0.09
			8	425.71	80.97	2.0	684.72	420.93	0.99	0.58	0.43	0.15
			10	424.48	80.65	5.0	660.90	382.46	0.91	0.61	0.47	0.14
control	2	0-5	11	426.79	80.19	71.5	512.96	265.67	0.75	0.67	0.47	0.20
			13	428.20	80.72	57.5	478.02	231.30	0.62	0.73	0.45	0.28
			15	424.62	80.65	55.5	481.44	243.69	0.66	0.71	0.43	0.29
			17	423.60	80.75	17.5	533.98	273.54	0.67	0.71	0.44	0.26
			19	421.39	80.52	38.0	538.88	318.15	0.83	0.64	0.37	0.27
control	2	5-10	12	428.11	80.26	6.0	642.02	362.60	0.86	0.64	0.47	0.16
			14	423.43	80.26	2.0	646.08	365.39	0.87	0.63	0.48	0.16
			16	424.56	80.92	6.0	654.30	419.00	1.00	0.58	0.37	0.21
			18	427.78	80.37	3.0	629.46	391.66	0.92	0.61	0.37	0.24
			20	425.28	81.30	2.0	648.44	384.32	0.91	0.61	0.43	0.18
24 hour	3	0-5	21	422.33	80.32	28.0	546.32	318.85	0.81	0.65	0.37	0.27
			23	427.34	80.47	57.0	536.12	285.51	0.77	0.66	0.46	0.21
			25	424.42	80.66	25.0	648.54	375.76	0.94	0.59	0.48	0.11
			27	426.98	80.28	62.0	524.22	279.39	0.77	0.67	0.45	0.22
			29	421.00	81.33	38.0	542.24	279.49	0.73	0.68	0.47	0.21
24 hour	3	5-10	22	425.70	80.63	15.0	641.86	379.72	0.92	0.61	0.44	0.17
			24	424.87	80.79	1.0	681.82	444.52	1.05	0.55	0.37	0.19
			26	423.81	81.34	1.0	687.98	420.70	1.00	0.58	0.44	0.14
			28	426.38	80.60	2.5	668.06	394.43	0.93	0.60	0.46	0.15
			30	425.14	80.56	23.0	621.88	374.57	0.93	0.60	0.41	0.19
control	4	0-5	31	432.17	81.65	69.0	477.60	223.01	0.61	0.73	0.48	0.26
			33	425.84	80.43	65.0	488.90	249.98	0.69	0.70	0.44	0.26
			35	427.45	81.13	24.0	644.16	359.91	0.89	0.61	0.50	0.11
			37	422.80	80.98	73.0	504.66	280.15	0.80	0.65	0.41	0.24
			39	425.65	80.22	21.0	549.74	272.90	0.67	0.71	0.49	0.22
control	4	5-10	32	424.22	81.06	1.0	682.62	406.70	0.96	0.59	0.46	0.13
			34	427.71	80.66	9.0	659.16	391.88	0.94	0.60	0.45	0.16
			36	426.15	80.69	5.0	681.56	406.70	0.97	0.59	0.46	0.13
			38	424.98	80.35	32.0	624.50	363.23	0.92	0.61	0.46	0.15
			40	424.78	80.86	1.0	671.18	385.21	0.91	0.61	0.48	0.13
24 hour	5	0-5	41	425.73	79.89	52.0	548.08	289.03	0.77	0.66	0.48	0.18
			43	424.55	80.34	50.0	544.32	296.50	0.79	0.66	0.45	0.21
			45	427.97	80.54	71.0	422.58	187.06	0.52	0.77	0.43	0.34
			47	426.51	80.26	29.0	612.30	351.70	0.88	0.62	0.45	0.16
			49	425.20	81.17	3.0	641.66	371.27	0.88	0.62	0.45	0.17
24 hour	5	5-10	42	429.22	80.70	7.0	669.48	404.57	0.96	0.59	0.44	0.16
			44	426.55	80.00	7.0	681.92	425.89	1.02	0.57	0.42	0.15
			46	424.73	80.07	7.0	710.44	452.41	1.08	0.54	0.43	0.11
			48	425.08	80.72	9.0	647.56	399.42	0.96	0.59	0.40	0.19
			50	424.62	80.97	2.0	631.64	367.68	0.87	0.63	0.43	0.20
9 hour	6	0-5	51	423.81	80.60	67.0	510.24	251.69	0.71	0.69	0.50	0.19
			53	427.54	80.48	45.0	492.64	234.31	0.61	0.73	0.46	0.27
			55	426.55	80.54	117.5	398.67	173.48	0.56	0.76	0.47	0.29
			57	425.84	79.88	74.0	535.76	283.76	0.81	0.65	0.49	0.16
			59	427.71	81.56	48.0	585.16	323.18	0.85	0.63	0.48	0.15
9 hour	6	5-10	52	425.57	80.64	3.0	683.06	411.76	0.97	0.59	0.45	0.14
			54	423.64	80.92	3.0	678.76	414.75	0.99	0.58	0.44	0.15
			56	425.67	80.44	4.0	688.24	411.58	0.98	0.59	0.47	0.12
			58	426.79	80.71	2.0	706.66	446.85	1.05	0.55	0.42	0.13
			60	428.87	81.30	2.0	686.70	426.90	1.00	0.58	0.42	0.16

3 hour	7	0-5	61	423.78	79.99	66.0	529.94	270.89	0.76	0.67	0.50	0.17
			63	422.50	80.30	61.5	491.44	223.28	0.62	0.73	0.52	0.21
			65	429.54	80.16	53.0	520.42	253.00	0.67	0.71	0.50	0.21
			67	428.55	80.37	38.0	526.84	253.77	0.65	0.72	0.49	0.22
			69	432.16	80.99	30.0	595.26	311.28	0.77	0.66	0.50	0.16
3 hour	7	5-10	62	423.70	80.60	1.0	660.04	382.03	0.90	0.62	0.47	0.15
			64	425.63	80.07	1.0	634.92	383.05	0.90	0.62	0.40	0.21
			66	426.13	80.55	3.0	661.68	385.95	0.91	0.61	0.46	0.15
			68	425.30	80.80	1.5	646.02	373.23	0.88	0.63	0.45	0.17
			70	429.01	80.43	0.5	659.76	381.93	0.89	0.62	0.46	0.16
control	8	0-5	71	477.15	80.45	38.0	543.64	278.86	0.64	0.72	0.42	0.30
			73	425.34	80.00	48.0	555.06	291.67	0.77	0.66	0.49	0.18
			75	430.22	80.61	10.0	547.38	248.42	0.59	0.74	0.52	0.22
			77	425.62	80.99	45.0	599.70	356.23	0.94	0.59	0.43	0.17
			79	424.49	80.68	32.0	566.00	306.94	0.78	0.66	0.45	0.21
control	8	5-10	72	425.96	81.05	7.0	657.54	408.54	0.98	0.59	0.40	0.19
			74	425.96	79.89	8.0	652.60	389.76	0.93	0.60	0.44	0.17
			76	426.16	80.90	7.0	695.16	439.15	1.05	0.56	0.42	0.14
			78	422.95	80.87	2.0	687.76	416.31	0.99	0.58	0.45	0.13
			80	424.89	80.11	3.0	683.40	422.59	1.00	0.57	0.43	0.15
9 hour	9	0-5	81	425.67	80.31	38.0	564.54	302.20	0.78	0.66	0.47	0.19
			83	424.85	80.18	53.0	517.12	254.71	0.68	0.70	0.49	0.21
			85	428.19	80.51	38.0	587.90	348.40	0.89	0.61	0.41	0.20
			87	423.95	80.84	47.0	496.96	224.86	0.60	0.74	0.51	0.23
			89	424.20	80.73	89.0	494.68	272.55	0.81	0.65	0.42	0.22
9 hour	9	5-10	82	425.70	81.12	3.0	670.00	447.48	1.06	0.55	0.33	0.22
			84	426.52	80.83	0.5	681.14	415.54	0.98	0.59	0.43	0.15
			86	428.65	81.21	2.0	683.16	423.70	0.99	0.58	0.42	0.16
			88	423.59	80.66	3.0	661.78	398.97	0.95	0.60	0.43	0.16
			90	425.23	80.77	6.0	684.22	416.63	0.99	0.58	0.45	0.13
3 hour	10	0-5	91	426.12	80.27	46.0	493.24	232.64	0.61	0.73	0.47	0.26
			93	428.97	80.70	42.0	543.28	288.29	0.75	0.68	0.45	0.23
			95	425.72	80.74	57.0	498.50	240.98	0.65	0.72	0.48	0.24
			97	426.52	80.94	9.0	621.06	336.76	0.81	0.65	0.49	0.16
			99	426.55	81.30	45.0	568.30	308.13	0.81	0.65	0.47	0.18
3 hour	10	5-10	92	420.67	80.38	1.0	673.20	416.11	0.99	0.58	0.42	0.16
			94	430.71	80.92	15.0	622.48	355.93	0.86	0.64	0.45	0.19
			96	425.26	80.69	3.0	657.70	408.32	0.97	0.59	0.40	0.19
			98	428.17	80.80	4.0	682.62	401.50	0.95	0.60	0.47	0.13
			100	427.78	80.66	2.0	675.16	417.35	0.98	0.58	0.42	0.17
24 hour	11	0-5	101	426.48	80.58	38.5	595.52	329.06	0.85	0.63	0.48	0.15
			103	423.18	80.79	15.0	585.96	327.04	0.80	0.65	0.44	0.21
			105	427.75	80.18	9.0	594.34	309.49	0.74	0.68	0.49	0.19
			107	426.39	80.99	38.5	491.48	220.43	0.57	0.75	0.49	0.26
			109	425.81	81.21	58.0	524.06	269.51	0.73	0.68	0.47	0.21
24 hour	11	5-10	102	427.32	79.79	3.0	674.90	404.40	0.95	0.60	0.45	0.15
			104	425.70	80.65	2.0	628.14	351.76	0.83	0.65	0.46	0.19
			106	427.12	81.21	4.5	670.16	392.40	0.93	0.61	0.47	0.14
			108	424.48	80.90	2.0	639.78	366.09	0.87	0.63	0.46	0.18
			110	425.13	80.58	4.0	651.38	377.54	0.90	0.62	0.46	0.16
3 hour	12	0-5	111	427.77	80.98	67.0	467.92	211.53	0.59	0.74	0.49	0.26
			113	427.53	80.79	5.0	621.02	359.80	0.85	0.63	0.43	0.20
			115	424.31	80.24	8.0	620.90	352.93	0.85	0.63	0.45	0.18
			117	426.94	80.61	13.0	580.96	323.09	0.78	0.66	0.43	0.23
			119	424.25	80.52	41.0	567.28	312.88	0.82	0.64	0.45	0.19
3 hour	12	5-10	112	425.45	80.32	2.0	657.00	403.38	0.95	0.60	0.41	0.19
			114	428.12	80.07	5.0	656.24	378.89	0.90	0.62	0.47	0.15
			116	428.18	80.41	3.0	647.54	375.57	0.88	0.62	0.45	0.17
			118	426.55	80.21	4.0	651.68	360.27	0.85	0.64	0.50	0.14
			120	423.22	80.70	15.0	645.78	382.45	0.94	0.60	0.45	0.15

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.4.2 After Treading Treatment (1-week)

Date sampled: 9/8/01

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
9 hour	1	0-5	121	422.69	79.74	60.0	519.64	237.07	0.65	0.72	0.56	0.16
			123	426.73	81.49	74.0	520.52	216.86	0.61	0.73	0.63	0.10
			125	425.31	80.70	16.0	623.14	308.68	0.75	0.67	0.57	0.10
			127	426.52	80.12	57.0	541.82	237.96	0.64	0.72	0.61	0.11
			129	426.52	80.59	56.0	556.16	255.57	0.69	0.70	0.59	0.11
9 hour	1	5-10	122	426.85	80.56	3.0	683.18	407.28	0.96	0.59	0.46	0.13
			124	424.22	80.04	7.0	676.94	373.30	0.89	0.62	0.54	0.08
			126	426.52	80.64	14.0	681.42	419.05	1.02	0.57	0.44	0.13
			128	423.19	80.25	4.0	666.88	395.80	0.94	0.60	0.46	0.14
			130	428.17	80.46	1.0	686.76	414.99	0.97	0.59	0.45	0.14
control	2	0-5	131	428.17	80.59	14.0	606.82	321.05	0.78	0.66	0.50	0.17
			133	428.58	81.03	88.0	440.68	190.93	0.56	0.76	0.50	0.26
			135	428.19	80.38	57.0	546.60	288.18	0.78	0.66	0.48	0.18
			137	425.85	80.24	39.0	571.26	304.14	0.79	0.66	0.48	0.17
			139	426.44	80.44	19.0	597.04	318.48	0.78	0.66	0.49	0.17
control	2	5-10	132	425.67	81.09	3.0	649.68	358.93	0.85	0.64	0.50	0.14
			134	424.03	81.12	8.0	627.86	397.71	0.96	0.59	0.36	0.24
			136	430.64	80.68	6.0	661.54	376.71	0.89	0.62	0.48	0.14
			138	424.34	80.18	1.0	644.70	353.33	0.83	0.65	0.50	0.15
			140	425.80	81.00	0.5	678.64	405.40	0.95	0.60	0.45	0.14
24 hour	3	0-5	141	428.59	80.60	113.0	488.36	209.42	0.66	0.71	0.63	0.08
			143	424.98	80.93	41.0	586.76	240.21	0.63	0.73	0.69	0.04
			145	426.88	80.60	59.0	588.12	300.90	0.82	0.64	0.56	0.08
			147	424.88	81.04	10.0	594.60	270.92	0.65	0.72	0.58	0.13
			149	426.50	80.55	87.0	534.46	257.01	0.76	0.67	0.58	0.09
24 hour	3	5-10	142	424.81	80.27	4.0	693.92	413.11	0.98	0.58	0.48	0.11
			144	426.61	80.42	8.0	649.64	378.22	0.90	0.62	0.46	0.16
			146	425.65	80.56	4.0	665.74	381.78	0.91	0.62	0.48	0.13
			148	425.67	80.67	28.0	600.06	324.61	0.82	0.65	0.49	0.16
			150	425.70	80.84	4.5	634.94	361.35	0.86	0.64	0.46	0.18
control	4	0-5	151	427.62	80.24	59.5	523.06	262.82	0.71	0.69	0.49	0.20
			153	427.36	80.86	54.0	472.32	221.26	0.59	0.74	0.46	0.29
			155	425.42	80.58	14.5	625.56	343.84	0.84	0.64	0.49	0.15
			157	425.70	80.00	50.0	524.68	274.65	0.73	0.68	0.45	0.23
			159	424.06	80.86	60.0	518.44	262.52	0.72	0.69	0.48	0.21
control	4	5-10	152	428.56	80.36	6.0	678.48	410.74	0.97	0.59	0.44	0.14
			154	428.03	80.38	2.0	667.44	385.67	0.91	0.62	0.47	0.14
			156	422.38	80.40	3.0	643.32	372.28	0.89	0.62	0.45	0.17
			158	424.03	80.47	13.0	648.70	377.32	0.92	0.61	0.46	0.15
			160	428.19	80.62	1.0	637.56	360.43	0.84	0.64	0.46	0.18
24 hour	5	0-5	161	423.24	80.47	139.0	433.45	160.60	0.57	0.75	0.68	0.08
			163	427.96	80.28	109.5	499.68	235.00	0.74	0.68	0.58	0.10
			165	426.80	80.46	77.0	524.14	239.96	0.69	0.70	0.58	0.12
			167	429.35	80.06	30.0	583.02	284.38	0.71	0.69	0.55	0.14
			169	427.53	80.00	90.0	498.42	232.13	0.69	0.70	0.55	0.15
24 hour	5	5-10	162	425.31	80.19	19.5	692.06	432.42	1.07	0.55	0.44	0.11
			164	425.55	81.04	3.0	675.76	411.35	0.97	0.59	0.43	0.15
			166	425.32	79.78	3.5	684.74	398.95	0.95	0.60	0.49	0.11
			168	426.24	81.92	4.0	690.90	408.13	0.97	0.59	0.48	0.11
			170	425.12	80.85	2.0	689.56	402.43	0.95	0.60	0.49	0.11
9 hour	6	0-5	171	426.60	80.40	58.0	568.26	310.21	0.84	0.63	0.48	0.15
			173	425.46	80.76	139.0	425.34	186.21	0.65	0.72	0.55	0.16
			175	424.98	80.60	5.0	671.22	396.88	0.95	0.59	0.46	0.13
			177	430.11	80.52	41.0	587.40	320.55	0.82	0.64	0.48	0.16
			179	426.84	80.57	75.0	527.74	252.40	0.72	0.69	0.55	0.13
9 hour	6	5-10	172	425.62	80.83	1.0	691.52	417.42	0.98	0.58	0.46	0.13
			174	424.57	80.45	2.0	652.18	340.29	0.81	0.66	0.55	0.11
			176	425.80	80.59	78.0	492.64	244.38	0.70	0.70	0.48	0.22
			178	427.28	80.26	4.0	684.48	413.29	0.98	0.59	0.45	0.13
			180	426.50	80.43	1.5	664.58	381.75	0.90	0.62	0.48	0.14
3 hour	7	0-5	181	422.19	80.17	129.0	432.72	168.86	0.58	0.75	0.63	0.12
			183	427.72	80.13	25.0	596.64	282.07	0.70	0.70	0.58	0.11
			185	429.46	80.05	37.0	587.94	278.19	0.71	0.69	0.59	0.11
			187	423.57	80.72	35.0	581.44	295.90	0.76	0.67	0.53	0.14
			189	427.86	80.38	10.0	626.36	313.59	0.75	0.67	0.56	0.12

3 hour	7	5-10	182	425.96	80.60	3.0	687.62	410.91	0.97	0.59	0.46	0.12
			184	426.05	80.63	6.0	641.86	363.74	0.87	0.63	0.47	0.16
			186	423.58	80.30	1.5	676.08	398.84	0.94	0.60	0.47	0.13
			188	426.10	80.81	4.0	637.36	354.04	0.84	0.64	0.48	0.16
			190	426.75	80.92	4.0	644.26	365.16	0.86	0.63	0.47	0.16
control	8	0-5	201	420.48	85.45	52.0	580.66	328.46	0.89	0.61	0.45	0.16
			203	425.65	84.80	18.0	553.84	266.84	0.65	0.72	0.50	0.22
			206	424.70	87.27	25.0	596.62	314.82	0.79	0.66	0.49	0.17
			207	430.95	84.85	14.0	577.06	300.87	0.72	0.69	0.46	0.23
			209	423.99	84.31	38.0	571.80	292.76	0.76	0.67	0.50	0.17
control	8	5-10	202	422.75	85.04	3.0	687.94	422.76	1.01	0.57	0.43	0.14
			204	424.86	86.48	3.5	694.50	425.96	1.01	0.57	0.43	0.14
			205	422.66	84.71	0.5	662.40	391.98	0.93	0.61	0.44	0.17
			208	421.39	85.09	5.0	642.98	379.05	0.91	0.61	0.43	0.18
			210	423.33	84.24	12.0	679.70	407.50	0.99	0.58	0.46	0.12
9 hour	9	0-5	211	423.40	83.44	5.0	620.56	290.86	0.70	0.70	0.59	0.11
			213	422.69	85.06	66.0	541.34	217.30	0.61	0.73	0.67	0.06
			215	424.68	84.54	49.0	598.52	280.05	0.75	0.68	0.62	0.05
			217	424.85	84.67	23.0	599.58	294.46	0.73	0.68	0.55	0.13
			219	426.76	83.91	50.0	598.98	310.87	0.83	0.64	0.54	0.10
9 hour	9	5-10	212	421.19	84.80	2.0	662.94	390.07	0.93	0.60	0.45	0.16
			214	419.81	84.43	2.0	667.90	371.77	0.89	0.62	0.51	0.12
			216	425.75	84.34	2.0	694.42	407.16	0.96	0.59	0.48	0.11
			218	422.38	83.97	4.0	669.04	379.33	0.91	0.62	0.49	0.12
			220	420.87	85.28	3.0	716.22	438.30	1.05	0.55	0.46	0.09
3 hour	10	0-5	221	425.02	85.68	60.5	529.60	266.02	0.73	0.68	0.49	0.19
			223	424.86	87.20	52.0	541.70	272.82	0.73	0.68	0.49	0.19
			225	425.92	84.18	42.0	513.34	251.53	0.66	0.71	0.46	0.25
			227	421.90	83.95	67.0	513.54	243.69	0.69	0.70	0.52	0.18
			230	426.43	84.30	39.0	556.34	276.03	0.71	0.69	0.51	0.18
3 hour	10	5-10	222	420.68	85.19	4.0	656.60	384.99	0.92	0.61	0.45	0.16
			224	425.35	84.64	0.5	673.24	379.67	0.89	0.62	0.49	0.13
			226	427.24	83.14	2.0	693.94	405.97	0.95	0.59	0.48	0.11
			228	425.18	84.74	4.0	666.10	380.66	0.90	0.62	0.48	0.14
			229	426.41	84.92	3.0	653.96	370.44	0.87	0.63	0.47	0.16
24 hour	11	0-5	231	424.34	84.82	43.0	589.44	293.90	0.77	0.66	0.55	0.11
			233	419.81	84.30	69.0	560.40	248.02	0.71	0.69	0.65	0.04
			235	419.55	85.14	51.0	626.42	351.73	0.95	0.58	0.51	0.07
			237	421.54	83.91	72.0	529.66	240.99	0.69	0.70	0.59	0.11
			239	422.29	85.06	12.0	613.00	265.91	0.65	0.72	0.64	0.08
24 hour	11	5-10	232	423.17	84.53	4.0	692.86	411.90	0.98	0.58	0.47	0.11
			234	428.03	85.17	4.0	634.58	345.03	0.81	0.65	0.48	0.17
			236	426.84	85.51	1.0	693.36	397.88	0.93	0.60	0.49	0.11
			238	420.77	85.19	2.0	650.46	360.23	0.86	0.63	0.49	0.15
			240	422.44	84.84	18.0	638.80	353.18	0.87	0.63	0.50	0.13
3 hour	12	0-5	241	425.73	83.52	30.0	607.30	332.39	0.84	0.63	0.48	0.15
			243	423.10	84.59	13.0	627.26	326.86	0.80	0.65	0.53	0.13
			245	422.51	85.63	10.0	576.86	292.64	0.71	0.69	0.48	0.21
			247	424.37	86.04	31.5	570.86	288.64	0.73	0.68	0.50	0.18
			249	426.75	83.91	38.0	614.76	331.53	0.85	0.63	0.51	0.12
3 hour	12	5-10	242	421.38	85.02	3.0	660.44	376.03	0.90	0.62	0.48	0.14
			244	426.26	83.82	3.0	642.66	357.76	0.85	0.64	0.48	0.17
			246	423.34	84.72	2.0	655.30	364.86	0.87	0.63	0.49	0.14
			248	419.31	84.77	2.0	634.14	347.09	0.83	0.65	0.48	0.16
			250	422.43	84.81	9.0	631.66	339.60	0.82	0.65	0.50	0.15

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.4.3 After Treading Treatment (4-weeks)

Date sampled: 6/9/01

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density (Mg m^{-3})	Total porosity (cm^3 cm^{-3})	Micro-porosity (cm^3 cm^{-3})	Macro-porosity (cm^3 cm^{-3})
9 hour	1	0-5	1	424.85	81.09	128.0	457.84	176.06	0.59	0.74	0.68	0.07
			3	424.03	81.12	5.0	690.98	400.71	0.96	0.58	0.50	0.08
			5	421.60	81.00	71.0	487.68	236.28	0.67	0.71	0.49	0.22
			7	426.53	80.85	40.0	539.60	239.92	0.62	0.73	0.57	0.16
			9	425.70	80.57	75.0	535.46	279.92	0.80	0.65	0.50	0.15
9 hour	1	5-10	2	425.70	80.91	6.0	681.64	391.77	0.93	0.60	0.50	0.11
			4	424.85	81.25	75.0	427.84	189.72	0.54	0.77	0.45	0.32
			6	425.69	81.59	3.0	699.96	428.87	1.01	0.57	0.45	0.12
			8	425.71	80.97	5.0	686.20	421.29	1.00	0.57	0.44	0.14
			10	424.48	80.65	6.0	686.60	415.50	0.99	0.58	0.46	0.12
control	2	0-5	11	426.79	80.19	21.0	575.32	294.87	0.73	0.68	0.49	0.19
			13	428.20	80.72	6.0	606.54	319.92	0.76	0.67	0.49	0.18
			15	424.62	80.65	36.0	580.64	314.48	0.81	0.65	0.48	0.17
			17	423.60	80.75	54.0	534.08	278.70	0.75	0.67	0.47	0.20
			19	421.39	80.52	36.0	526.42	259.11	0.67	0.71	0.48	0.22
control	2	5-10	12	428.11	80.26	11.0	635.38	355.58	0.85	0.64	0.48	0.16
			14	423.43	80.26	9.0	620.38	339.66	0.82	0.65	0.48	0.17
			16	424.56	80.92	9.0	686.18	408.42	0.98	0.58	0.47	0.11
			18	427.78	80.37	12.0	675.74	400.70	0.96	0.59	0.47	0.12
			20	425.28	81.30	3.0	676.08	406.76	0.96	0.59	0.45	0.15
24 hour	3	0-5	21	422.33	80.32	80.0	498.92	222.30	0.65	0.72	0.57	0.14
			23	427.34	80.47	121.0	482.40	202.16	0.66	0.71	0.65	0.06
			25	424.42	80.66	40.0	543.62	262.66	0.68	0.70	0.52	0.18
			27	426.98	80.28	91.5	515.54	257.91	0.77	0.67	0.53	0.14
			29	421.00	81.33	143.0	435.62	175.45	0.63	0.73	0.64	0.08
24 hour	3	5-10	22	425.70	80.63	3.0	689.38	405.78	0.96	0.59	0.48	0.11
			24	424.87	80.79	4.0	710.06	423.20	1.01	0.57	0.49	0.08
			26	423.81	81.34	7.0	650.38	352.57	0.85	0.64	0.52	0.12
			28	426.38	80.60	3.0	674.82	374.42	0.88	0.62	0.52	0.11
			30	425.14	80.56	5.0	680.78	396.10	0.94	0.60	0.49	0.11
control	4	0-5	31	432.17	81.65	56.0	501.02	248.92	0.66	0.71	0.45	0.26
			33	425.84	80.43	17.0	543.26	272.54	0.67	0.71	0.47	0.24
			35	427.45	81.13	34.0	579.40	303.59	0.77	0.66	0.49	0.17
			37	422.80	80.98	30.0	595.34	331.27	0.84	0.63	0.47	0.17
			39	425.65	80.22	38.0	543.40	276.54	0.71	0.69	0.48	0.21
control	4	5-10	32	424.22	81.06	10.0	657.74	391.30	0.94	0.60	0.45	0.15
			34	427.71	80.66	5.0	670.88	402.30	0.95	0.60	0.44	0.15
			36	426.15	80.69	1.0	697.00	412.62	0.97	0.59	0.48	0.11
			38	424.98	80.35	7.0	679.14	397.77	0.95	0.60	0.48	0.12
			40	424.78	80.86	2.0	657.50	378.74	0.90	0.62	0.47	0.15
24 hour	5	0-5	41	425.73	79.89	220.0	334.77	144.89	0.70	0.69	0.53	0.16
			43	424.55	80.34	122.0	449.88	193.69	0.64	0.72	0.58	0.14
			45	427.97	80.54	177.0	396.87	174.98	0.70	0.70	0.56	0.13
			47	426.51	80.26	136.0	447.82	196.77	0.68	0.71	0.59	0.12
			49	425.20	81.17	121.0	469.36	231.19	0.76	0.67	0.52	0.15
24 hour	5	5-10	42	429.22	80.70	14.0	696.72	430.87	1.04	0.56	0.45	0.11
			44	426.55	80.00	10.0	652.74	366.80	0.88	0.63	0.49	0.13
			46	424.73	80.07	3.0	715.94	446.27	1.06	0.55	0.45	0.10
			48	425.08	80.72	4.0	699.38	403.32	0.96	0.59	0.51	0.08
			50	424.62	80.97	4.0	676.32	376.95	0.90	0.62	0.52	0.10
9 hour	6	0-5	51	423.81	80.60	171.0	347.99	152.00	0.60	0.74	0.46	0.28
			53	427.54	80.48	102.0	469.00	232.27	0.71	0.69	0.48	0.21
			55	426.55	80.54	53.0	531.90	265.21	0.71	0.69	0.50	0.19
			57	425.84	79.88	67.0	525.76	273.29	0.76	0.67	0.48	0.19
			59	427.71	81.56	68.0	489.20	237.10	0.66	0.71	0.47	0.24
9 hour	6	5-10	52	425.57	80.64	2.0	690.64	412.64	0.97	0.59	0.47	0.12
			54	423.64	80.92	2.0	681.74	407.33	0.97	0.59	0.46	0.13
			56	425.67	80.44	4.0	686.34	410.00	0.97	0.59	0.46	0.12
			58	426.79	80.71	8.0	672.10	399.03	0.95	0.60	0.46	0.14
			60	428.87	81.30	6.0	679.34	403.98	0.96	0.59	0.46	0.14
3 hour	7	0-5	61	423.78	79.99	100.0	480.92	229.55	0.71	0.69	0.53	0.16
			63	422.50	80.30	65.0	526.76	220.69	0.62	0.73	0.63	0.10
			65	429.54	80.16	56.0	543.44	248.20	0.66	0.71	0.58	0.14
			67	428.55	80.37	63.0	516.12	240.01	0.66	0.71	0.54	0.18
			69	432.16	80.99	24.0	568.10	245.69	0.60	0.74	0.59	0.15

3 hour	7	5-10	62	423.70	80.60	2.0	673.78	400.00	0.95	0.60	0.46	0.14
			64	425.63	80.07	3.0	654.78	365.89	0.87	0.63	0.49	0.14
			66	426.13	80.55	2.0	657.02	378.88	0.89	0.62	0.47	0.15
			68	425.30	80.80	3.0	669.16	374.64	0.89	0.62	0.51	0.12
			70	429.01	80.43	6.0	652.72	376.03	0.89	0.62	0.46	0.16
control	8	0-5	71	477.15	80.45	67.0	564.64	317.48	0.77	0.66	0.41	0.26
			73	425.34	80.00	59.0	522.26	276.86	0.76	0.67	0.45	0.22
			75	430.22	80.61	48.0	558.24	298.76	0.78	0.66	0.47	0.19
			77	425.62	80.99	55.0	561.24	304.15	0.82	0.64	0.48	0.17
			79	424.49	80.68	50.0	571.24	310.71	0.83	0.64	0.48	0.16
control	8	5-10	72	425.96	81.05	3.0	714.60	431.50	1.02	0.57	0.48	0.09
			74	425.96	79.89	7.0	680.56	412.30	0.98	0.58	0.45	0.13
			76	426.16	80.90	2.0	696.50	432.11	1.02	0.57	0.43	0.13
			78	422.95	80.87	6.0	669.00	396.49	0.95	0.60	0.46	0.14
			80	424.89	80.11	5.0	694.74	426.69	1.02	0.57	0.45	0.12
9 hour	9	0-5	81	425.70	81.12	77.0	493.00	232.66	0.67	0.71	0.51	0.20
			83	424.85	80.18	59.0	550.04	297.72	0.81	0.65	0.47	0.18
			85	428.19	80.51	55.0	507.24	253.57	0.68	0.70	0.46	0.24
			87	423.95	80.84	89.0	494.04	199.79	0.60	0.74	0.64	0.10
			89	424.20	80.73	72.0	513.80	268.13	0.76	0.67	0.47	0.20
9 hour	9	5-10	82	425.67	80.31	5.0	695.92	415.60	0.99	0.58	0.48	0.11
			84	426.52	80.83	7.0	661.60	373.43	0.89	0.62	0.49	0.13
			86	428.65	81.21	5.0	668.70	390.00	0.92	0.61	0.47	0.14
			88	423.59	80.66	2.0	683.70	391.19	0.93	0.61	0.50	0.10
			90	425.23	80.77	2.0	699.48	410.91	0.97	0.59	0.49	0.10
3 hour	10	0-5	91	426.12	80.27	37.0	502.50	242.65	0.62	0.73	0.46	0.27
			93	428.97	80.70	77.0	421.18	175.38	0.50	0.78	0.47	0.31
			95	425.72	80.74	50.0	508.40	254.37	0.68	0.71	0.46	0.24
			97	426.52	80.94	42.0	536.26	279.18	0.73	0.68	0.46	0.23
			99	426.55	81.30	57.0	528.56	259.00	0.70	0.70	0.51	0.19
3 hour	10	5-10	92	420.67	80.38	10.0	657.54	392.07	0.95	0.59	0.45	0.14
			94	430.71	80.92	9.0	691.82	415.72	0.99	0.58	0.46	0.12
			96	425.26	80.69	4.0	689.48	409.46	0.97	0.59	0.47	0.11
			98	428.17	80.80	2.0	670.84	376.06	0.88	0.63	0.50	0.12
			100	427.78	80.66	3.0	626.52	361.52	0.85	0.64	0.43	0.20
24 hour	11	0-5	101	426.48	80.58	42.0	558.50	266.04	0.69	0.70	0.55	0.15
			103	423.18	80.79	29.0	544.54	221.75	0.56	0.76	0.61	0.14
			105	427.75	80.18	118.0	483.24	211.72	0.68	0.70	0.62	0.08
			107	426.39	80.99	11.0	584.24	289.88	0.70	0.70	0.51	0.18
			109	425.81	81.21	23.0	543.78	261.07	0.65	0.72	0.50	0.22
24 hour	11	5-10	102	427.32	79.79	8.0	667.36	394.48	0.94	0.60	0.46	0.14
			104	425.70	80.65	13.0	644.32	353.19	0.86	0.64	0.51	0.13
			106	427.12	81.21	13.0	695.60	421.34	1.02	0.57	0.47	0.10
			108	424.48	80.90	3.0	678.60	366.70	0.87	0.63	0.55	0.08
			110	425.13	80.58	13.0	639.88	358.67	0.87	0.63	0.49	0.14
3 hour	12	0-5	111	427.77	80.98	43.0	490.68	230.50	0.60	0.74	0.47	0.27
			113	427.53	80.79	40.0	544.62	279.93	0.72	0.69	0.47	0.21
			115	424.31	80.24	48.0	589.32	319.56	0.85	0.63	0.50	0.13
			117	426.94	80.61	45.0	579.56	306.50	0.80	0.65	0.50	0.15
			119	424.25	80.52	55.0	506.54	243.28	0.66	0.71	0.49	0.22
3 hour	12	5-10	112	425.45	80.32	4.0	670.96	387.24	0.92	0.61	0.48	0.13
			114	428.12	80.07	17.0	640.12	367.20	0.89	0.62	0.47	0.15
			116	428.18	80.41	10.0	627.44	355.94	0.85	0.64	0.46	0.18
			118	426.55	80.21	2.0	639.60	357.62	0.84	0.64	0.48	0.17
			120	423.22	80.70	4.0	637.18	361.21	0.86	0.63	0.47	0.17

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.4.4 After Treading Treatment (13-weeks)

Date sampled: 9/11/01

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
9 hour	1	0-5	2	425.70	80.91	16.0	628.16	351.91	0.86	0.63	0.48	0.15
			3	424.03	81.12	6.0	666.10	393.41	0.94	0.59	0.46	0.13
			6	425.69	81.59	8.0	627.80	344.71	0.83	0.64	0.48	0.16
			7	426.53	80.85	8.0	574.72	297.91	0.71	0.69	0.47	0.22
			9	425.70	80.57	36.0	500.90	251.50	0.65	0.72	0.43	0.29
9 hour	1	5-10	1	424.85	81.09	5.0	678.14	424.64	1.01	0.57	0.41	0.16
			4	424.85	81.25	3.0	694.68	431.51	1.02	0.57	0.43	0.13
			5	421.60	81.00	4.0	711.72	460.63	1.10	0.53	0.41	0.12
			8	425.71	80.97	6.0	709.52	448.11	1.07	0.55	0.43	0.12
			10	424.48	80.65	2.0	692.54	438.50	1.04	0.56	0.41	0.15
control	2	0-5	11	426.79	80.19	9.0	599.88	313.02	0.75	0.67	0.49	0.18
			13	428.20	80.72	13.0	508.86	244.94	0.59	0.74	0.44	0.30
			15	424.62	80.65	3.0	628.86	332.16	0.79	0.66	0.51	0.14
			17	423.60	80.75	7.0	631.80	345.31	0.83	0.64	0.49	0.15
			19	421.39	80.52	43.0	495.06	237.29	0.63	0.73	0.47	0.26
control	2	5-10	12	428.11	80.26	2.0	646.10	362.53	0.85	0.64	0.48	0.16
			14	423.43	80.26	7.0	646.86	365.30	0.88	0.63	0.48	0.14
			16	424.56	80.92	3.0	649.04	370.69	0.88	0.63	0.47	0.16
			18	427.78	80.37	2.0	676.28	409.90	0.96	0.59	0.44	0.15
			20	425.28	81.30	9.0	682.58	415.58	1.00	0.58	0.45	0.13
24 hour	3	0-5	21	422.33	80.32	17.0	630.92	362.67	0.89	0.61	0.46	0.15
			23	427.34	80.47	38.0	565.38	301.05	0.77	0.66	0.47	0.19
			25	424.42	80.66	20.0	630.36	339.85	0.84	0.63	0.52	0.12
			27	426.98	80.28	4.0	682.16	397.50	0.94	0.59	0.48	0.11
			29	421.00	81.33	16.0	640.16	361.35	0.89	0.61	0.49	0.12
24 hour	3	5-10	22	425.70	80.63	13.0	659.18	390.88	0.95	0.60	0.45	0.14
			24	424.87	80.79	5.0	666.52	400.18	0.95	0.60	0.44	0.15
			26	423.81	81.34	4.0	671.24	398.06	0.95	0.60	0.46	0.14
			28	426.38	80.60	3.0	680.70	407.29	0.96	0.59	0.46	0.14
			30	425.14	80.56	22.0	645.98	379.81	0.94	0.60	0.46	0.14
control	4	0-5	31	432.17	81.65	61.0	530.00	265.76	0.72	0.69	0.49	0.20
			33	425.84	80.43	19.0	607.66	331.14	0.81	0.65	0.48	0.16
			35	427.45	81.13	19.0	621.58	350.81	0.86	0.63	0.46	0.16
			37	422.80	80.98	13.0	642.46	364.16	0.89	0.61	0.48	0.13
			39	425.65	80.22	22.0	585.24	307.33	0.76	0.67	0.49	0.18
control	4	5-10	32	424.22	81.06	2.0	686.26	403.76	0.96	0.59	0.48	0.12
			34	427.71	80.66	8.0	646.58	373.56	0.89	0.62	0.46	0.16
			36	426.15	80.69	4.0	608.84	336.56	0.80	0.66	0.45	0.21
			38	424.98	80.35	2.0	684.50	406.13	0.96	0.59	0.47	0.12
			40	424.78	80.86	4.0	642.06	375.02	0.89	0.62	0.44	0.18
24 hour	5	0-5	41	425.73	79.89	14.0	602.84	331.20	0.80	0.65	0.47	0.18
			43	424.55	80.34	18.0	563.30	288.85	0.71	0.69	0.48	0.21
			45	427.97	80.54	8.0	666.10	388.83	0.93	0.60	0.47	0.13
			47	426.51	80.26	63.0	580.72	319.02	0.88	0.62	0.50	0.12
			49	425.20	81.17	4.0	610.74	330.59	0.78	0.66	0.47	0.19
24 hour	5	5-10	42	429.22	80.70	5.0	709.78	449.87	1.06	0.55	0.42	0.13
			44	426.55	80.00	4.0	709.36	435.51	1.03	0.56	0.46	0.10
			46	424.73	80.07	5.0	672.50	401.73	0.96	0.59	0.45	0.14
			48	425.08	80.72	3.0	719.20	455.24	1.08	0.54	0.43	0.11
			50	424.62	80.97	5.0	658.88	389.49	0.93	0.61	0.45	0.16
9 hour	6	0-5	51	423.81	80.60	61.0	563.10	307.53	0.85	0.63	0.48	0.15
			53	427.54	80.48	50.0	463.94	222.02	0.59	0.74	0.43	0.32
			55	426.55	80.54	4.0	641.58	345.33	0.82	0.64	0.51	0.13
			57	425.84	79.88	53.0	552.70	295.31	0.79	0.66	0.48	0.18
			59	427.71	81.56	54.0	546.84	296.18	0.79	0.66	0.45	0.20
9 hour	6	5-10	52	425.57	80.64	4.0	688.24	414.00	0.98	0.58	0.46	0.12
			54	423.64	80.92	5.0	686.08	428.67	1.02	0.57	0.42	0.14
			56	425.67	80.44	3.0	707.24	434.62	1.03	0.56	0.45	0.11
			58	426.79	80.71	13.0	701.78	436.45	1.05	0.55	0.45	0.11
			60	428.87	81.30	4.0	716.04	460.16	1.08	0.54	0.41	0.13
3 hour	7	0-5	61	423.78	79.99	13.0	642.98	372.57	0.91	0.61	0.46	0.14
			63	422.50	80.30	30.0	504.72	237.74	0.61	0.74	0.48	0.26
			65	429.54	80.16	32.0	561.24	286.02	0.72	0.69	0.49	0.20
			67	428.55	80.37	42.0	488.94	234.26	0.61	0.74	0.45	0.29
			69	432.16	80.99	50.0	565.30	298.73	0.78	0.66	0.49	0.17

3 hour	7	5-10	62	423.70	80.60	3.0	681.66	415.05	0.99	0.58	0.44	0.14
			64	425.63	80.07	4.0	649.34	373.71	0.89	0.62	0.46	0.16
			66	426.13	80.55	7.0	676.48	398.06	0.95	0.60	0.47	0.12
			68	425.30	80.80	4.0	644.24	363.93	0.86	0.63	0.47	0.16
			70	429.01	80.43	1.0	647.50	358.62	0.84	0.64	0.49	0.16
control	8	0-5	71	477.15	80.45	61.0	515.86	266.85	0.64	0.72	0.41	0.32
			73	425.34	80.00	12.0	592.20	317.52	0.77	0.67	0.47	0.19
			75	430.22	80.61	45.0	516.00	252.93	0.66	0.71	0.47	0.24
			77	425.62	80.99	6.0	657.64	366.16	0.87	0.62	0.50	0.12
			79	424.89	80.11	30.0	597.44	327.55	0.83	0.64	0.48	0.16
control	8	5-10	72	425.96	81.05	3.0	684.90	414.02	0.98	0.58	0.45	0.14
			74	425.96	79.89	3.0	665.24	407.28	0.96	0.59	0.42	0.17
			76	426.16	80.90	4.0	714.02	443.57	1.05	0.55	0.45	0.10
			78	422.95	80.87	1.0	689.08	418.07	0.99	0.58	0.45	0.13
			80	424.49	80.68	18.0	633.86	369.80	0.91	0.61	0.45	0.16
9 hour	9	0-5	81	425.70	81.12	63.0	527.52	268.80	0.74	0.68	0.49	0.19
			83	424.85	80.18	64.0	549.80	296.59	0.82	0.64	0.48	0.16
			85	428.19	80.51	25.0	638.70	357.92	0.89	0.61	0.50	0.12
			87	423.95	80.84	23.0	617.52	335.24	0.84	0.64	0.50	0.13
			89	424.20	80.73	24.0	581.12	312.05	0.78	0.66	0.47	0.19
9 hour	9	5-10	82	425.67	80.31	2.0	690.56	409.92	0.97	0.59	0.47	0.12
			84	426.52	80.83	5.0	668.92	398.64	0.95	0.60	0.45	0.15
			86	428.65	81.21	5.0	697.02	417.28	0.98	0.58	0.47	0.11
			88	423.59	80.66	2.0	689.54	415.37	0.99	0.58	0.46	0.12
			90	425.23	80.77	7.0	721.52	457.15	1.09	0.54	0.44	0.10
3 hour	10	0-5	91	426.12	80.27	77.0	488.04	236.66	0.68	0.71	0.49	0.21
			93	428.97	80.70	38.0	579.16	295.77	0.76	0.67	0.52	0.15
			95	425.72	80.74	5.0	675.70	386.64	0.92	0.60	0.50	0.10
			97	426.52	80.94	70.0	503.02	257.92	0.72	0.69	0.46	0.22
			99	426.55	81.30	13.0	610.40	333.05	0.81	0.65	0.47	0.18
3 hour	10	5-10	92	420.67	80.38	4.0	682.72	408.95	0.98	0.58	0.46	0.12
			94	430.71	80.92	8.0	656.44	380.83	0.90	0.62	0.46	0.16
			96	425.26	80.69	5.0	681.88	415.30	0.99	0.58	0.44	0.14
			98	428.17	80.80	3.0	643.72	369.45	0.87	0.63	0.46	0.18
			100	427.78	80.66	9.0	663.74	405.61	0.97	0.59	0.42	0.17
24 hour	11	0-5	101	426.48	80.58	21.0	625.60	340.79	0.84	0.63	0.50	0.13
			103	423.18	80.79	17.0	634.76	354.48	0.87	0.62	0.49	0.13
			105	427.75	80.18	13.0	661.22	388.27	0.94	0.59	0.46	0.13
			107	426.39	80.99	4.0	679.98	384.83	0.91	0.60	0.51	0.10
			109	425.81	81.21	64.0	527.38	268.62	0.74	0.68	0.49	0.19
24 hour	11	5-10	102	427.32	79.79	12.0	688.12	416.14	1.00	0.57	0.46	0.11
			104	425.70	80.65	5.0	665.66	378.85	0.90	0.62	0.49	0.13
			106	427.12	81.21	10.0	683.86	416.38	1.00	0.58	0.45	0.13
			108	424.48	80.90	4.0	684.48	390.70	0.93	0.61	0.51	0.10
			110	425.13	80.58	3.0	673.62	404.31	0.96	0.59	0.45	0.15
3 hour	12	0-5	111	427.77	80.98	8.0	648.72	362.35	0.86	0.62	0.49	0.14
			113	427.53	80.79	23.0	611.26	335.57	0.83	0.64	0.48	0.16
			115	424.31	80.24	5.0	667.06	399.09	0.95	0.59	0.45	0.14
			117	426.94	80.61	3.0	671.64	412.21	0.97	0.58	0.42	0.16
			119	424.25	80.52	11.0	643.74	367.95	0.89	0.61	0.47	0.14
3 hour	12	5-10	112	425.45	80.32	3.0	693.78	421.70	1.00	0.58	0.45	0.12
			114	428.12	80.07	1.0	662.52	379.82	0.89	0.62	0.47	0.15
			116	428.18	80.41	4.0	682.56	413.50	0.97	0.59	0.44	0.14
			118	426.55	80.21	2.0	661.16	369.95	0.87	0.63	0.50	0.13
			120	423.22	80.70	2.0	688.98	413.86	0.98	0.58	0.46	0.12

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

V.4.5 After Treading Treatment (26-weeks)

Date sampled: 1/2/02

Treatment	Plot #	Depth (cm)	Core #	Core-holder volume (cm^{-3})	Core-holder weight (g)	Seed volume (cm^3) [a]	Weight at 10 kPa (g) [b]	Oven-dry weight (g) [c]	Soil dry bulk density ($Mg\ m^{-3}$)	Total porosity ($cm^3\ cm^{-3}$)	Micro-porosity ($cm^3\ cm^{-3}$)	Macro-porosity ($cm^3\ cm^{-3}$)
9 hour	1	0-5	1	424.85	81.09	30.0	666.16	420.52	1.07	0.54	0.42	0.12
			3	424.03	81.12	52.0	599.80	338.64	0.91	0.60	0.48	0.12
			5	421.60	81.00	70.0	596.94	341.85	0.97	0.58	0.50	0.08
			7	426.53	80.85	7.0	706.80	439.75	1.05	0.54	0.44	0.10
			9	425.70	80.57	70.0	492.92	258.42	0.73	0.68	0.43	0.25
9 hour	1	5-10	2	425.70	80.91	5.0	753.28	476.85	1.13	0.52	0.46	0.05
			4	424.85	81.25	15.0	723.92	448.29	1.09	0.54	0.47	0.06
			6	425.69	81.59	10.0	748.92	476.79	1.15	0.51	0.46	0.05
			8	425.71	80.97	4.0	743.18	462.43	1.10	0.53	0.47	0.06
			10	424.48	80.65	38.0	674.62	420.90	1.09	0.54	0.45	0.09
control	2	0-5	11	426.79	80.19	100.0	525.98	287.28	0.88	0.62	0.49	0.13
			13	428.20	80.72	36.0	620.90	330.07	0.84	0.63	0.54	0.10
			15	424.62	80.65	15.0	684.76	378.30	0.92	0.60	0.55	0.05
			17	423.60	80.75	17.0	652.28	356.28	0.88	0.62	0.53	0.09
			19	421.39	80.52	53.0	595.16	324.91	0.88	0.62	0.52	0.10
control	2	5-10	12	428.11	80.26	6.0	719.02	426.61	1.01	0.57	0.50	0.07
			14	423.43	80.26	25.0	626.54	352.48	0.88	0.62	0.49	0.14
			16	424.56	80.92	3.0	713.68	431.00	1.02	0.57	0.48	0.09
			18	427.78	80.37	6.0	685.80	406.02	0.96	0.59	0.47	0.12
			20	425.28	81.30	15.0	706.04	439.78	1.07	0.54	0.45	0.09
24 hour	3	0-5	21	422.33	80.32	87.0	569.42	315.19	0.94	0.59	0.52	0.07
			23	427.34	80.47	65.0	609.14	347.20	0.96	0.58	0.50	0.08
			25	424.42	80.66	59.0	580.38	324.07	0.89	0.61	0.48	0.13
			27	426.98	80.28	75.0	550.76	303.19	0.86	0.63	0.48	0.15
			29	421.00	81.33	130.0	508.18	274.70	0.94	0.59	0.52	0.07
24 hour	3	5-10	22	425.70	80.63	4.0	731.66	449.86	1.07	0.55	0.48	0.07
			24	424.87	80.79	17.0	704.64	423.28	1.04	0.56	0.49	0.07
			26	423.81	81.34	38.0	690.50	407.31	1.06	0.55	0.52	0.03
			28	426.38	80.60	4.0	718.48	422.25	1.00	0.58	0.51	0.07
			30	425.14	80.56	15.0	683.34	413.80	1.01	0.57	0.46	0.11
control	4	0-5	31	432.17	81.65	32.0	627.40	355.31	0.89	0.61	0.48	0.14
			33	425.84	80.43	33.0	621.14	349.08	0.89	0.61	0.49	0.13
			36	426.15	80.69	11.0	654.90	377.94	0.91	0.60	0.47	0.13
			37	422.80	80.98	45.0	629.68	376.64	1.00	0.57	0.46	0.11
			39	425.65	80.22	73.0	580.49	331.20	0.94	0.59	0.48	0.11
control	4	5-10	32	424.22	81.06	9.0	701.64	427.68	1.03	0.56	0.46	0.10
			34	427.71	80.66	11.0	719.30	440.78	1.06	0.55	0.47	0.08
			35	427.45	81.13	17.0	670.80	398.70	0.97	0.59	0.47	0.12
			38	424.98	80.35	25.0	632.48	420.87	1.05	0.55	0.33	0.23
			40	424.78	80.86	1.0	720.34	444.79	1.05	0.55	0.46	0.10
24 hour	5	0-5	41	425.73	79.89	40.0	657.94	386.42	1.00	0.56	0.50	0.07
			43	424.55	80.34	42.0	621.22	358.23	0.94	0.59	0.48	0.12
			45	427.97	80.54	81.0	602.12	357.68	1.03	0.55	0.47	0.08
			47	426.51	80.26	82.0	509.98	269.71	0.78	0.66	0.46	0.19
			49	425.20	81.17	70.0	553.13	297.47	0.84	0.64	0.49	0.14
24 hour	5	5-10	42	429.22	80.70	13.0	709.54	443.15	1.06	0.55	0.45	0.10
			44	426.55	80.00	13.0	695.88	428.73	1.04	0.56	0.45	0.11
			46	424.73	80.07	13.0	682.96	403.29	0.98	0.58	0.48	0.10
			48	425.08	80.72	9.0	703.10	428.24	1.03	0.56	0.47	0.10
			50	424.62	80.97	9.0	688.40	405.09	0.97	0.59	0.49	0.10
9 hour	6	0-5	51	423.81	80.60	50.0	595.46	319.58	0.85	0.63	0.52	0.11
			53	427.54	80.48	33.0	604.98	311.25	0.79	0.66	0.54	0.12
			55	426.55	80.54	103.0	544.34	313.01	0.97	0.58	0.47	0.11
			57	425.84	79.88	57.0	668.46	404.62	1.10	0.52	0.50	0.02
			59	427.71	81.56	91.0	544.93	299.77	0.89	0.61	0.49	0.13
9 hour	6	5-10	52	425.57	80.64	4.0	719.64	443.56	1.05	0.55	0.46	0.09
			54	423.64	80.92	6.0	694.76	424.15	1.02	0.57	0.45	0.11
			56	425.67	80.44	18.0	715.86	451.40	1.11	0.53	0.45	0.08
			58	426.79	80.71	3.0	701.84	427.31	1.01	0.57	0.46	0.11
			60	428.87	81.30	0.0	781.62	498.56	1.16	0.51	0.47	0.04
3 hour	7	0-5	61	423.78	79.99	62.0	535.79	281.07	0.78	0.66	0.48	0.18
			63	422.50	80.30	35.0	524.79	261.77	0.68	0.71	0.47	0.23
			65	429.54	80.16	23.0	597.00	323.78	0.80	0.65	0.47	0.18
			67	428.55	80.37	99.0	478.33	247.37	0.75	0.67	0.46	0.22
			69	432.16	80.99	38.0	559.53	299.03	0.76	0.67	0.46	0.21

3 hour	7	5-10	62	423.70	80.60	3.0	698.70	429.95	1.02	0.57	0.45	0.12
			64	425.63	80.07	3.0	645.94	369.69	0.87	0.63	0.46	0.16
			66	426.13	80.55	4.0	702.02	431.18	1.02	0.57	0.45	0.12
			68	425.30	80.80	5.0	637.08	373.52	0.89	0.62	0.43	0.19
			70	429.01	80.43	4.0	627.64	345.94	0.81	0.65	0.47	0.18
control	8	0-5	71	477.15	80.45	104.0	494.68	271.81	0.73	0.68	0.38	0.30
			73	425.34	80.00	89.0	456.81	242.43	0.72	0.69	0.40	0.29
			75	430.22	80.61	63.0	551.86	307.71	0.84	0.64	0.45	0.19
			77	425.62	80.99	54.0	580.62	320.06	0.86	0.63	0.48	0.14
			79	424.49	80.68	74.0	560.89	315.68	0.90	0.61	0.47	0.14
control	8	5-10	72	425.96	81.05	9.0	727.64	452.18	1.08	0.54	0.47	0.07
			74	425.96	79.89	8.0	707.32	440.12	1.05	0.55	0.45	0.10
			76	426.16	80.90	35.0	652.26	394.81	1.01	0.57	0.45	0.12
			78	422.95	80.87	7.0	697.28	425.33	1.02	0.57	0.46	0.11
			80	424.89	80.11	29.0	665.34	430.83	1.09	0.54	0.39	0.15
9 hour	9	0-5	81	425.70	81.12	31.0	650.08	379.82	0.96	0.58	0.48	0.10
			83	424.85	80.18	44.0	649.16	381.13	1.00	0.56	0.49	0.07
			85	428.19	80.51	14.0	694.98	410.34	0.99	0.57	0.49	0.08
			87	423.95	80.84	58.0	621.00	357.14	0.98	0.58	0.50	0.08
			89	424.20	80.73	80.0	510.40	262.55	0.76	0.67	0.49	0.18
9 hour	9	5-10	82	425.67	80.31	18.0	696.46	422.90	1.04	0.56	0.47	0.09
			84	426.52	80.83	3.0	693.58	442.49	1.04	0.56	0.40	0.15
			86	428.65	81.21	2.0	734.38	455.30	1.07	0.55	0.46	0.08
			88	423.59	80.66	15.0	727.68	445.21	1.09	0.54	0.49	0.04
			90	425.23	80.77	4.0	733.68	470.59	1.12	0.53	0.43	0.09
3 hour	10	0-5	91	426.12	80.27	20.0	626.34	361.72	0.89	0.61	0.45	0.16
			93	428.97	80.70	107.0	510.52	289.65	0.90	0.61	0.44	0.17
			95	425.72	80.74	31.0	654.08	386.46	0.98	0.57	0.47	0.10
			97	426.52	80.94	82.0	488.89	269.04	0.78	0.66	0.40	0.26
			99	426.55	81.30	52.0	592.25	325.48	0.87	0.62	0.50	0.13
3 hour	10	5-10	92	420.67	80.38	9.0	712.70	440.29	1.07	0.55	0.47	0.08
			94	430.71	80.92	7.0	709.74	411.62	0.97	0.59	0.51	0.07
			96	425.26	80.69	16.0	702.38	431.38	1.05	0.55	0.47	0.09
			98	428.17	80.80	5.0	701.66	411.32	0.97	0.59	0.50	0.09
			100	427.78	80.66	5.0	710.50	425.29	1.01	0.57	0.48	0.09
24 hour	11	0-5	101	426.48	80.58	96.0	554.84	308.89	0.93	0.59	0.50	0.09
			103	423.18	80.79	95.0	467.86	229.87	0.70	0.70	0.48	0.22
			105	427.75	80.18	55.0	586.71	314.03	0.84	0.63	0.52	0.12
			107	426.39	80.99	74.0	555.31	303.45	0.86	0.63	0.48	0.14
			109	425.81	81.21	70.0	584.66	320.58	0.90	0.61	0.51	0.09
24 hour	11	5-10	102	427.32	79.79	4.0	722.16	435.46	1.03	0.56	0.49	0.07
			104	425.70	80.65	13.0	648.68	355.04	0.86	0.63	0.52	0.12
			106	427.12	81.21	13.0	690.86	387.97	0.94	0.60	0.54	0.07
			108	424.48	80.90	5.0	684.58	387.68	0.92	0.61	0.51	0.09
			110	425.13	80.58	10.0	699.28	423.47	1.02	0.57	0.47	0.10
3 hour	12	0-5	111	427.77	80.98	78.0	519.38	272.54	0.78	0.66	0.47	0.19
			113	427.53	80.79	58.0	602.12	348.98	0.94	0.59	0.47	0.12
			115	424.31	80.24	44.0	589.44	327.25	0.86	0.63	0.48	0.15
			117	426.94	80.61	60.0	621.79	354.86	0.97	0.58	0.51	0.07
			119	424.25	80.52	48.0	608.66	326.90	0.87	0.62	0.53	0.09
3 hour	12	5-10	112	425.45	80.32	13.0	714.28	434.44	1.05	0.55	0.48	0.07
			114	428.12	80.07	4.0	693.40	413.73	0.98	0.59	0.47	0.12
			116	428.18	80.41	10.0	631.28	348.77	0.83	0.65	0.48	0.16
			118	426.55	80.21	4.0	674.48	400.43	0.95	0.60	0.46	0.14
			120	423.22	80.70	28.0	580.98	322.79	0.82	0.65	0.45	0.20

[a] seed volume was the volume of soil 'missing' from the total PVC core-holder volume
[b] weight at 10 kPa was inclusive the weight of the PVC core-holder
[c] over-dry weight was exclusive the weight of the PVC core-holder

Appendix VI

Unsaturated Hydraulic Conductivity

Appendix VI Unsaturated Hydraulic Conductivity

VI.1 Treatment Means

65% GSM Unsaturated (K_{-40}) Hydraulic Conductivity (mm hr^{-1}) 0-5 cm soil depth					
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	51.37	74.35	40.51	79.79	74.09
3 hour	39.70	41.44	37.06	81.16	68.00
9 hour	35.97	19.90	20.77	52.84	80.20
24 hour	37.33	15.37	25.62	60.87	72.71
F.pr	0.273	0.008	0.214	0.165	0.955
(log) e.s.e	0.0720	0.1187	0.1435	0.0768	0.0677
(log) s.e.d	0.1018	0.1679	0.2029	0.1085	0.0957
(log) l.s.d	0.2348	0.3871	0.4679	0.2503	0.2207

Note: the treatment means are the geometric mean of the plots means, F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%). Data is presented as unlogged data (on graphs it is shown against a logged y-axis), however, statistical analysis was carried out on logged data as unlogged data were non-normally distributed.

65% GSM Unsaturated (K_{-40}) Hydraulic Conductivity (mm hr^{-1}) 5-10 cm soil depth					
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	51.10	71.81	48.68	55.90	59.18
3 hour	72.43	82.34	52.19	66.27	68.05
9 hour	56.76	66.38	63.18	57.81	65.63
24 hour	57.06	57.93	43.52	47.04	63.58
F.pr	0.523	0.371	0.695	0.398	0.915
(log) e.s.e	0.0677	0.0572	0.1036	0.0672	0.0544
(log) s.e.d	0.0958	0.0809	0.1466	0.0951	0.0770
(log) l.s.d	0.2209	0.1865	0.3380	0.2192	0.1775

71% GSM Unsaturated (K_{-40}) Hydraulic Conductivity (mm hr^{-1}) 0-5 cm soil depth					
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	29.38	19.21	69.65	95.03	128.63
3 hour	28.92	12.77	33.45	50.34	107.76
9 hour	24.59	7.42	30.48	92.06	77.25
24 hour	29.74	5.38	18.31	72.74	125.36
F.pr	0.441	0.133	0.062	0.275	0.038
(log) e.s.e	0.1458	0.273	0.1363	0.0956	0.0516
(log) s.e.d	0.2062	0.386	0.1928	0.1352	0.0730
(log) l.s.d	0.4756	0.890	0.4445	0.3118	0.1684

71% GSM Unsaturated (K_{-40}) Hydraulic Conductivity (mm hr^{-1}) 5-10 cm soil depth					
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	22.59	38.43	50.19	84.78	111.48
3 hour	22.82	24.30	30.54	40.90	93.92
9 hour	21.88	14.21	22.71	57.43	90.39
24 hour	34.21	16.54	16.98	50.17	97.68
F.pr	0.584	0.059	0.079	0.244	0.705
(log) e.s.e	0.1363	0.1441	0.1334	0.1096	0.0745
(log) s.e.d	0.1928	0.2038	0.1887	0.1550	0.1054
(log) l.s.d	0.4447	0.470	0.4351	0.3574	0.2430

81% GSM Unsaturated (K_{-40}) Hydraulic Conductivity (mm hr^{-1}) 0-5 cm soil depth					
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	36.71	39.39	76.60	44.69	143.12
3 hour	51.74	29.13	67.62	30.96	174.76
9 hour	29.04	26.44	91.77	44.37	131.54
24 hour	48.06	17.25	73.65	45.56	134.02
F.pr	0.759	0.007	0.629	0.735	0.581
(log) e.s.e	0.1201	0.1076	0.1035	0.1842	0.0659
(log) s.e.d	0.1698	0.1522	0.1463	0.2604	0.0932
(log) l.s.d	0.3916	0.3509	0.3374	0.6006	0.2148

81% GSM Unsaturated (K_{-40}) Hydraulic Conductivity (mm hr^{-1}) 5-10 cm soil depth					
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	29.97	28.14	20.50	40.88	47.28
3 hour	23.47	32.46	38.61	50.91	93.86
9 hour	38.13	16.14	19.16	44.46	42.40
24 hour	38.77	16.62	18.95	53.52	81.89
F.pr	0.576	0.027	0.295	0.710	0.137
(log) e.s.e	0.1244	0.1198	0.1212	0.0802	0.1256
(log) s.e.d	0.1759	0.1694	0.1714	0.1134	0.1776
(log) l.s.d	0.4057	0.3907	0.3951	0.2615	0.4095

VI.2 Individual Results for 65% GSM Experiment

VI.2.1 Before Treading Treatment

Date sampled: 17/6/99

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
control	1	0-5	1	185.00	295.00	3.55	101.19
			3	201.00	330.00	12.51	36.17
			5	135.00	250.00	20.53	19.84
			7	140.00	266.00	7.55	57.35
			9	145.00	265.00	14.05	30.70
control	1	5-10	2	150.00	260.00	7.06	55.82
			4	175.00	310.00	4.47	101.69
			6	140.00	280.00	15.01	33.59
			8	140.00	315.00	10.31	59.96
			10	145.00	320.00	10.23	60.73
3 hour	2	0-5	11	135.00	265.00	14.47	31.69
			13	135.00	250.00	15.29	26.76
			15	210.00	330.00	3.56	109.93
			17	135.00	295.00	10.25	55.34
			19	205.00	325.00	17.47	24.31
3 hour	2	5-10	12	185.00	465.00	11.42	86.23
			14	155.00	270.00	5.18	78.18
			16	160.00	335.00	5.36	112.60
			18	180.00	300.00	3.12	135.12
			20	150.00	265.00	12.12	33.96
24 hour	3	0-5	21	150.00	260.00	14.35	27.18
			23	140.00	290.00	9.20	57.91
			25	150.00	265.00	11.37	35.67
			27	145.00	270.00	6.47	66.40
			29	125.00	165.00	32.58	4.37
24 hour	3	5-10	22	195.00	380.00	9.17	71.80
			24	175.00	315.00	5.03	99.89
			26	140.00	250.00	10.22	38.23
			28	150.00	340.00	8.09	84.00
			30	165.00	355.00	8.45	78.24
3 hour	4	0-5	31	200.00	325.00	13.14	34.03
			33	235.00	385.00	7.20	73.70
			35	145.00	255.00	25.24	15.60
			37	165.00	330.00	12.01	49.47
			39	285.00	380.00	5.49	58.85
3 hour	4	5-10	32	170.00	355.00	12.20	54.05
			34	190.00	355.00	8.57	66.43
			36	175.00	360.00	6.15	106.65
			38	165.00	310.00	5.28	95.57
			40	165.00	360.00	9.08	76.93
9 hour	5	0-5	41	205.00	345.00	15.24	32.76
			43	165.00	290.00	20.17	22.21
			45	150.00	305.00	19.16	28.99
			46	145.00	240.00	3.41	92.93
			49	110.00	175.00	18.21	12.76
9 hour	5	5-10	42	210.00	335.00	11.34	38.94
			44	145.00	255.00	7.07	55.69
			47	235.00	330.00	5.15	65.20
			48	165.00	295.00	6.39	70.44
			50	175.00	295.00	7.02	61.48
control	6	0-5	51	130.00	235.00	12.06	31.27
			53	140.00	320.00	21.37	30.00
			55	117.00	270.00	23.16	23.69
			57	115.00	275.00	22.10	26.01
			59	150.00	265.00	4.26	93.47
control	6	5-10	52	190.00	355.00	9.47	60.77
			54	110.00	215.00	5.30	68.79
			56	125.00	265.00	11.29	43.93
			58	125.00	260.00	12.46	38.10
			60	130.00	295.00	13.50	42.98
9 hour	7	0-5	61	141.00	305.00	13.44	43.03
			63	150.00	275.00	9.47	46.04
			65	105.00	172.00	29.31	8.18

			67	160.00	300.00	13.13	38.17
			69	130.00	235.00	19.49	19.09
9 hour	7	5-10	62	130.00	235.00	9.18	40.68
			64	145.00	250.00	12.54	29.33
			66	130.00	281.00	13.53	39.19
			68	245.00	405.00	6.29	88.92
			70	155.00	255.00	13.13	27.26
3 hour	8	0-5	71	130.00	270.00	11.48	42.75
			73	145.00	280.00	12.34	38.71
			75	140.00	265.00	20.56	21.52
			78	125.00	235.00	22.50	17.36
			79	125.00	235.00	25.09	15.76
3 hour	8	5-10	72	132.00	230.00	18.17	19.31
			74	130.00	255.00	16.46	26.86
			76	195.00	360.00	7.33	78.74
			77	200.00	330.00	4.30	104.09
			80	135.00	300.00	15.53	37.43
24 hour	9	0-5	81	135.00	275.00	13.31	37.32
			83	150.00	252.00	29.49	12.33
			85	115.00	185.00	38.33	6.54
			87	175.00	290.00	13.30	30.69
			89	60.00	200.00	11.39	43.30
24 hour	9	5-10	82	160.00	280.00	4.40	92.65
			84	215.00	335.00	10.24	41.57
			86	180.00	310.00	7.10	65.36
			88	120.00	222.00	17.08	21.45
			90	175.00	225.00	3.58	45.42
24 hour	10	0-5	91	175.00	290.00	14.21	28.88
			93	150.00	275.00	6.43	67.06
			95	185.00	325.00	14.40	34.39
			97	155.00	300.00	8.53	58.81
			99	215.00	360.00	7.18	71.57
24 hour	10	5-10	92	152.00	260.00	19.14	20.23
			94	150.00	335.00	14.45	45.19
			96	205.00	325.00	5.02	85.90
			98	170.00	280.00	5.44	69.13
			100	120.00	220.00	26.12	13.75
control	11	0-5	101	137.00	265.00	9.13	50.04
			103	120.00	255.00	17.58	27.07
			105	200.00	420.00	4.34	173.58
			107	140.00	270.00	7.01	66.76
			109	130.00	245.00	20.16	20.45
control	11	5-10	102	171.00	275.00	9.37	38.97
			104	120.00	220.00	8.31	42.31
			106	170.00	315.00	8.39	60.40
			108	175.00	310.00	25.52	18.81
			110	135.00	240.00	7.37	49.67
9 hour	12	0-5	111	225.00	360.00	13.48	35.25
			113	86.00	110.00	42.10	2.05
			115	110.00	215.00	14.23	26.30
			117	140.00	396.00	8.15	111.81
			119	100.00	230.00	20.14	23.15
9 hour	12	5-10	112	100.00	340.00	32.08	26.91
			114	100.00	220.00	19.08	22.60
			116	135.00	280.00	2.42	193.50
			118	160.00	325.00	9.09	64.97
			120	160.00	260.00	9.06	39.60

VI.2.2 After Treading Treatment (1-week)

Date sampled: 29/6/99

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
control	1	0-5	1	180.00	340.00	9.44	59.23
			3	170.00	330.00	4.39	123.98
			5	225.00	340.00	8.41	47.72
			7	145.00	275.00	6.37	70.79
			9	110.00	300.00	28.39	23.90
control	1	5-10	2	130.00	270.00	8.43	57.87
			4	150.00	410.00	8.52	105.66
			6	130.00	335.00	8.48	83.94
			8	140.00	260.00	13.26	32.19
			10	140.00	340.00	12.09	59.31
3 hour	2	0-5	21	188.00	290.00	12.31	29.36
			23	135.00	255.00	6.06	70.88
			25	220.00	340.00	3.14	133.73
			27	116.00	270.00	22.22	24.81
			29	160.00	325.00	17.19	34.33
3 hour	2	5-10	22	171.00	440.00	13.09	73.71
			24	125.00	320.00	19.07	36.75
			26	110.00	290.00	9.14	70.24
			28	120.00	350.00	17.35	47.13
			30	155.00	380.00	7.56	102.19
24 hour	3	0-5	31	190.00	320.00	21.54	21.39
			33	123.00	243.00	35.30	12.18
			35	110.00	220.00	18.02	21.98
			37	131.00	173.00	55.06	2.75
			39	120.00	125.00	27.08	0.66
24 hour	3	5-10	32	140.00	330.00	9.32	71.81
			34	170.00	315.00	9.47	53.40
			36	175.00	400.00	15.16	53.10
			38	155.00	255.00	14.55	24.16
			40	125.00	450.00	23.46	49.27
3 hour	4	0-5	11	140.00	340.00	15.03	47.88
			13	120.00	310.00	25.36	26.74
			15	111.00	220.00	44.35	8.81
			17	145.00	325.00	24.48	26.15
			19	125.00	280.00	18.15	30.60
3 hour	4	5-10	12	135.00	320.00	6.01	110.79
			14	160.00	310.00	2.16	238.44
			16	165.00	370.00	4.24	167.87
			18	135.00	350.00	13.48	56.14
			20	140.00	280.00	14.05	35.82
9 hour	5	0-5	41	178.00	191.00	65.46	0.71
			43	141.00	310.00	19.34	31.12
			45	125.00	255.00	33.00	14.19
			46	98.00	210.00	53.70	7.45
			49	111.00	260.00	21.57	24.46
9 hour	5	5-10	42	110.00	275.00	6.53	86.37
			44	310.00	420.00	8.49	44.95
			47	125.00	245.00	12.15	35.30
			48	290.00	475.00	7.11	92.80
			50	215.00	500.00	7.52	130.54
control	6	0-5	51	110.00	260.00	2.55	185.31
			53	140.00	310.00	11.57	51.26
			55	131.00	250.00	8.44	49.10
			57	91.00	231.00	26.34	18.99
			59	125.00	245.00	5.47	74.76
control	6	5-10	52	150.00	265.00	6.51	60.49
			54	120.00	265.00	11.15	46.44
			56	150.00	270.00	4.25	97.90
			58	105.00	335.00	15.44	52.67
			60	111.00	245.00	11.26	42.23
9 hour	7	0-5	61	70.00	179.00	39.03	10.06
			63	94.00	208.00	60.56	6.74
			65	81.00	191.00	42.56	9.23
			67	150.00	270.00	15.24	28.08
			69	59.00	182.00	31.58	13.86
9 hour	7	5-10	62	190.00	360.00	3.45	163.34
			64	155.00	326.00	9.19	66.13

			66	131.00	250.00	13.52	30.92
			68	125.00	280.00	11.19	49.35
			70	157.00	285.00	10.41	43.17
3 hour	8	0-5	71	125.00	262.00	14.43	33.54
			73	140.00	305.00	6.44	88.30
			75	130.00	246.00	16.22	25.54
			78	110.00	246.00	30.58	15.82
			79	140.00	322.00	12.19	53.24
3 hour	8	5-10	72	190.00	305.00	3.53	106.70
			74	133.00	240.00	9.46	39.47
			76	115.00	336.00	13.35	58.62
			77	150.00	275.00	4.52	92.55
			80	126.00	245.00	8.36	49.86
24 hour	9	0-5	81	95.00	204.00	31.34	12.44
			83	75.00	113.00	67.56	2.02
			85	90.00	225.00	25.49	18.84
			87	95.00	300.00	37.42	19.59
			89	121.00	252.00	18.17	25.82
24 hour	9	5-10	82	110.00	260.00	13.43	39.40
			84	156.00	325.00	8.49	69.07
			86	110.00	270.00	11.35	49.77
			88	*no data*	*no data*	*no data*	*no data*
			90	105.00	260.00	10.11	54.84
24 hour	10	0-5	91	70.00	256.00	54.11	12.37
			93	92.00	212.00	16.56	25.53
			95	90.00	235.00	29.22	17.79
			97	88.00	200.00	14.02	28.76
			99	110.00	215.00	28.17	13.38
24 hour	10	5-10	92	110.00	290.00	14.35	44.47
			94	115.00	250.00	8.08	59.81
			96	105.00	315.00	17.50	42.43
			98	130.00	325.00	7.05	99.19
			100	125.00	290.00	5.06	116.57
control	11	0-5	101	100.00	235.00	6.56	70.16
			103	180.00	305.00	4.33	98.99
			105	272.00	435.00	6.43	87.44
			107	110.00	240.00	3.41	127.17
			109	130.00	280.00	16.52	32.04
control	11	5-10	102	102.00	250.00	11.27	46.57
			104	130.00	410.00	7.00	144.13
			106	250.00	360.00	5.19	74.55
			108	125.00	300.00	5.24	116.77
			110	110.00	315.00	10.03	73.50

9 hour	12	0-5	111	135.00	275.00	13.17	37.98
			113	140.00	280.00	22.31	22.40
			115	143.00	250.00	10.44	35.92
			117	95.00	251.00	30.00	18.74
			119	285.00	470.00	9.23	71.04
9 hour	12	5-10	112	120.00	330.00	5.43	132.36
			114	195.00	326.00	8.58	52.64
			116	112.00	250.00	29.08	17.07
			118	132.00	352.00	21.27	36.96
			120	100.00	350.00	33.51	26.61

VI.2.3 After Treading Treatment (4-weeks)

Date sampled: 22/7/99

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
control	1	0-5	1	140.0	228.0	14.46	21.47
			3	127.0	276.0	24.44	21.71
			5	75.0	235.0	14.50	38.87
			7	200.0	360.0	9.49	58.73
			9	95.0	335.0	19.35	44.16
control	1	5-10	2	103.0	250.0	7.09	74.08
			4	345.0	540.0	12.45	55.11
			6	155.0	270.0	13.25	30.88
			8	115.0	310.0	6.17	111.82
			10	195.0	290.0	11.22	30.11
3 hour	2	0-5	11	285.0	380.0	24.58	13.71
			13	103.0	422.0	24.40	46.60
			15	158.0	260.0	10.45	34.19
			17	121.0	249.0	20.37	22.37
			19	80.0	357.0	32.00	31.19
3 hour	2	5-10	12	326.0	506.0	15.30	41.84
			14	80.0	280.0	16.05	44.81
			16	86.0	223.0	16.13	30.44
			18	80.0	199.0	13.30	31.76
			20	70.0	171.0	11.02	32.98
24 hour	3	0-5	22	105.0	205.0	19.18	18.67
			23	60.0	245.0	21.52	30.48
			25	108.0	240.0	34.47	13.67
			27	134.0	350.0	22.46	34.19
			29	65.0	150.0	65.57	4.64
24 hour	3	5-10	21	78.0	210.0	17.11	27.68
			24	103.0	216.0	14.10	28.74
			26	108.0	323.0	13.51	55.93
			28	195.0	505.0	8.00	139.62
			30	90.0	230.0	7.07	70.88
3 hour	4	0-5	31	136.0	265.0	10.47	43.10
			33	115.0	300.0	12.15	54.41
			35	124.0	265.0	14.15	35.65
			37	90.0	335.0	11.39	75.77
			39	80.0	301.0	24.36	32.37
3 hour	4	5-10	32	105.0	365.0	8.41	107.89
			34	105.0	301.0	11.44	60.19
			36	95.0	325.0	8.39	95.81
			38	90.0	250.0	12.16	47.00
			40	110.0	340.0	9.48	84.56
9 hour	5	0-5	41	76.0	242.0	28.36	20.91
			43	76.0	185.0	43.04	9.12
			45	110.0	250.0	7.27	67.71
			47	57.0	135.0	91.59	3.06
			49	120.0	411.0	23.55	43.84
9 hour	5	5-10	42	100.0	360.0	10.20	90.66
			44	132.0	338.0	14.46	50.27
			46	80.0	282.0	5.27	133.55
			48	80.0	350.0	5.59	162.59
			50	125.0	356.0	14.33	57.20
control	6	0-5	51	100.0	501.0	12.32	115.28
			53	110.0	196.0	20.35	15.05
			55	100.0	262.0	6.30	89.80
			57	210.0	386.0	5.27	116.36
			59	80.0	182.0	52.29	7.00
control	6	5-10	52	226.0	443.0	8.51	88.35
			54	104.0	306.0	36.15	20.08
			56	67.0	250.0	18.46	35.14
			58	85.0	281.0	8.10	86.48
			60	50.0	220.0	23.45	25.79
9 hour	7	0-5	61	78.0	230.0	19.40	27.85
			63	100.0	252.0	25.57	21.11
			65	65.0	207.0	29.10	17.54
			67	126.0	227.0	13.35	26.79
			69	128.0	229.0	39.25	9.23
9 hour	7	5-10	62	67.0	350.0	17.00	59.98
			64	105.0	256.0	11.56	45.59
			66	105.0	300.0	14.08	49.71
			68	186.0	466.0	9.17	108.68

			70	75.0	265.0	7.43	88.72
3 hour	8	0-5	71	106.0	275.0	15.17	39.84
			73	100.0	215.0	16.41	24.84
			75	95.0	250.0	10.05	55.39
			77	102.0	211.0	15.42	25.02
			79	135.0	274.0	15.09	33.06
3 hour	8	5-10	72	83.0	206.0	13.22	33.16
			74	127.0	216.0	8.50	36.30
			76	91.0	235.0	7.41	67.53
			78	236.0	374.0	8.00	62.15
			80	90.0	252.0	12.11	47.91
24 hour	9	0-5	81	75.0	184.0	33.42	11.65
			84	120.0	410.0	9.02	115.67
			85	97.0	345.0	39.07	22.84
			87	215.0	370.0	4.34	122.30
			89	77.0	182.0	28.41	13.19
24 hour	9	5-10	82	131.0	201.0	15.55	15.85
			83	103.0	260.0	14.40	38.57
			86	55.0	205.0	33.33	16.11
			88	77.0	191.0	21.42	18.93
			90	73.0	190.0	9.17	45.41
24 hour	10	0-5	91	55.0	73.0	61.10	1.06
			93	98.0	308.0	15.56	47.49
			95	70.0	220.0	32.18	16.73
			97	84.0	112.0	53.44	1.88
			99	106.0	175.0	47.24	5.25
24 hour	10	5-10	92	268.0	385.0	8.39	48.74
			94	144.0	255.0	12.00	33.33
			96	95.0	205.0	8.07	48.83
			98	105.0	345.0	13.02	66.35
			100	152.0	274.0	11.10	39.37
control	11	0-5	101	141.0	255.0	23.49	17.25
			103	70.0	127.0	52.57	3.88
			105	104.0	230.0	5.29	82.80
			107	70.0	247.0	38.54	16.39
			109	94.0	257.0	55.46	10.53
control	11	5-10	102	107.0	300.0	11.00	63.22
			104	151.0	249.0	13.09	26.85
			106	130.0	240.0	8.24	47.18
			108	110.0	220.0	11.08	35.60
			110	48.0	251.0	52.57	13.81
9 hour	12	0-5	111	55.0	170.0	37.47	10.97
			113	132.0	151.0	34.43	1.97
			115	97.0	123.0	46.52	2.00
			117	76.0	280.0	26.54	27.33
			119	255.0	375.0	12.59	33.30
9 hour	12	5-10	112	103.0	215.0	18.34	21.74
			114	84.0	232.0	34.50	15.31
			116	130.0	235.0	8.22	45.22
			118	256.0	390.0	6.23	75.64
			120	101.0	210.0	17.06	22.97

VI.2.4 After Treading Treatment (13-weeks)

Date sampled: 23/9/99

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
control	1	0-5	1	140.0	342.0	10.20	70.44
			3	146.0	545.0	15.21	93.66
			5	190.0	490.0	5.31	195.94
			7	288.0	440.0	7.30	73.02
			9	260.0	391.0	13.51	34.08
control	1	5-10	2	76.0	250.0	9.35	65.42
			4	85.0	277.0	18.43	36.96
			6	126.0	286.0	27.44	20.79
			8	117.0	316.0	12.28	57.52
			10	101.0	232.0	13.13	35.71
3 hour	2	0-5	11	110.0	247.0	9.53	49.95
			13	70.0	254.0	18.48	35.26
			15	123.0	290.0	9.17	64.82
			18	166.0	342.0	6.43	94.42
			19	93.0	255.0	13.16	44.00
3 hour	2	5-10	12	102.0	335.0	11.06	75.63
			14	110.0	230.0	10.59	39.37
			16	112.0	331.0	4.52	162.14
			17	115.0	322.0	17.38	42.30
			20	310.0	465.0	6.35	84.83
24 hour	3	0-5	21	80.0	206.0	15.12	29.87
			23	150.0	310.0	5.55	97.44
			26	195.0	460.0	8.00	119.35
			27	100.0	235.0	16.55	28.75
			29	125.0	278.0	15.58	34.53
24 hour	3	5-10	22	116.0	250.0	7.02	68.65
			24	56.0	240.0	25.44	25.76
			25	46.0	250.0	44.00	16.71
			28	279.0	390.0	12.21	32.38
			30	131.0	277.0	26.19	19.99
3 hour	4	0-5	31	375.0	540.0	4.00	148.63
			33	237.0	502.0	9.12	103.79
			35	175.0	470.0	9.26	112.68
			37	125.0	255.0	13.28	34.78
			39	195.0	405.0	7.04	107.07
3 hour	4	5-10	32	110.0	300.0	14.47	46.31
			34	140.0	430.0	16.47	62.26
			36	136.0	370.0	12.39	66.65
			38	120.0	280.0	4.31	127.64
			40	130.0	264.0	13.52	34.82
9 hour	5	0-5	41	125.0	390.0	11.42	81.61
			43	95.0	261.0	27.34	21.70
			45	131.0	350.0	22.39	34.84
			47	225.0	365.0	15.46	31.99
			49	115.0	351.0	21.50	38.95
9 hour	5	5-10	42	130.0	281.0	11.15	48.36
			44	270.0	440.0	13.10	46.52
			46	126.0	282.0	8.04	69.68
			48	100.0	310.0	7.52	96.19
			50	142.0	316.0	8.51	70.84
control	6	0-5	51	101.0	361.0	18.12	51.47
			53	166.0	320.0	4.20	128.05
			55	130.0	270.0	11.55	42.33
			57	80.0	390.0	37.23	29.88
			59	94.0	223.0	22.12	20.94
control	6	5-10	52	151.0	260.0	11.56	32.91
			54	160.0	535.0	9.39	140.02
			56	132.0	335.0	11.51	61.72
			58	110.0	230.0	5.18	81.58
			60	151.0	302.0	10.53	49.99
9 hour	7	0-5	61	192.0	476.0	8.09	125.56
			63	56.0	161.0	57.20	6.60
			65	51.0	246.0	34.41	20.26
			67	105.0	470.0	17.11	76.54
			69	81.0	295.0	27.53	27.65
9 hour	7	5-10	62	125.0	362.0	8.11	104.35
			64	20.0	217.0	25.05	28.30
			66	131.0	407.0	14.38	67.96
			68	143.0	275.0	6.26	73.93

			70	65.0	430.0	23.58	54.87
3 hour	8	0-5	71	150.0	310.0	5.47	99.68
			73	100.0	260.0	10.55	52.81
			75	220.0	351.0	5.47	81.62
			77	175.0	315.0	3.11	158.46
			79	98.0	345.0	13.49	64.41
3 hour	8	5-10	72	110.0	391.0	15.24	65.75
			74	86.0	275.0	14.25	47.24
			76	110.0	270.0	19.36	29.41
			78	75.0	295.0	8.25	94.18
			80	117.0	205.0	10.37	29.87
24 hour	9	0-5	81	71.0	175.0	14.46	25.38
			83	70.0	190.0	15.34	27.78
			85	155.0	260.0	4.39	81.36
			87	100.0	226.0	5.42	79.65
			89	100.0	200.0	7.43	46.69
24 hour	9	5-10	82	210.0	340.0	6.32	71.70
			84	94.0	254.0	15.55	36.22
			86	80.0	230.0	10.03	53.78
			88	121.0	231.0	11.10	35.49
			90	81.0	239.0	25.11	22.61
24 hour	10	0-5	91	105.0	225.0	16.22	26.42
			93	190.0	340.0	6.05	88.84
			95	91.0	350.0	13.20	69.99
			97	85.0	290.0	11.34	63.86
			99	100.0	205.0	3.48	99.56
24 hour	10	5-10	92	96.0	220.0	14.53	30.02
			94	110.0	355.0	10.26	84.61
			96	250.0	430.0	3.38	178.50
			98	69.0	200.0	15.36	30.26
			100	96.0	247.0	14.04	38.68
control	11	0-5	101	90.0	325.0	6.45	125.44
			103	65.0	306.0	11.23	76.28
			105	158.0	491.0	11.10	107.45
			107	80.0	227.0	9.46	54.23
			109	140.0	466.0	8.42	135.01
control	11	5-10	102	205.0	351.0	10.44	49.01
			104	80.0	227.0	15.04	35.15
			106	55.0	220.0	12.35	47.25
			108	103.0	190.0	4.19	72.62
			110	98.0	352.0	12.48	71.50
9 hour	12	0-5	111	95.0	195.0	4.26	81.27
			113	153.0	360.0	6.12	120.30
			115	45.0	145.0	13.01	27.68
			117	172.0	290.0	7.18	58.24
			119	187.0	315.0	8.12	56.24
9 hour	12	5-10	112	80.0	325.0	13.41	64.51
			114	260.0	390.0	5.46	81.23
			116	58.0	258.0	23.49	30.26
			118	143.0	220.0	12.35	22.05
			120	83.0	176.0	14.31	23.08

VI.2.5 After Treading Treatment (26-weeks)

Date sampled: 17/12/99

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
control	1	0-5	1	125.0	393.0	15.15	63.32
			3	260.0	400.0	5.51	86.23
			5	105.0	510.0	36.28	40.02
			7	77.0	356.0	21.52	45.97
			9	118.0	265.0	11.56	44.39
control	1	5-10	2	119.0	372.0	13.38	66.87
			4	198.0	353.0	9.21	59.73
			6	270.0	391.0	9.37	45.34
			8	126.0	330.0	9.22	78.47
			10	100.0	380.0	13.56	72.41
3 hour	2	0-5	11	106.0	231.0	22.22	20.14
			13	144.0	389.0	24.07	36.60
			15	165.0	412.0	7.13	123.32
			17	151.0	260.0	10.43	36.65
			19	125.0	391.0	9.56	96.49
3 hour	2	5-10	12	126.0	250.0	12.15	36.47
			14	125.0	297.0	7.18	84.90
			16	161.0	300.0	9.13	54.34
			18	75.0	235.0	6.53	83.75
			20	85.0	326.0	30.38	28.35
24 hour	3	0-5	21	131.0	260.0	6.56	67.04
			23	161.0	320.0	13.50	41.41
			26	141.0	300.0	29.22	19.51
			27	194.0	503.0	10.40	104.38
			29	265.0	395.0	2.45	170.33
24 hour	3	5-10	22	163.0	360.0	6.16	113.27
			24	352.0	496.0	8.50	58.74
			25	162.0	460.0	9.30	113.03
			28	67.0	320.0	45.40	19.96
			30	106.0	317.0	13.55	54.63
3 hour	4	0-5	31	227.0	330.0	4.15	87.32
			33	150.0	354.0	12.20	59.60
			35	140.0	410.0	11.35	83.99
			37	75.0	390.0	23.45	47.79
			39	135.0	311.0	11.11	56.71
3 hour	4	5-10	32	136.0	268.0	9.54	48.04
			34	100.0	390.0	8.03	129.80
			36	161.0	310.0	2.52	187.28
			38	95.0	238.0	13.30	38.17
			40	92.0	330.0	9.38	89.02
9 hour	5	0-5	41	182.0	378.0	19.28	36.28
			43	178.0	375.0	9.13	77.01
			45	111.0	366.0	9.09	100.42
			47	185.0	446.0	8.06	116.10
			49	235.0	412.0	9.24	67.85
9 hour	5	5-10	42	150.0	561.0	9.41	152.93
			44	225.0	490.0	5.34	171.53
			46	87.0	280.0	13.33	51.32
			48	400.0	521.0	9.26	46.22
			50	149.0	268.0	12.30	34.30
control	6	0-5	51	153.0	387.0	8.36	98.04
			53	185.0	484.0	6.28	166.60
			55	345.0	351.0	7.46	2.78
			57	131.0	340.0	13.09	57.27
			59	108.0	217.0	12.20	31.84
control	6	5-10	52	92.0	252.0	19.33	29.49
			54	240.0	319.0	7.34	37.62
			56	135.0	360.0	10.41	75.89
			58	145.0	272.0	6.26	71.13
			60	162.0	297.0	9.29	51.29
9 hour	7	0-5	61	140.0	304.0	7.26	79.50
			63	230.0	455.0	3.45	216.19
			65	188.0	319.0	11.40	40.46
			67	85.0	219.0	24.18	19.87
			69	211.0	300.0	5.37	57.09

9 hour	7	5-10	62	191.0	355.0	17.20	34.09
			64	131.0	345.0	13.47	55.94
			66	110.0	238.0	7.03	65.42
			68	121.0	242.0	9.03	48.17
			70	150.0	350.0	18.03	39.92
3 hour	8	0-5	71	125.0	240.0	12.42	32.63
			74	210.0	526.0	9.07	124.89
			75	140.0	315.0	16.48	37.53
			77	211.0	551.0	12.28	98.27
			79	163.0	277.0	5.05	80.81
3 hour	8	5-10	72	85.0	236.0	11.44	46.37
			73	115.0	407.0	15.12	69.22
			76	120.0	313.0	15.21	45.30
			78	186.0	295.0	5.04	77.52
			80	115.0	370.0	23.13	39.58
24 hour	9	0-5	81	182.0	400.0	6.49	115.23
			83	140.0	260.0	6.08	70.50
			85	215.0	475.0	7.26	126.03
			87	95.0	519.0	35.51	42.61
			89	271.0	466.0	8.02	87.46
24 hour	9	5-10	82	95.0	335.0	21.16	40.66
			84	145.0	260.0	11.57	34.67
			86	132.0	332.0	13.41	52.66
			88	61.0	281.0	21.04	37.63
			90	66.0	250.0	14.52	44.60
24 hour	10	0-5	91	190.0	390.0	8.27	85.28
			93	177.0	445.0	16.07	59.92
			95	167.0	271.0	5.58	62.80
			97	248.0	398.0	17.16	31.30
			99	193.0	307.0	13.20	30.81
24 hour	10	5-10	92	138.0	333.0	12.38	55.62
			94	105.0	440.0	8.27	142.85
			96	99.0	335.0	35.19	24.08
			98	81.0	280.0	20.57	34.23
			100	110.0	495.0	8.15	168.15
control	11	0-5	101	285.0	450.0	2.58	200.40
			103	250.0	365.0	9.40	42.87
			105	180.0	290.0	4.03	97.86
			107	182.0	475.0	14.29	72.89
			109	210.0	441.0	8.44	95.30
control	11	5-10	102	85.0	370.0	14.52	69.07
			104	90.0	220.0	12.21	37.93
			106	210.0	411.0	18.18	39.58

			108	90.0	341.0	10.11	88.81
			110	132.0	451.0	17.09	67.02
9 hour	12	0-5	111	116.0	240.0	15.56	28.04
			113	145.0	339.0	8.37	81.12
			115	175.0	337.0	20.55	27.91
			117	90.0	482.0	35.58	39.27
			119	290.0	460.0	2.50	216.19
9 hour	12	5-10	112	111.0	267.0	7.45	72.53
			114	101.0	270.0	22.48	26.71
			116	84.0	334.0	31.23	28.70
			118	288.0	400.0	3.10	127.44
			120	136.0	267.0	7.33	62.52

VI.3 Individual Results for 71% GSM Experiment

VI.3.1 Before Treading Treatment

Date sampled: 22/8/00

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	1	27.0	318.0	57.50	15.51
			3	43.0	300.0	18.09	43.63
			5	104.0	245.0	8.31	51.02
			7	8.0	206.0	49.43	12.27
			9	106.0	211.0	9.33	33.88
9 hour	1	5-10	2	36.0	200.0	25.20	19.95
			4	21.0	47.0	62.34	1.28
			6	57.0	270.0	21.34	30.43
			8	52.0	388.0	21.19	48.57
			10	31.0	240.0	25.16	25.49
control	2	0-5	11	157.0	270.0	9.34	36.40
			13	34.0	175.0	26.54	16.15
			15	25.0	150.0	44.03	8.74
			17	165.0	265.0	7.48	39.51
			19	34.0	181.0	25.10	18.00
control	2	5-10	12	75.0	352.0	24.16	35.18
			14	28.0	226.0	20.44	29.43
			16	175.0	315.0	12.23	34.84
			18	57.0	245.0	21.48	26.57
			20	76.0	336.0	23.39	33.88
24 hour	3	0-5	21	80.0	290.0	23.42	27.30
			23	26.0	169.0	78.03	5.65
			25	26.0	158.0	27.31	14.78
			27	5.0	60.0	44.28	3.81
			29	119.0	278.0	9.27	51.85
24 hour	3	5-10	22	74.0	251.0	7.15	75.23
			24	9.0	158.0	33.31	13.70
			26	204.0	340.0	6.05	68.89
			28	55.0	232.0	13.01	41.90
			30	65.0	217.0	11.25	41.03
3 hour	4	0-5	32	27.0	163.0	38.26	10.90
			33	58.0	225.0	10.48	47.65
			35	57.0	200.0	14.58	29.44
			37	75.0	173.0	19.26	15.54
			39	5.0	45.0	24.59	4.93
3 hour	4	5-10	31	100.0	187.0	5.37	47.73
			34	152.0	290.0	8.45	48.60
			36	120.0	226.0	5.27	59.93
			38	80.0	245.0	12.37	40.30
			40	135.0	320.0	11.31	49.50
9 hour	5	0-5	41	0.0	70.0	44.00	4.90
			43	46.0	260.0	17.43	37.22
			45	90.0	101.0	34.40	0.98
			47	1.0	53.0	38.01	4.21
			49	5.0	27.0	42.33	1.59
9 hour	5	5-10	42	37.0	181.0	52.29	8.45
			44	62.0	224.0	23.41	21.08
			46	70.0	252.0	15.00	37.39
			48	65.0	194.0	15.05	26.35
			50	50.0	285.0	25.56	27.92
3 hour	6	0-5	51	32.0	201.0	20.04	25.95
			53	180.0	213.0	5.54	17.24
			55	22.0	214.0	6.27	91.73
			57	4.0	61.0	20.57	8.38
			59	25.0	190.0	9.17	54.77
3 hour	6	5-10	52	29.0	212.0	46.55	12.02
			54	36.0	208.0	17.21	30.55
			56	27.0	142.0	43.25	8.16
			58	40.0	158.0	27.18	13.32
			60	45.0	144.0	68.39	4.44
24 hour	7	0-5	61	68.0	205.0	9.15	45.64
			63	29.0	220.0	34.41	16.97
			65	90.0	350.0	11.39	68.77

			67	29.0	188.0	8.22	58.56
			69	150.0	366.0	11.58	55.62
24 hour	7	5-10	62	59.0	356.0	36.47	24.88
			64	102.0	319.0	12.28	53.64
			66	110.0	285.0	19.46	27.28
			68	88.0	201.0	22.53	15.22
			70	74.0	226.0	20.24	22.96
control	8	0-5	71	130.0	355.0	4.47	144.95
			73	110.0	214.0	7.29	42.83
			75	21.0	130.0	43.53	7.65
			77	25.0	159.0	48.55	8.44
			79	34.0	75.0	21.14	5.95
control	8	5-10	72	56.0	197.0	26.57	16.12
			74	25.0	240.0	33.33	19.75
			76	115.0	304.0	11.39	49.99
			78	104.0	334.0	18.50	37.63
			80	46.0	236.0	69.00	8.49
9 hour	9	0-5	81	103.0	335.0	3.30	204.26
			83	6.0	82.0	43.54	5.33
			85	0.0	18.0	52.48	1.05
			87	57.0	280.0	25.52	26.57
			89	20.0	114.0	47.58	6.04
9 hour	9	5-10	82	56.0	216.0	27.59	17.62
			84	10.0	155.0	68.28	6.53
			86	30.0	225.0	15.03	39.93
			88	27.0	200.0	57.06	9.34
			90	14.0	188.0	42.46	12.54
24 hour	10	0-5	91	25.0	260.0	21.56	33.02
			93	120.0	241.0	20.08	18.52
			95	70.0	215.0	9.48	45.59
			97	17.0	106.0	43.39	6.28
			99	17.0	230.0	25.08	26.12
24 hour	10	5-10	92	50.0	220.0	34.58	14.98
			94	32.0	223.0	22.54	25.70
			96	19.0	137.0	26.36	13.67
			98	25.0	225.0	15.01	41.04
			100	122.0	275.0	9.37	49.03
3 hour	11	0-5	101	45.0	391.0	17.20	61.51
			103	85.0	262.0	9.26	57.82
			105	50.0	139.0	30.35	8.97
			107	22.0	77.0	24.18	6.97
			109	38.0	73.0	19.38	5.49
3 hour	11	5-10	102	200.0	327.0	9.56	39.40

			104	21.0	154.0	38.10	10.74
			106	123.0	263.0	22.35	19.10
			108	23.0	153.0	50.46	7.89
			110	68.0	230.0	45.17	11.02
control	12	0-5	111	111.0	266.0	29.36	16.14
			113	66.0	260.0	17.49	33.55
			115	0.0	46.0	34.24	4.12
			117	30.0	366.0	16.32	62.62
			119	73.0	160.0	25.05	10.69
control	12	5-10	112	57.0	280.0	26.36	25.83
			114	60.0	298.0	28.09	26.05
			116	23.0	142.0	49.45	7.37
			118	114.0	130.0	37.28	1.32
			120	30.0	135.0	42.11	7.67

VI.3.2 After Treading Treatment (1-week)

Date sampled: 1/9/00

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	111	70.0	214.0	10.18	43.08
			113	0.0	0.0	0.00	0.10
			115	6.0	10.0	45.25	0.27
			117	36.0	45.0	49.52	0.56
			119	48.0	54.0	42.23	0.44
9 hour	1	5-10	112	47.0	165.0	28.29	12.77
			114	116.0	260.0	7.09	62.06
			116	56.0	151.0	28.00	10.46
			118	5.0	133.0	38.34	10.23
			120	65.0	130.0	28.11	7.11
control	2	0-5	1	0.0	62.0	44.26	4.30
			3	27.0	94.0	29.28	7.01
			5	35.0	189.0	15.46	30.10
			7	0.0	342.0	46.08	22.84
			9	46.0	175.0	36.14	10.97
control	2	5-10	2	35.0	382.0	16.44	63.90
			4	80.0	254.0	18.55	28.34
			6	22.0	191.0	8.15	63.12
			8	68.0	211.0	6.13	70.88
			10	5.0	320.0	22.37	42.92
24 hour	3	0-5	11	16.0	22.0	51.08	0.36
			13	24.0	63.0	46.09	2.60
			15	0.0	0.0	0.00	0.10
			17	0.0	0.0	0.00	0.10
			19	6.0	9.0	42.33	0.22
24 hour	3	5-10	12	34.0	246.0	31.32	20.72
			14	8.0	174.0	40.03	12.77
			16	100.0	350.0	12.33	61.39
			18	33.0	167.0	51.54	7.96
			20	72.0	285.0	20.07	32.63
3 hour	4	0-5	21	73.0	180.0	54.47	6.02
			23	14.0	102.0	51.05	5.31
			25	3.0	43.0	44.17	2.78
			27	4.0	36.0	58.56	1.67
			29	120.0	300.0	9.07	60.84
3 hour	4	5-10	22	31.0	190.0	20.55	23.42
			24	10.0	110.0	44.28	6.93
			26	83.0	261.0	15.01	36.53
			28	18.0	227.0	9.22	68.76
			30	97.0	292.0	16.32	36.34
9 hour	5	0-5	31	20.0	258.0	28.58	25.32
			33	2.0	73.0	37.59	5.76
			35	40.0	63.0	44.10	1.60
			37	85.0	190.0	39.19	8.23
			39	0.0	0.0	0.00	0.10
9 hour	5	5-10	32	62.0	137.0	31.57	7.23
			34	57.0	223.0	14.23	35.56
			36	95.0	200.0	26.42	12.12
			38	0.0	19.0	43.21	1.35
			40	6.0	263.0	33.57	23.33
3 hour	6	0-5	41	31.0	162.0	27.30	14.68
			43	12.0	174.0	42.52	11.65
			45	35.0	62.0	41.02	2.03
			47	17.0	26.0	45.26	0.61
			49	0.0	0.0	0.00	0.10
3 hour	6	5-10	42	50.0	130.0	29.59	8.22
			44	53.0	222.0	15.47	33.00
			46	14.0	250.0	42.37	17.06
			48	0.0	113.0	43.41	7.97
			50	30.0	145.0	45.26	7.80
24 hour	7	0-5	51	89.0	197.0	42.00	7.92
			53	0.0	0.0	0.00	0.10
			55	39.0	195.0	20.18	23.68
			57	116.0	200.0	42.25	6.10
			59	28.0	196.0	48.35	10.66
24 hour	7	5-10	52	4.0	31.0	47.25	1.75
			54	9.0	149.0	50.24	8.56
			56	7.0	12.0	53.45	0.29
			58	9.0	177.0	50.17	10.30

			60	15.0	176.0	24.42	20.09
control	8	0-5	61	72.0	162.0	14.45	18.80
			63	0.0	256.0	50.07	15.74
			65	0.0	39.0	47.05	2.55
			67	0.0	35.0	48.30	2.22
			69	18.0	202.0	27.15	20.81
control	8	5-10	62	17.0	315.0	39.22	23.33
			64	21.0	194.0	21.23	24.93
			66	105.0	268.0	9.52	50.91
			68	200.0	307.0	26.01	12.67
			70	136.0	308.0	9.23	56.49
9 hour	9	0-5	71	0.0	0.0	0.00	0.10
			73	20.0	160.0	45.18	9.52
			75	12.0	46.0	47.59	2.18
			77	11.0	175.0	31.17	16.15
			79	0.0	0.0	0.00	0.10
9 hour	9	5-10	72	50.0	84.0	43.07	2.43
			74	13.0	219.0	40.31	15.67
			76	49.0	215.0	28.55	17.69
			78	0.0	9.0	47.22	0.59
			80	14.0	129.0	47.11	7.51
24 hour	10	0-5	81	102.0	238.0	11.48	35.52
			83	156.0	441.0	16.39	52.75
			85	29.0	118.0	46.54	5.85
			87	138.0	142.0	42.13	0.29
			89	170.0	286.0	14.45	24.23
24 hour	10	5-10	82	66.0	320.0	19.17	40.59
			84	30.0	124.0	69.04	4.19
			86	139.0	315.0	12.32	43.27
			88	10.0	178.0	45.14	11.45
			90	5.0	39.0	42.45	2.45
3 hour	11	0-5	91	75.0	151.0	44.55	5.21
			93	52.0	67.0	46.57	0.98
			95	135.0	385.0	10.53	70.79
			97	31.0	386.0	28.30	38.38
			99	3.0	23.0	42.57	1.43
3 hour	11	5-10	92	6.0	188.0	42.55	13.07
			94	72.0	360.0	18.36	47.71
			96	30.0	135.0	22.13	14.56
			98	76.0	225.0	11.45	39.08
			100	13.0	300.0	33.26	26.45
control	12	0-5	101	106.0	278.0	10.20	51.29
			103	10.0	209.0	46.35	13.16
			105	42.0	367.0	13.43	73.01
			107	34.0	152.0	46.34	7.81
			109	15.0	360.0	21.02	50.55
control	12	5-10	102	139.0	278.0	11.48	36.30
			104	0.0	332.0	43.12	23.68
			106	5.0	210.0	43.24	14.56
			108	20.0	273.0	14.47	52.74
			110	9.0	252.0	25.33	29.31

VI.3.3 After Treading Treatment (4-weeks)

Date sampled: 28/9/00

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	1	234.0	373.0	8.21	51.30
			3	40.0	289.0	14.35	52.62
			5	9.0	118.0	68.46	4.88
			7	16.0	200.0	50.15	11.28
			9	40.0	269.0	22.00	32.08
9 hour	1	5-10	2	2.0	197.0	38.03	15.79
			4	8.0	200.0	45.42	12.95
			6	5.0	311.0	34.06	27.65
			8	82.0	309.0	30.34	22.88
			10	64.0	370.0	8.52	106.35
control	2	0-5	11	11.0	391.0	16.48	69.70
			13	50.0	362.0	20.53	46.04
			15	109.0	234.0	17.11	22.42
			17	42.0	246.0	12.21	50.90
			19	10.0	397.0	5.43	208.61
control	2	5-10	12	2.0	313.0	18.46	51.07
			14	86.0	270.0	15.41	36.15
			16	56.0	315.0	22.57	34.78
			18	101.0	320.0	11.27	58.94
			20	28.0	377.0	14.28	74.34
24 hour	3	0-5	21	61.0	225.0	49.08	10.29
			23	81.0	236.0	17.14	27.72
			25	19.0	192.0	79.57	6.67
			27	163.0	224.0	8.49	21.32
			29	75.0	311.0	16.30	44.08
24 hour	3	5-10	22	0.0	307.0	26.16	36.02
			24	85.0	266.0	14.45	37.81
			26	165.0	286.0	16.11	23.04
			28	0.0	185.0	36.56	15.44
			30	51.0	275.0	9.31	72.53
3 hour	4	0-5	31	35.0	312.0	12.30	68.29
			33	0.0	165.0	33.33	15.16
			35	8.0	265.0	21.12	37.36
			37	9.0	312.0	20.51	44.78
			39	13.0	244.0	19.39	36.23
3 hour	4	5-10	32	74.0	347.0	18.32	45.39
			34	56.0	295.0	22.08	33.28
			36	17.0	306.0	22.26	39.70
			38	106.0	306.0	65.27	9.42
			40	115.0	455.0	8.45	119.74
9 hour	5	0-5	41	1.0	124.0	58.08	6.52
			43	11.0	417.0	24.34	50.93
			45	0.0	211.0	38.57	16.69
			47	0.0	78.0	46.19	5.19
			49	54.0	365.0	23.41	40.47
9 hour	5	5-10	42	0.0	72.0	33.07	6.70
			44	16.0	284.0	15.56	51.83
			46	0.0	286.0	28.51	30.55
			48	66.0	119.0	62.32	2.61
			50	1.0	19.0	40.55	1.36
3 hour	6	0-5	51	9.0	226.0	20.58	31.89
			53	30.0	300.0	16.40	49.92
			55	43.0	234.0	32.24	18.17
			57	0.0	144.0	38.16	11.60
			59	8.0	193.0	43.52	13.00
3 hour	6	5-10	52	31.0	291.0	21.49	36.72
			54	83.0	291.0	34.10	18.76
			56	126.0	247.0	20.38	18.07
			58	0.0	245.0	61.43	12.23
			60	31.0	356.0	24.26	40.99
24 hour	7	0-5	61	94.0	108.0	37.47	1.14
			63	25.0	268.0	59.34	12.57
			65	0.0	29.0	44.32	2.01
			67	41.0	116.0	56.16	4.11
			69	69.0	288.0	49.32	13.62
24 hour	7	5-10	62	16.0	84.0	33.04	6.34
			64	206.0	340.0	15.04	27.41
			66	17.0	221.0	29.19	21.44
			68	0.0	242.0	29.03	25.67

			70	41.0	75.0	42.05	2.49
control	8	0-5	71	28.0	440.0	29.34	42.94
			73	76.0	400.0	8.46	113.89
			75	135.0	358.0	5.19	129.25
			77	65.0	446.0	37.08	31.62
			79	20.0	231.0	10.24	62.52
control	8	5-10	72	9.0	330.0	44.22	22.30
			74	130.0	294.0	10.34	47.83
			76	185.0	350.0	5.19	95.63
			78	120.0	373.0	29.36	26.34
			80	7.0	263.0	33.38	23.46
9 hour	9	0-5	81	56.0	235.0	13.23	41.22
			83	51.0	391.0	13.12	79.37
			85	40.0	260.0	27.00	25.11
			87	15.0	360.0	27.25	38.78
			89	9.0	120.0	35.28	9.64
9 hour	9	5-10	82	35.0	280.0	24.40	30.61
			84	56.0	175.0	39.21	9.32
			86	6.0	94.0	38.45	7.00
			88	6.0	222.0	30.23	21.91
			90	12.0	335.0	62.34	15.91
24 hour	10	0-5	91	194.0	354.0	13.09	37.49
			93	130.0	294.0	7.59	63.30
			95	95.0	359.0	9.38	84.45
			97	47.0	91.0	31.39	4.28
			99	11.0	355.0	55.53	18.97
24 hour	10	5-10	92	17.0	87.0	53.02	4.07
			94	25.0	172.0	58.04	7.80
			96	16.0	274.0	47.20	16.80
			98	95.0	201.0	44.32	7.33
			100	31.0	94.0	52.18	3.71
3 hour	11	0-5	101	85.0	440.0	9.14	118.48
			103	135.0	338.0	16.14	38.54
			105	4.0	197.0	49.56	11.91
			107	56.0	199.0	39.07	11.27
			109	4.0	64.0	31.09	5.94
3 hour	11	5-10	102	70.0	205.0	66.02	6.30
			104	0.0	270.0	38.56	21.37
			106	18.0	395.0	41.16	28.15
			108	120.0	353.0	47.14	15.20
			110	49.0	382.0	24.11	42.43
control	12	0-5	111	34.0	321.0	8.44	101.27
			113	21.0	308.0	57.47	15.31

			115	5.0	249.0	13.59	53.77
			117	2.0	291.0	39.38	22.47
			119	39.0	430.0	13.56	86.47
control	12	5-10	112	10.0	365.0	30.11	36.24
			114	37.0	321.0	22.24	39.07
			116	82.0	372.0	17.17	51.71
			118	25.0	428.0	14.38	84.87
			120	70.0	304.0	9.34	75.37

VI.3.4 After Treading Treatment (13-weeks)

Date sampled: 23/11/00

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{40} (mm hr^{-1})
9 hour	1	0-5	1	118.0	215.0	2.19	129.03
			3	1.0	84.0	51.16	4.99
			5	26.0	150.0	7.44	49.41
			7	67.0	333.0	6.46	121.14
			9	9.0	212.0	10.27	59.86
9 hour	1	5-10	2	15.0	320.0	14.27	65.04
			4	0.0	249.0	15.24	49.82
			6	30.0	276.0	14.29	52.34
			8	21.0	305.0	14.55	58.67
			10	54.0	355.0	9.40	95.95
control	2	0-5	11	32.0	210.0	7.06	77.26
			13	14.0	225.0	14.09	45.95
			15	59.0	345.0	8.30	103.68
			17	25.0	361.0	11.05	93.42
			19	69.0	381.0	6.37	145.31
control	2	5-10	12	15.0	305.0	13.01	68.65
			14	0.0	321.0	20.13	48.93
			16	80.0	270.0	3.31	166.49
			18	24.0	282.0	16.50	47.23
			20	130.0	304.0	8.10	65.66
24 hour	3	0-5	21	20.0	319.0	13.20	69.10
			23	0.0	286.0	12.54	68.32
			25	10.0	235.0	17.47	38.99
			27	16.0	334.0	6.49	143.75
			29	31.0	256.0	8.52	78.20
24 hour	3	5-10	22	0.0	257.0	33.45	23.47
			24	11.0	329.0	15.57	61.44
			26	0.0	288.0	20.02	44.30
			28	165.0	350.0	4.02	141.34
			30	0.0	190.0	11.14	52.12
3 hour	4	0-5	31	5.0	295.0	10.23	86.07
			33	6.0	241.0	37.20	19.40
			35	52.0	240.0	9.03	64.01
			37	8.0	312.0	25.30	36.74
			39	16.0	210.0	15.30	38.57
3 hour	4	5-10	32	26.0	383.0	12.17	89.56
			34	6.0	336.0	24.34	41.39
			36	17.0	321.0	14.39	63.94
			38	94.0	320.0	12.43	54.76
			40	19.0	245.0	22.59	30.30
9 hour	5	0-5	41	118.0	365.0	3.30	217.47
			43	10.0	375.0	9.56	113.23
			45	1.0	274.0	23.05	36.44
			47	265.0	385.0	2.07	174.70
			49	17.0	345.0	7.11	140.71
9 hour	5	5-10	42	5.0	201.0	17.41	34.16
			44	20.0	285.0	14.00	58.33
			46	21.0	275.0	15.16	51.27
			48	30.0	331.0	17.43	52.35
			50	15.0	245.0	12.39	56.03
3 hour	6	0-5	51	55.0	336.0	9.37	90.04
			53	19.0	270.0	15.20	50.44
			55	35.0	250.0	36.05	18.36
			57	13.0	387.0	35.10	32.77
			59	2.0	156.0	38.28	12.34
3 hour	6	5-10	52	125.0	315.0	5.37	104.24
			54	1.0	206.0	46.17	13.65
			56	7.0	145.0	44.11	9.62
			58	0.0	213.0	48.00	13.67
			60	15.0	210.0	37.51	15.88
24 hour	7	0-5	61	40.0	265.0	17.59	38.55
			63	175.0	273.0	40.17	7.50
			65	70.0	190.0	2.31	146.93
			67	15.0	192.0	26.37	20.49
			69	20.0	150.0	8.07	49.36
24 hour	7	5-10	62	28.0	264.0	23.02	31.57
			64	1.0	260.0	48.18	16.52
			66	0.0	214.0	58.14	11.32
			68	0.0	322.0	31.47	31.22

			70	0.0	286.0	33.40	26.18
control	8	0-5	71	16.0	287.0	9.25	88.68
			73	90.0	375.0	7.04	124.28
			75	12.0	340.0	18.20	55.13
			77	1.0	262.0	9.45	82.49
			79	9.0	283.0	10.06	83.60
control	8	5-10	72	151.0	370.0	2.10	311.47
			74	90.0	341.0	9.31	81.27
			76	38.0	287.0	17.36	43.60
			78	25.0	298.0	13.10	63.89
			80	97.0	345.0	5.40	134.86
9 hour	9	0-5	81	91.0	237.0	15.02	29.93
			83	0.0	274.0	15.50	53.33
			85	30.0	326.0	4.39	196.16
			87	4.0	377.0	24.02	47.83
			89	4.0	302.0	14.09	64.90
9 hour	9	5-10	82	12.0	264.0	32.28	23.92
			84	1.0	249.0	20.21	37.55
			86	26.0	234.0	11.36	55.26
			88	0.0	216.0	31.36	21.06
			90	91.0	320.0	3.95	153.96
24 hour	10	0-5	91	50.0	296.0	12.14	61.97
			93	11.0	381.0	8.43	130.80
			95	34.0	256.0	11.15	60.81
			97	206.0	375.0	4.12	124.00
			99	9.0	270.0	9.49	81.93
24 hour	10	5-10	92	54.0	330.0	8.14	103.30
			94	5.0	277.0	13.24	62.55
			96	0.0	282.0	15.26	56.31
			98	1.0	276.0	19.52	42.66
			100	266.0	395.0	2.35	153.88
3 hour	11	0-5	101	5.0	329.0	20.39	48.35
			103	25.0	244.0	10.31	64.17
			105	9.0	237.0	11.17	62.27
			107	0.0	238.0	7.27	98.44
			109	19.0	277.0	17.13	46.18
3 hour	11	5-10	102	25.0	295.0	14.10	58.73
			104	10.0	247.0	33.23	21.88
			106	0.0	347.0	22.48	46.90
			108	20.0	251.0	17.36	40.45
			110	0.0	282.0	32.43	26.56
control	12	0-5	111	12.0	215.0	23.30	26.62
			113	2.0	248.0	10.26	72.66

			115	40.0	370.0	7.35	134.10
			117	20.0	370.0	4.27	242.37
			119	6.0	286.0	15.43	54.90
control	12	5-10	112	2.0	322.0	27.53	35.36
			114	16.0	200.0	11.40	48.60
			116	3.0	350.0	14.34	73.41
			118	34.0	330.0	14.17	63.86
			120	6.0	301.0	11.14	80.92

VI.3.5 After Treading Treatment (26-weeks)

Date sampled: 19/2/01

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	1	40.0	440.0	14.23	85.70
			4	44.0	326.0	7.54	110.00
			6	11.0	218.0	32.20	19.73
			7	120.0	323.0	4.39	134.53
			9	222.0	317.0	4.01	72.88
9 hour	1	5-10	2	21.0	326.0	9.00	104.43
			3	36.0	330.0	9.20	97.07
			5	54.0	411.0	11.46	93.49
			8	20.0	312.0	10.44	83.83
			10	110.0	330.0	7.31	90.19
control	2	0-5	11	49.0	360.0	7.53	121.57
			13	9.0	284.0	16.08	52.53
			15	32.0	296.0	6.20	128.45
			17	17.0	315.0	12.08	75.68
			19	8.0	390.0	5.56	198.40
control	2	5-10	12	81.0	351.0	5.39	147.26
			14	6.0	324.0	27.59	35.02
			16	106.0	350.0	4.15	176.92
			18	66.0	480.0	10.50	117.76
			20	86.0	425.0	6.11	168.94
24 hour	3	0-5	21	95.0	340.0	4.19	174.90
			23	45.0	330.0	13.29	65.14
			25	96.0	500.0	6.59	178.27
			27	85.0	288.0	4.54	127.66
			29	24.0	298.0	8.55	94.69
24 hour	3	5-10	22	60.0	317.0	9.17	85.31
			24	41.0	296.0	8.14	95.44
			26	97.0	350.0	4.16	182.73
			28	62.0	303.0	8.51	83.92
			30	15.0	427.0	13.11	96.30
3 hour	4	0-5	31	44.0	406.0	10.55	102.18
			33	0.0	313.0	9.25	102.43
			35	14.0	203.0	6.54	84.41
			37	85.0	403.0	7.28	131.24
			39	0.0	152.0	7.30	62.45
3 hour	4	5-10	32	10.0	362.0	9.11	118.12
			34	41.0	325.0	8.17	105.65
			36	46.0	390.0	6.41	158.61
			38	65.0	425.0	16.42	66.43
			40	58.0	394.0	8.57	115.69
9 hour	5	0-5	41	0.0	110.0	14.13	23.84
			43	30.0	354.0	6.15	159.75
			45	48.0	291.0	19.38	38.14
			47	88.0	370.0	8.58	96.91
			49	16.0	301.0	14.48	59.34
9 hour	5	5-10	42	18.0	397.0	11.03	105.69
			44	58.0	284.0	13.01	53.50
			46	26.0	307.0	9.24	92.12
			48	71.0	435.0	10.28	107.17
			50	50.0	313.0	5.55	136.98
3 hour	6	0-5	51	144.0	436.0	6.02	149.14
			53	10.0	322.0	10.50	88.75
			55	13.0	155.0	9.38	45.42
			57	52.0	230.0	4.15	129.06
			59	66.0	340.0	21.17	39.67
3 hour	6	5-10	52	178.0	357.0	3.44	147.75
			54	18.0	264.0	15.33	48.75
			56	42.0	319.0	33.42	25.33
			58	0.0	285.0	32.59	26.63
			60	150.0	376.0	7.01	99.25
24 hour	7	0-5	61	47.0	196.0	5.11	88.58
			63	0.0	218.0	6.55	97.12
			65	18.0	229.0	10.00	65.02
			67	13.0	191.0	18.43	29.31
			69	182.0	387.0	3.08	201.61
24 hour	7	5-10	62	2.0	162.0	36.59	13.33
			64	20.0	400.0	17.44	66.03
			66	56.0	340.0	19.03	45.94
			68	0.0	440.0	6.17	215.79

			70	11.0	359.0	27.39	38.78
control	8	0-5	71	110.0	341.0	2.34	277.34
			73	17.0	228.0	8.15	78.81
			75	134.0	310.0	3.01	179.78
			77	110.0	331.0	8.58	75.95
			79	20.0	260.0	6.39	111.21
control	8	5-10	72	32.0	345.0	10.34	91.28
			74	19.0	452.0	19.11	69.56
			76	31.0	348.0	12.01	81.29
			78	135.0	402.0	6.41	123.11
			80	70.0	318.0	10.14	74.68
9 hour	9	0-5	81	6.0	350.0	20.21	52.09
			83	72.0	390.0	7.56	123.52
			85	18.0	285.0	15.58	51.53
			87	64.0	383.0	12.29	78.75
			89	20.0	328.0	17.22	54.65
9 hour	9	5-10	82	40.0	449.0	19.57	63.18
			84	65.0	306.0	9.15	80.29
			86	43.0	286.0	18.14	41.07
			88	40.0	400.0	8.03	137.81
			90	191.0	328.0	5.38	74.94
24 hour	10	0-5	91	47.0	341.0	9.36	94.37
			93	162.0	431.0	2.20	355.26
			95	61.0	225.0	5.00	101.07
			97	33.0	382.0	12.45	84.35
			99	116.0	250.0	2.32	163.00
24 hour	10	5-10	92	110.0	321.0	3.18	197.03
			94	67.0	390.0	15.09	65.70
			96	25.0	352.0	17.30	57.58
			98	98.0	380.0	5.59	145.24
			100	98.0	376.0	8.42	98.47
3 hour	11	0-5	101	30.0	342.0	13.07	73.30
			103	64.0	268.0	4.41	134.23
			105	90.0	301.0	4.04	159.89
			107	74.0	334.0	3.49	209.92
			109	24.0	410.0	8.32	139.39
3 hour	11	5-10	102	81.0	395.0	9.45	99.24
			104	20.0	330.0	12.15	77.98
			106	74.0	351.0	5.56	143.86
			108	56.0	270.0	13.34	48.61
			110	85.0	348.0	5.08	157.88
control	12	0-5	111	0.0	241.0	7.20	101.27
			113	21.0	390.0	6.55	164.40

			115	49.0	382.0	7.39	134.14
			117	98.0	386.0	5.14	169.58
			119	7.0	270.0	11.49	68.58
control	12	5-10	112	8.0	216.0	7.03	90.92
			114	96.0	330.0	5.49	123.97
			116	77.0	302.0	5.39	122.72
			118	20.0	337.0	7.00	139.55
			120	238.0	311.0	1.42	132.32

VI.4 Individual Results for 81% GSM Experiment

VI.4.1 Before Treading Treatment

Date sampled: 28/7/01

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	1	0.0	291.0	27.18	32.85
			3	32.0	211.0	21.38	25.50
			5	77.0	300.0	9.32	72.08
			7	87.0	280.0	14.39	40.60
			9	10.0	76.0	42.58	4.73
9 hour	1	5-10	2	21.0	323.0	9.59	93.22
			4	148.0	290.0	4.10	105.02
			6	24.0	162.0	21.21	19.92
			8	34.0	99.0	27.25	7.31
			10	25.0	232.0	31.36	20.19
control	2	0-5	11	1.0	88.0	33.28	8.01
			13	14.0	287.0	26.31	31.73
			15	8.0	296.0	43.05	20.60
			17	1.0	105.0	35.54	8.93
			19	0.0	350.0	43.14	24.95
control	2	5-10	12	46.0	204.0	15.49	30.78
			14	52.0	221.0	13.44	37.92
			16	18.0	267.0	27.01	28.40
			18	38.0	159.0	21.26	17.40
			20	0.0	266.0	27.44	29.56
24 hour	3	0-5	21	0.0	105.0	29.19	11.04
			23	86.0	370.0	18.58	46.14
			25	56.0	344.0	9.16	95.77
			27	41.0	307.0	47.16	17.34
			29	36.0	192.0	43.12	11.13
24 hour	3	5-10	22	0.0	41.0	37.10	3.40
			24	11.0	143.0	27.29	14.80
			26	121.0	270.0	3.06	148.11
			28	0.0	339.0	9.55	105.34
			30	35.0	252.0	26.05	25.64
control	4	0-5	32	105.0	269.0	7.54	63.97
			33	48.0	403.0	36.59	29.58
			35	38.0	81.0	43.49	3.02
			37	4.0	265.0	46.35	17.27
			39	40.0	339.0	19.16	47.82
control	4	5-10	31	9.0	209.0	50.42	12.16
			34	60.0	279.0	22.12	30.40
			36	32.0	215.0	19.21	29.14
			38	0.0	302.0	26.04	35.70
			40	0.0	86.0	37.03	7.15
24 hour	5	0-5	41	10.0	236.0	31.47	21.91
			43	8.0	283.0	15.37	54.26
			45	185.0	469.0	4.23	199.66
			47	67.0	461.0	7.53	154.01
			49	50.0	300.0	23.13	33.18
24 hour	5	5-10	42	34.0	153.0	21.27	17.10
			44	45.0	256.0	10.52	59.83
			46	24.0	188.0	23.21	21.64
			48	21.0	149.0	12.27	31.68
			50	4.0	131.0	23.27	16.69
9 hour	6	0-5	51	10.0	425.0	14.21	89.12
			53	0.0	308.0	39.50	23.83
			55	26.0	221.0	18.37	32.28
			57	32.0	228.0	45.17	13.34
			59	5.0	375.0	42.11	27.03
9 hour	6	5-10	52	45.0	208.0	13.00	38.64
			54	35.0	290.0	11.29	68.43
			56	90.0	250.0	5.55	83.33
			58	38.0	206.0	31.09	16.62
			60	0.0	71.0	29.31	7.41
3 hour	7	0-5	61	6.0	381.0	45.21	25.48
			63	65.0	395.0	13.42	74.23
			65	67.0	435.0	18.58	59.79

			67	34.0	435.0	27.05	45.63
			69	5.0	120.0	44.57	7.88
3 hour	7	5-10	62	39.0	150.0	13.20	25.65
			64	7.0	330.0	23.39	42.09
			66	0.0	167.0	40.01	12.86
			68	66.0	295.0	12.53	54.77
			70	29.0	224.0	21.27	28.01
control	8	0-5	71	21.0	437.0	55.53	22.94
			73	130.0	440.0	7.58	119.91
			75	96.0	395.0	6.27	142.85
			77	14.0	406.0	15.27	78.19
			79	40.0	290.0	18.21	41.98
control	8	5-10	72	26.0	351.0	16.33	60.51
			74	14.0	208.0	38.42	15.45
			76	19.0	236.0	9.19	71.77
			78	8.0	194.0	29.11	19.64
			80	20.0	245.0	18.58	36.56
9 hour	9	0-5	81	61.0	356.0	44.21	20.50
			83	72.0	317.0	44.28	16.98
			85	0.0	240.0	41.41	17.74
			87	0.0	381.0	56.21	20.84
			89	0.0	321.0	55.42	17.76
9 hour	9	5-10	82	1.0	204.0	24.19	25.73
			84	42.0	161.0	21.36	16.98
			86	32.0	221.0	22.48	25.54
			88	4.0	145.0	36.57	11.76
			90	2.0	162.0	9.34	51.54
3 hour	10	0-5	91	90.0	211.0	42.59	8.67
			93	8.0	296.0	37.30	23.67
			95	16.0	235.0	19.20	34.91
			97	46.0	315.0	5.11	159.92
			99	100.0	364.0	8.19	97.82
3 hour	10	5-10	92	3.0	15.0	55.12	0.67
			94	46.0	387.0	27.01	38.89
			96	0.0	64.0	45.52	4.30
			98	7.0	103.0	30.44	9.63
			100	1.0	71.0	33.30	6.44
24 hour	11	0-5	101	14.0	400.0	15.20	77.57
			103	16.0	200.0	24.12	23.43
			105	0.0	134.0	23.13	17.79
			107	47.0	225.0	29.10	18.81
			109	0.0	378.0	42.15	27.57
24 hour	11	5-10	102	0.0	164.0	30.36	16.52

			104	26.0	272.0	23.34	32.17
			106	31.0	244.0	14.53	44.10
			108	76.0	328.0	15.23	50.48
			110	39.0	350.0	40.47	23.50
3 hour	12	0-5	111	11.0	306.0	35.35	25.55
			113	30.0	402.0	10.39	107.64
			115	4.0	39.0	42.29	2.54
			117	35.0	216.0	9.28	58.92
			119	58.0	321.0	14.36	55.51
3 hour	12	5-10	112	0.0	191.0	23.45	24.78
			114	2.0	325.0	46.39	21.34
			116	167.0	380.0	9.49	66.86
			118	0.0	171.0	26.31	19.87
			120	71.0	313.0	23.09	32.21

VI.4.2 After Treading Treatment (1-week)

Date sampled: 9/8/01

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	1	2.0	3.0	35.21	0.10
			3	0.0	314.0	36.28	26.53
			5	24.0	406.0	25.20	46.47
			7	15.0	317.0	25.21	36.71
			9	0.0	202.0	27.58	22.26
9 hour	1	5-10	2	13.0	314.0	40.23	22.97
			4	5.0	355.0	26.08	41.27
			6	4.0	14.0	41.24	0.74
			8	54.0	180.0	19.00	20.44
			10	0.0	0.0	0.00	0.10
control	2	0-5	11	21.0	410.0	17.20	69.16
			13	10.0	299.0	26.54	33.11
			15	10.0	320.0	9.25	101.45
			17	21.0	325.0	12.44	73.57
			19	15.0	304.0	46.19	19.23
control	2	5-10	12	11.0	215.0	37.48	16.63
			14	35.0	245.0	11.39	55.55
			16	0.0	51.0	42.20	3.71
			18	118.0	208.0	6.10	44.97
			20	6.0	221.0	44.08	15.01
24 hour	3	0-5	21	48.0	270.0	60.42	11.27
			23	6.0	320.0	51.42	18.72
			25	6.0	23.0	55.48	0.94
			27	7.0	156.0	55.23	8.29
			29	4.0	344.0	22.33	46.46
24 hour	3	5-10	22	10.0	191.0	27.32	20.26
			24	56.0	92.0	55.26	2.00
			26	5.0	92.0	40.42	6.59
			28	11.0	18.0	16.20	1.32
			30	96.0	407.0	10.25	92.00
control	4	0-5	31	0.0	285.0	8.12	107.10
			33	0.0	80.0	30.53	7.98
			35	14.0	360.0	29.04	36.68
			37	0.0	266.0	25.17	32.42
			39	13.0	280.0	20.18	40.53
control	4	5-10	32	8.0	201.0	40.43	14.61
			34	0.0	105.0	58.45	5.51
			36	0.0	120.0	52.11	7.09
			38	21.0	332.0	18.59	50.48
			40	3.0	277.0	31.45	26.59
24 hour	5	0-5	41	0.0	2.0	47.29	0.13
			43	164.0	224.0	9.29	19.50
			45	119.0	356.0	12.18	59.38
			47	11.0	132.0	61.19	6.08
			49	0.0	332.0	40.01	25.57
24 hour	5	5-10	42	81.0	180.0	52.25	5.82
			44	125.0	271.0	21.14	21.19
			46	26.0	167.0	50.33	8.60
			48	12.0	21.0	52.57	0.52
			50	6.0	100.0	50.58	5.68
9 hour	6	0-5	51	67.0	433.0	6.57	162.28
			53	12.0	302.0	40.12	22.23
			55	24.0	215.0	31.31	18.68
			57	16.0	293.0	28.08	30.34
			59	0.0	0.0	0.00	0.10
9 hour	6	5-10	52	62.0	166.0	21.04	15.21
			54	6.0	239.0	28.01	25.63
			56	36.0	255.0	45.05	14.97
			58	0.0	385.0	38.29	30.83
			60	0.0	114.0	44.21	7.92
3 hour	7	0-5	61	35.0	422.0	21.50	54.62
			63	27.0	334.0	31.18	30.22
			65	1.0	264.0	61.30	13.18
			67	11.0	416.0	24.13	51.54
			69	9.0	379.0	25.22	44.95
3 hour	7	5-10	62	14.0	235.0	46.25	14.67
			64	60.0	143.0	56.22	4.54

			66	31.0	282.0	19.70	38.35
			68	10.0	400.0	21.00	57.23
			70	0.0	297.0	44.15	20.68
control	8	0-5	71	25.0	237.0	39.28	16.55
			73	25.0	333.0	31.45	29.89
			75	10.0	325.0	48.07	20.17
			77	16.0	269.0	31.17	24.92
			79	5.0	335.0	43.58	23.13
control	8	5-10	72	0.0	330.0	49.50	20.41
			74	38.0	364.0	15.21	65.45
			76	48.0	211.0	30.23	16.53
			78	1.0	420.0	14.22	89.87
			80	92.0	167.0	53.44	4.30
9 hour	9	0-5	81	30.0	394.0	20.48	53.93
			83	25.0	171.0	51.20	8.76
			85	1.0	19.0	49.52	1.11
			87	4.0	165.0	46.25	10.69
			89	13.0	18.0	43.06	0.36
9 hour	9	5-10	82	19.0	70.0	41.19	3.80
			84	0.0	56.0	51.19	3.36
			86	13.0	298.0	27.04	32.45
			88	0.0	12.0	51.41	0.72
			90	66.0	351.0	35.37	24.66
3 hour	10	0-5	91	35.0	333.0	12.32	73.27
			93	16.0	182.0	40.08	12.75
			95	21.0	282.0	36.59	21.75
			97	2.0	20.0	47.52	1.16
			99	24.0	265.0	36.36	20.29
3 hour	10	5-10	92	20.0	387.0	31.01	36.46
			94	11.0	69.0	41.33	4.30
			96	12.0	261.0	27.12	28.21
			98	51.0	420.0	20.10	56.38
			100	0.0	311.0	48.11	19.89
24 hour	11	0-5	101	41.0	341.0	26.33	34.82
			103	5.0	75.0	46.19	4.66
			105	15.0	296.0	35.51	24.15
			107	3.0	68.0	54.22	3.68
			109	0.0	8.0	62.00	0.40
24 hour	11	5-10	102	4.0	270.0	31.23	26.12
			104	5.0	100.0	44.33	6.57
			106	138.0	156.0	53.48	1.03
			108	46.0	335.0	14.50	60.04
			110	12.0	130.0	19.30	18.65
3 hour	12	0-5	111	25.0	70.0	42.47	3.24
			113	19.0	330.0	24.17	39.47
			115	21.0	94.0	46.56	4.79
			117	34.0	421.0	27.17	43.71
			119	5.0	292.0	27.52	31.74
3 hour	12	5-10	112	66.0	272.0	20.48	30.52
			114	122.0	342.0	11.32	58.78
			116	8.0	209.0	18.17	33.88
			118	4.0	218.0	10.56	60.32
			120	11.0	234.0	20.19	33.82

VI.4.3 After Treading Treatment (4-weeks)

Date sampled: 6/9/01

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{40} (mm hr^{-1})
9 hour	1	0-5	1	34.0	402.0	18.12	62.31
			3	49.0	490.0	8.04	168.47
			5	20.0	309.0	12.38	70.49
			7	9.0	372.0	16.59	65.86
			9	20.0	388.0	15.49	71.70
9 hour	1	5-10	2	0.0	0.0	0.00	1.85
			4	16.0	348.0	14.07	72.47
			6	10.0	40.0	40.19	2.29
			8	21.0	244.0	30.13	22.74
			10	5.0	249.0	32.48	22.92
control	2	0-5	11	81.0	297.0	4.38	143.66
			13	42.0	347.0	17.11	54.70
			15	35.0	365.0	13.57	72.90
			17	54.0	368.0	11.18	85.63
			19	80.0	360.0	3.54	221.24
control	2	5-10	12	6.0	310.0	21.55	42.74
			14	2.0	51.0	27.21	5.52
			16	16.0	93.0	29.13	8.12
			18	9.0	91.0	43.05	5.87
			20	23.0	135.0	29.18	11.78
24 hour	3	0-5	21	38.0	136.0	26.31	11.39
			23	52.0	415.0	7.49	143.10
			25	86.0	360.0	5.00	168.87
			27	132.0	372.0	2.55	253.57
			29	62.0	334.0	17.15	48.59
24 hour	3	5-10	22	13.0	54.0	30.52	4.09
			24	25.0	166.0	42.19	10.27
			26	113.0	229.0	10.57	32.64
			28	0.0	39.0	22.46	5.28
			30	16.0	257.0	31.05	23.89
control	4	0-5	31	31.0	294.0	29.37	27.36
			33	15.0	239.0	14.35	47.33
			35	49.0	268.0	15.46	42.80
			37	6.0	135.0	9.15	42.97
			39	30.0	302.0	8.57	93.65
control	4	5-10	32	0.0	217.0	45.39	14.65
			34	11.0	81.0	17.18	12.47
			36	26.0	173.0	30.20	14.93
			38	76.0	319.0	23.36	31.73
			40	35.0	355.0	35.57	27.43
24 hour	5	0-5	41	35.0	187.0	18.29	25.34
			43	45.0	254.0	8.42	74.03
			45	2.0	279.0	42.08	20.26
			47	34.0	360.0	42.13	23.80
			49	105.0	315.0	17.15	37.51
24 hour	5	5-10	42	69.0	362.0	37.21	24.17
			44	0.0	221.0	21.46	31.29
			46	5.0	294.0	21.34	41.29
			48	100.0	142.0	15.22	8.42
			50	17.0	376.0	24.42	44.79
9 hour	6	0-5	51	106.0	427.0	4.24	224.81
			53	86.0	430.0	5.31	192.15
			55	35.0	240.0	17.05	36.98
			57	36.0	247.0	8.23	77.56
			59	29.0	380.0	15.16	70.85
9 hour	6	5-10	52	105.0	132.0	16.29	5.05
			54	95.0	221.0	7.41	50.53
			56	1.0	229.0	45.13	15.54
			58	15.0	174.0	24.50	19.73
			60	0.0	51.0	43.46	3.59
3 hour	7	0-5	61	12.0	331.0	24.40	39.85
			63	46.0	332.0	14.17	61.70
			65	81.0	371.0	6.38	134.72
			67	56.0	194.0	8.12	51.86
			69	130.0	470.0	5.24	194.02
3 hour	7	5-10	62	5.0	174.0	15.24	33.82
			64	12.0	289.0	15.11	56.22
			66	30.0	435.0	21.47	57.29
			68	6.0	142.0	21.53	19.15

			70	8.0	336.0	23.14	43.50
control	8	0-5	71	34.0	340.0	25.06	37.57
			73	33.0	391.0	22.31	48.99
			75	65.0	480.0	8.56	143.15
			77	75.0	357.0	10.01	86.75
			79	88.0	328.0	11.13	65.93
control	8	5-10	72	118.0	143.0	16.01	4.81
			74	63.0	135.0	16.55	13.12
			76	10.0	350.0	20.41	50.66
			78	19.0	425.0	21.43	57.61
			80	102.0	195.0	16.19	17.56
9 hour	9	0-5	81	30.0	190.0	36.20	13.57
			83	11.0	296.0	24.57	35.20
			85	29.0	330.0	7.58	116.43
			87	15.0	357.0	41.46	25.23
			89	118.0	385.0	4.42	175.06
9 hour	9	5-10	82	30.0	246.0	15.22	43.32
			84	1.0	69.0	43.11	4.85
			86	7.0	142.0	46.44	8.90
			88	11.0	215.0	45.47	13.73
			90	51.0	132.0	46.43	5.34
3 hour	10	0-5	91	9.0	186.0	10.46	50.66
			93	57.0	470.0	14.07	90.15
			95	35.0	250.0	10.33	62.80
			97	43.0	295.0	9.10	84.71
			99	40.0	239.0	16.05	38.13
3 hour	10	5-10	92	5.0	351.0	18.40	57.12
			94	0.0	0.0	0.00	0.10
			96	16.0	228.0	23.05	28.30
			98	29.0	236.0	15.14	41.87
			100	20.0	315.0	46.26	19.58
24 hour	11	0-5	101	111.0	446.0	3.34	289.43
			103	0.0	174.0	38.59	13.75
			105	19.0	388.0	20.22	55.83
			107	0.0	136.0	41.56	9.99
			109	5.0	401.0	16.53	72.28
24 hour	11	5-10	102	18.0	184.0	30.32	16.75
			104	10.0	237.0	37.37	18.60
			106	17.0	194.0	23.05	23.63
			108	16.0	50.0	43.12	2.43
			110	0.0	160.0	37.55	13.00
3 hour	12	0-5	111	7.0	250.0	66.41	11.23
			113	6.0	349.0	35.19	29.93
			115	55.0	270.0	6.37	100.13
			117	10.0	388.0	13.52	84.00
			119	5.0	200.0	29.44	20.21
3 hour	12	5-10	112	17.0	325.0	22.54	41.45
			114	14.0	178.0	38.34	13.10
			116	20.0	350.0	16.33	61.44
			118	0.0	395.0	16.16	74.83
			120	16.0	328.0	22.43	42.32

VI.4.4 After Treading Treatment (13-weeks)

Date sampled: 9/11/01

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{40} (mm hr^{-1})
9 hour	1	0-5	1	18.0	94.0	21.57	10.67
			3	14.0	165.0	36.58	12.59
			5	0.0	111.0	18.29	18.51
			7	46.0	316.0	11.23	73.09
			9	17.0	290.0	59.39	14.10
9 hour	1	5-10	2	14.0	360.0	62.13	17.14
			4	11.0	318.0	23.11	40.81
			6	0.0	382.0	37.00	31.81
			8	3.0	271.0	51.19	16.09
			10	45.0	368.0	17.13	57.81
control	2	0-5	11	17.0	361.0	21.18	49.77
			13	44.0	413.0	12.50	88.60
			15	59.0	260.0	8.22	74.03
			17	0.0	159.0	42.07	11.63
			19	0.0	34.0	30.12	3.47
control	2	5-10	12	16.0	335.0	23.25	41.98
			14	26.0	276.0	11.18	68.18
			16	7.0	142.0	47.40	8.73
			18	0.0	207.0	14.36	43.69
			20	16.0	132.0	58.26	6.12
24 hour	3	0-5	21	106.0	345.0	2.27	300.61
			23	38.0	296.0	17.04	46.58
			25	70.0	156.0	33.38	7.88
			27	26.0	42.0	30.48	1.60
			29	31.0	365.0	22.30	45.74
24 hour	3	5-10	22	2.0	297.0	19.14	47.26
			24	40.0	326.0	9.03	97.38
			26	24.0	308.0	13.21	65.55
			28	44.0	361.0	11.41	83.61
			30	1.0	231.0	25.53	27.38
control	4	0-5	31	8.0	410.0	19.08	64.74
			33	45.0	378.0	11.07	92.31
			35	35.0	366.0	35.25	28.80
			37	18.0	182.0	41.57	12.05
			39	6.0	337.0	30.56	32.97
control	4	5-10	32	61.0	222.0	17.30	28.35
			34	16.0	371.0	28.38	38.21
			36	29.0	369.0	16.57	61.81
			38	0.0	324.0	28.52	34.59
			40	11.0	201.0	32.14	18.16
24 hour	5	0-5	41	21.0	151.0	31.07	12.87
			43	24.0	272.0	13.59	54.65
			45	171.0	340.0	22.06	23.56
			47	0.0	340.0	42.20	24.75
			49	6.0	145.0	15.31	27.60
24 hour	5	5-10	42	33.0	500.0	12.51	111.99
			44	0.0	260.0	28.57	27.68
			46	10.0	447.0	23.06	58.30
			48	1.0	231.0	54.33	12.99
			50	14.0	232.0	20.52	32.19
9 hour	6	0-5	51	72.0	420.0	10.40	100.54
			53	25.0	277.0	35.31	21.86
			55	45.0	380.0	9.05	113.65
			57	10.0	380.0	10.37	107.39
			59	12.0	309.0	13.24	68.30
9 hour	6	5-10	52	6.0	348.0	18.24	57.28
			54	0.0	286.0	32.36	27.03
			56	19.0	270.0	11.09	69.37
			58	0.0	333.0	38.14	26.84
			60	32.0	382.0	20.00	53.93
3 hour	7	0-5	61	8.0	249.0	42.37	17.43
			63	0.0	194.0	30.34	19.56
			65	0.0	456.0	15.23	91.34
			67	16.0	325.0	21.18	44.70
			69	96.0	340.0	4.41	160.55
3 hour	7	5-10	62	21.0	303.0	22.04	39.38
			64	39.0	411.0	8.46	130.76
			66	20.0	385.0	13.25	83.83
			68	12.0	390.0	23.33	49.46

			70	9.0	329.0	27.02	36.48
control	8	0-5	71	115.0	454.0	10.27	99.97
			73	9.0	376.0	29.44	38.04
			75	3.0	305.0	20.09	46.18
			77	1.0	81.0	41.53	5.89
			79	25.0	300.0	37.52	22.38
control	8	5-10	72	15.0	345.0	17.33	57.94
			74	86.0	274.0	16.57	34.18
			76	82.0	319.0	16.53	43.26
			78	94.0	316.0	9.00	76.01
			80	19.0	404.0	17.24	68.18
9 hour	9	0-5	81	0.0	407.0	23.44	52.84
			83	40.0	121.0	45.56	5.43
			85	9.0	435.0	15.10	86.55
			87	8.0	175.0	42.38	12.07
			89	1.0	321.0	20.15	48.70
9 hour	9	5-10	82	1.0	405.0	24.09	51.55
			84	25.0	440.0	23.38	54.11
			86	16.0	393.0	15.40	74.15
			88	126.0	343.0	8.46	76.28
			90	104.0	269.0	16.49	30.24
3 hour	10	0-5	91	11.0	36.0	42.51	1.80
			93	21.0	381.0	22.46	48.73
			95	50.0	419.0	9.02	125.88
			97	15.0	382.0	17.57	63.00
			99	26.0	380.0	35.15	30.95
3 hour	10	5-10	92	11.0	335.0	23.05	43.25
			94	30.0	306.0	26.47	31.76
			96	16.0	309.0	14.12	63.58
			98	0.0	221.0	24.25	27.89
			100	4.0	319.0	51.19	18.92
24 hour	11	0-5	101	0.0	89.0	47.01	5.83
			103	19.0	271.0	21.24	36.29
			105	6.0	374.0	12.34	90.24
			107	9.0	138.0	32.02	12.41
			109	36.0	290.0	13.03	59.98
24 hour	11	5-10	102	40.0	375.0	10.23	99.42
			104	25.0	258.0	22.14	32.29
			106	2.0	316.0	19.51	48.75
			108	0.0	249.0	21.12	36.19
			110	0.0	240.0	25.42	28.78
3 hour	12	0-5	111	0.0	5.0	43.35	0.35
			113	12.0	76.0	40.35	4.86
			115	19.0	59.0	44.58	2.74
			117	11.0	170.0	42.06	11.64
			119	0.0	219.0	31.21	21.53
3 hour	12	5-10	112	15.0	394.0	9.27	123.59
			114	63.0	239.0	17.38	30.76
			116	55.0	302.0	22.45	33.46
			118	72.0	336.0	16.48	48.42
			120	30.0	326.0	35.42	25.55

VI.4.5 After Treading Treatment (26-weeks)

Date sampled: 1/2/02

Treat-ment	Plot #	Depth (cm)	Core #	Start volume (mm)	End volume (mm)	Total time (m.s)	K_{-40} (mm hr^{-1})
9 hour	1	0-5	1	0.0	180.0	10.16	54.03
			4	66.0	203.0	6.46	62.39
			6	24.0	84.0	6.50	27.06
			7	94.0	434.0	3.07	336.17
			9	58.0	241.0	9.36	58.74
9 hour	1	5-10	2	74.0	318.0	12.15	61.38
			3	7.0	72.0	44.39	4.49
			5	20.0	318.0	25.22	36.20
			8	39.0	326.0	6.37	133.66
			10	11.0	348.0	28.42	36.18
control	2	0-5	11	105.0	366.0	3.02	265.15
			13	41.0	316.0	10.45	78.83
			15	85.0	356.0	4.33	183.54
			17	56.0	270.0	4.45	138.83
			19	51.0	272.0	6.49	99.91
control	2	5-10	12	15.0	248.0	51.49	13.86
			14	84.0	331.0	15.30	49.11
			16	0.0	305.0	10.28	89.80
			18	24.0	326.0	30.23	30.63
			20	98.0	350.0	36.16	21.41
24 hour	3	0-5	21	56.0	179.0	10.00	37.90
			24	58.0	400.0	6.31	161.72
			25	50.0	225.0	5.31	97.75
			27	74.0	270.0	6.40	90.60
			29	25.0	392.0	10.33	107.20
24 hour	3	5-10	22	22.0	300.0	56.23	15.19
			23	18.0	349.0	14.56	68.30
			26	0.0	89.0	42.47	6.41
			28	46.0	315.0	12.15	67.67
			30	0.0	301.0	24.14	38.28
control	4	0-5	31	71.0	325.0	4.31	173.29
			33	0.0	420.0	5.08	252.13
			35	44.0	344.0	19.21	47.78
			37	48.0	350.0	7.36	122.45
			39	71.0	314.0	5.46	129.85
control	4	5-10	32	4.0	315.0	34.53	27.47
			34	29.0	445.0	44.09	29.04
			36	40.0	336.0	32.38	27.95
			38	25.0	287.0	33.58	23.77
			40	18.0	414.0	17.40	69.07
24 hour	5	0-5	41	60.0	310.0	11.55	64.65
			43	40.0	380.0	4.00	261.93
			45	35.0	234.0	7.43	79.47
			47	32.0	304.0	9.13	90.94
			49	60.0	308.0	4.40	163.76
24 hour	5	5-10	42	0.0	326.0	49.21	20.36
			44	61.0	326.0	5.32	147.58
			46	16.0	352.0	5.45	180.07
			48	156.0	345.0	2.33	228.40
			50	14.0	416.0	13.43	90.31
9 hour	6	0-5	51	2.0	230.0	9.03	77.63
			53	136.0	335.0	6.22	96.32
			55	43.0	288.0	7.27	101.34
			57	50.0	360.0	5.19	179.68
			59	35.0	335.0	4.29	206.20
9 hour	6	5-10	52	84.0	269.0	25.18	22.53
			54	12.0	196.0	66.24	8.54
			56	52.0	415.0	15.16	73.27
			58	11.0	300.0	38.48	22.95
			60	31.0	361.0	25.21	40.11
3 hour	7	0-5	61	75.0	415.0	3.11	329.13
			63	25.0	171.0	15.36	28.84
			65	49.0	330.0	7.30	115.46
			67	30.0	345.0	6.19	153.67
			69	35.0	375.0	9.52	106.19
3 hour	7	5-10	62	15.0	396.0	14.38	80.23
			64	126.0	281.0	2.53	165.66

			66	4.0	222.0	10.02	66.95
			68	60.0	330.0	12.24	67.10
			70	72.0	412.0	10.01	104.60
control	8	0-5	71	94.0	281.0	9.32	60.45
			73	45.0	405.0	4.08	268.39
			75	21.0	326.0	17.55	52.46
			77	11.0	335.0	8.02	124.28
			79	34.0	270.0	4.44	153.64
control	8	5-10	72	22.0	348.0	25.35	39.27
			74	6.0	410.0	10.50	114.92
			76	41.0	317.0	7.36	111.91
			78	107.0	319.0	25.20	25.79
			80	49.0	335.0	12.16	71.85
9 hour	9	0-5	81	79.0	390.0	3.24	281.87
			83	81.0	301.0	7.26	91.20
			86	28.0	220.0	9.44	60.79
			87	55.0	331.0	5.22	158.48
			89	46.0	385.0	5.03	206.86
9 hour	9	5-10	82	25.0	380.0	9.54	110.50
			84	6.0	256.0	37.04	20.78
			85	20.0	322.0	41.21	22.51
			88	0.0	347.0	25.01	42.74
			90	17.0	244.0	54.34	12.82
3 hour	10	0-5	91	76.0	426.0	3.18	326.83
			93	51.0	386.0	9.05	113.65
			95	51.0	172.0	7.19	50.96
			97	95.0	350.0	4.19	182.04
			99	56.0	400.0	4.32	233.83
3 hour	10	5-10	92	18.0	258.0	35.03	21.10

			94	5.0	345.0	20.03	52.26
			96	7.0	321.0	13.27	71.94
			98	0.0	325.0	15.15	65.67
			100	1.0	300.0	25.39	35.92
24 hour	11	0-5	101	31.0	314.0	7.12	121.12
			103	49.0	211.0	5.01	99.51
			105	30.0	280.0	6.45	114.13
			107	10.0	328.0	5.20	183.74
			109	111.0	380.0	2.04	401.10
24 hour	11	5-10	102	8.0	360.0	21.53	49.57
			104	115.0	390.0	5.30	154.08
			106	36.0	409.0	6.33	175.48
			108	4.0	300.0	28.26	32.08
			110	81.0	354.0	7.21	114.46
3 hour	12	0-5	111	44.0	295.0	13.35	56.94
			113	49.0	390.0	3.38	289.21
			115	48.0	330.0	4.26	196.01
			117	25.0	255.0	2.43	260.89
			119	62.0	385.0	4.59	199.73
3 hour	12	5-10	112	30.0	316.0	6.45	130.57
			114	183.0	357.0	1.22	392.33
			116	123.0	355.0	9.12	77.71
			118	86.0	345.0	5.34	143.37
			120	0.0	388.0	9.58	119.96

Appendix VII

Saturated Hydraulic Conductivity

Appendix VII Saturated Conductivity

VII.1 Treatment Means

	65% GSM				
	Saturated Hydraulic Conductivity (mm hr^{-1})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	1761.13	1825.06	2010.35	4183.12	1658.81
3 hour	1077.20	991.85	824.44	2076.07	1346.85
9 hour	1250.06	401.34	560.94	1271.53	1037.52
24 hour	1064.19	361.31	1012.68	3964.42	1820.29
F.pr	0.874	0.014	0.110	0.005	0.476
(log) e.s.e	0.1909	0.181	0.1388	0.0970	0.1587
(log) s.e.d	0.2700	0.256	0.1962	0.1371	0.2244
(log) l.s.d	0.6227	0.590	0.4525	0.3162	0.5174

Note: the treatment means are the geometric mean of the plots means, F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%). Data is presented as unlogged data (on graphs it is shown against a logged y-axis), however, statistical analysis was carried out on logged data as unlogged data were non-normally distributed.

	65% GSM				
	Saturated Hydraulic Conductivity (mm hr^{-1})			5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	2477.67	2812.81	3224.25	2461.10	1145.82
3 hour	2640.62	3347.07	1807.27	2267.97	827.86
9 hour	1865.19	2200.60	2304.31	2328.15	1010.78
24 hour	1801.14	2830.54	1569.06	2815.37	1539.68
F.pr	0.017	0.046	0.514	0.493	0.624
(log) e.s.e	0.0980	0.143	0.257	0.189	0.2422
(log) s.e.d	0.1386	0.202	0.364	0.268	0.3425
(log) l.s.d	0.3195	0.465	0.839	0.617	0.7899

	71% GSM				
	Saturated Hydraulic Conductivity (mm hr^{-1})			0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	354.56	879.33	1558.61	1161.59	1061.33
3 hour	948.73	586.61	516.35	430.34	1206.60
9 hour	491.95	281.54	396.03	481.36	1008.04
24 hour	562.87	77.52	171.96	586.35	821.50
F.pr	0.392	0.026	0.144	0.391	0.043
(log) e.s.e	0.1537	0.333	0.2948	0.1735	0.0918
(log) s.e.d	0.2174	0.470	0.4169	0.2453	0.1298
(log) l.s.d	0.5013	1.085	0.9614	0.5658	0.2993

71% GSM Saturated Hydraulic Conductivity (mm hr^{-1})				5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	632.81	2996.32	2412.41	2875.24	4142.04
3 hour	1712.80	2577.02	1834.88	1616.07	1799.71
9 hour	1459.67	1167.65	706.75	1187.21	2250.85
24 hour	2405.85	133.53	268.04	1248.05	2286.34
F.pr	0.188	0.004	0.060	0.316	0.003
(log) e.s.e	0.219	0.248	0.253	0.2018	0.0791
(log) s.e.d	0.310	0.350	0.358	0.2853	0.1119
(log) l.s.d	0.715	0.808	0.825	0.6580	0.2580

81% GSM Saturated Hydraulic Conductivity (mm hr^{-1})				0-5 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	652.79	1104.94	2394.78	457.34	1112.01
3 hour	1015.44	570.06	1191.83	244.74	1043.13
9 hour	1371.36	486.86	2565.92	866.77	706.58
24 hour	2016.35	225.09	917.88	659.63	2976.81
F.pr	0.579	0.057	0.446	0.492	0.038
(log) e.s.e	0.1677	0.195	0.2247	0.2505	0.0924
(log) s.e.d	0.2372	0.276	0.3178	0.3543	0.1307
(log) l.s.d	0.5469	0.636	0.7327	0.8170	0.3013

81% GSM Saturated Hydraulic Conductivity (mm hr^{-1})				5-10 cm soil depth	
	Before	**After**	**4 weeks**	**13 weeks**	**26 weeks**
Control	2280.96	1530.73	2239.38	1750.54	943.97
3 hour	2500.71	947.88	2528.80	1987.51	2454.93
9 hour	1660.05	713.46	1271.08	1376.72	671.52
24 hour	2831.24	414.66	281.03	1643.72	2713.49
F.pr	0.458	0.043	0.007	0.672	0.112
(log) e.s.e	0.1589	0.175	0.168	0.2179	0.240
(log) s.e.d	0.2247	0.248	0.237	0.3082	0.340
(log) l.s.d	0.5182	0.572	0.546	0.7107	0.783

VII.2 Individual Results for the 0-5 cm Soil Depth

VII.2.1 The 65% GSM Experiment

VII.2.1.1 Before Treading Treatment

17/6/99			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	1	18	19	31	31	33	27	20	99.0	0.25	1335.29
		3	20	20	26	30	21	21	16	405.0	0.51	2887.83
		5	21	25	22	20	35	25	22	99.0	15.48	34.61
		7	31	22	16	21	24	23	15	495.0	5.30	553.88
		9	21	26	30	29	22	31	21	95.0	19.11	27.44
3 hour	2	11	17	24	25	31	25	24	19	99.0	14.46	38.68
		13	19	20	18	14	29	21	17	236.0	13.47	103.57
		15	23	16	21	33	35	20	12	38.0	10.12	23.83
		17	13	21	30	28	33	23	20	365.0	1.19	1574.10
		19	25	30	23	16	19	24	16	490.0	4.27	667.86
24 hour	3	21	26	14	12	14	20	16	14	490.0	3.41	848.39
		23	10	9	23	28	21	16	15	465.0	0.59	2966.35
		25	20	27	28	29	15	14	10	245.0	2.27	665.45
		27	27	16	14	27	22	19	14	94.0	0.47	755.21
		29	26	18	34	20	25	26	15	240.0	0.31	2834.38
3 hour	4	31	25	14	19	23	25	19	14	82.0	0.19	1629.67
		33	21	27	25	21	15	9	6	425.0	1.27	2090.14
		35	30	24	21	22	30	28	20	98.0	25.05	22.04
		37	15	19	27	23	17	15	12	235.0	2.00	765.12
		39	17	16	20	20	15	20	16	92.0	0.39	875.35
9 hour	5	41	26	26	19	15	18	19	16	83.0	0.38	802.68
		43	21	12	18	20	20	18	16	475.0	1.23	2122.28
		45	16	18	24	23	23	21	17	42.0	2.26	104.11
		46	18	22	18	32	23	13	10	428.0	1.42	1680.94
		49	20	19	18	19	11	15	14	89.0	5.26	104.46
control	6	51	22	29	23	22	19	23	18	500.0	0.28	6310.88
		53	20	19	23	19	20	16	14	100.0	2.55	216.81
		55	18	28	32	20	17	23	16	95.0	11.25	50.43
		57	34	22	18	18	23	19	16	500.0	6.41	454.74
		59	19	24	26	20	18	23	18	495.0	0.53	3321.37
9 hour	7	61	24	12	28	30	31	23	20	475.0	4.23	615.33
		63	22	24	17	16	18	22	15	455.0	0.37	4594.86
		65	20	29	29	22	12	24	20	500.0	2.48	1024.75
		67	19	23	25	30	21	24	17	85.0	6.37	76.51
		69	16	21	25	29	22	21	16	95.0	17.16	33.44
3 hour	8	71	15	12	25	30	22	17	12	500.0	0.36	5412.26
		73	21	19	13	20	27	16	14	98.0	0.40	930.12
		75	32	31	20	14	15	16	15	248.0	3.44	411.30
		78	18	30	27	20	23	24	16	500.0	0.36	5035.86
		79	26	25	19	15	13	18	15	100.0	2.21	265.49
24 hour	9	81	31	19	13	15	19	22	16	100.0	6.14	98.52
		83	21	15	14	29	15	17	15	500.0	3.04	1020.33
		85	26	31	34	31	28	27	19	240.0	2.00	672.21
		87	18	26	16	19	17	15	14	96.0	4.16	142.78
		89	20	22	19	17	14	12	11	460.0	7.34	403.95
24 hour	10	91	25	32	24	28	23	27	20	98.0	3.16	168.60
		93	24	33	31	29	14	24	19	490.0	3.10	885.57
		95	27	21	13	27	24	28	25	100.0	1.03	509.59
		97	33	20	18	21	26	13	11	440.0	0.42	4122.59
		99	21	19	40	29	24	24	20	490.0	1.12	2299.22

control	11	101	21	16	18	20	20	21	19	498.0	2.46	1063.66
		103	21	20	22	19	18	6	9	495.0	0.42	4833.96
		105	15	30	23	15	17	17	12	500.0	0.50	3904.98
		107	29	26	24	13	25	20	16	246.0	4.35	325.54
		109	21	27	27	15	14	19	15	485.0	2.45	1095.52
9 hour	12	111	21	16	17	22	10	17	15	240.0	0.31	2920.66
		113	20	22	30	22	16	18	15	94.0	4.45	122.53
		115	32	30	22	27	30	25	19	97.0	6.37	83.03
		117	30	17	31	16	15	16	15	500.0	2.42	1148.84
		119	15	23	22	11	12	14	10	495.0	0.54	3718.37

VII.2.1.2 After Treading Treatment (1-week)

29/6/99			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	1	22	31	31	29	23	28	15	250.0	1.36	942.43
		3	25	22	27	29	29	28	18	250.0	1.12	1204.42
		5	19	8	14	27	25	26	23	502.0	1.42	1653.10
		7	15	14	19	23	20	9	18	250.0	2.16	667.72
		9	24	26	36	32	24	33	19	101.0	11.28	49.44
3 hour	2	21	23	19	15	23	21	28	17	100.0	6.45	89.10
		23	25	24	28	37	32	19	12	495.0	2.25	1295.64
		25	29	20	23	33	39	23	15	100.0	2.08	282.04
		27	21	19	26	31	19	15	12	250.0	2.00	807.44
		29	24	19	32	21	25	24	16	100.0	4.54	123.05
24 hour	3	31	19	26	4	23	25	26	20	500.0	1.45	1657.25
		33	29	20	19	9	22	18	15	500.0	2.56	1062.82
		35	21	29	28	22	19	21	16	150.0	2.08	425.53
		37	28	26	20	21	5	17	14	72.0	49.22	9.22
		39	28	15	13	29	33	23	14	250.0	1.30	1038.23
3 hour	4	11	26	20	27	26	24	27	16	99.0	8.06	73.41
		13	24	29	30	33	24	20	11	500.0	1.30	2150.66
		15	26	11	13	20	34	10	6	101.0	89.32	8.05
		17	36	20	23	26	26	28	18	250.0	2.11	662.57
		19	11	32	28	24	26	32	27	250.0	0.47	1640.94
9 hour	5	41	26	29	38	30	15	19	15	23.0	105.08	1.33
		43	34	20	21	17	30	24	15	101.0	6.16	98.56
		45	24	36	22	19	16	29	20	100.0	2.55	195.04
		47	14	20	17	19	10	16	11	100.0	1.06	606.19
		49	19	22	21	31	20	26	20	499.0	3.23	844.19
control	6	51	29	25	32	32	24	25	16	240.0	1.26	991.77
		53	18	33	21	17	16	15	12	500.0	2.43	1195.97
		55	25	16	21	20	14	17	12	500.0	1.13	2680.12
		57	20	20	16	13	21	16	15	495.0	1.05	2867.92
		59	30	21	18	25	30	24	16	246.0	1.28	1008.98
9 hour	7	61	10	9	11	30	20	16	15	95.0	16.38	36.05
		63	29	29	30	29	28	27	18	97.0	59.54	9.26
		65	21	21	21	18	24	22	19	99.0	15.34	37.27
		67	24	14	20	27	30	21	15	98.0	1.34	385.23
		69	28	17	32	16	24	21	25	495.0	1.39	1608.47
3 hour	8	71	29	26	17	28	28	28	17	502.0	0.25	7094.46
		73	26	21	16	18	22	22	21	93.0	3.31	151.14
		73	20	12	19	35	30	17	15	475.0	1.28	1998.59
		75	14	20	26	20	16	24	15	250.0	1.43	906.34
		77	23	15	24	25	23	22	13	99.0	3.06	203.10
24 hour	9	79	20	16	11	14	12	10	9	35.0	44.36	5.41
		81	25	24	20	14	19	15	12	100.0	14.46	44.07
		85	23	25	23	22	11	17	13	99.0	1.37	391.94
		87	15	21	16	22	32	15	10	100.0	5.01	133.40
		89	24	21	28	27	21	22	16	96.0	3.39	158.82
24 hour	10	91	18	18	14	17	19	18	14	99.0	7.27	84.65
		93	22	13	5	12	24	13	10	246.0	0.56	1787.50
		95	12	30	20	24	27	25	20	100.0	25.33	22.42

		97	32	38	18	12	39	25	17	49.0	80.14	3.57
		99	26	14	10	8	21	14	11	99.0	35.46	18.48
control	11	101	19	32	31	21	8	17	13	500.0	0.56	3415.00
		103	18	21	30	24	10	21	16	500.0	1.12	2550.31
		105	35	25	26	24	27	29	26	99.0	2.42	188.12
		107	31	35	30	22	34	20	15	1000.0	0.48	7489.73
		109	20	16	30	21	20	18	11	99.0	1.23	470.82
9 hour	12	111	24	16	21	20	36	24	16	100.0	0.41	885.00
		113	21	26	22	19	19	25	12	98.0	19.24	32.61
		115	25	26	31	20	26	24	15	98.0	7.07	83.84
		117	34	38	25	29	29	31	15	90.0	2.39	200.99
		119	16	8	31	31	34	19	16	246.0	1.27	1027.51

VII.2.1.3 After Treading Treatment (4-weeks)

22/7/99			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	1	26	15	9	14	21	20	19	500.0	0.57	3134.80
		3	12	16	25	27	14	13	12	480.0	0.52	3622.78
		5	24	15	22	24	25	18	10	99.0	10.10	64.95
		7	14	2	9	18	24	10	9	98.0	1.17	527.41
		9	36	26	10	11	30	18	17	485.0	2.13	1314.03
3 hour	2	11	13	15	15	13	10	16	15	95.0	17.07	35.30
		13	21	19	29	32	18	24	18	250.0	2.32	578.92
		15	25	30	25	29	25	30	19	92.0	3.11	164.01
		17	17	20	25	18	11	13	10	245.0	1.11	1395.77
		19	16	21	19	14	3	15	14	100.0	1.08	566.84
24 hour	3	22	21	13	16	14	11	22	14	96.0	2.36	236.10
		23	14	21	30	26	30	20	16	980.0	1.18	4558.91
		25	15	14	11	15	26	16	11	500.0	2.28	1351.06
		27	22	19	21	30	29	22	20	255.0	2.28	589.65
		29	21	29	20	21	19	21	12	96.0	3.59	155.68
3 hour	4	31	20	27	25	20	16	27	15	240.0	2.24	616.27
		33	26	32	25	30	24	31	20	100.0	3.07	178.71
		35	19	14	13	16	21	18	16	101.0	2.30	250.92
		37	21	16	6	28	33	18	12	495.0	1.04	3012.35
		39	21	19	19	13	17	19	11	500.0	4.57	669.97
9 hour	5	41	25	1	14	14	25	12	10	100.0	9.45	69.50
		43	22	22	25	27	18	24	19	245.0	1.53	755.60
		45	46	43	21	29	30	28	18	98.0	5.05	107.35
		47	28	30	26	31	25	30	18	99.0	3.48	149.22
		49	20	25	24	24	19	19	18	100.0	3.56	150.57
control	6	51	35	23	32	30	31	26	18	500.0	1.04	2666.51
		53	28	14	20	19	16	15	11	500.0	0.22	9027.81
		55	37	29	18	28	29	31	16	505.0	6.59	426.45
		57	29	25	36	16	20	21	20	500.0	1.17	2214.32
		59	18	19	15	16	21	15	14	500.0	2.15	1415.64
9 hour	7	61	17	9	1	6	21	16	11	98.0	0.50	792.44
		63	34	29	16	15	5	17	16	505.0	3.16	951.24
		65	30	31	29	24	21	26	16	101.0	1.54	316.46
		67	24	21	21	10	29	16	12	500.0	0.47	4145.56
		69	21	19	16	20	16	20	16	99.0	8.57	68.24
3 hour	8	71	24	15	17	21	30	26	20	99.0	8.28	67.27
		73	20	20	20	8	13	21	15	250.0	3.29	451.52
		75	24	19	16	22	16	24	15	500.0	1.04	2915.45
		77	30	23	24	7	30	19	14	100.0	0.48	782.76
		79	11	16	26	19	10	20	16	252.0	1.19	1188.02
24 hour	9	81	26	18	25	18	16	20	16	100.0	6.20	96.71
		84	15	11	43	42	24	26	20	495.0	1.31	1830.62
		85	7	34	24	19	29	25	20	99.0	17.15	32.88
		87	26	39	55	50	41	39	19	500.0	8.14	308.48
		89	21	29	25	18	7	22	18	500.0	3.13	926.82
24 hour	10	91	24	17	16	20	15	18	16	500.0	1.17	2406.54

		93	19	25	30	26	25	28	20	252.0	2.03	694.80
		95	24	5	11	31	29	20	15	99.0	3.22	183.01
		97	14	19	31	27	24	24	16	252.0	1.14	1237.48
		99	26	20	22	26	29	28	21	500.0	2.02	1373.07
control	11	101	24	16	19	22	11	16	15	500.0	1.23	2265.99
		103	20	24	20	17	13	16	15	500.0	3.54	802.79
		105	22	36	23	21	11	17	13	99.0	1.16	497.64
		107	26	27	26	24	21	23	18	100.0	7.24	79.01
		109	19	2	10	28	11	13	11	500.0	1.36	2095.09
9 hour	12	111	19	21	24	23	21	29	19	100.0	0.32	1089.97
		113	28	21	21	17	24	26	20	43.0	23.29	10.50
		115	26	18	30	22	21	28	18	100.0	2.53	203.12
		117	20	19	12	11	16	17	15	248.0	1.24	1118.83
		119	23	42	31	25	25	26	20	254.0	3.16	431.30

VII.2.1.4 After Treading Treatment (13-weeks)

23/9/99			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	1	3	15	28	28	20	12	11	490.0	1.07	2913.11
		3	11	18	27	24	20	23	11	500.0	1.09	2863.21
		5	35	19	11	16	19	18	15	500.0	1.17	2427.80
		7	21	25	19	15	19	15	13	485.0	0.30	6232.43
		9	40	19	24	10	11	18	17	485.0	0.46	3823.88
3 hour	2	11	30	21	18	9	20	13	12	100.0	0.56	699.45
		13	22	25	25	27	12	21	18	250.0	1.39	896.66
		15	21	21	26	31	20	21	18	252.0	1.01	1457.65
		18	36	15	15	34	36	27	18	500.0	0.43	4022.40
		19	18	19	18	20	28	12	11	500.0	2.27	1349.19
24 hour	3	21	6	31	25	20	16	23	18	485.0	0.39	4452.24
		23	25	23	25	34	31	19	15	500.0	0.55	3308.18
		26	27	29	25	22	27	17	16	495.0	0.44	4063.65
		27	25	21	24	15	25	25	24	490.0	1.52	1429.85
		29	20	25	25	25	25	18	14	490.0	1.41	1816.92
3 hour	4	31	14	12	15	20	19	17	15	94.0	1.16	468.19
		33	19	21	16	18	23	19	18	252.0	1.01	1484.34
		35	29	28	24	44	19	25	18	495.0	0.15	11351.65
		37	34	25	11	10	30	21	20	97.0	0.45	745.32
		39	15	13	26	29	31	26	25	500.0	3.33	753.62
9 hour	5	41	18	28	36	24	29	20	15	500.0	1.17	2366.62
		43	16	10	15	20	18	12	11	100.0	1.55	348.64
		45	26	14	16	22	29	23	22	49.0	0.44	375.28
		47	24	21	21	32	14	17	15	51.0	2.19	136.22
		49	24	21	16	15	20	14	13	97.0	1.46	353.54
control	6	51	30	10	25	11	17	19	16	100.0	0.52	711.81
		53	35	15	18	15	13	16	15	470.0	0.47	3752.57
		55	40	29	28	11	20	18	17	500.0	0.32	5566.02
		57	21	25	25	8	19	18	17	500.0	1.14	2460.68
		59	8	16	16	16	7	18	16	98.0	0.55	671.64
9 hour	7	61	19	42	41	30	15	18	13	495.0	1.10	2640.18
		63	32	18	15	2	30	20	19	101.0	2.25	246.78
		65	24	25	13	11	11	18	17	102.0	8.00	78.10
		67	31	35	24	23	27	24	21	95.0	0.29	1083.41
		69	22	29	26	17	12	18	16	95.0	1.34	371.15
3 hour	8	71	15	35	24	21	18	22	18	250.0	1.01	1451.84
		73	21	15	18	16	20	21	19	100.0	1.15	474.47
		75	13	32	25	19	19	10	8	500.0	2.12	1570.31
		77	14	20	35	36	25	21	20	505.0	0.50	3431.57
		79	13	32	28	26	27	20	19	495.0	1.24	2039.77
24 hour	9	81	21	18	11	25	25	15	14	490.0	0.29	6418.36
		83	21	35	31	23	15	12	10	495.0	0.57	3460.53
		85	29	30	34	30	12	21	20	240.0	2.47	485.99
		87	24	16	16	31	34	28	20	51.0	1.16	228.42

		89	20	19	16	5	28	18	18	500.0	0.17	10641.04
24 hour	10	91	18	15	21	18	18	21	18	500.0	2.52	1048.15
		93	30	20	25	26	35	17	16	500.0	0.26	6913.96
		95	30	34	28	15	23	22	19	500.0	0.19	9060.96
		97	29	19	28	35	23	11	10	100.0	0.38	1044.39
		99	21	33	25	29	10	20	16	500.0	0.29	6269.88
control	11	101	16	15	35	33	35	21	20	505.0	0.10	17093.70
		103	28	28	20	8	20	16	15	500.0	1.58	1582.26
		105	22	24	36	35	21	24	19	248.0	1.19	1070.96
		107	28	38	20	22	18	18	16	495.0	0.19	9432.06
		109	24	16	22	24	29	17	16	505.0	1.26	2144.61
9 hour	12	111	23	35	28	8	10	21	20	250.0	1.52	775.59
		113	24	22	30	31	17	24	22	94.0	0.43	724.47
		115	25	25	22	14	10	16	15	490.0	0.47	3912.26
		117	21	35	28	21	15	28	20	82.0	2.51	163.37
		119	30	27	28	15	20	22	16	500.0	0.17	10664.18

VII.2.1.5 After Treading Treatment (26-weeks)

17/12/99			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	1	29	29	34	22	31	21	17	100.0	1.20	437.81
		3	22	18	20	22	19	24	20	100.0	0.25	1389.86
		5	19	29	31	22	23	16	15	495.0	0.38	4800.02
		7	15	19	15	12	20	12	10	250.0	2.26	695.69
		9	12	11	12	19	15	16	15	100.0	0.59	645.78
3 hour	2	11	19	24	16	18	21	15	14	250.0	1.19	1203.48
		13	15	5	15	18	18	15	14	250.0	0.40	2411.49
		15	32	31	28	33	31	32	25	98.0	2.32	195.97
		17	19	18	21	26	23	21	16	500.0	1.53	1620.54
		19	21	17	32	20	27	28	24	250.0	1.21	998.77
24 hour	3	21	29	28	28	25	20	20	13	510.0	0.37	5200.19
		23	16	40	27	15	11	16	14	500.0	0.22	8581.98
		25	30	29	25	24	19	29	20	100.0	22.15	25.33
		27	23	21	21	19	10	12	11	500.0	2.04	1606.14
		29	31	25	25	25	23	24	19	500.0	1.00	2866.72
3 hour	4	31	17	17	29	35	22	26	22	102.0	0.33	1026.33
		33	16	15	14	20	16	15	11	250.0	1.05	1538.79
		35	3	24	25	21	7	19	18	500.0	1.44	1747.48
		37	26	16	21	31	25	18	15	100.0	0.38	971.73
		39	5	9	18	18	11	18	12	500.0	1.00	3312.64
9 hour	5	41	24	15	17	16	22	16	15	500.0	1.40	1878.54
		43	24	15	31	31	29	28	19	99.0	1.08	498.55
		45	21	21	31	34	14	16	15	102.0	2.57	212.79
		47	25	15	25	25	21	27	20	250.0	0.47	1828.33
		49	28	28	29	27	25	28	20	100.0	1.22	408.79
control	6	51	21	26	25	21	21	26	25	100.0	0.37	867.68
		53	30	29	30	24	28	22	14	100.0	0.22	1672.49
		55	29	12	22	28	20	20	19	100.0	0.38	922.35
		57	19	29	31	37	20	24	20	100.0	3.11	176.37
		59	13	13	24	20	17	16	14	99.0	1.02	610.66
9 hour	7	61	22	26	26	18	21	28	19	100.0	5.04	114.35
		63	26	29	29	34	35	24	20	490.0	0.42	3862.23
		65	11	27	21	25	30	22	16	100.0	7.07	85.29
		67	25	21	15	20	25	22	20	102.0	28.50	20.44
		69	21	22	25	29	26	25	19	495.0	1.53	1513.65
3 hour	8	71	19	22	5	18	21	19	18	102.0	1.02	596.01
		74	25	19	18	12	25	18	16	505.0	1.32	2025.23
		75	30	30	21	21	19	29	21	98.0	7.55	69.19
		77	25	19	21	16	22	19	16	250.0	2.20	656.67
		79	24	28	30	14	27	15	14	250.0	0.43	2177.37
24 hour	9	81	21	34	26	25	23	27	20	510.0	0.32	5389.55
		83	30	35	34	30	28	27	23	246.0	0.56	1379.72

		85	20	26	18	21	21	19	16	500.0	1.44	1764.40
		87	24	21	15	15	19	24	18	500.0	0.50	3587.92
		89	21	22	19	18	26	20	16	500.0	1.20	2292.16
24 hour	10	91	31	29	28	21	16	33	25	495.0	2.40	974.28
		93	26	23	21	10	26	23	16	100.0	2.09	283.71
		95	25	32	23	20	16	21	19	250.0	1.37	898.94
		97	19	20	29	18	15	24	21	100.0	9.52	57.92
		99	28	24	32	36	25	31	21	495.0	4.10	646.48
control	11	101	16	11	34	36	35	29	20	500.0	0.23	7316.05
		103	19	20	31	29	19	23	16	100.0	1.22	442.50
		105	30	22	24	24	21	29	20	248.0	0.36	2342.73
		107	21	15	21	21	25	25	21	505.0	1.17	2243.26
		109	25	28	25	31	30	22	19	99.0	1.46	318.92
9 hour	12	111	14	18	16	18	20	16	15	252.0	2.16	699.43
		113	26	17	31	25	22	23	17	98.0	1.59	293.83
		115	20	20	18	22	24	21	20	99.0	0.56	614.27
		117	18	21	6	15	15	21	16	250.0	0.36	2595.59
		119	30	15	17	16	25	22	20	250.0	1.30	965.18

VII.2.2 The 71% GSM Experiment

VII.2.2.1 Before Treading Treatment

22/8/00			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	18	21	22	20	14	16	13	51.0	0.41	480.31
		3	27	10	7	11	20	15	11	495.0	2.40	1240.92
		5	26	22	25	29	42	22	17	500.0	2.32	1152.12
		7	10	21	26	20	13	22	16	500.0	2.04	1492.50
		9	26	18	10	28	28	21	19	51.0	1.47	167.06
control	2	11	31	32	24	20	26	20	19	50.0	1.12	238.89
		13	30	25	23	15	15	21	16	248.0	1.47	848.27
		15	15	19	15	13	12	13	11	49.0	1.07	293.71
		17	18	13	10	3	10	14	14	50.0	0.48	405.40
		19	22	18	11	18	23	18	15	49.0	33.41	9.11
24 hour	3	21	18	25	40	18	10	24	20	52.0	3.09	94.81
		23	24	15	8	18	25	13	12	49.0	8.52	36.22
		25	20	18	31	35	22	17	16	49.0	3.52	76.52
		27	25	33	16	24	19	17	15	51.0	2.04	152.18
		29	25	24	18	22	27	18	16	500.0	0.48	3799.00
3 hour	4	32	22	21	13	5	19	17	12	50.0	15.01	21.88
		33	20	18	21	26	32	21	16	250.0	0.22	4132.42
		35	28	22	25	23	18	22	20	50.0	1.27	197.54
		37	15	19	17	14	28	15	12	250.0	1.00	1634.48
		39	29	20	20	24	23	19	19	50.0	1.48	161.74
9 hour	5	41	28	24	26	11	17	21	19	47.0	5.26	50.69
		43	20	25	20	24	27	33	22	500.0	2.00	1379.50
		45	21	24	23	25	23	21	17	49.0	12.05	24.25
		47	16	23	15	19	14	17	12	49.0	5.43	56.15
		49	21	11	11	5	28	21	18	51.0	3.35	86.33
3 hour	6	51	25	30	25	26	27	20	17	51.0	4.36	65.45
		53	25	29	31	30	23	21	20	50.0	0.32	526.87
		55	25	35	34	25	211	19	13	250.0	3.15	351.06
		57	25	19	20	28	15	15	14	48.0	2.52	105.57
		59	30	25	18	15	25	23	18	250.0	0.55	1608.96
24 hour	7	61	15	28	33	25	18	18	18	52.0	1.30	204.35
		63	26	23	15	15	14	24	20	51.0	2.25	122.98
		65	26	21	20	15	16	18	16	500.0	3.22	913.84
		67	22	21	15	18	30	16	15	49.0	1.52	163.16
		69	29	20	18	21	24	17	14	250.0	0.47	2003.59
control	8	71	15	14	15	25	36	19	15	500.0	2.18	1349.51
		73	18	25	25	30	20	12	11	248.0	2.12	739.72

		75	18	21	25	34	24	27	21	50.0	2.35	108.28
		77	21	24	25	20	20	22	20	48.0	4.15	65.03
		79	24	30	25	22	20	21	18	50.0	10.28	28.05
9 hour	9	81	35	28	16	12	8	36	24	500.0	2.36	1047.51
		83	19	15	11	8	13	14	11	50.0	0.57	353.28
		85	24	23	26	22	28	22	16	250.0	2.49	535.16
		87	22	10	25	21	19	18	17	50.0	2.37	116.06
		89	24	23	14	25	26	21	19	13.0	19.15	3.94
24 hour	10	91	22	22	21	21	18	21	15	50.0	1.55	161.84
		93	25	19	18	19	20	17	16	246.0	3.54	387.62
		95	24	19	19	21	20	21	15	49.0	0.46	396.76
		97	22	19	21	18	12	20	16	50.0	20.51	14.79
		99	40	34	14	18	32	34	20	250.0	2.16	611.78
3 hour	11	101	24	31	30	20	9	17	16	51.0	0.50	372.79
		103	14	24	26	23	21	13	12	500.0	0.41	4752.22
		105	40	28	15	19	25	30	20	248.0	2.31	554.87
		107	20	1	18	15	26	14	13	255.0	3.08	528.32
		109	21	35	29	18	15	15	15	49.0	0.56	323.98
control	12	111	24	23	25	27	25	25	18	51.0	1.16	235.02
		113	29	29	20	14	30	22	16	50.0	1.19	229.14
		115	14	19	15	26	22	26	16	38.0	16.33	14.07
		117	19	28	29	15	19	19	15	240.0	1.54	781.59
		119	13	16	15	19	18	14	14	48.0	3.14	95.03

VII.2.2.2 After Treading Treatment (1-week)

1/9/00			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	111	15	15	12	19	26	13	13	50.0	3.18	98.07
		113	16	28	31	25	22	21	18	12.0	58.11	1.21
		115	10	8	30	23	26	17	16	16.0	30.23	3.24
		117	21	15	20	26	16	20	19	50.0	45.04	6.55
		119	17	26	12	13	21	17	15	9.0	62.31	0.90
control	2	1	16	22	18	21	15	13	12	102.0	2.06	318.02
		3	24	23	18	21	23	19	18	100.0	1.14	481.30
		5	12	12	13	20	25	13	12	47.0	3.03	101.37
		7	25	25	21	23	19	20	18	100.0	1.13	486.03
		9	16	26	25	22	15	19	19	47.0	22.40	12.19
24 hour	3	11	24	21	10	15	21	16	15	48.0	4.02	74.65
		13	11	15	18	21	15	24	20	25.0	52.39	2.79
		15	16	18	15	8	11	13	12	6.0	59.29	0.67
		17	10	12	3	24	25	26	15	6.0	58.33	0.65
		19	19	21	24	30	29	22	18	100.0	1.21	433.83
3 hour	4	21	15	21	19	21	17	11	10	102.0	1.29	463.57
		23	11	11	13	17	21	14	14	505.0	1.31	2140.12
		25	18	25	26	21	25	19	16	46.0	59.38	4.69
		27	11	16	16	21	12	11	11	498.0	1.14	2702.68
		29	20	20	28	22	23	21	21	100.0	0.21	1620.39
9 hour	5	31	27	35	18	21	36	19	19	252.0	0.57	1516.73
		33	27	20	29	26	26	19	19	498.0	0.37	4654.85
		35	16	20	24	24	26	24	18	505.0	0.54	3315.47
		37	15	18	20	19	14	19	15	19.0	59.15	2.01
		39	31	15	14	30	27	27	20	53.0	36.26	8.29
3 hour	6	41	25	24	19	25	16	18	16	50.0	0.52	352.40
		43	19	12	28	15	18	22	18	250.0	0.52	1729.86
		45	30	27	25	14	20	22	15	502.0	0.55	3367.97
		47	15	18	19	16	14	13	9	19.0	77.36	1.68
		49	21	29	19	24	24	26	20	50.0	3.01	94.54
24 hour	7	51	25	25	22	24	14	18	18	50.0	37.47	7.86
		53	15	19	21	12	20	15	12	1.0	60.05	0.11
		55	30	21	25	28	31	26	20	54.0	9.21	32.39
		57	30	16	16	11	18	36	15	31.0	51.39	3.72
		59	19	25	34	34	25	34	19	11.0	61.52	1.00

control	8	61	27	20	24	22	28	26	20	252.0	0.59	1456.50
		63	35	30	16	10	10	21	20	46.0	2.46	96.52
		65	24	31	32	32	24	25	16	100.0	4.12	140.90
		67	20	21	14	10	14	14	12	490.0	0.45	4301.91
		69	20	21	21	22	21	26	20	49.0	45.00	6.28
9 hour	9	71	15	20	14	28	35	16	14	6.0	64.51	0.58
		73	20	22	34	28	21	20	17	500.0	1.27	2048.90
		75	20	27	26	18	10	23	14	250.0	2.34	613.37
		78	13	20	24	15	16	18	14	50.0	43.29	7.32
		79	29	21	22	18	22	24	18	5.0	55.57	0.53
24 hour	10	81	15	16	24	21	29	16	15	51.0	11.55	26.62
		83	25	10	23	26	24	20	16	51.0	11.07	28.00
		85	15	14	14	9	11	11	11	498.0	1.22	2451.67
		87	13	24	25	22	14	19	16	1.0	59.03	0.10
		89	30	28	14	36	35	28	21	50.0	19.54	13.75
3 hour	11	91	25	30	30	10	11	13	10	52.0	6.52	50.72
		93	30	30	30	25	25	22	21	52.0	31.09	9.22
		95	20	20	12	13	30	12	12	50.0	1.00	327.06
		97	38	25	20	15	18	23	21	49.0	15.31	17.83
		99	21	30	20	25	30	25	19	54.0	1.14	251.48
control	12	101	25	18	9	22	24	17	15	50.0	2.10	144.07
		103	24	26	24	17	23	27	19	500.0	2.20	1241.53
		105	30	23	28	25	21	23	16	500.0	1.22	2197.41
		107	15	28	31	25	17	25	20	504.0	1.40	1727.87
		109	20	21	24	21	23	17	11	500.0	0.41	4811.33

VII.2.2.3 After Treading Treatment (4-weeks)

28/9/00			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	22	21	6	26	25	19	15	49.0	9.50	31.03
		3	16	22	26	18	15	24	19	50.0	0.50	353.23
		5	19	27	21	15	20	23	18	51.0	8.33	35.49
		7	24	19	16	22	24	25	15	48.0	11.06	26.74
		9	25	26	26	24	28	26	16	101.0	1.43	351.98
control	2	11	31	30	24	24	31	26	20	500.0	0.55	3044.26
		13	25	25	28	26	25	21	18	480.0	0.33	5089.89
		15	16	29	26	24	13	16	15	52.0	0.41	472.40
		17	22	15	19	15	20	24	15	500.0	0.37	5061.81
		19	30	43	34	14	6	25	14	505.0	0.38	4929.58
24 hour	3	21	25	16	25	24	19	27	25	49.0	9.21	28.15
		23	25	30	21	25	24	26	21	49.0	1.02	264.78
		25	24	16	13	13	25	18	15	49.0	1.37	189.90
		27	20	21	23	35	16	27	14	100.0	0.12	3112.62
		29	26	21	24	16	21	28	21	52.0	1.31	194.11
3 hour	4	31	21	23	29	35	18	26	20	50.0	1.04	265.19
		33	25	25	19	11	15	16	16	51.0	3.41	85.47
		35	35	30	20	23	26	36	35	51.0	1.02	224.56
		37	16	28	28	16	19	17	17	100.0	1.01	593.72
		39	18	21	17	24	29	36	20	50.0	0.55	310.56
9 hour	5	41	24	21	21	21	24	22	20	50.0	39.36	7.26
		43	20	15	15	22	18	15	15	490.0	0.50	3692.79
		45	34	36	25	20	25	25	19	16.0	49.24	1.84
		47	22	20	23	21	16	26	20	18.0	14.58	6.95
		49	15	12	21	20	12	8	18	49.0	2.03	145.81
3 hour	6	51	30	25	29	26	30	29	19	96.0	2.17	237.44
		53	30	31	31	21	29	28	20	250.0	0.35	2382.17
		55	19	19	28	15	20	28	25	102.0	1.05	509.30
		57	25	19	24	34	32	27	20	51.0	7.15	39.46
		59	30	25	16	19	25	26	16	250.0	1.16	1193.59
24 hour	7	61	24	26	21	16	20	23	21	15.0	15.49	5.40
		63	21	30	15	16	25	19	17	49.0	6.44	43.86
		65	20	28	22	20	15	24	20	54.0	48.58	6.37

		67	25	20	30	18	20	21	18	51.0	31.52	9.46
		69	26	30	30	31	16	26	20	47.0	4.18	61.43
control	8	71	19	14	26	34	21	21	20	52.0	0.48	373.33
		73	26	24	25	30	36	28	20	49.0	2.31	108.33
		75	18	38	35	25	15	24	20	51.0	0.36	479.53
		77	23	22	22	21	15	17	15	505.0	1.21	2328.07
		79	30	28	21	19	13	24	20	49.0	0.32	527.68
9 hour	9	81	29	22	16	19	30	26	20	98.0	0.52	645.54
		83	10	30	35	30	19	18	15	52.0	0.21	911.16
		85	9	20	30	30	27	0	15	50.0	4.12	74.27
		87	22	19	28	19	8	16	15	49.0	0.28	656.70
		89	28	7	13	18	21	29	21	102.0	2.30	234.89
24 hour	10	91	22	19	18	22	20	21	19	52.0	1.35	193.20
		93	25	31	30	15	30	28	20	250.0	1.41	834.64
		95	19	25	29	29	32	28	21	50.0	0.58	285.69
		97	14	24	16	16	26	23	20	15.0	15.49	5.52
		99	25	23	17	16	25	22	21	50.0	42.52	6.65
3 hour	11	101	16	21	21	24	27	20	18	480.0	1.14	2308.49
		103	29	15	25	20	15	24	20	48.0	0.59	282.00
		105	25	29	29	25	28	25	20	48.0	5.00	53.85
		107	19	19	19	33	39	21	19	50.0	35.00	8.21
		109	26	18	21	28	34	25	21	36.0	14.21	13.99
control	12	111	21	34	44	34	21	33	21	50.0	1.11	227.05
		113	25	23	25	21	22	19	16	49.0	20.07	14.80
		115	15	23	30	29	24	30	21	51.0	1.50	155.33
		117	26	27	25	25	21	25	19	101.0	1.13	477.66
		119	20	29	35	29	17	24	12	500.0	0.33	5792.31

VII.2.2.4 After Treading Treatment (13-weeks)

23/11/00			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	18	19	22	25	33	23	19	50.0	0.34	511.65
		3	20	11	14	15	19	21	20	50.0	46.22	6.36
		5	18	26	24	16	26	22	19	50.0	0.50	350.21
		7	29	23	21	25	28	27	19	50.0	1.43	166.99
		9	14	26	21	31	22	25	16	50.0	1.56	156.63
control	2	11	22	18	26	27	18	23	17	50.0	0.29	619.90
		13	25	18	19	22	24	25	16	500.0	0.21	8689.60
		15	15	24	14	12	11	19	18	97.0	0.24	1472.84
		17	18	15	10	24	30	20	18	49.0	2.05	140.75
		19	19	25	25	31	21	19	15	50.0	0.19	969.70
24 hour	3	21	31	21	26	16	19	20	17	50.0	2.15	133.26
		23	18	24	23	26	17	23	18	49.0	1.37	179.51
		25	28	35	30	29	29	30	22	48.0	7.28	34.27
		27	29	27	19	22	24	25	16	250.0	0.45	2008.28
		29	25	21	21	24	31	28	19	51.0	2.12	133.27
3 hour	4	31	9	20	36	35	24	22	18	50.0	0.29	605.37
		33	29	23	21	25	25	29	21	50.0	10.54	25.59
		35	20	28	35	28	25	24	21	49.0	1.36	169.50
		37	18	20	21	16	10	20	19	52.0	1.51	167.42
		39	23	31	24	16	10	22	21	500.0	0.41	4178.26
9 hour	5	41	36	24	26	29	25	27	21	50.0	0.29	568.44
		43	34	24	28	28	27	32	22	52.0	0.32	524.63
		45	26	30	25	26	33	27	15	50.0	3.55	76.81
		47	3	35	25	33	18	21	18	500.0	1.24	2108.62
		49	26	28	38	35	25	31	20	49.0	0.53	304.05
3 hour	6	51	31	34	35	32	29	29	21	50.0	2.02	131.66
		53	19	31	34	22	11	24	16	50.0	1.56	156.40
		55	14	16	19	31	35	18	17	51.0	1.39	185.36
		57	25	34	29	24	24	21	18	48.0	0.57	292.89
		59	14	23	42	42	14	23	18	49.0	8.01	35.40
24 hour	7	61	28	26	21	29	28	27	20	50.0	3.37	77.69

		63	34	38	24	25	23	28	20	50.0	15.21	18.07
		65	25	39	35	45	40	30	21	50.0	0.31	502.15
		67	21	23	19	26	21	21	17	50.0	5.01	59.86
		69	35	29	28	36	35	31	20	50.0	3.41	73.46
control	8	71	31	25	25	22	20	24	18	250.0	0.35	2505.85
		73	31	9	22	28	25	19	12	500.0	1.39	1954.14
		75	20	15	19	17	18	22	16	52.0	2.16	141.61
		77	32	31	30	26	21	23	18	50.0	2.50	101.74
		79	28	31	31	20	31	32	21	50.0	2.52	95.23
9 hour	9	81	36	31	27	25	27	28	23	51.0	5.06	52.98
		83	13	15	12	11	20	18	18	50.0	0.37	494.31
		85	25	31	30	34	28	28	21	510.0	1.12	2312.76
		87	10	29	25	23	22	16	15	50.0	1.15	248.15
		89	26	29	15	19	14	24	19	50.0	1.52	156.97
24 hour	10	91	29	25	15	10	11	16	16	50.0	2.04	149.81
		93	10	11	11	25	22	21	19	1000.0	0.28	12807.21
		95	26	25	27	28	21	15	20	49.0	0.53	316.68
		97	23	19	21	30	24	26	21	49.0	1.09	239.71
		99	28	18	20	21	29	24	22	50.0	0.50	333.94
3 hour	11	101	25	16	16	27	21	24	16	98.0	0.29	1236.79
		103	30	26	28	25	28	29	21	49.0	1.34	172.04
		105	29	35	25	30	32	34	20	50.0	2.58	92.17
		107	32	30	26	26	21	21	20	50.0	1.07	252.36
		109	21	15	11	14	18	17	16	46.0	0.26	661.28
control	12	111	22	21	9	18	19	23	20	51.0	2.47	107.19
		113	29	28	29	31	28	24	19	50.0	0.25	677.69
		115	25	31	25	24	26	31	24	52.0	0.36	459.02
		117	35	32	25	36	28	27	19	250.0	0.40	2087.33
		119	22	24	26	21	18	26	31	50.0	2.27	101.72

VII.2.2.5 After Treading Treatment (26-weeks)

19/2/01			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	26	26	21	20	21	23	18	100.0	0.54	654.98
		4	23	14	25	26	18	21	17	50.0	1.11	254.50
		6	13	14	21	21	6	17	16	50.0	5.15	59.47
		7	24	26	26	25	21	29	21	99.0	0.19	1745.68
		9	14	12	16	20	9	16	16	51.0	1.03	304.13
control	2	11	26	25	21	28	18	21	18	49.0	0.27	640.86
		13	15	25	16	14	14	17	16	50.0	0.22	846.95
		15	19	22	21	15	11	15	13	50.0	0.42	461.61
		17	20	21	15	16	19	19	15	250.0	1.21	1159.59
		19	19	25	26	27	26	27	21	100.0	0.45	745.22
24 hour	3	21	26	18	18	25	28	24	19	50.0	0.19	916.34
		23	21	22	25	20	21	18	16	99.0	0.33	1099.48
		25	26	27	21	23	25	25	21	98.0	0.31	1063.15
		27	24	29	9	3	15	16	16	49.0	0.43	425.92
		29	25	25	21	24	23	25	18	50.0	0.44	399.98
3 hour	4	31	26	28	21	20	19	25	20	100.0	1.30	381.59
		33	18	12	11	16	28	15	11	500.0	1.11	2812.61
		35	10	11	21	34	25	17	15	505.0	1.25	2221.29
		37	19	23	18	16	22	22	19	101.0	0.21	1700.16
		39	25	31	31	29	24	24	16	51.0	3.49	79.35
9 hour	5	41	30	21	21	22	25	21	19	50.0	13.55	20.83
		43	24	30	24	25	26	26	20	50.0	0.22	769.29
		45	12	27	21	21	13	21	20	41.0	4.32	52.79
		47	25	22	16	16	29	17	16	51.0	0.25	748.67
		49	22	25	26	31	21	28	20	49.0	1.44	159.78
3 hour	6	51	16	21	19	29	24	23	18	500.0	0.24	7397.42
		53	29	21	25	35	31	28	19	52.0	0.47	374.89
		55	22	18	14	24	29	22	20	48.0	0.40	415.61
		57	22	9	16	21	26	17	10	48.0	0.37	523.20

		59	26	24	25	28	30	29	21	51.0	0.41	412.23
24 hour	7	61	18	21	29	35	29	25	20	48.0	2.05	129.73
		63	34	28	21	21	24	29	21	495.0	1.49	1512.59
		65	36	31	21	25	25	28	21	252.0	1.18	1066.28
		67	21	25	22	16	24	23	21	50.0	3.53	73.21
		69	34	33	31	26	30	32	21	50.0	0.13	1241.53
control	8	71	15	30	29	29	25	24	21	500.0	0.54	3099.14
		73	22	22	22	15	15	17	16	102.0	0.37	1019.74
		75	41	24	11	22	29	25	16	100.0	0.32	1124.41
		77	30	36	30	22	14	29	21	49.0	1.35	171.11
		79	22	31	23	21	26	24	21	250.0	1.30	934.17
9 hour	9	81	26	29	19	23	26	23	16	50.0	2.06	143.45
		83	29	18	13	18	25	16	15	495.0	0.08	23119.46
		85	18	18	14	14	16	13	12	50.0	0.50	395.07
		87	21	36	33	25	23	30	22	52.0	2.14	125.98
		89	26	32	24	23	24	25	21	52.0	0.40	434.28
24 hour	10	91	26	26	25	21	24	27	23	50.0	1.31	179.46
		93	21	21	26	36	36	26	15	500.0	1.29	2029.81
		95	24	24	25	24	17	23	15	49.0	0.13	1391.81
		97	24	27	26	27	23	25	20	50.0	0.56	303.07
		99	30	28	27	32	34	31	18	100.0	1.07	506.84
3 hour	11	101	23	14	16	24	31	23	20	50.0	0.36	480.23
		103	24	24	24	23	23	26	22	50.0	0.35	475.26
		105	19	18	26	21	14	22	19	102.0	0.36	1001.58
		107	31	29	29	30	31	31	21	255.0	1.37	853.53
		109	25	31	31	25	15	16	12	100.0	1.12	534.58
control	12	111	31	32	31	23	24	30	16	48.0	0.33	515.12
		113	21	24	29	26	26	26	21	100.0	0.20	1673.54
		115	14	27	32	35	29	28	21	98.0	0.49	660.77
		117	27	32	24	20	21	21	16	50.0	0.17	1064.01
		119	20	15	14	15	15	15	12	100.0	0.18	2193.85

VII.2.3 The 81% GSM Experiment

VII.2.3.1 Before Treading Treatment

28/7/01			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	23	29	34	33	27	24	15	500.0	1.14	2433.19
		3	30	11	24	20	30	25	21	502.0	1.05	2614.06
		5	35	29	28	30	20	20	15	502.0	0.39	4665.69
		7	16	14	16	20	15	16	16	49.0	0.25	732.15
		9	25	25	24	23	24	26	19	49.0	1.29	190.41
control	2	11	34	24	25	25	35	36	20	48.0	0.43	368.74
		13	24	26	28	18	27	18	18	200.0	0.55	1282.03
		15	9	5	3	25	36	20	19	500.0	3.57	757.57
		17	16	19	15	24	25	18	15	48.0	0.56	320.67
		19	15	10	24	26	31	19	16	250.0	0.23	3989.08
24 hour	3	21	20	25	20	20	20	22	21	100.0	0.21	1630.14
		23	32	31	28	22	23	24	21	250.0	0.56	1482.49
		25	20	19	31	32	26	25	19	246.0	0.57	1484.66
		27	25	26	20	12	15	17	15	250.0	0.43	2177.76
		29	25	25	23	26	30	24	20	50.0	0.30	565.21
control	4	31	36	25	24	31	34	29	20	49.0	0.26	622.55
		33	26	24	24	35	31	22	16	51.0	5.23	56.35
		35	11	11	31	32	30	18	18	50.0	1.11	249.86
		37	12	15	23	20	21	16	16	51.0	0.47	402.90
		39	11	29	29	30	28	22	20	248.0	1.46	796.37
24 hour	5	41	25	20	25	25	26	21	15	49.0	0.36	500.84
		43	31	25	24	29	31	33	15	49.0	1.53	155.76
		45	23	20	25	25	30	21	16	500.0	0.41	4415.10
		47	34	26	21	15	32	20	15	498.0	0.22	8293.44
		49	31	37	38	31	32	34	20	52.0	5.49	47.85
9 hour	6	51	26	28	31	36	25	30	21	500.0	1.05	2511.59
		53	31	12	15	32	27	24	21	48.0	0.32	507.25
		55	28	30	29	23	25	26	21	50.0	0.42	394.93
		57	28	27	21	30	32	28	19	49.0	7.48	35.58
		59	18	25	21	14	26	21	18	50.0	2.00	148.73
3 hour	7	61	11	19	29	30	20	23	21	51.0	2.01	143.67
		63	35	28	20	15	25	22	19	49.0	1.56	146.34
		65	28	18	15	25	31	19	14	248.0	0.49	1897.95
		67	25	17	26	35	28	19	18	500.0	1.09	2535.73
		69	15	8	25	24	23	15	12	49.0	1.02	309.72
control	8	71	24	31	31	26	30	26	18	52.0	3.37	82.51
		73	26	26	26	22	18	20	18	51.0	0.37	487.13
		75	33	34	29	29	31	32	16	49.0	0.42	406.67
		77	21	29	25	24	17	21	19	500.0	2.03	1417.84
		79	31	24	24	20	27	26	21	49.0	7.10	38.14
9 hour	9	81	24	29	24	25	26	29	20	500.0	1.15	2252.30
		83	26	31	29	39	36	26	18	500.0	0.45	3753.43
		85	20	18	14	2	20	19	16	51.0	0.50	381.90
		87	11	31	30	35	10	18	15	250.0	2.03	751.55
		89	18	35	24	24	31	26	20	99.0	0.26	1285.17
3 hour	10	91	28	25	25	25	18	23	20	50.0	1.31	187.87
		93	21	24	25	20	24	20	19	50.0	2.14	130.47
		95	26	34	16	12	9	15	15	52.0	0.49	398.23
		97	31	25	24	30	35	26	25	500.0	1.09	2247.69
		99	25	31	28	25	22	26	20	252.0	1.19	1077.68
24 hour	11	101	21	19	24	21	23	16	15	500.0	0.23	8097.08
		103	25	25	25	21	9	20	20	52.0	6.37	45.51
		105	10	29	29	24	25	24	21	505.0	1.19	2161.71
		107	39	26	31	24	34	28	22	49.0	8.48	29.65
		109	30	25	21	25	30	26	20	47.0	3.34	74.20
3 hour	12	111	22	24	21	36	33	25	25	99.0	0.36	863.09
		113	8	5	9	25	40	16	15	500.0	0.40	4715.65
		115	24	22	21	19	29	20	20	37.0	17.26	12.19
		117	28	31	16	9	6	2	15	51.0	0.28	691.38
		119	19	28	29	20	18	26	21	49.0	1.50	150.77

VII.2.3.2 After Treading Treatment (1-week)

9/8/01			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	21	11	3	9	7	19	19	3.0	37.18	0.49
		3	18	16	16	7	10	15	14	250.0	2.08	755.09
		5	26	29	28	10	29	19	18	500.0	1.39	1780.60
		7	11	18	45	49	11	13	16	100.0	1.37	372.38
		9	22	12	20	25	23	20	19	500.0	1.43	1713.41
control	2	11	23	24	29	39	37	24	19	500.0	1.42	1649.27
		13	20	21	26	31	34	28	16	25.0	1.47	83.53
		15	21	28	30	20	21	24	20	510.0	0.26	6707.00
		17	33	28	32	20	26	29	16	105.0	0.51	731.04
		19	29	21	30	24	28	26	21	505.0	3.32	792.62
24 hour	3	21	5	9	26	26	19	18	17	26.0	4.06	38.82
		23	25	14	25	44	26	25	19	250.0	1.34	909.89
		25	13	15	15	1	20	13	10	50.0	14.31	23.46
		27	3	11	0	17	20	12	11	5.0	43.16	0.78
		29	4	34	11	5	0.6	9	5	50.0	4.56	74.29
control	4	31	24	22	19	34	42	25	20	495.0	1.34	1763.40
		33	18	15	31	21	19	16	15	49.0	4.35	66.54
		35	37	32	25	18	20	27	20	49.0	0.32	516.33
		37	15	15	20	22	29	16	12	98.0	1.43	371.54
		39	18	25	36	28	18	14	14	250.0	1.20	1169.57
24 hour	5	41	33	24	26	15	11	20	19	252.0	1.40	884.65
		43	15	38	41	10	2	15	10	49.0	5.01	65.36
		45	24	21	12	30	26	21	20	500.0	3.21	857.96
		47	10	20	22	11	15	19	18	50.0	0.58	313.75
		49	26	12	14	11	26	18	15	49.0	2.47	110.43
9 hour	6	51	46	11	16	30	49	24	16	101.0	3.16	181.68
		53	16	16	19	21	0	12	11	505.0	2.48	1208.68
		55	18	17	21	31	30	22	19	49.0	11.51	24.00
		57	35	35	31	11	11	23	21	49.0	6.25	42.84
		59	23	21	24	30	26	18	16	2.0	75.01	0.16
3 hour	7	61	35	35	30	25	35	31	21	500.0	5.58	448.14
		63	16	20	26	29	38	24	21	50.0	13.33	20.56
		65	16	14	13	36	35	19	19	50.0	5.20	54.68
		67	39	37	31	33	32	34	20	100.0	0.16	1999.30
		69	16	30	19	15	23	25	19	500.0	1.57	1501.40
control	8	71	20	20	25	22	18	20	15	98.0	0.33	1105.40
		73	14	25	25	24	28	16	16	505.0	1.04	2881.82
		75	6	20	21	24	16	18	16	50.0	1.46	175.36
		77	9	9	22	24	24	22	20	49.0	2.18	124.82
		79	10	24	25	15	11	15	11	50.0	5.01	66.34
9 hour	9	81	24	31	17	25	32	19	18	102.0	1.07	533.63
		83	2	1	0	35	35	22	19	102.0	0.24	1529.20
		85	24	18	24	20	20	16	14	50.0	50.42	6.22
		87	6	32	13	21	20	19	19	50.0	4.57	59.91
		89	9	20	21	24	3	11	11	49.0	25.59	12.62
3 hour	10	91	21	35	35	26	25	32	16	50.0	0.18	981.10
		93	29	29	30	30	21	25	20	50.0	6.49	41.02
		95	19	15	16	21	25	18	14	100.0	0.45	844.63
		97	25	24	23	24	22	22	20	50.0	9.33	29.94
		99	30	35	26	27	39	27	14	51.0	4.36	66.84
24 hour	11	101	5	29	28	30	2	16	16	48.0	1.03	282.37
		103	9	8	9	25	34	16	15	51.0	1.41	190.71
		105	16	21	16	15	23	18	12	50.0	3.23	96.57
		107	7	21	30	25	10	20	15	49.0	11.38	26.33
		109	26	18	18	12	11	15	15	51.0	23.11	13.86
3 hour	12	111	21	28	31	28	21	25	20	50.0	0.43	393.96
		113	28	35	38	16	18	25	21	500.0	1.32	1804.77
		115	18	21	11	2	21	13	11	102.0	1.21	505.93
		117	16	25	40	29	21	26	25	52.0	1.51	147.69
		119	26	27	30	25	24	24	18	49.0	3.38	78.25

VII.2.3.3 After Treading Treatment (4-weeks)

6/9/01			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	35	37	35	39	28	33	22	49.0	40.38	6.22
		3	42	52	29	4	14	21	19	505.0	0.22	7830.98
		5	19	31	29	20	15	31	20	50.0	1.06	258.80
		7	31	24	19	8	5	19	16	245.0	1.00	1517.08
		9	29	31	34	25	19	29	21	505.0	0.35	4757.00
control	2	11	20	13	25	38	37	22	17	500.0	0.47	3761.79
		13	18	16	20	29	19	21	21	100.0	0.19	1807.75
		15	21	35	36	37	37	26	20	50.0	0.57	285.51
		17	24	35	41	31	21	32	25	51.0	0.23	676.64
		19	39	39	35	35	31	32	14	505.0	0.11	16185.62
24 hour	3	21	42	42	16	25	2	22	18	49.0	1.26	199.55
		23	34	35	21	35	33	37	20	500.0	1.41	1605.55
		25	9	19	34	36	18	18	16	500.0	0.35	5210.05
		27	25	35	25	9	14	22	17	500.0	0.59	3055.99
		29	21	22	24	25	25	21	16	101.0	0.41	895.83
control	4	31	25	25	27	26	26	27	26	101.0	1.08	462.63
		33	21	38	25	25	24	24	19	500.0	0.18	9520.92
		35	23	26	24	29	31	25	20	495.0	0.45	3712.73
		37	24	25	22	24	30	22	20	100.0	0.35	974.30
		39	8	3	20	31	34	9	9	500.0	0.35	5861.58
24 hour	5	41	36	36	26	21	15	26	21	50.0	2.41	103.13
		43	2	15	16	31	36	19	15	101.0	0.18	2096.58
		45	24	36	37	26	10	27	18	50.0	0.40	433.59
		47	3	25	28	40	40	20	15	49.0	7.27	39.92
		49	25	14	14	19	22	22	17	505.0	1.16	2419.89
9 hour	6	51	1	3	32	43	25	19	16	245.0	0.18	5001.97
		53	40	31	36	40	40	31	22	100.0	0.29	1050.12
		55	21	24	25	10	18	19	16	245.0	1.21	1115.97
		57	26	36	36	30	34	38	25	50.0	2.55	85.29
		59	10	25	31	30	21	26	24	242.0	0.19	4130.00
3 hour	7	61	25	25	21	30	25	25	18	50.0	2.07	137.65
		63	29	30	32	29	24	33	21	50.0	2.11	124.48
		65	18	21	35	34	37	30	21	505.0	0.51	3236.63
		67	32	26	26	20	20	26	21	50.0	3.35	77.99
		69	31	26	23	34	34	34	11	490.0	1.16	2459.88
control	8	71	15	28	31	26	18	26	16	51.0	0.35	527.54
		73	16	28	24	26	21	28	21	50.0	0.19	888.29
		75	24	29	34	23	24	27	19	252.0	0.47	1830.89
		77	27	31	28	24	20	24	22	49.0	0.53	304.58
		79	36	26	39	38	25	34	20	52.0	2.10	129.26
9 hour	9	81	29	25	31	20	24	27	21	101.0	1.31	370.04
		83	25	35	37	31	25	24	21	500.0	0.50	3261.44
		85	29	19	20	10	12	24	21	500.0	0.39	4435.54
		87	21	26	15	24	30	27	22	495.0	0.47	3507.13
		89	19	25	39	48	32	29	21	50.0	0.12	1335.33
3 hour	10	91	24	24	15	35	34	25	20	49.0	0.44	376.24
		93	24	34	25	30	26	26	20	48.0	0.25	643.60
		95	6	21	34	32	21	20	16	51.0	0.21	885.71
		97	35	30	24	24	34	27	17	50.0	1.57	148.58
		99	21	42	29	22	19	28	20	51.0	1.47	160.41
24 hour	11	101	30	45	30	30	35	31	26	98.0	0.24	1199.43
		103	16	16	16	16	7	19	15	50.0	3.46	84.07
		105	21	34	19	0	16	16	15	49.0	2.49	109.19
		107	34	32	25	15	8	24	17	50.0	15.09	19.72
		109	25	31	40	31	19	28	16	100.0	1.51	318.20
3 hour	12	111	21	15	29	30	25	24	21	500.0	0.26	6485.41
		113	24	25	20	9	14	24	21	250.0	2.35	557.14
		115	9	14	19	26	40	18	16	500.0	0.38	4825.60
		117	19	29	29	20	19	23	19	100.0	1.03	552.72
		119	15	19	35	24	4	19	19	500.0	0.52	3409.18

VII.2.3.4 After Treading Treatment (13-weeks)

9/11/01			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	25	26	24	31	35	26	21	49.0	7.39	35.20
		3	21	19	35	45	31	26	20	500.0	2.31	1096.19
		5	15	14	35	36	24	25	20	500.0	2.18	1233.28
		7	21	26	28	28	32	28	19	50.0	0.18	946.74
		9	8	15	28	25	26	15	15	490.0	0.57	3216.06
control	2	11	26	26	23	20	22	24	20	50.0	0.46	372.64
		13	11	21	19	15	15	16	13	50.0	0.23	845.50
		15	40	32	15	15	22	25	21	50.0	0.23	729.71
		17	3	18	20	18	5	12	11	100.0	0.44	916.76
		19	6	15	19	26	19	15	15	100.0	0.51	740.98
24 hour	3	21	31	21	14	41	38	24	21	500.0	3.32	775.94
		23	20	25	34	29	15	21	19	50.0	1.04	270.89
		25	41	25	24	19	16	33	27	51.0	23.06	11.29
		27	29	24	14	23	30	21	16	20.0	57.44	2.09
		29	50	35	20	15	20	25	15	49.0	1.07	264.45
control	4	31	30	26	28	31	29	25	21	50.0	3.07	87.97
		33	21	18	26	41	37	30	21	100.0	1.18	419.98
		35	25	21	19	20	15	19	19	50.0	0.46	384.53
		37	11	15	21	15	11	15	14	49.0	2.23	132.08
		39	30	35	31	21	21	26	19	50.0	6.16	45.28
24 hour	5	41	25	21	11	18	20	18	21	50.0	18.03	15.99
		43	11	28	31	25	9	20	19	500.0	0.40	4405.28
		45	41	21	32	25	36	36	22	48.0	7.26	34.01
		47	26	34	25	25	28	29	25	50.0	4.01	64.66
		49	21	21	23	24	26	28	24	50.0	3.37	74.71
9 hour	6	51	20	23	40	25	15	21	17	500.0	1.58	1511.83
		53	6	8	9	11	9	7	6	245.0	1.09	1544.12
		55	21	29	25	26	33	26	20	50.0	0.59	285.48
		57	19	16	22	9	35	22	21	500.0	1.43	1667.34
		59	25	28	29	22	26	29	24	51.0	0.33	492.76
3 hour	7	61	23	16	26	30	23	19	18	50.0	0.59	299.74
		63	14	24	24	24	25	19	18	50.0	9.59	29.68
		65	30	36	30	21	37	28	27	48.0	1.31	156.94
		67	19	16	19	31	28	22	21	50.0	0.53	320.74
		69	22	29	34	34	15	28	22	50.0	0.28	583.46
control	8	71	29	28	30	31	39	31	18	51.0	2.35	111.03
		73	11	25	26	21	26	17	17	50.0	0.35	516.65
		75	25	11	2	11	21	14	11	100.0	0.18	2233.86
		77	22	25	26	20	16	21	17	50.0	2.50	106.06
		79	21	26	25	22	14	21	20	50.0	2.11	132.19
9 hour	9	81	24	19	31	44	29	27	18	50.0	2.42	105.66
		83	31	31	25	19	21	23	17	51.0	57.53	5.21
		85	29	19	15	24	44	32	22	49.0	0.23	695.36
		87	8	13	24	34	25	27	14	50.0	1.29	211.35
		89	35	41	16	15	26	29	21	98.0	0.26	1249.14
3 hour	10	91	16	19	22	26	30	17	16	49.0	2.43	109.94
		93	32	31	30	24	23	31	19	50.0	1.03	268.39
		95	39	31	22	25	22	24	20	100.0	1.00	559.79
		97	38	25	24	24	24	25	19	100.0	0.50	683.59
		99	12	24	21	22	19	16	16	99.0	0.36	1016.59
24 hour	11	101	21	21	23	18	9	21	20	50.0	1.02	282.85
		103	25	30	30	26	25	29	22	49.0	0.19	839.95
		105	30	21	27	34	31	24	20	50.0	0.31	539.56
		107	23	26	26	19	17	18	15	500.0	0.45	4125.05
		109	35	31	25	11	41	21	16	49.0	2.43	107.11
3 hour	12	111	16	26	26	23	19	20	18	22.0	54.38	2.39
		113	21	20	16	22	19	18	15	50.0	1.12	259.96
		115	18	36	25	14	13	22	16	51.0	2.48	111.18
		117	32	28	27	35	36	36	15	50.0	13.03	22.50
		119	22	25	31	34	26	27	20	50.0	2.42	103.46

VII.2.3.5 After Treading Treatment (26-weeks)

1/2/02			Depth from top of soil core to the soil surface									
Treat-ment	Plot #	Core #	Depth 1 (mm)	Depth 2 (mm)	Depth 3 (mm)	Depth 4 (mm)	Depth 5 (mm)	Depth 6 (mm)	Pin height (mm)	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	1	26	26	28	30	28	28	21	49.0	0.36	449.22
		3	24	31	36	31	26	26	19	49.0	1.37	170.31
		5	21	19	28	16	14	21	19	51.0	6.34	45.79
		7	31	24	20	18	22	24	21	99.0	0.31	1081.91
		9	27	19	14	20	23	21	16	49.0	0.40	449.87
control	2	11	24	25	30	48	48	28	16	49.0	0.22	764.41
		13	19	32	29	26	14	28	19	99.0	0.35	977.39
		15	36	31	32	26	29	31	20	50.0	0.20	820.34
		17	31	36	31	31	29	34	21	50.0	0.20	801.20
		19	29	28	30	14	11	25	21	49.0	0.13	1279.22
24 hour	3	21	28	15	12	14	25	25	22	51.0	3.06	93.28
		24	26	21	24	26	21	25	21	500.0	1.25	1985.60
		25	26	24	18	21	23	27	21	500.0	0.33	5133.01
		27	29	21	31	31	16	24	21	49.0	1.04	256.26
		29	24	29	11	20	30	19	16	500.0	0.59	3092.91
control	4	31	30	31	28	27	34	31	18	48.0	0.35	466.19
		33	35	22	25	35	25	33	20	99.0	0.50	656.88
		35	27	25	24	31	30	30	22	49.0	1.54	139.69
		37	30	12	14	14	19	18	15	505.0	0.53	3586.22
		39	21	31	18	17	29	31	16	100.0	0.24	1505.06
24 hour	5	41	31	23	18	22	31	4	21	490.0	0.20	8372.90
		43	30	40	25	15	28	21	19	252.0	0.35	2463.24
		45	27	26	29	31	31	35	21	50.0	2.33	106.34
		47	25	25	29	23	25	27	17	49.0	0.30	578.04
		49	26	14	21	39	36	24	16	99.0	0.32	1105.99
9 hour	6	51	26	29	26	20	16	23	13	50.0	1.08	279.20
		53	27	10	25	25	26	28	19	50.0	2.12	131.68
		55	15	20	21	28	25	20	16	495.0	0.45	4025.88
		57	35	35	28	22	25	26	21	50.0	0.45	364.77
		59	34	34	30	21	16	19	16	49.0	0.23	765.34
3 hour	7	61	40	30	25	26	26	26	21	50.0	0.16	1023.70
		63	14	10	16	18	9	17	17	49.0	3.45	80.92
		65	30	28	21	29	40	34	23	49.0	0.17	907.53
		67	2	15	30	24	21	20	19	50.0	0.28	634.99
		69	18	29	28	21	33	24	21	49.0	0.34	481.91
control	8	71	28	25	21	24	31	25	20	48.0	3.10	85.59
		73	25	26	22	25	25	27	21	102.0	0.08	4275.71
		75	21	22	19	16	18	19	16	51.0	0.38	495.82
		77	36	25	29	34	36	34	21	50.0	0.35	456.70
		79	31	22	21	37	31	29	21	50.0	0.32	512.96
9 hour	9	81	42	31	25	28	36	27	20	50.0	0.17	960.69
		83	29	32	30	31	26	27	24	248.0	1.14	1049.05
		86	27	31	27	21	26	24	22	50.0	3.57	69.36
		87	30	29	24	28	29	31	22	50.0	0.15	1078.57
		89	21	16	24	39	37	28	19	50.0	0.38	447.59
3 hour	10	91	22	21	32	33	22	27	19	500.0	1.13	2347.62
		93	24	36	37	37	18	22	16	49.0	0.40	432.67
		95	24	23	24	25	24	24	21	49.0	0.27	612.03
		97	20	25	25	16	23	21	21	49.0	0.16	1045.72
		99	30	21	30	34	40	29	21	498.0	1.53	1425.93
24 hour	11	101	30	29	32	40	36	32	21	50.0	0.40	397.10
		103	26	34	29	20	16	26	26	51.0	0.45	354.99
		105	27	24	26	8	19	21	20	495.0	0.39	4410.14
		107	30	35	31	20	29	26	20	500.0	0.11	15143.54
		109	17	31	46	40	40	27	19	500.0	0.37	4421.22
3 hour	12	111	26	23	20	20	15	20	20	49.0	1.31	187.25
		113	38	31	27	30	31	34	21	49.0	0.14	1123.05
		115	29	30	35	32	28	31	21	49.0	0.32	494.86
		117	34	19	26	26	19	21	19	99.0	0.38	902.58
		119	28	32	5	1	16	16	16	498.0	0.37	5024.76

VII.3 Individual Results for the 5-10 cm Soil Depth

VII.3.1 The 65% GSM Experiment

VII.3.1.1 Before Treading Treatment

17/6/99					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	2	301.0	15.21	364.51
		4	90.0	0.28	3585.00
		6	275.0	1.33	3298.03
		8	85.0	14.47	106.88
		10	120.0	0.51	2624.32
3 hour	2	12	106.0	7.16	271.16
		14	153.0	3.15	875.11
		16	220.0	0.50	4907.47
		18	118.0	0.28	4700.34
		20	237.0	6.56	635.42
24 hour	3	22	136.0	9.43	260.18
		24	134.0	24.09	103.14
		26	175.0	22.15	146.20
		28	135.0	0.26	5791.16
		30	200.0	6.33	567.60
3 hour	4	32	99.0	32.52	55.99
		34	180.0	0.43	4668.84
		36	100.0	0.23	4849.28
		38	275.0	8.23	609.78
		40	199.0	0.55	4035.48
9 hour	5	42	200.0	1.30	2478.52
		44	200.0	0.34	6560.79
		47	145.0	8.28	318.35
		48	150.0	10.24	268.11
		50	165.0	18.11	168.68
control	6	52	330.0	0.56	6572.50
		54	338.0	8.22	750.96
		56	285.0	7.28	709.53
		58	270.0	10.40	470.53
		60	350.0	17.12	378.26
9 hour	7	62	180.0	0.46	4364.35
		64	158.0	42.07	69.74
		66	179.0	23.28	141.79
		68	301.0	19.36	285.47
		70	170.0	0.35	5417.34
3 hour	8	72	290.0	2.02	2651.20
		74	220.0	2.25	1692.23
		76	310.0	2.01	2857.47
		77	140.0	1.10	2230.67
		80	270.0	1.03	4780.00
24 hour	9	82	130.0	0.50	2899.87
		84	152.0	0.25	6781.23
		86	263.0	22.29	217.44
		88	118.0	36.44	59.71
		90	170.0	9.01	350.47
24 hour	10	92	254.0	2.59	1582.65
		94	150.0	35.18	78.99
		96	213.0	15.21	257.94
		98	240.0	0.32	8365.01
		100	66.0	39.22	31.17
control	11	102	290.0	0.47	6881.85
		104	165.0	29.45	103.10
		106	205.0	0.50	4572.87
		108	180.0	0.36	5576.67
		110	120.0	0.31	4317.42
9 hour	12	112	370.0	2.04	3328.01
		114	320.0	7.36	782.69
		116	175.0	1.59	1640.20
		118	153.0	20.39	137.73
		120	208.0	1.47	2168.13

VII.3.1.2 After Treading Treatment (1-week)

29/6/99					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	2	179.0	52.52	62.94
		4	361.0	1.51	3627.35
		6	213.0	1.19	3007.17
		8	294.0	1.46	3093.47
		10	239.0	0.50	5331.30
3 hour	2	22	289.0	6.48	790.03
		24	80.0	3.24	437.39
		26	331.0	2.21	2618.27
		28	155.0	0.23	7516.38
		30	426.0	30.45	257.52
24 hour	3	32	211.0	37.14	105.34
		34	326.0	0.37	9827.00
		36	324.0	19.00	316.99
		38	104.0	72.03	26.83
		40	324.0	1.06	5475.28
3 hour	4	12	261.0	21.23	226.89
		14	140.0	0.47	3322.27
		16	325.0	0.50	7249.67
		18	225.0	1.10	3585.00
		20	335.0	1.41	3699.38
9 hour	5	42	219.0	51.00	79.82
		44	291.0	1.04	5071.28
		46	98.0	63.09	28.85
		48	259.0	1.36	3009.08
		50	125.0	0.29	4807.47
control	6	52	59.0	6.40	164.51
		54	267.0	48.03	103.29
		56	361.0	0.57	7063.78
		58	243.0	59.52	75.45
		60	286.0	2.13	2398.39
9 hour	7	62	345.0	1.56	3317.16
		64	105.0	0.18	6506.12
		66	84.0	0.76	1232.74
		68	252.0	84.54	55.18
		70	225.0	79.19	52.73
3 hour	8	72	310.0	0.54	6402.84
		74	80.0	0.19	4696.14
		76	371.0	24.27	282.06
		78	274.0	0.41	7453.70
		80	358.0	1.55	3472.08
24 hour	9	82	350.0	0.52	7507.06
		84	217.0	1.21	2987.99
		86	195.0	65.54	55.01
		88	*No data*	*No data*	*No data*
		90	86.0	63.02	25.36
24 hour	10	92	287.0	0.54	5927.79
		94	200.0	78.25	47.41
		96	224.0	35.30	117.29
		98	226.0	3.08	1340.77
		100	266.0	0.48	6180.81
control	11	102	108.0	36.34	54.90
		104	130.0	0.28	5178.34
		106	258.0	0.51	5642.28
		108	198.0	0.30	7361.20
		110	256.0	9.05	523.90
9 hour	12	112	335.0	10.37	586.56
		114	144.0	0.19	8453.06
		116	60.0	56.49	19.63
		118	84.0	38.55	40.12
		120	227.0	51.41	81.64

VII.3.1.3 After Treading Treatment (4-weeks)

22/7/99					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	2	146.0	0.27	6031.07
		4	359.0	0.52	7700.09
		6	115.0	0.30	4275.45
		8	323.0	0.56	6433.09
		10	111.0	37.05	55.64
3 hour	2	21	125.0	0.36	3872.69
		24	139.0	59.37	43.34
		26	103.0	41.15	46.42
		28	210.0	0.47	4983.41
		30	260.0	32.47	147.43
24 hour	3	32	223.0	0.55	4522.17
		34	366.0	1.10	5831.60
		36	240.0	39.51	111.95
		38	238.0	0.45	5898.88
		40	457.0	14.41	578.56
3 hour	4	12	227.0	39.08	107.83
		14	335.0	1.19	4729.58
		16	390.0	17.41	409.97
		18	271.0	0.54	5597.32
		20	360.0	21.24	312.71
9 hour	5	42	294.0	2.26	2245.95
		44	286.0	1.08	4690.96
		46	352.0	2.29	2634.88
		48	386.0	22.44	315.63
		50	392.0	22.05	329.97
control	6	52	311.0	3.37	1598.47
		54	312.0	0.48	7249.67
		56	295.0	1.24	3916.95
		58	340.0	2.32	2494.83
		60	295.0	37.06	147.81
9 hour	7	62	240.0	8.18	537.51
		64	340.0	1.07	5659.90
		66	114.0	33.29	63.29
		68	145.0	0.26	6220.13
		70	247.0	53.59	85.05
3 hour	8	72	100.0	61.06	30.42
		74	174.0	59.13	54.62
		76	318.0	0.50	7093.52
		78	148.0	45.10	60.91
		80	96.0	53.39	33.26
24 hour	9	82	29.0	62.31	8.62
		83	345.0	14.13	451.10
		86	315.0	8.33	684.85
		88	500.0	3.25	822.54
		90	50.0	52.53	17.58
24 hour	10	92	293.0	1.04	5106.14
		94	415.0	2.53	2675.51
		96	391.0	5.57	1221.56
		98	396.0	25.41	286.61
		100	150.0	0.33	5069.70
control	11	102	418.0	13.56	557.67
		104	217.0	1.01	3967.66
		106	170.0	51.43	61.10
		108	274.0	0.47	6502.16
		110	50.0	73.13	12.69
9 hour	12	112	179.0	54.58	60.54
		114	281.0	6.58	749.78
		116	380.0	1.20	5297.84
		118	185.0	63.57	53.78
		120	397.0	1.17	5750.49

VII.3.1.4 After Treading Treatment (13-weeks)

23/9/99					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	2	252.0	53.50	87.02
		4	360.0	8.03	831.30
		6	382.0	2.00	3550.48
		8	295.0	3.05	1778.51
		10	270.0	1.50	2737.64
3 hour	2	12	218.0	67.36	59.95
		14	286.0	11.09	476.81
		16	331.0	6.09	1000.48
		17	340.0	9.43	650.45
		20	422.0	0.58	8115.02
24 hour	3	22	335.0	1.01	6125.20
		24	355.0	51.27	128.26
		25	405.0	1.48	4182.50
		28	330.0	0.46	8001.31
		30	272.0	3.21	1509.31
3 hour	4	32	386.0	1.39	4348.68
		34	165.0	35.55	85.40
		36	115.0	22.10	96.44
		38	399.0	1.53	3938.21
		40	186.0	101.16	34.14
9 hour	5	42	269.0	1.39	3030.55
		44	321.0	1.16	4710.82
		46	270.0	7.19	685.97
		48	255.0	0.45	6320.23
		50	381.0	19.48	357.70
control	6	52	194.0	0.29	7461.20
		54	201.0	0.36	6227.28
		56	430.0	6.04	1317.56
		58	351.0	2.15	2899.87
		60	380.0	3.02	2328.72
9 hour	7	62	387.0	2.12	3269.96
		64	62.0	34.27	33.45
		66	340.0	21.25	295.11
		68	184.0	36.50	92.86
		70	390.0	1.12	6041.39
3 hour	8	72	406.0	1.25	5327.36
		74	398.0	1.05	6829.28
		76	128.0	64.57	36.63
		78	423.0	4.40	1684.95
		80	402.0	2.42	2767.68
24 hour	9	82	336.0	0.47	7973.45
		84	428.0	14.54	533.96
		86	376.0	9.39	724.29
		88	193.0	47.37	22.78
		90	353.0	13.43	478.39
24 hour	10	92	369.0	22.19	307.36
		94	273.0	27.17	186.00
		96	321.0	1.09	5188.73
		98	283.0	1.05	4855.99
		100	261.0	1.16	3830.29
control	11	102	381.0	1.41	4207.35
		104	333.0	1.46	3503.83
		106	301.0	6.10	907.34
		108	210.0	54.07	72.13
		110	422.0	5.02	1558.51
9 hour	12	112	363.0	0.53	7638.99
		114	375.0	2.26	2864.73
		116	250.0	80.57	57.41
		118	101.0	54.41	34.33
		120	281.0	38.59	133.99

VII.3.1.5 After Treading Treatment (26-weeks)

17/12/99					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
control	1	2	380.0	1.58	3591.75
		4	363.0	2.01	3346.00
		6	302.0	9.10	612.42
		8	374.0	1.13	5714.18
		10	402.0	3.31	2124.95
3 hour	2	12	144.0	44.33	60.09
		14	391.0	1.25	5130.54
		16	308.0	39.20	145.56
		17	342.0	39.56	159.20
		20	435.0	6.41	1209.90
24 hour	3	22	401.0	1.06	6776.50
		24	354.0	23.16	282.83
		25	365.0	1.41	4030.66
		28	188.0	59.35	58.65
		30	363.0	39.43	169.90
3 hour	4	32	414.0	11.26	673.10
		34	354.0	0.57	6926.81
		36	417.0	1.17	6040.19
		38	290.0	65.56	81.76
		40	355.0	4.12	1571.20
9 hour	5	42	369.0	7.46	883.17
		44	366.0	1.28	4638.78
		46	192.0	57.43	61.84
		48	165.0	51.39	59.38
		50	264.0	45.49	107.11
control	6	52	360.0	43.27	154.02
		54	325.0	55.27	108.95
		56	398.0	22.55	322.84
		58	301.0	46.02	121.55
		60	249.0	38.30	120.22
9 hour	7	62	347.0	64.34	99.90
		64	286.0	32.02	165.97
		66	207.0	72.37	52.99
		68	402.0	1.16	5899.53
		70	416.0	21.14	364.19
3 hour	8	72	283.0	57.54	90.86
		73	196.0	51.12	71.16
		76	273.0	39.10	129.57
		78	306.0	25.53	219.76
		80	359.0	37.01	180.28
24 hour	9	82	338.0	1.24	4487.89
		84	123.0	43.40	52.36
		86	390.0	4.53	1484.57
		88	405.0	1.06	6844.10
		90	341.0	7.56	799.01
24 hour	10	92	297.0	42.08	131.03
		94	397.0	4.36	1604.30
		96	341.0	9.25	673.15
		98	306.0	48.26	117.44
		100	345.0	15.09	423.31
control	11	102	430.0	1.14	6481.00
		104	381.0	7.18	970.19
		106	230.0	65.06	65.68
		108	330.0	0.56	6572.50
		110	347.0	9.33	675.43
9 hour	12	112	332.0	20.26	302.03
		114	367.0	10.29	650.76
		116	162.0	56.43	53.10
		118	356.0	2.52	2308.48
		120	241.0	46.40	96.00

VII.3.2 The 71% GSM Experiment

VII.3.2.1 Before Treading Treatment

22/8/00					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	395.0	2.58	2475.04
		4	6.0	49.11	2.27
		6	122.0	57.49	39.22
		8	325.0	1.14	4898.43
		10	163.0	61.12	49.51
control	2	12	22.8	1.35	267.68
		14	350.0	4.02	1613.09
		16	130.0	62.48	38.48
		18	410.0	1.19	5788.44
		20	109.0	60.41	33.39
24 hour	3	22	380.0	0.38	11153.34
		24	325.0	2.35	2338.60
		26	369.0	52.50	129.83
		28	400.0	1.15	5948.45
		30	78.0	23.33	61.57
3 hour	4	31	398.0	3.54	1897.02
		34	380.0	1.11	5969.39
		36	325.0	36.25	165.90
		38	260.0	57.22	84.25
		40	397.0	1.40	4427.88
9 hour	5	42	370.0	2.52	2399.27
		44	277.0	41.20	124.58
		46	18.0	56.56	5.88
		48	56.0	53.52	19.33
		50	408.0	3.16	2321.72
3 hour	6	52	155.0	69.02	41.74
		54	98.0	59.20	30.70
		56	351.0	1.26	4552.12
		58	298.0	14.31	381.60
		60	390.0	10.22	699.33
24 hour	7	62	348.0	42.03	153.84
		64	413.0	2.03	3744.98
		66	121.0	66.02	34.06
		68	354.0	15.18	430.10
		70	399.0	2.34	2889.73
control	8	72	395.0	4.32	1619.69
		74	191.0	57.22	61.89
		76	245.0	1.34	2906.99
		78	356.0	15.47	419.28
		80	204.0	61.15	61.91
9 hour	9	82	435.0	1.06	7351.07
		84	25.0	74.17	6.26
		86	395.0	2.21	3124.52
		88	366.0	36.30	186.40
		90	91.0	69.57	24.18
24 hour	10	92	374.0	45.24	153.13
		94	340.0	2.40	2370.08
		96	243.0	55.28	81.44
		98	406.0	1.17	5880.85
		100	399.0	1.59	3739.65
3 hour	11	102	415.0	0.54	8571.55
		104	140.0	52.58	49.13
		106	300.0	46.00	121.23
		108	44.0	62.46	13.03
		110	83.0	74.15	20.78
control	12	112	444.0	11.41	706.43
		114	139.0	59.28	43.45
		116	135.0	60.40	41.37
		118	35.0	74.40	8.71
		120	23.0	59.36	7.17

VII.3.2.2 After Treading Treatment (1-week)

1/9/00					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	112	42.0	69.29	11.24
		114	352.0	4.28	1464.92
		116	335.0	3.42	1683.05
		118	50.0	80.51	11.50
		120	16.0	64.09	4.64
control	2	2	367.0	10.11	669.93
		4	229.0	55.24	76.84
		6	394.0	3.03	2401.32
		8	421.0	1.48	4347.74
		10	425.0	1.07	7074.88
24 hour	3	12	48.0	62.30	14.28
		14	39.0	60.39	11.95
		16	393.0	13.22	546.54
		18	15.0	48.01	5.81
		20	100.0	46.14	40.21
3 hour	4	22	58.0	41.33	25.95
		24	108.0	61.47	32.49
		26	405.0	1.27	5192.07
		28	410.0	2.25	3153.70
		30	366.0	1.05	6280.19
9 hour	5	32	20.0	49.44	7.48
		34	415.0	1.42	4537.88
		36	386.0	5.41	1262.52
		38	354.0	35.52	183.47
		40	381.0	4.21	1628.13
3 hour	6	42	25.0	91.26	5.08
		44	173.0	48.19	66.56
		46	52.0	48.03	20.12
		48	315.0	0.36	9759.17
		50	18.0	50.35	6.61
24 hour	7	52	0.0	0.00	0.10
		54	350.0	32.12	202.05
		56	0.0	0.00	0.10
		58	155.0	56.59	50.56
		60	340.0	15.11	416.26
control	8	62	333.0	3.18	1875.79
		64	410.0	1.00	7621.45
		66	405.0	1.07	6741.94
		68	412.0	5.50	1312.91
		70	312.0	29.36	195.94
9 hour	9	72	419.0	1.08	6872.43
		74	341.0	12.02	526.77
		76	319.0	18.37	318.52
		77	61.0	61.32	0.10
		80	361.0	13.14	507.10
24 hour	10	82	179.0	50.17	66.17
		84	367.0	10.42	637.58
		86	35.0	50.20	12.93
		88	5.0	45.40	2.04
		90	0.0	0.00	0.10
3 hour	11	92	399.0	2.24	3090.40
		94	385.0	1.46	4050.98
		96	56.0	57.08	18.22
		98	159.0	49.29	59.73
		100	427.0	1.03	7559.49
control	12	102	372.0	13.32	510.97
		104	389.0	1.40	4338.65
		106	96.0	47.28	37.60
		108	421.0	0.58	8095.79
		110	65.0	60.23	20.01

VII.3.2.3 After Treading Treatment (4-weeks)

28/9/00					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	49.0	50.23	18.08
		4	420.0	20.25	382.40
		6	101.0	61.00	30.78
		8	351.0	62.17	104.76
		10	286.0	2.23	2230.67
control	2	12	307.0	69.40	81.92
		14	175.0	72.01	45.17
		16	423.0	2.59	2635.68
		18	356.0	2.17	2898.24
		20	275.0	1.11	4319.96
24 hour	3	22	235.0	59.37	73.27
		24	275.0	1.31	3370.51
		26	240.0	65.22	68.25
		28	49.0	63.12	14.41
		30	215.0	2.34	1557.12
3 hour	4	32	381.0	1.37	4380.85
		34	370.0	3.30	1965.11
		36	388.0	7.42	936.69
		38	395.0	1.04	6883.70
		40	405.0	38.14	196.91
9 hour	5	42	47.0	83.28	10.47
		44	373.0	7.46	892.75
		46	81.0	60.50	24.75
		48	391.0	4.54	1483.32
		50	71.0	63.31	20.78
3 hour	6	52	380.0	15.52	445.20
		54	231.0	36.08	118.84
		56	146.0	62.27	43.46
		58	377.0	76.20	91.81
		60	345.0	1.10	5497.00
24 hour	7	62	388.0	4.32	1590.99
		64	417.0	28.27	272.46
		66	407.0	2.39	2854.97
		68	156.0	46.06	62.90
		70	8.0	55.43	2.67
control	8	72	397.0	1.50	4025.34
		74	414.0	55.04	139.75
		76	342.0	4.12	1513.67
		78	290.0	3.18	1633.57
		80	66.0	23.18	52.66
9 hour	9	82	356.0	1.04	6204.05
		84	253.0	47.15	99.53
		86	276.0	28.12	181.93
		88	56.0	37.50	27.51
		90	185.0	76.32	44.93
24 hour	10	92	13.0	70.10	3.44
		94	104.0	69.56	27.64
		96	93.0	58.44	29.43
		98	45.0	59.13	14.13
		100	91.0	69.32	24.33
3 hour	11	102	16.0	70.26	4.22
		104	1871.0	69.32	500.19
		106	61.0	63.08	17.96
		108	426.0	1.14	6420.71
		110	387.0	4.09	1733.47
control	12	112	390.0	1.35	4578.74
		114	370.0	1.35	4343.93
		116	154.0	38.52	73.65
		118	435.0	1.12	6738.48
		120	270.0	0.37	8138.92

VII.3.2.4 After Treading Treatment (13-weeks)

23/11/00					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	331.0	4.01	1531.85
		4	299.0	10.07	549.40
		6	344.0	57.07	111.96
		8	375.0	1.46	3945.76
		10	415.0	0.52	8901.22
control	2	12	415.0	1.15	6171.51
		14	302.0	54.45	102.54
		16	337.0	6.45	928.07
		18	305.0	34.11	165.86
		20	391.0	2.04	3516.90
24 hour	3	22	197.0	47.38	76.88
		24	290.0	39.26	136.71
		26	98.0	51.37	35.29
		28	392.0	1.56	3769.06
		30	331.0	3.36	1709.15
3 hour	4	32	405.0	8.33	880.53
		34	346.0	1.23	4649.46
		36	300.0	44.15	126.03
		38	316.0	6.20	927.49
		40	168.0	47.38	65.56
9 hour	5	42	449.0	7.27	1120.32
		44	374.0	38.30	180.58
		46	244.0	46.15	98.07
		48	213.0	62.00	63.86
		50	341.0	48.25	130.92
3 hour	6	52	420.0	7.34	1031.81
		54	390.0	1.43	4223.11
		56	414.0	2.46	2781.62
		58	228.0	44.39	94.92
		60	181.0	62.33	53.79
24 hour	7	62	236.0	48.02	91.33
		64	137.0	31.02	82.06
		66	220.0	62.16	65.68
		68	275.0	26.54	190.04
		70	395.0	2.33	2879.46
control	8	72	312.0	1.33	3741.77
		74	400.0	1.05	6863.59
		76	360.0	1.03	6373.34
		78	393.0	2.05	3506.61
		80	358.0	11.17	589.79
9 hour	9	82	45.0	31.51	26.26
		84	134.0	54.48	45.45
		86	390.0	2.53	2514.34
		88	425.0	2.10	1102.52
		90	411.0	1.31	5037.39
24 hour	10	92	341.0	5.31	1149.03
		94	325.0	1.11	5105.40
		96	313.0	21.57	265.07
		98	346.0	13.09	489.11
		100	365.0	1.10	5815.67
3 hour	11	102	211.0	33.37	116.68
		104	409.0	2.03	3708.71
		106	405.0	2.09	3501.63
		108	189.0	52.31	66.90
		110	365.0	2.57	2299.98
control	12	112	155.0	37.08	77.59
		114	410.0	1.32	4970.51
		116	303.0	21.45	258.96
		118	370.0	1.37	4254.37
		120	380.0	2.05	3390.62

VII.3.2.5 After Treading Treatment (26-weeks)

19/2/01					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	391.0	17.14	421.76
		3	381.0	31.40	223.65
		5	351.0	1.06	5931.55
		8	396.0	8.42	846.12
		10	298.0	4.18	1288.25
control	2	12	366.0	2.55	2332.64
		14	406.0	1.07	6758.59
		16	331.0	3.28	1774.88
		18	379.0	1.45	4025.82
		20	381.0	1.04	6639.72
24 hour	3	22	367.0	45.03	151.43
		24	331.0	4.31	1362.27
		26	395.0	1.32	4788.66
		28	301.0	20.24	274.28
		30	401.0	1.09	6481.87
3 hour	4	32	371.0	1.41	4096.92
		34	307.0	16.19	349.75
		36	369.0	2.23	2878.03
		38	418.0	22.26	346.37
		40	329.0	29.01	210.77
9 hour	5	42	370.0	31.36	217.65
		44	302.0	13.06	428.54
		46	241.0	17.21	258.21
		48	415.0	1.19	5859.03
		50	365.0	1.56	3509.46
3 hour	6	52	318.0	9.46	605.25
		54	330.0	45.14	135.62
		56	428.0	10.08	785.14
		58	285.0	8.04	656.76
		60	410.0	0.50	9145.74
24 hour	7	62	292.0	43.11	125.70
		64	371.0	3.03	2261.14
		66	239.0	17.27	254.60
		68	325.0	5.52	1029.78
		70	400.0	2.02	3656.83
control	8	72	318.0	4.37	1280.42
		74	385.0	1.16	5650.05
		76	326.0	2.00	3029.99
		78	376.0	1.20	5242.07
		80	435.0	1.16	6383.82
9 hour	9	82	217.0	5.37	718.18
		84	425.0	0.54	8778.09
		86	257.0	6.02	791.83
		88	367.0	16.31	413.04
		90	389.0	1.23	5227.29
24 hour	10	92	388.0	9.47	737.22
		94	429.0	1.30	5316.43
		96	397.0	20.20	362.94
		98	368.0	1.25	4828.74
		100	368.0	1.34	4366.41
3 hour	11	102	406.0	2.51	2648.10
		104	174.0	11.49	273.72
		106	408.0	3.08	2420.51
		108	395.0	13.48	532.07
		110	330.0	2.41	2286.09
control	12	112	382.0	2.39	2679.61
		114	332.0	1.07	5526.73
		116	382.0	5.46	1231.38
		118	465.0	3.42	2336.17
		120	375.0	0.57	7337.72

VII.3.3 The 81% GSM Experiment

VII.3.3.1 Before Treading Treatment

28/7/01					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	270.0	3.31	1427.20
		4	304.0	0.51	6648.27
		6	383.0	1.21	5273.74
		8	108.0	42.28	47.27
		10	262.0	4.45	1025.32
control	2	12	238.0	27.02	163.66
		14	383.0	1.06	6472.32
		16	381.0	1.47	3971.42
		18	250.0	4.40	995.83
		20	354.0	1.36	4112.79
24 hour	3	22	386.0	0.57	7552.96
		24	401.0	0.50	8944.98
		26	417.0	7.10	1081.61
		28	384.0	2.25	2953.71
		30	375.0	1.11	5890.85
control	4	32	310.0	4.07	1399.81
		34	330.0	2.15	2726.37
		36	339.0	3.01	2088.94
		38	398.0	2.58	2493.84
		40	294.0	11.56	457.97
24 hour	5	42	77.0	24.01	59.60
		44	357.0	2.38	2520.09
		46	300.0	28.16	197.29
		48	301.0	3.29	1606.29
		50	370.0	2.57	2331.49
9 hour	6	52	386.0	31.54	224.93
		54	354.0	4.26	1484.32
		56	315.0	11.18	518.19
		58	272.0	5.38	897.55
		60	350.0	10.01	649.53
3 hour	7	62	389.0	1.05	6674.85
		64	276.0	21.44	236.07
		66	332.0	3.17	1879.65
		68	265.0	0.59	5009.55
		70	79.0	47.05	31.19
control	8	72	98.0	23.55	76.17
		74	130.0	20.10	119.83
		76	360.0	1.20	5019.00
		78	304.0	3.59	1418.67
		80	312.0	1.35	3662.99
9 hour	9	82	376.0	1.18	5376.48
		84	126.0	39.43	58.97
		86	381.0	1.31	4669.70
		88	152.0	34.36	81.66
		90	299.0	17.28	318.21
3 hour	10	92	298.0	5.43	969.01
		94	334.0	1.09	5398.86
		96	258.0	5.44	836.50
		98	256.0	20.19	234.23
		100	88.0	31.15	52.35
24 hour	11	102	145.0	31.53	84.54
		104	354.0	2.32	2597.55
		106	300.0	1.05	5147.70
		108	351.0	2.47	2344.21
		110	391.0	1.15	5814.61
3 hour	12	112	255.0	21.45	217.94
		114	392.0	0.55	7949.29
		116	373.0	1.14	5621.89
		118	286.0	15.22	345.97
		120	280.0	1.06	4731.72

VII.3.3.2 After Treading Treatment (1-week)

9/8/01					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	343.0	4.41	1361.42
		4	371.0	2.00	3448.24
		6	322.0	8.53	673.80
		8	326.0	33.17	182.07
		10	1.0	50.40	0.37
control	2	12	361.0	10.35	634.07
		14	420.0	4.22	1787.94
		16	341.0	10.08	625.54
		18	392.0	1.15	5829.48
		20	381.0	6.20	1118.27
24 hour	3	22	386.0	2.12	3261.51
		24	119.0	54.48	40.37
		26	313.0	51.49	112.29
		28	82.0	47.30	32.09
		30	338.0	8.26	745.03
control	4	32	328.0	0.56	6532.67
		34	358.0	14.29	459.48
		36	281.0	43.18	120.63
		38	348.0	10.02	644.74
		40	322.0	7.34	791.05
24 hour	5	42	64.0	49.22	24.10
		44	337.0	6.39	942.02
		46	155.0	47.38	60.49
		48	6.0	57.51	1.93
		50	312.0	38.32	150.51
9 hour	6	52	361.0	3.02	2212.28
		54	380.0	13.55	507.58
		56	294.0	53.48	101.58
		58	304.0	51.52	108.95
		60	160.0	31.54	93.24
3 hour	7	62	27.0	42.52	11.71
		64	0.0	0.00	11.15
		66	374.0	1.43	4049.85
		68	403.0	1.25	5288.00
		70	390.0	6.58	1040.62
control	8	72	355.0	5.58	1105.99
		74	294.0	34.25	158.79
		76	72.0	56.21	23.75
		78	396.0	1.55	3840.63
		80	318.0	50.09	117.87
9 hour	9	82	30.0	47.39	11.70
		84	343.0	23.54	266.78
		86	390.0	7.03	1028.32
		88	355.0	5.32	1192.60
		90	199.0	24.35	150.48
3 hour	10	92	204.0	48.26	78.30
		94	339.0	5.17	1192.74
		96	221.0	55.43	73.73
		98	295.0	22.48	240.51
		100	326.0	51.44	117.14
24 hour	11	102	349.0	7.13	898.96
		104	41.0	68.56	11.06
		106	3.0	54.37	1.02
		108	341.0	17.34	360.84
		110	336.0	11.45	531.56
3 hour	12	112	364.0	3.31	1924.08
		114	296.0	11.29	479.16
		116	311.0	5.28	1057.53
		118	352.0	9.24	696.10
		120	331.0	3.19	1855.15

VII.3.3.3 After Treading Treatment (4-weeks)

6/9/01					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	28.0	45.32	11.43
		4	267.0	26.15	189.08
		6	269.0	17.48	280.92
		8	360.0	1.21	4957.04
		10	6.0	46.19	2.41
control	2	12	313.0	14.32	400.34
		14	31.0	57.32	10.02
		16	305.0	3.00	1889.87
		18	397.0	2.33	2894.04
		20	340.0	2.19	2728.16
24 hour	3	22	11.0	29.21	6.97
		24	370.0	29.20	234.47
		26	269.0	6.58	717.76
		28	97.0	27.24	65.81
		30	345.0	0.59	6521.87
control	4	32	350.0	2.09	3026.10
		34	374.0	1.55	3627.26
		36	395.0	1.27	5063.87
		38	382.0	7.48	910.38
		40	359.0	3.30	1906.69
24 hour	5	42	43.0	26.35	30.07
		44	57.0	15.22	68.95
		46	303.0	78.15	71.98
		48	41.0	40.01	19.05
		50	252.0	18.26	254.13
9 hour	6	52	289.0	20.37	260.58
		54	380.0	1.25	4986.20
		56	305.0	33.47	167.82
		58	341.0	1.21	4695.42
		60	14.0	16.18	15.97
3 hour	7	62	365.0	1.28	4626.10
		64	395.0	36.32	200.98
		66	290.0	1.21	3993.17
		68	65.0	59.54	20.17
		70	345.0	12.09	527.83
control	8	72	201.0	2.30	1494.55
		74	367.0	2.01	3382.87
		76	321.0	3.09	1894.30
		78	368.0	1.28	4664.12
		80	325.0	8.00	755.17
9 hour	9	82	398.0	1.52	3963.42
		84	275.0	28.05	182.03
		86	340.0	36.18	174.11
		88	102.0	78.14	24.24
		90	86.0	5.04	315.52
3 hour	10	92	322.0	1.02	5792.54
		94	6.0	32.11	3.47
		96	331.0	1.20	4614.69
		98	350.0	1.49	3581.35
		100	351.0	2.33	2558.71
24 hour	11	102	55.0	25.44	39.73
		104	12.0	10.04	22.16
		106	285.0	26.46	197.93
		108	249.0	32.13	143.67
		110	332.0	14.33	424.16
3 hour	12	112	304.0	1.50	3082.38
		114	76.0	47.25	29.79
		116	350.0	0.54	7229.02
		118	371.0	2.36	2652.49
		120	111.0	47.40	43.29

VII.3.3.4 After Treading Treatment (13-weeks)

9/11/01					
Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	391.0	23.13	313.06
		4	19.0	33.35	10.52
		6	298.0	5.29	1010.24
		8	208.0	37.11	103.98
		10	380.0	6.02	1170.79
control	2	12	364.0	2.06	3222.08
		14	360.0	1.53	3553.28
		16	398.0	28.25	260.35
		18	177.0	29.24	111.91
		20	116.0	32.28	66.42
24 hour	3	22	224.0	39.50	104.53
		24	220.0	1.00	4089.56
		26	346.0	6.21	1012.88
		28	184.0	29.58	114.14
		30	351.0	17.28	373.55
control	4	32	368.0	1.40	4104.43
		34	91.0	40.46	41.49
		36	374.0	1.51	3757.97
		38	348.0	15.48	409.43
		40	306.0	32.42	173.95
24 hour	5	42	326.0	0.24	15149.95
		44	137.0	42.38	59.73
		46	405.0	1.05	6949.39
		48	395.0	5.40	1295.76
		50	251.0	14.37	319.21
9 hour	6	52	314.0	22.19	261.55
		54	52.0	54.44	17.66
		56	354.0	1.05	6074.28
		58	221.0	40.19	101.90
		60	361.0	2.20	2875.97
3 hour	7	62	400.0	1.19	5647.26
		64	374.0	1.59	3505.34
		66	382.0	1.57	3641.52
		68	338.0	2.51	2204.58
		70	377.0	3.13	2178.66
control	8	72	333.0	1.03	5895.34
		74	373.0	3.01	2298.45
		76	375.0	8.01	869.54
		78	207.0	3.01	1275.55
		80	411.0	12.28	612.84
9 hour	9	82	375.0	5.07	1362.38
		84	360.0	1.06	6083.64
		86	392.0	1.40	4372.11
		88	339.0	14.21	439.14
		90	126.0	2.03	1142.54
3 hour	10	92	382.0	4.00	1775.24
		94	372.0	3.00	2305.02
		96	399.0	1.28	5057.03
		98	169.0	54.45	57.38
		100	355.0	1.49	3632.51
24 hour	11	102	424.0	6.33	1203.31
		104	56.0	21.43	47.93
		106	268.0	22.43	219.30
		108	405.0	3.48	1981.19
		110	378.0	10.50	648.61
3 hour	12	112	341.0	8.31	744.28
		114	212.0	53.22	73.84
		116	314.0	12.25	470.09
		118	316.0	1.58	2986.83
		120	259.0	26.54	178.98

VII.3.3.5 After Treading Treatment (26-weeks)

1/2/02 Treatment	Plot #	Core #	Volume water used (mm)	Total time (m.s)	K_{sat} (mm hr^{-1})
9 hour	1	2	234.0	8.01	542.59
		4	1.0	60.00	0.31
		6	194.0	2.59	1208.80
		8	101.0	8.12	228.96
		10	318.0	2.31	2348.85
control	2	12	10.0	31.29	5.90
		14	229.0	3.13	1323.38
		16	286.0	3.26	1548.47
		18	74.0	7.41	179.03
		20	18.0	12.23	27.02
24 hour	3	22	38.0	31.18	22.57
		23	315.0	1.01	5759.51
		26	136.0	5.93	385.97
		28	163.0	11.40	259.71
		30	15.0	13.26	20.76
control	4	32	56.0	22.33	46.16
		34	43.0	8.39	92.41
		36	339.0	3.25	1844.38
		38	324.0	3.05	1953.34
		40	270.0	6.11	811.70
24 hour	5	42	328.0	1.48	3387.31
		44	333.0	0.55	6752.84
		46	350.0	1.49	3581.35
		48	325.0	1.20	4531.04
		50	490.0	1.41	5411.03
9 hour	6	52	38.0	18.40	37.84
		54	12.0	6.53	32.41
		56	284.0	17.26	302.82
		58	316.0	1.33	3789.74
		60	330.0	23.14	264.03
3 hour	7	62	315.0	1.25	4133.30
		64	330.0	1.02	5936.46
		66	365.0	2.33	2660.76
		68	330.0	0.55	6692.00
		70	257.0	23.23	204.31
control	8	72	115.0	11.55	179.39
		74	295.0	3.14	1696.00
		76	19.0	1.38	216.24
		78	330.0	1.14	4973.79
		80	40.0	6.26	115.58
9 hour	9	82	320.0	16.18	364.94
		84	88.0	13.11	124.08
		85	39.0	19.52	36.49
		88	295.0	4.03	1354.01
		90	26.0	5.04	95.39
3 hour	10	92	286.0	1.32	3467.23
		94	102.0	5.26	348.97
		96	291.0	0.54	6010.41
		98	100.0	19.00	97.84
		100	71.0	8.17	159.33
24 hour	11	102	278.0	24.34	210.35
		104	382.0	1.14	5757.54
		106	260.0	5.43	845.44
		108	295.0	1.55	2861.07
		110	366.0	1.01	6692.00
3 hour	12	112	125.0	5.45	404.11
		114	399.0	10.47	687.82
		116	244.0	53.00	85.58
		118	270.0	0.47	6407.24
		120	213.0	2.15	1759.75

Appendix VIII

Continuous Soil Pores

Appendix VIII Continuous Soil Pores

VIII.1 Treatment Means

	65% GSM Continuous soil pores (pores m^{-2})					
	0-5 cm		5-10 cm		Combined	
	Before	**After**	**Before**	**After**	**Before**	**After**
Control	200	280	240	480	440	760
3 hour	160	160	160	280	320	440
9 hour	160	120	320	400	480	520
24 hour	240	160	280	240	520	400
F.pr	0.627	0.528	0.341	0.112	0.274	0.284
e.s.e	49.0	77.5	60.0	66.3	96.3	131.1
s.e.d	69.3	109.5	84.9	93.8	98.0	185.5
l.s.d	159.8	252.6	195.7	216.3	225.9	427.7

Note: Combined data is the sum of the 0-5 cm and 5-10 cm soil depths, F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	71% GSM Continuous soil pores (pores m^{-2})					
	0-5 cm		5-10 cm		Combined	
	Before	**After**	**Before**	**After**	**Before**	**After**
Control	40	280	200	320	240	600
3 hour	160	200	240	280	400	480
9 hour	200	200	240	200	440	400
24 hour	120	40	280	160	400	200
F.pr	0.341	0.386	0.900	0.512	0.563	0.190
e.s.e	60.0	93.8	74.8	80.0	103.9	118.3
s.e.d	84.9	132.7	105.8	113.1	147.0	167.3
l.s.d	195.7	305.9	244.0	260.9	338.9	385.9

	81% GSM Continuous soil pores (pores m^{-2})					
	0-5 cm		5-10 cm		Combined	
	Before	**After**	**Before**	**After**	**Before**	**After**
Control	80	240	280	200	360	440
3 hour	120	80	240	240	360	320
9 hour	200	80	160	200	360	280
24 hour	200	80	400	80	600	160
F.pr	0.552	0.330	0.181	0.330	0.441	0.373
e.s.e	69.3	69.3	69.36	60.0	120.0	105.8
s.e.d	98.0	98.0	98.0	84.9	169.7	149.7
l.s.d	225.9	225.9	225.9	195.7	391.3	345.1

VIII.2 Individual Results

VIII.2.1 The 65% GSM Experiment

	No. of continuous pores observed						No. of continuous pores m^{-2}					
	Before treading			After treading			Before treading			After treading		
Treatment	0-5 cm	5-10 cm	combined	0-5 cm	5-10 cm	Combined	0-5 cm	5-10 cm	combined	0-5 cm	5-10 cm	combined
control	1	2	3	3	5	8	120	240	360	360	600	960
control	2	2	4	3	4	7	240	240	480	360	480	840
control	2	2	4	1	3	4	240	240	480	120	360	480
3 hour	1	2	3	1	2	3	120	240	360	120	240	360
3 hour	1	1	2	1	3	4	120	120	240	120	360	480
3 hour	2	1	3	2	2	4	240	120	360	240	240	480
9 hour	2	2	4	1	4	5	240	240	480	120	480	600
9 hour	2	3	5	2	4	6	240	360	600	240	480	720
9 hour	0	3	3	0	2	2	0	360	360	0	240	240
24 hour	2	1	3	0	2	2	240	120	360	0	240	240
24 hour	2	4	6	3	3	6	240	480	720	360	360	720
24 hour	2	2	4	1	1	2	240	240	480	120	120	240

VIII.2.2 The 71% GSM Experiment

	No. of continuous pores observed						No. of continuous pores m^{-2}					
	Before treading			After treading			Before treading			After treading		
Treatment	0-5 cm	5-10 cm	combined	0-5 cm	5-10 cm	Combined	0-5 cm	5-10 cm	combined	0-5 cm	5-10 cm	combined
control	0	3	3	1	3	4	0	360	360	120	360	480
control	1	2	3	2	3	5	120	240	360	240	360	600
control	0	0	0	4	2	6	0	0	0	480	240	720
3 hour	2	3	5	3	3	6	240	360	600	360	360	720
3 hour	1	2	3	2	1	3	120	240	360	240	120	360
3 hour	1	1	2	0	3	3	120	120	240	0	360	360
9 hour	3	2	5	0	1	1	360	240	600	0	120	120
9 hour	1	2	3	3	3	6	120	240	360	360	360	720
9 hour	1	2	3	2	1	3	120	240	360	240	120	360
24 hour	2	3	5	0	1	1	240	360	600	0	120	120
24 hour	1	1	2	0	3	3	120	120	240	0	360	360
24 hour	0	3	3	1	0	1	0	360	360	120	0	120

VIII.2.3 The 81% GSM Experiment

	No. of continuous pores observed						No. of continuous pores m^{-2}					
	Before treading			After treading			Before treading			After treading		
Treatment	0-5 cm	5-10 cm	combined	0-5 cm	5-10 cm	Combined	0-5 cm	5-10 cm	combined	0-5 cm	5-10 cm	combined
control	2	3	5	3	3	6	240	360	600	360	360	720
control	0	2	2	1	1	2	0	240	240	120	120	240
control	0	2	2	2	1	3	0	240	240	240	120	360
3 hour	1	2	3	1	3	4	120	240	360	120	360	480
3 hour	1	1	2	0	1	1	120	120	240	0	120	120
3 hour	1	3	4	1	2	3	120	360	480	120	240	360
9 hour	3	2	5	2	2	4	360	240	600	240	240	480
9 hour	0	0	0	0	1	1	0	0	0	0	120	120
9 hour	2	2	4	0	2	2	240	240	480	0	240	240
24 hour	1	4	5	0	1	1	120	480	600	0	120	120
24 hour	2	2	4	2	0	2	240	240	480	240	0	240
24 hour	2	4	6	0	1	1	240	480	720	0	120	120

Appendix IX

Soil Surface Roughness Index and Depth of Pugging

Appendix IX Soil Surface Roughness Index and Depth of Pugs

IX.1 Treatment Means

IX.1.1 Soil Surface Roughness Index

	65% GSM			
	Soil Surface Roughness Index (%)			
	Before	**After**	**6 weeks**	**14 weeks**
Control	4.47	4.70	4.03	5.53
3 hour	4.90	6.23	5.83	5.50
9 hour	4.80	7.83	5.80	5.07
24 hour	5.27	11.17	6.83	5.20
F.pr	0.800	<0.001	0.018	0.817
e.s.e	0.568	0.594	0.472	0.433
s.e.d	0.803	0.841	0.667	0.612
l.s.d	1.851	1.939	1.538	1.411

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	71% GSM			
	Soil Surface Roughness Index (%)			
	Before	**After**	**6 weeks**	**11 weeks**
Control	6.0	5.5	6.4	4.1
3 hour	5.5	8.1	7.3	4.8
9 hour	6.5	11.6	6.6	5.6
24 hour	5.9	12.5	7.3	6.3
F.pr	0.355	<0.001	0.461	0.014
e.s.e	0.357	0.746	0.462	0.386
s.e.d	0.505	1.055	0.654	0.545
l.s.d	1.165	2.434	1.507	1.258

	81% GSM							
	Soil Surface Roughness Index (%)							
	Before	**After**	**7 weeks**	**8 weeks**	**12 weeks**	**15 weeks**	**19 weeks**	**21 weeks**
Control	4.3	3.3	4.7	6.3	3.1	2.8	3.0	3.7
3 hour	3.8	7.9	5.2	5.1	4.6	3.2	3.3	4.0
9 hour	4.4	22.6	12.5	9.8	6.9	4.4	3.8	5.2
24 hour	4.3	21.6	18.8	14.6	9.7	5.9	5.4	7.0
F.pr	0.691	<0.001	<0.001	0.001	0.004	0.130	0.069	0.223
e.s.e	0.401	0.728	0.833	1.089	0.898	0.876	0.578	1.107
s.e.d	0.567	1.030	1.178	1.540	1.270	1.239	0.817	1.565
l.s.d	1.308	2.375	2.716	3.550	2.928	2.856	1.885	3.610

IX.1.2 Depth of Pug Prints and Hoof Skids

	Depth of Pug Prints (mm)		
	65% GSM	71% GSM	81% GSM
Control	*n.a.*	*n.a.*	*n.a.*
3 hour	29	35	35
9 hour	34	45	59
24 hour	37	55	80
F.pr	0.025	<0.001	<0.001
e.s.e	1.55	0.95	2.609
s.e.d	2.20	1.35	3.689
l.s.d	5.38	3.30	9.027

Note: F.pr indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	Depth of Hoof Skids (mm)		
	65% GSM	71% GSM	81% GSM
Control	*n.a.*	*n.a.*	*n.a.*
3 hour	38	66	59
9 hour	56	67	79
24 hour	49	64	106
F.pr	0.062	0.568	<0.001
e.s.e	4.16	3.59	2.64
s.e.d	5.89	5.08	3.74
l.s.d	14.41	12.42	9.15

IX.2 Individual Results for Soil Surface Roughness Index

IX.2.1 The 65% GSM Experiment

Time	Treatment	Plot #	Length of chain on soil surface (mm)					Mean length loss (mm)	Mean Roughnex Index (%)
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
Before	control	1	98.0	98.5	97.0	97.0	95.0	97.1	2.9
5/6/99	3 hour	2	97.5	95.0	96.0	95.0	93.0	95.3	4.7
	24 hour	3	96.0	93.5	95.0	94.5	95.5	94.9	5.1
	3 hour	4	94.0	98.0	96.0	94.0	94.0	95.2	4.8
	9 hour	5	96.0	95.0	93.5	94.5	93.0	94.4	5.6
	control	6	93.5	94.0	94.0	93.5	94.5	93.9	6.1
	9 hour	7	96.0	96.5	95.0	96.0	95.0	95.7	4.3
	3 hour	8	97.0	95.5	94.0	94.5	93.0	94.8	5.2
	24 hour	9	93.0	94.5	95.0	93.0	93.5	93.8	6.2
	24 hour	10	94.5	97.0	94.5	96.5	95.0	95.5	4.5
	control	11	97.5	97.0	96.0	94.0	93.5	95.6	4.4
	9 hour	12	95.5	97.0	94.0	95.5	95.5	95.5	4.5
After	control	1	94.5	97.0	94.5	96.5	96.0	95.7	4.3
26/6/99	3 hour	2	94.0	93.5	94.5	90.0	95.0	93.4	6.6
	24 hour	3	88.5	82.0	89.5	92.0	87.0	87.8	12.2
	3 hour	4	93.0	93.0	96.5	96.5	93.5	94.5	5.5
	9 hour	5	95.5	84.0	93.5	94.0	87.5	90.9	9.1
	control	6	94.5	95.5	93.5	95.5	96.5	95.1	4.9
	9 hour	7	95.0	96.5	92.0	91.0	96.0	94.1	5.9
	3 hour	8	91.0	93.0	95.0	93.0	95.0	93.4	6.6
	24 hour	9	92.0	91.5	87.0	88.0	87.5	89.2	10.8
	24 hour	10	89.5	86.0	92.0	87.5	92.5	89.5	10.5
	control	11	96.5	96.5	93.0	94.5	95.0	95.1	4.9
	9 hour	12	89.5	95.0	94.5	89.0	89.5	91.5	8.5
8 weeks	control	1	94.0	98.5	97.5	95.5	97.0	96.5	3.5
22/8/99	3 hour	2	96.0	97.0	93.5	93.5	95.5	95.1	4.9
	24 hour	3	96.0	93.5	89.5	93.5	94.5	93.4	6.6
	3 hour	4	92.0	95.0	91.5	93.5	92.5	92.9	7.1
	9 hour	5	94.0	97.0	92.0	95.0	93.0	94.2	5.8
	control	6	94.0	97.0	96.0	94.5	96.5	95.6	4.4
	9 hour	7	92.5	95.5	94.5	94.5	93.5	94.1	5.9
	3 hour	8	94.0	96.0	95.5	93.5	93.5	94.5	5.5
	24 hour	9	89.0	89.5	95.0	94.0	92.5	92.0	8.0
	24 hour	10	95.0	96.0	94.5	94.0	91.0	94.1	5.9
	control	11	94.0	97.5	95.5	96.5	95.5	95.8	4.2
	9 hour	12	93.5	95.0	94.5	93.5	95.0	94.3	5.7
17 weeks	control	1	97.0	94.5	95.0	95.5	94.5	95.3	4.7
27/10/99	3 hour	2	91.0	94.0	93.5	95.5	94.5	93.7	6.3
	24 hour	3	95.0	94.5	94.0	95.0	95.5	94.8	5.2
	3 hour	4	95.5	95.0	95.5	95.5	93.5	95.0	5.0
	9 hour	5	95.5	95.5	97.5	96.0	95.5	96.0	4.0
	control	6	94.0	95.0	95.0	95.0	94.0	94.6	5.4
	9 hour	7	96.5	96.0	95.5	95.0	91.0	94.8	5.2
	3 hour	8	93.0	97.0	95.5	94.0	94.5	94.8	5.2
	24 hour	9	95.5	94.5	95.5	95.0	93.0	94.7	5.3
	24 hour	10	94.5	95.0	95.0	95.0	95.0	94.9	5.1
	control	11	94.5	92.0	94.5	91.0	95.5	93.5	6.5
	9 hour	12	91.5	97.0	92.5	93.5	96.0	94.1	5.9

IX.2.2 The 71% GSM Experiment

Time	Treatment	Plot #	Length of chain on soil surface (mm)						Mean length loss (mm)	Mean Roughnex Index (%)
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6		
Before	9 hour	1	93.0	92.0	93.0	92.0	94.0	92.0	92.7	7.3
2/8/00	control	2	93.5	93.0	94.5	94.0	91.0	94.0	93.3	6.7
	24 hour	3	93.0	93.0	94.0	96.0	94.5	93.5	94.0	6.0
	3 hour	4	94.5	96.0	95.0	95.5	94.0	94.0	94.8	5.2
	9 hour	5	95.0	93.5	92.0	94.5	93.0	95.0	93.8	6.2
	3 hour	6	95.0	94.0	95.0	91.0	93.5	93.5	93.7	6.3
	24 hour	7	94.5	95.0	95.0	94.0	93.0	95.0	94.4	5.6
	control	8	94.0	95.0	94.5	95.0	95.5	91.5	94.3	5.8
	9 hour	9	95.5	92.5	92.5	93.5	96.0	94.5	94.1	5.9
	24 hour	10	94.0	95.0	95.5	94.5	94.0	90.0	93.8	6.2
	3 hour	11	95.0	96.0	95.0	94.0	96.0	94.0	95.0	5.0
	control	12	93.5	94.5	95.0	96.0	94.0	93.5	94.4	5.6
After	9 hour	1	88.0	82.0	89.0	84.0	82.0	90.0	85.8	14.2
30/8/00	control	2	93.0	93.5	94.5	96.0	94.0	95.5	94.4	5.6
	24 hour	3	87.5	92.0	89.5	89.0	91.0	81.0	88.3	11.7
	3 hour	4	92.0	92.0	89.5	92.5	89.0	93.0	91.3	8.7
	9 hour	5	92.0	93.5	87.0	91.5	89.5	89.0	90.4	9.6
	3 hour	6	89.5	89.0	94.0	90.0	94.5	93.0	91.7	8.3
	24 hour	7	84.5	88.5	78.0	88.0	90.0	93.0	87.0	13.0
	control	8	94.0	93.5	94.0	96.0	96.0	97.0	95.1	4.9
	9 hour	9	91.0	91.5	84.0	88.5	84.0	94.0	88.8	11.2
	24 hour	10	94.0	83.5	84.0	86.0	86.0	90.0	87.3	12.8
	3 hour	11	91.0	95.0	93.5	91.0	93.5	91.5	92.6	7.4
	control	12	91.0	94.0	94.0	96.5	93.5	94.5	93.9	6.1
6 weeks	9 hour	1	93.0	94.0	93.0	92.0	95.0	91.0	93.0	7.0
10/10/00	control	2	95.0	96.0	95.0	93.0	93.5	92.0	94.1	5.9
	24 hour	3	96.0	93.0	93.0	92.5	93.5	94.0	93.7	6.3
	3 hour	4	92.0	92.0	92.0	94.0	95.0	93.0	93.0	7.0
	9 hour	5	95.0	93.5	96.0	96.0	93.5	94.5	94.8	5.3
	3 hour	6	88.5	96.0	91.0	93.5	93.0	93.0	92.5	7.5
	24 hour	7	91.0	90.0	94.0	96.0	92.0	93.0	92.7	7.3
	control	8	92.0	94.0	92.0	93.5	94.0	93.0	93.1	6.9
	9 hour	9	95.0	93.0	95.0	88.0	93.5	90.0	92.4	7.6
	24 hour	10	92.0	92.0	93.0	90.5	93.0	91.0	91.9	8.1
	3 hour	11	94.0	90.0	93.0	92.0	94.5	92.5	92.7	7.3
	control	12	92.0	95.0	93.0	93.0	93.0	96.0	93.7	6.3
11 weeks	9 hour	1	98.0	95.5	94.5	95.5	94.5	94.0	95.3	4.7
1/11/01	control	2	97.0	94.5	97.0	95.0	95.0	94.0	95.4	4.6
	24 hour	3	92.0	93.0	94.5	92.0	94.0	93.0	93.1	6.9
	3 hour	4	95.5	96.0	95.5	96.0	95.5	94.5	95.5	4.5
	9 hour	5	96.0	95.0	95.5	93.0	93.0	92.5	94.2	5.8
	3 hour	6	94.0	97.0	96.5	93.0	96.5	96.0	95.5	4.5
	24 hour	7	95.0	93.0	93.0	94.5	93.5	91.0	93.3	6.7
	control	8	93.0	95.0	95.0	96.5	95.5	98.0	95.5	4.5
	9 hour	9	96.5	94.5	92.5	90.0	95.5	93.0	93.7	6.3
	24 hour	10	96.0	96.0	95.5	95.0	93.0	90.0	94.3	5.8
	3 hour	11	95.0	96.5	96.0	93.5	95.5	92.0	94.8	5.3
	control	12	95.5	96.0	96.0	96.0	97.5	99.0	96.7	3.3

IX.2.3 The 81% GSM Experiment

Time	Treatment	Plot #	Length of chain on soil surface (mm)						Mean length loss (mm)	Mean Roughnex Index (%)
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6		
Before	9 hour	1	97.0	96.5	97.0	97.0	98.0	95.0	96.8	3.3
15/7/01	control	2	95.5	97.0	95.5	97.0	97.5	96.0	96.4	3.6
	24 hour	3	96.5	93.5	95.0	97.0	97.0	95.0	95.7	4.3
	control	4	96.5	95.0	96.0	95.0	94.0	94.5	95.2	4.8
	24 hour	5	95.0	96.0	93.0	97.0	95.0	95.0	95.2	4.8
	9 hour	6	95.0	96.0	92.0	94.0	96.0	97.0	95.0	5.0
	3 hour	7	96.0	96.0	94.0	97.0	97.5	97.5	96.3	3.7
	control	8	98.0	96.0	94.0	95.5	96.0	94.0	95.6	4.4
	9 hour	9	94.0	95.5	96.0	96.5	94.0	95.0	95.2	4.8
	3 hour	10	94.5	95.0	97.0	96.0	95.5	96.0	95.7	4.3
	24 hour	11	96.0	97.0	96.0	97.0	97.0	94.5	96.3	3.8
	3 hour	12	97.0	97.0	98.0	96.5	95.0	97.0	96.8	3.3
After	9 hour	1	76.0	70.0	78.0	71.0	82.0	81.0	76.3	23.7
7/8/01	control	2	94.0	96.0	95.5	98.0	96.5	97.5	96.3	3.8
	24 hour	3	83.0	77.0	80.0	69.0	74.0	81.0	77.3	22.7
	control	4	97.5	99.0	96.5	96.0	97.0	96.5	97.1	2.9
	24 hour	5	86.0	76.0	77.0	82.0	85.0	79.0	80.8	19.2
	9 hour	6	85.0	80.0	79.5	68.0	76.5	77.5	77.8	22.3
	3 hour	7	93.0	92.0	95.0	94.0	87.0	95.0	92.7	7.3
	control	8	95.0	96.5	97.0	97.5	98.0	96.5	96.8	3.3
	9 hour	9	83.0	77.0	82.0	81.0	68.5	78.0	78.3	21.8
	3 hour	10	97.0	87.0	91.5	91.0	92.0	89.0	91.3	8.8
	24 hour	11	79.0	80.0	76.0	75.5	74.0	77.0	76.9	23.1
	3 hour	12	94.0	91.0	92.0	95.0	93.5	89.0	92.4	7.6
5 weeks	9 hour	1	87.0	86.0	84.0	91.0	87.0	89.0	87.3	12.7
10/9/01	control	2	95.0	94.0	96.0	97.0	95.0	95.0	95.3	4.7
	24 hour	3	79.0	79.0	85.0	72.0	80.0	77.0	78.7	21.3
	control	4	94.0	95.0	94.0	96.0	95.0	95.0	94.8	5.2
	24 hour	5	87.0	83.0	84.0	77.0	78.0	79.0	81.3	18.7
	9 hour	6	85.0	92.0	79.0	89.0	93.0	87.0	87.5	12.5
	3 hour	7	94.0	93.0	92.0	94.0	95.0	92.0	93.3	6.7
	control	8	96.0	97.0	95.0	94.0	96.0	96.0	95.7	4.3
	9 hour	9	85.0	89.0	87.0	91.0	85.0	89.0	87.7	12.3
	3 hour	10	97.0	95.0	96.0	95.0	97.0	96.0	96.0	4.0
	24 hour	11	88.0	81.0	79.0	81.0	89.0	84.0	83.7	16.3
	3 hour	12	96.0	95.0	97.0	92.0	94.0	97.0	95.2	4.8
6 weeks	9 hour	1	87.0	90.0	87.0	83.0	85.0	91.0	87.2	12.8
19/9/01	control	2	89.0	93.0	95.0	94.0	95.0	93.0	93.2	6.8
	24 hour	3	79.0	87.0	86.0	85.0	88.0	83.0	84.7	15.3
	control	4	93.0	94.0	93.0	92.0	95.0	93.0	93.3	6.7
	24 hour	5	88.0	81.0	82.0	85.0	88.0	87.0	85.2	14.8
	9 hour	6	93.0	88.0	91.0	89.0	86.0	91.0	89.7	10.3
	3 hour	7	88.0	96.0	93.0	95.0	96.0	92.0	93.3	6.7
	control	8	93.0	96.0	96.0	95.0	93.0	95.0	94.7	5.3
	9 hour	9	94.0	95.0	95.0	93.0	92.0	93.0	93.7	6.3
	3 hour	10	97.0	93.0	95.0	96.0	95.0	95.0	95.2	4.8
	24 hour	11	92.0	94.0	86.0	80.0	85.0	81.0	86.3	13.7
	3 hour	12	96.0	95.0	98.0	94.0	98.0	96.0	96.2	3.8
10 weeks	9 hour	1	89.0	91.0	91.0	91.0	92.0	90.0	90.7	9.3
15/10/01	control	2	96.0	97.0	96.0	98.0	96.0	97.0	96.7	3.3
	24 hour	3	86.0	89.0	91.0	92.0	90.0	90.0	89.7	10.3
	control	4	97.0	96.0	98.0	97.0	96.0	96.0	96.7	3.3
	24 hour	5	93.0	94.0	92.0	93.0	92.0	92.0	92.7	7.3
	9 hour	6	96.0	92.0	94.0	93.0	94.0	94.0	93.8	6.2
	3 hour	7	96.0	94.0	95.0	96.0	97.0	94.0	95.3	4.7
	control	8	97.0	98.0	96.0	99.0	96.0	98.0	97.3	2.7
	9 hour	9	94.0	96.0	95.0	94.0	95.0	95.0	94.8	5.2
	3 hour	10	96.0	95.0	96.0	95.0	97.0	96.0	95.8	4.2

	24 hour	11	84.0	91.0	88.0	93.0	88.0	87.0	88.5	11.5
	3 hour	12	94.0	95.0	96.0	94.0	96.0	95.0	95.0	5.0
13 weeks	9 hour	1	95.0	94.0	96.0	95.0	98.0	96.0	95.7	4.3
6/11/01	control	2	97.0	98.0	99.0	96.0	97.0	97.0	97.3	2.7
	24 hour	3	92.0	95.0	91.0	95.0	94.0	92.0	93.2	6.8
	control	4	98.0	96.0	97.0	98.0	97.0	98.0	97.3	2.7
	24 hour	5	97.0	97.0	96.0	98.0	98.0	97.0	97.2	2.8
	9 hour	6	97.0	96.0	96.0	99.0	96.0	97.0	96.8	3.2
	3 hour	7	96.0	95.0	98.0	96.0	97.0	98.0	96.7	3.3
	control	8	97.0	98.0	96.0	95.0	98.0	98.0	97.0	3.0
	9 hour	9	93.0	94.0	92.0	95.0	96.0	95.0	94.2	5.8
	3 hour	10	97.0	98.0	95.0	96.0	97.0	97.0	96.7	3.3
	24 hour	11	91.0	95.0	92.0	91.0	90.0	93.0	92.0	8.0
	3 hour	12	97.0	96.0	99.0	98.0	96.0	96.0	97.0	3.0
17 weeks	9 hour	1	94.0	95.0	94.0	96.0	95.0	94.0	94.7	5.3
5/12/01	control	2	97.0	97.0	96.0	98.0	97.0	97.0	97.0	3.0
	24 hour	3	92.0	94.0	93.0	90.0	96.0	95.0	93.3	6.7
	control	4	95.0	96.0	97.0	96.0	98.0	96.0	96.3	3.7
	24 hour	5	98.0	97.0	93.0	95.0	95.0	96.0	95.7	4.3
	9 hour	6	98.0	96.0	98.0	97.0	97.0	97.0	97.2	2.8
	3 hour	7	95.0	96.0	97.0	95.0	97.0	96.0	96.0	4.0
	control	8	98.0	96.0	97.0	98.0	99.0	98.0	97.7	2.3
	9 hour	9	95.0	96.0	98.0	96.0	98.0	97.0	96.7	3.3
	3 hour	10	97.0	98.0	96.0	98.0	97.0	98.0	97.3	2.7
	24 hour	11	94.0	96.0	95.0	94.0	93.0	96.0	94.7	5.3
	3 hour	12	95.0	98.0	97.0	96.0	97.0	97.0	96.7	3.3
20 weeks	9 hour	1	92.0	92.0	95.0	92.0	95.0	95.0	93.5	6.5
20/12/01	control	2	95.0	96.0	97.0	96.0	95.0	95.0	95.7	4.3
	24 hour	3	83.0	90.0	91.0	89.0	93.0	90.0	89.3	10.7
	control	4	97.0	95.0	96.0	97.0	96.0	97.0	96.3	3.7
	24 hour	5	95.0	95.0	97.0	94.0	93.0	97.0	95.2	4.8
	9 hour	6	93.0	96.0	95.0	93.0	93.0	94.0	94.0	6.0
	3 hour	7	94.0	97.0	95.0	94.0	96.0	95.0	95.2	4.8
	control	8	97.0	96.0	98.0	97.0	96.0	97.0	96.8	3.2
	9 hour	9	97.0	96.0	98.0	97.0	97.0	97.0	97.0	3.0
	3 hour	10	97.0	95.0	98.0	97.0	96.0	97.0	96.7	3.3
	24 hour	11	92.0	95.0	93.0	95.0	95.0	97.0	94.5	5.5
	3 hour	12	96.0	95.0	96.0	97.0	98.0	95.0	96.2	3.8

IX.3 Individual Results for Depth of Pug Prints

IX.3.1 The 65% GSM Experiment

Treatment	Plot #	Depth of Pug Print (mm)										Mean depth (mm)
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
control	1											
3 hour	2	24	34	29	19	34	29	19	24	24	39	27.5
24 hour	3	39	44	24	59	49	29	59	24	29	24	38.0
3 hour	4	14	29	39	29	21	40	69	38	39	19	33.7
9 hour	5	29	39	30	29	30	29	34	34	49	24	32.7
control	6											
9 hour	7	30	18	44	54	21	39	34	37	29	24	33.0
3 hour	8	39	19	29	27	22	24	31	19	27	20	25.7
24 hour	9	50	30	31	54	49	32	27	26	29	27	35.5
24 hour	10	21	58	41	50	34	34	69	33	21	25	38.6
control	11											
9 hour	12	32	26	29	39	33	33	39	41	39	38	34.9

Note: there was no data for the control plots because of absence of pugs

IX.3.2 The 71% GSM Experiment

Treatment	Plot #	Depth of Pug Print (mm)										Mean depth (mm)
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
9 hour	1	50	50	35	40	50	45	45	65	40	40	46.0
control	2											
24 hour	3	55	40	45	80	30	60	65	50	55	65	54.5
3 hour	4	35	30	30	40	50	35	45	45	35	20	36.5
9 hour	5	35	65	50	45	50	45	55	40	35	35	45.5
3 hour	6	30	25	30	30	30	35	30	40	40	25	31.5
24 hour	7	40	40	50	45	40	65	70	70	60	70	55.0
control	8											
9 hour	9	40	35	40	50	40	40	55	45	45	50	44.0
24 hour	10	70	60	55	40	60	55	50	50	45	60	54.5
3 hour	11	30	35	35	40	30	20	40	35	55	35	35.5
control	12											

IX.3.2 The 81% GSM Experiment

Treatment	Plot #	Depth of Pug Print (mm)										Mean depth (mm)
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
9 hour	1	60	65	60	60	70	75	70	55	65	65	64.5
control	2											
24 hour	3	80	75	70	80	85	80	90	70	85	90	80.5
control	4											
24 hour	5	70	70	90	80	65	80	70	70	90	70	75.5
9 hour	6	50	40	55	45	40	60	70	60	80	70	57.0
3 hour	7	25	55	25	45	25	20	40	45	40	45	36.5
control	8											
9 hour	9	55	55	45	50	60	50	65	55	55	55	54.5
3 hour	10	40	35	30	50	35	30	35	35	45	45	38.0
24 hour	11	70	95	85	80	90	90	90	75	90	85	85.0
3 hour	12	30	30	35	50	30	30	35	35	10	30	31.5

IX.4 Individual Results for Depth of Hoof Skids

IX.4.1 The 65% GSM Experiment

Treatment	Plot #	Depth of Hoof Skid (mm)										Mean depth (mm)
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
control	1											
3 hour	2	34	34	41	39	44	47	29	31	19	29	34.7
24 hour	3	36	84	41	45	39	69	39	39	49	49	49.0
3 hour	4	44	14	59	69	49	69	43	48	59	39	49.3
9 hour	5	39	94	39	39	49	38	89	69	49	50	55.5
control	6											
9 hour	7	64	69	71	112	48	65	52	78	43	41	64.3
3 hour	8	29	19	21	31	29	49	48	37	24	25	31.2
24 hour	9	49	29	62	48	37	64	49	72	32	60	50.2
24 hour	10	55	54	15	41	38	60	71	65	35	40	47.4
control	11											
9 hour	12	38	57	68	43	42	41	69	37	54	37	48.6

Note: there is no data for the control plots due to absence of hoof skids

IX.4.2 The 71% GSM Experiment

Treatment	Plot #	Depth of Hoof Skid (mm)										Mean depth (mm)
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
9 hour	1	80	75	50	100	75	-	-	-	-	-	76
control	2											
24 hour	3	60	60	55	70	50	-	-	-	-	-	59
3 hour	4	55	45	60	70	90	-	-	-	-	-	64
9 hour	5	60	50	65	75	70	-	-	-	-	-	64
3 hour	6	65	50	35	95	70	-	-	-	-	-	63
24 hour	7	60	60	65	50	75	-	-	-	-	-	62
control	8											
9 hour	9	65	60	65	45	70	-	-	-	-	-	61
24 hour	10	75	70	90	50	70	-	-	-	-	-	71
3 hour	11	50	55	45	80	55	-	-	-	-	-	57
control	12											

Note: a hyphen denotes no data

IX.4.3 The 81% GSM Experiment

Treatment	Plot #	Depth of Hoof Skid (mm)										Mean depth (mm)
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
9 hour	1	70	70	65	90	85	85	95	-	-	-	80.0
control	2											
24 hour	3	90	110	85	120	115	90	115	110	-	-	104.4
control	4											
24 hour	5	110	105	100	110	130	80	120	110	-	-	108.1
9 hour	6	100	75	80	85	75	85	100	75	-	-	84.4
3 hour	7	50	50	60	55	65	45	50	80	-	-	56.9
control	8											
9 hour	9											
3 hour	10	65	75	70	65	75	45	60	-	-	-	65.0
24 hour	11	90	115	120	95	70	115	115	130	-	-	106.3
3 hour	12	50	55	50	70	75	35	55	-	-	-	55.7

Appendix X

Bare Ground

Appendix X Bare ground

X.1 Treatment Means

65% GSM Proportion of Bare ground (% frequency of hits using point frame analysis)								
	Before	After	8 weeks	13 weeks	21 weeks	25 weeks	27 weeks	38 weeks
Control	32	23	18	22	9	12	8	24
3 hour	25	39	29	24	15	12	10	20
9 hour	28	53	36	41	20	17	10	23
24 hour	30	66	39	42	21	17	10	22
F.pr	0.430	<0.001	<0.001	<0.001	0.004	0.250	0.943	0.798
e.s.e	3.06	3.28	3.04	3.45	2.60	2.38	2.01	3.01
s.e.d	4.32	4.64	4.30	4.87	3.68	3.37	2.84	4.26
l.s.d	8.58	9.22	8.54	9.68	7.31	6.70	5.65	8.46

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

71% GSM Proportion of Bare ground (% frequency of hits using point frame analysis)								
	Before	After	6 weeks	10 weeks	13 weeks	17 weeks	19 weeks	26 weeks
Control	30	24	22	14	19	20	22	23
3 hour	33	35	20	16	17	17	21	24
9 hour	31	69	48	36	33	23	13	16
24 hour	26	63	63	45	37	29	28	24
F.pr	0.445	<0.001	<0.001	<0.001	<0.001	0.139	0.013	0.195
e.s.e	2.99	3.04	3.77	3.21	2.66	3.68	2.98	2.98
s.e.d	4.23	4.29	5.33	4.54	3.76	5.21	4.21	4.21
l.s.d	8.39	8.53	10.58	9.01	7.47	10.34	8.36	8.36

81% GSM Proportion of Bare ground (% frequency of hits using point frame analysis)								
	Before	After	6 weeks	10 weeks	13 weeks	16 weeks	19 weeks	23 weeks
Control	24	14	15	18	15	20	20	16
3 hour	15	30	30	27	24	26	29	18
9 hour	21	63	44	42	33	28	26	15
24 hour	19	87	60	48	36	38	32	15
F.pr	0.23	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.825
e.s.e	2.19	2.71	2.63	2.64	2.69	2.57	2.37	1.81
s.e.d	3.09	3.83	3.72	3.74	3.81	3.63	3.36	2.56
l.s.d	6.14	7.61	7.38	7.42	7.56	7.21	6.67	5.09

X.2 Individual Results

X.2.1 The 65% GSM Experiment

Time	Treatment	Plot #	Proportion of Bare ground (# of hits from 10)								Bare ground (%)
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	
Before	control	1	3	2	1	3	3	3	5	2	27.50
5/6/99	3 hour	2	2	4	2	2	1	3	4	5	28.75
	24 hour	3	3	5	2	3	2	2	2	3	27.50
	3 hour	4	3	2	2	1	3	3	5	1	25.00
	9 hour	5	0	3	4	2	0	4	4	5	27.50
	control	6	3	2	1	3	4	3	3	4	28.75
	9 hour	7	5	2	0	0	1	4	4	2	22.50
	3 hour	8	3	2	0	0	3	4	4	1	21.25
	24 hour	9	1	1	4	2	3	5	2	3	26.25
	24 hour	10	3	5	2	3	2	5	3	7	37.50
	control	11	3	4	2	3	3	6	6	4	38.75
	9 hour	12	1	5	3	3	4	3	2	6	33.75
After	control	1	2	3	2	3	4	3	1	1	23.75
26/6/99	3 hour	2	2	2	4	4	3	5	3	5	35.00
	24 hour	3	8	9	7	5	6	6	7	8	70.00
	3 hour	4	5	5	7	4	5	3	2	4	43.75
	9 hour	5	5	7	2	8	5	6	7	5	56.25
	control	6	3	3	0	5	0	1	2	1	18.75
	9 hour	7	5	5	2	5	6	6	3	4	45.00
	3 hour	8	3	4	4	5	3	7	3	1	37.50
	24 hour	9	8	8	6	7	6	8	7	3	66.25
	24 hour	10	8	4	9	6	8	8	5	2	62.50
	control	11	5	4	1	2	1	1	2	5	26.25
	9 hour	12	7	6	5	5	8	6	4	4	56.25
8 weeks	control	1	1	3	0	1	2	1	3	1	15.00
24/8/99	3 hour	2	1	4	3	2	6	5	0	3	30.00
	24 hour	3	4	4	3	4	3	4	2	4	35.00
	3 hour	4	6	3	3	3	1	4	3	4	33.75
	9 hour	5	1	6	0	5	4	3	5	4	35.00
	control	6	2	4	0	1	1	0	1	3	15.00
	9 hour	7	5	4	5	1	1	2	6	4	35.00
	3 hour	8	3	4	1	2	4	1	2	2	23.75
	24 hour	9	5	2	2	5	7	2	3	5	38.75
	24 hour	10	3	5	4	4	4	4	5	5	42.50
	control	11	2	4	1	3	2	1	2	4	23.75
	9 hour	12	4	4	5	4	4	3	0	6	37.50
13 weeks	control	1	1	4	3	2	0	4	1	0	18.75
1/10/99	3 hour	2	1	1	2	5	1	2	2	1	18.75
	24 hour	3	0	4	2	5	4	2	2	10	36.25
	3 hour	4	2	3	3	1	5	1	4	2	26.25
	9 hour	5	0	4	5	1	3	3	6	4	32.50
	control	6	3	2	0	1	1	1	4	2	17.50
	9 hour	7	4	7	4	4	5	4	1	7	45.00
	3 hour	8	2	3	3	4	3	2	4	0	26.25
	24 hour	9	2	4	2	7	5	6	5	3	42.50
	24 hour	10	5	6	4	6	2	6	4	4	46.25
	control	11	4	3	3	1	2	3	5	2	28.75
	9 hour	12	5	5	6	5	3	4	4	4	45.00
21 weeks	control	1	2	1	0	0	1	0	1	2	8.75
28/11/99	3 hour	2	3	1	0	2	2	1	0	0	11.25
	24 hour	3	3	2	4	2	0	3	1	1	20.00
	3 hour	4	0	2	2	2	4	2	1	2	18.75
	9 hour	5	0	2	2	0	2	0	1	3	12.50
	control	6	1	1	0	0	0	1	0	0	3.75
	9 hour	7	4	3	2	1	4	1	0	1	20.00
	3 hour	8	3	1	0	0	2	2	0	4	15.00
	24 hour	9	2	0	2	7	2	0	2	1	20.00
	24 hour	10	2	2	4	2	3	2	2	1	22.50

	control	11	2	0	1	2	1	2	1	2	13.75
	9 hour	12	3	0	4	3	4	3	3	3	28.75
25 weeks	control	1	4	1	0	0	1	1	2	2	13.75
24/12/99	3 hour	2	2	0	0	3	1	1	0	0	8.75
	24 hour	3	4	1	1	5	0	2	1	0	17.50
	3 hour	4	2	1	1	1	2	0	2	1	12.50
	9 hour	5	2	1	3	2	1	0	1	2	15.00
	control	6	1	1	1	1	1	1	1	0	8.75
	9 hour	7	0	0	3	1	3	2	2	2	16.25
	3 hour	8	2	1	4	0	0	1	2	1	13.75
	24 hour	9	3	2	1	2	1	2	4	0	18.75
	24 hour	10	1	1	4	0	0	1	2	3	15.00
	control	11	0	1	1	4	1	1	1	1	12.50
	9 hour	12	2	1	0	0	2	2	4	2	16.25
27 weeks	control	1	2	1	0	0	1	0	2	0	7.50
13/1/00	3 hour	2	0	0	2	2	0	2	1	2	11.25
	24 hour	3	1	2	0	1	4	0	2	1	13.75
	3 hour	4	2	0	1	1	1	0	1	2	10.00
	9 hour	5	0	0	0	0	0	3	1	1	6.25
	control	6	0	2	1	2	1	3	0	0	11.25
	9 hour	7	2	1	1	2	0	0	0	3	11.25
	3 hour	8	1	1	2	1	0	0	0	1	7.50
	24 hour	9	1	0	0	0	1	0	3	0	6.25
	24 hour	10	2	1	0	2	0	1	0	2	10.00
	control	11	1	2	0	0	0	0	0	2	6.25
	9 hour	12	1	0	1	3	2	1	1	0	11.25
38 weeks	control	1	0	1	4	6	3	5	0	2	26.25
31/3/00	3 hour	2	2	1	1	2	1	1	2	1	13.75
	24 hour	3	0	4	1	0	1	3	1	3	16.25
	3 hour	4	2	4	1	2	2	3	1	2	21.25
	9 hour	5	2	2	3	1	5	1	3	3	25.00
	control	6	5	2	3	2	1	0	2	2	21.25
	9 hour	7	1	1	3	1	5	2	2	4	23.75
	3 hour	8	0	6	2	5	1	2	2	1	23.75
	24 hour	9	2	3	2	2	3	2	2	1	21.25
	24 hour	10	4	1	1	3	3	1	5	4	27.50
	control	11	4	3	0	2	1	5	3	1	23.75
	9 hour	12	1	1	3	1	2	1	1	5	18.75

X.2.2 The 71% GSM Experiment

Time	Treatment	Plot #	Proportion of Bare ground (# of hits from 10)								Bare ground (%)
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	
Before	9 hour	1	3	3	7	1	4	5	2	5	37.50
2/8/00	control	2	0	1	4	2	2	5	5	1	25.00
	24 hour	3	6	1	2	4	4	2	5	3	33.75
	3 hour	4	2	2	2	5	2	4	3	4	30.00
	9 hour	5	4	2	4	3	5	2	4	3	33.75
	3 hour	6	2	1	3	1	3	2	3	4	23.75
	24 hour	7	3	1	1	0	2	2	1	4	17.50
	control	8	8	3	2	3	2	3	3	3	33.75
	9 hour	9	2	2	5	5	2	3	2	2	28.75
	24 hour	10	2	4	2	3	3	3	3	4	30.00
	3 hour	11	3	2	2	6	3	4	3	4	33.75
	control	12	3	3	7	1	4	5	2	5	37.50
After	9 hour	1	9	10	7	9	7	6	7	6	76.25
30/8/00	control	2	3	1	3	3	1	3	2	3	23.75
	24 hour	3	5	7	5	9	5	9	7	4	63.75
	3 hour	4	4	3	3	3	3	2	5	4	33.75
	9 hour	5	9	9	8	7	6	3	5	3	62.50
	3 hour	6	2	5	4	2	3	6	3	2	33.75
	24 hour	7	8	7	4	6	6	7	6	5	61.25
	control	8	2	3	3	2	3	1	2	2	22.50
	9 hour	9	5	5	7	10	8	6	7	6	67.50

	24 hour	10	5	6	9	5	7	6	6	7	63.75
	3 hour	11	5	3	4	3	4	2	2	7	37.50
	control	12	3	2	3	2	6	1	1	3	26.25
6 weeks	9 hour	1	5	3	6	7	7	4	5	6	53.75
10/10/00	control	2	2	3	5	2	1	2	1	4	25.00
	24 hour	3	3	7	7	8	7	7	3	9	63.75
	3 hour	4	0	3	2	6	0	1	0	5	21.25
	9 hour	5	6	5	4	3	6	6	4	5	48.75
	3 hour	6	5	0	2	0	2	1	2	2	17.50
	24 hour	7	10	5	9	1	5	6	9	5	62.50
	control	8	1	3	1	0	3	1	2	5	20.00
	9 hour	9	5	3	4	6	4	5	3	4	42.50
	24 hour	10	1	8	9	5	7	3	8	8	61.25
	3 hour	11	2	0	1	1	4	4	3	2	21.25
	control	12	5	0	0	2	3	1	3	2	20.00
10 weeks	9 hour	1	4	3	5	2	3	6	3	8	42.50
5/11/00	control	2	3	1	0	1	1	2	0	1	11.25
	24 hour	3	3	4	3	5	6	4	6	4	43.75
	3 hour	4	0	3	1	2	5	1	1	0	16.25
	9 hour	5	2	1	4	4	9	4	2	1	33.75
	3 hour	6	0	1	0	3	2	2	2	0	12.50
	24 hour	7	4	3	4	3	4	6	5	5	42.50
	control	8	1	1	3	3	1	1	0	2	15.00
	9 hour	9	1	6	4	3	5	1	3	3	32.50
	24 hour	10	4	3	8	4	5	8	5	2	48.75
	3 hour	11	5	1	0	1	1	1	3	3	18.75
	control	12	2	3	2	3	1	1	0	1	16.25
13 weeks	9 hour	1	4	4	7	1	5	6	6	4	46.25
26/11/00	control	2	3	3	2	1	1	2	3	4	23.75
	24 hour	3	3	2	4	3	7	5	3	5	40.00
	3 hour	4	1	1	2	2	2	4	2	0	17.50
	9 hour	5	0	2	3	1	3	3	2	3	21.25
	3 hour	6	3	3	2	0	1	1	1	0	13.75
	24 hour	7	4	4	4	4	3	4	3	1	33.75
	control	8	1	2	4	2	1	3	2	1	20.00
	9 hour	9	2	4	2	4	3	2	4	3	30.00
	24 hour	10	5	3	5	2	5	3	4	3	37.50
	3 hour	11	3	3	1	1	2	2	2	2	20.00
	control	12	4	0	1	1	1	1	1	2	13.75
17 weeks	9 hour	1	0	1	2	5	2	5	3	2	25.00
22/12/00	control	2	0	2	2	1	1	3	2	4	18.75
	24 hour	3	4	4	4	4	3	2	2	1	30.00
	3 hour	4	6	0	1	0	5	2	0	2	20.00
	9 hour	5	4	2	5	1	1	0	3	2	22.50
	3 hour	6	2	1	1	0	3	2	2	0	13.75
	24 hour	7	1	0	2	0	0	2	7	5	21.25
	control	8	5	1	2	2	4	1	5	0	25.00
	9 hour	9	2	1	4	5	2	1	1	1	21.25
	24 hour	10	1	5	10	2	2	5	2	1	35.00
	3 hour	11	1	2	1	0	5	1	2	2	17.50
	control	12	1	2	1	1	2	2	3	0	15.00
19 weeks	9 hour	1	1	1	3	5	1	1	1	2	18.75
21/1/01	control	2	2	2	1	2	5	0	4	1	21.25
	24 hour	3	2	3	5	4	4	2	0	2	27.50
	3 hour	4	3	5	2	3	3	1	1	2	25.00
	9 hour	5	1	1	0	1	0	2	0	1	7.50
	3 hour	6	2	0	3	1	0	1	4	1	15.00
	24 hour	7	5	0	2	6	4	2	5	2	32.50
	control	8	4	2	2	2	3	0	5	2	25.00
	9 hour	9	1	2	0	1	0	6	1	0	13.75
	24 hour	10	1	4	4	1	2	2	2	2	22.50
	3 hour	11	4	1	2	3	3	4	1	1	23.75
	control	12	2	2	3	1	1	2	1	3	18.75
26 weeks	9 hour	1	1	1	1	3	1	2	1	4	17.5
29/2/01	control	2	3	3	2	1	1	3	4	0	21.25

	24 hour	3	0	3	4	4	3	1	4	2	26.25
	3 hour	4	4	3	4	2	1	3	1	2	25.00
	9 hour	5	1	1	0	0	3	2	0	0	8.75
	3 hour	6	0	2	3	3	2	3	3	1	21.25
	24 hour	7	2	3	6	3	1	3	1	2	26.25
	control	8	4	4	1	1	3	0	3	1	21.25
	9 hour	9	3	1	2	6	3	0	1	2	22.50
	24 hour	10	0	2	1	3	2	3	2	3	20.00
	3 hour	11	2	0	4	1	2	7	3	2	26.25
	control	12	3	4	3	1	3	5	1	0	25.00

X.2.3 The 81% GSM Experiment

Time	Treatment	Plot #	Proportion of Bare ground (# of hits from 10)								Bare ground (%)
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	
Before	9 hour	1	3	4	2	2	2	0	0	1	17.50
15/7/01	control	2	1	3	2	2	1	1	2	3	18.75
	24 hour	3	2	2	2	2	1	3	2	4	22.50
	control	4	4	3	2	3	2	3	4	3	30.00
	24 hour	5	3	0	2	1	2	1	2	2	16.25
	9 hour	6	1	5	2	2	2	1	3	3	23.75
	3 hour	7	2	3	3	1	1	2	1	1	17.50
	control	8	2	1	3	2	2	2	4	3	23.75
	9 hour	9	1	1	4	2	1	4	2	2	21.25
	3 hour	10	4	2	0	0	0	2	1	1	12.50
	24 hour	11	2	2	2	0	2	2	2	3	18.75
	3 hour	12	1	0	3	1	0	3	2	1	13.75
After	9 hour	1	6	7	9	8	7	6	7	6	70.00
7/8/01	control	2	1	0	1	2	2	5	1	2	17.50
	24 hour	3	8	10	10	9	8	8	7	8	85.00
	control	4	1	1	0	0	4	1	2	1	12.50
	24 hour	5	6	10	9	9	7	9	10	8	85.00
	9 hour	6	5	5	6	6	6	8	7	9	65.00
	3 hour	7	2	1	4	4	3	2	1	2	23.75
	control	8	0	2	3	0	0	0	3	2	12.50
	9 hour	9	5	7	4	7	4	5	6	4	52.50
	3 hour	10	1	2	4	3	3	2	4	5	30.00
	24 hour	11	9	10	9	9	8	9	10	9	91.25
	3 hour	12	2	3	1	6	5	3	3	5	35.00
6 weeks	9 hour	1	6	6	3	5	5	4	5	4	47.50
19/9/01	control	2	1	4	0	4	1	2	1	1	17.50
	24 hour	3	6	5	9	8	7	5	4	6	62.50
	control	4	0	1	2	1	2	2	1	1	12.50
	24 hour	5	5	5	4	7	5	7	5	5	53.75
	9 hour	6	4	3	4	5	4	4	3	5	40.00
	3 hour	7	1	4	2	5	4	2	2	2	27.50
	control	8	0	0	2	1	3	2	2	1	13.75
	9 hour	9	5	4	6	6	2	6	2	4	43.75
	3 hour	10	2	5	5	3	1	3	3	5	33.75
	24 hour	11	7	6	4	6	7	8	6	7	63.75
	3 hour	12	2	4	2	2	4	3	6	1	30.00
10 weeks	9 hour	1	4	3	4	3	6	6	5	7	47.50
15/10/01	control	2	2	2	3	1	1	4	2	1	20.00
	24 hour	3	5	7	3	3	5	7	6	5	51.25
	control	4	3	1	2	2	2	2	0	0	15.00
	24 hour	5	7	3	5	4	3	4	3	6	43.75
	9 hour	6	4	1	4	4	3	5	6	4	38.75
	3 hour	7	3	2	2	2	1	4	3	2	23.75
	control	8	0	1	2	3	2	1	2	3	17.50
	9 hour	9	4	6	3	3	4	5	4	3	40.00
	3 hour	10	8	2	1	2	2	3	2	1	26.25
	24 hour	11	5	4	6	5	6	4	5	3	47.50
	3 hour	12	3	2	3	3	3	3	3	4	30.00
13 weeks	9 hour	1	3	7	5	5	5	3	4	6	47.5

6/11/01	control	2	3	0	3	3	2	2	2	1	20.00
	24 hour	3	4	5	4	4	3	3	1	4	35.00
	control	4	0	1	0	2	3	0	0	2	10.00
	24 hour	5	3	4	3	4	2	3	1	4	30.00
	9 hour	6	2	3	2	2	4	2	3	2	25.00
	3 hour	7	4	1	3	0	2	2	4	4	25.00
	control	8	3	0	1	2	1	1	0	3	13.75
	9 hour	9	3	3	3	3	2	1	3	2	25.00
	3 hour	10	3	2	2	3	1	2	1	3	21.25
	24 hour	11	4	7	4	3	6	4	3	3	42.50
	3 hour	12	4	3	2	1	4	5	1	1	26.25
16 weeks	9 hour	1	4	3	4	1	2	2	2	0	22.50
30/11/01	control	2	2	3	2	3	2	3	1	3	23.75
	24 hour	3	5	5	3	5	4	3	3	3	38.75
	control	4	2	0	2	1	0	3	3	2	16.25
	24 hour	5	1	3	2	1	6	2	3	4	27.50
	9 hour	6	3	3	3	1	3	2	2	4	26.25
	3 hour	7	6	2	2	3	2	1	1	1	22.50
	control	8	2	0	1	2	3	2	2	3	18.75
	9 hour	9	4	4	3	3	3	3	4	3	33.75
	3 hour	10	3	5	3	2	0	2	1	3	23.75
	24 hour	11	5	5	5	5	4	3	4	6	46.25
	3 hour	12	3	3	5	3	5	2	3	2	32.50
19 weeks	9 hour	1	3	4	3	4	1	3	2	3	28.75
18/12/01	control	2	2	3	2	3	2	2	4	3	26.25
	24 hour	3	3	3	3	4	3	4	4	3	33.75
	control	4	2	1	1	2	3	2	1	2	17.50
	24 hour	5	1	1	3	4	3	3	1	4	25.00
	9 hour	6	2	3	0	4	4	3	3	2	26.25
	3 hour	7	3	3	3	0	0	3	3	3	22.50
	control	8	2	0	2	1	3	1	4	1	17.50
	9 hour	9	1	3	1	3	3	3	3	2	23.75
	3 hour	10	0	5	2	4	3	2	4	3	28.75
	24 hour	11	5	3	2	5	4	2	3	5	36.25
	3 hour	12	3	2	4	5	3	5	3	3	35.00
23 weeks	9 hour	1	3	2	0	1	2	2	1	2	16.25
19/1/02	control	2	2	1	2	3	0	1	2	2	16.25
	24 hour	3	3	2	2	0	0	2	3	0	15.00
	control	4	1	1	1	4	1	1	2	1	15.00
	24 hour	5	2	1	0	3	1	2	1	2	15.00
	9 hour	6	2	1	2	1	0	1	3	1	13.75
	3 hour	7	1	2	3	1	2	2	3	1	18.75
	control	8	2	1	2	1	3	1	2	1	16.25
	9 hour	9	3	2	1	3	1	0	1	2	16.25
	3 hour	10	2	2	2	1	1	2	2	1	16.25
	24 hour	11	3	2	1	0	1	3	2	1	16.25
	3 hour	12	2	2	2	1	2	2	1	2	17.50

Appendix XI

Botanical Composition

Appendix XI Botanical Composition

XI.1 Treatment Means

XI.1.1 The 65% GSM Experiment

	Ryegrass (% DM)			Other grasses (% DM)		
	Before	6 weeks	20 weeks	Before	6 weeks	20 weeks
Control	76.04	93.87	78.40	7.82	2.00	4.82
3 hour	65.22	94.96	77.58	16.31	1.01	4.49
9 hour	70.40	94.61	84.19	5.79	1.28	1.04
24 hour	73.89	93.37	81.45	4.70	1.49	2.45
F.pr	0.789	0.903	0.348	0.679	0.907	0.344
e.s.e	7.96	1.66	3.34	7.29	0.99	1.84
s.e.d	11.26	2.34	4.72	10.31	1.39	2.60
l.s.d	25.96	5.40	10.89	23.77	3.215	5.985

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	Clover (% DM)			Weed (% DM)		
	Before	6 weeks	20 weeks	Before	6 weeks	20 weeks
Control	3.96	0.10	0.38	2.06	0.21	0.11
3 hour	1.27	0.00	0.30	7.00	1.10	2.90
9 hour	5.40	0.45	0.74	3.40	1.25	0.42
24 hour	4.93	2.98	2.28	3.04	0.06	0.00
F.pr	0.665	0.219	0.455	0.406	0.273	0.254
e.s.e	2.50	1.042	0.936	2.07	0.486	1.079
s.e.d	3.53	1.474	1.324	2.92	0.688	1.525
l.s.d	8.15	3.399	3.052	6.74	1.586	3.518

	Dead (% DM)		
	Before	6 weeks	20 weeks
Control	10.12	3.82	16.29
3 hour	10.21	2.93	14.72
9 hour	15.01	2.41	13.61
24 hour	13.44	2.10	13.82
F.pr	0.501	0.476	0.278
e.s.e	2.62	0.787	1.632
s.e.d	3.71	1.113	2.308
l.s.d	8.56	2.586	5.322

XI.1.1 The 71% GSM Experiment

	Ryegrass (% DM)				Other grasses (% DM)			
	Before	6 weeks	18 weeks	34 weeks	Before	6 weeks	18 weeks	34 weeks
Control	59.38	70.89	66.40	71.27	8.87	13.60	1.49	1.47
3 hour	67.33	72.85	69.21	69.73	11.14	9.45	1.20	0.06
9 hour	63.32	72.75	71.75	50.85	11.70	8.10	1.18	1.62
24 hour	60.90	77.03	71.16	49.89	8.83	5.75	1.69	0.92
F.pr	0.839	0.843	0.918	0.035	0.929	0.036	0.971	0.411
e.s.e	6.57	4.96	5.96	5.36	3.91	1.526	0.892	0.680
s.e.d	9.30	7.01	8.44	7.59	5.54	2.159	1.261	0.962
l.s.d	21.44	16.17	19.45	17.49	12.77	4.978	2.908	2.219

Note: F.pr indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	Clover (% DM)				Weed (% DM)			
	Before	6 weeks	18 weeks	34 weeks	Before	6 weeks	18 weeks	34 weeks
Control	0.78	0.50	1.12	0.89	15.16	8.37	14.77	22.42
3 hour	0.13	0.24	3.58	3.24	11.78	7.91	10.34	23.23
9 hour	0.11	0.97	1.26	1.29	12.14	11.52	13.31	42.74
24 hour	1.51	0.78	1.79	0.93	12.27	13.88	18.01	45.68
F.pr	0.443	0.480	0.551	0.248	0.949	0.662	0.502	0.016
e.s.e	0.663	0.336	1.308	0.862	4.61	3.78	3.45	4.88
s.e.d	0.937	4.76	1.850	1.219	6.52	5.35	4.88	6.90
l.s.d	2.161	1.097	4.267	2.811	15.03	12.34	11.25	15.91

	Dead (% DM)			
	Before	6 weeks	18 weeks	34 weeks
Control	15.82	6.65	16.22	3.96
3 hour	9.61	9.55	15.67	3.74
9 hour	12.73	6.67	12.51	3.50
24 hour	16.49	2.57	7.34	2.58
F.pr	0.184	0.201	0.190	0.835
e.s.e	2.20	2.06	2.87	1.136
s.e.d	3.11	2.91	4.05	1.607
l.s.d	7.17	6.72	9.35	3.705

XI.1.1 The 81% GSM Experiment

	Ryegrass (% DM)			Other grasses (% DM)		
	Before	6 weeks	18 weeks	Before	6 weeks	18 weeks
Control	70.72	74.47	75.70	12.23	6.05	3.77
3 hour	68.29	63.61	76.15	18.25	14.03	2.30
9 hour	71.11	73.71	72.96	13.34	7.11	7.69
24 hour	70.91	81.16	70.56	16.14	10.04	4.97
F.pr	0.809	0.626	0.140	0.930	0.696	0.177
e.s.e	4.31	8.11	4.54	5.03	3.71	1.41
s.e.d	6.09	11.46	6.42	7.11	5.25	1.99
l.s.d	14.05	26.43	14.81	16.39	12.10	4.59

Note: F.pr indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	Clover (% DM)			Weed (% DM)		
	Before	6 weeks	18 weeks	Before	6 weeks	18 weeks
Control	1.29	7.36	8.18	4.95	1.64	6.70
3 hour	0.61	6.85	9.29	2.24	9.07	7.13
9 hour	1.53	8.25	6.82	1.63	5.77	4.70
24 hour	1.55	3.13	11.37	3.70	3.32	7.66
F.pr	0.804	0.655	0.404	0.802	0.614	0.795
e.s.e	0.578	3.69	3.27	2.58	4.22	3.20
s.e.d	0.818	5.22	4.62	3.65	5.96	4.52
l.s.d	1.887	12.04	10.65	8.42	13.75	10.42

	Dead (% DM)		
	Before	6 weeks	18 weeks
Control	10.81	10.47	5.65
3 hour	10.61	6.44	5.13
9 hour	12.39	5.16	7.83
24 hour	7.70	2.36	5.43
F.pr	0.593	0.013	0.536
e.s.e	3.17	1.277	1.882
s.e.d	4.49	1.807	2.662
l.s.d	10.34	4.166	6.138

XI.2 Individual Results

XI.2.1 The 65% GSM Experiment

Time	Treat ment	Plot #	Dry matter weight (g)					DM weight of sample (g)	Botanical Composition (%)				
			Rye grass	Other Grass-es	Clover	Weeds	Dead		Rye grass	Other Grass-es	Clover	Weeds	Dead
Before	control	1	5.613	0.076	0.000	0.154	0.119	5.962	94.1	1.3	0.0	2.6	2.0
23/6/99	3 hour	2	6.363	5.380	0.222	0.000	0.868	12.833	49.6	41.9	1.7	0.0	6.8
	24 hour	3	4.238	0.547	0.482	0.343	0.782	6.392	66.3	8.6	7.5	5.4	12.2
	3 hour	4	5.056	0.468	0.011	0.721	0.934	7.190	70.3	6.5	0.2	10.0	13.0
	9 hour	5	2.798	0.486	0.276	0.293	0.563	4.416	63.4	11.0	6.2	6.6	12.7
	control	6	2.964	1.112	0.662	0.053	0.964	5.755	51.5	19.3	11.5	0.9	16.8
	9 hour	7	4.461	0.158	0.082	0.149	1.036	5.886	75.8	2.7	1.4	2.5	17.6
	3 hour	8	3.277	0.021	0.083	0.475	0.470	4.326	75.8	0.5	1.9	11.0	10.9
	24 hour	9	3.635	0.031	0.334	0.129	0.509	4.638	78.4	0.7	7.2	2.8	11.0
	24 hour	10	4.670	0.296	0.002	0.059	1.038	6.065	77.0	4.9	0.0	1.0	17.1
	control	11	5.408	0.188	0.025	0.175	0.762	6.558	82.5	2.9	0.4	2.7	11.6
	9 hour	12	3.648	0.186	0.433	0.053	0.743	5.063	72.1	3.7	8.6	1.0	14.7
6 weeks	control	1	3.420	0.011	0.000	0.010	0.089	3.530	96.9	0.3	0.0	0.3	2.5
21/8/99	3 hour	2	3.960	0.080	0.000	0.000	0.093	4.133	95.8	1.9	0.0	0.0	2.3
	24 hour	3	5.040	0.135	0.400	0.009	0.112	5.696	88.5	2.4	7.0	0.2	2.0
	3 hour	4	7.590	0.066	0.000	0.200	0.172	8.028	94.5	0.8	0.0	2.5	2.1
	9 hour	5	5.550	0.102	0.023	0.130	0.060	5.865	94.6	1.7	0.4	2.2	1.0
	control	6	6.230	0.358	0.000	0.000	0.185	6.773	92.0	5.3	0.0	0.0	2.7
	9 hour	7	6.610	0.002	0.000	0.005	0.203	6.820	96.9	0.0	0.0	0.1	3.0
	3 hour	8	6.900	0.020	0.001	0.059	0.320	7.300	94.5	0.3	0.0	0.8	4.4
	24 hour	9	6.290	0.138	0.113	0.000	0.125	6.666	94.4	2.1	1.7	0.0	1.9
	24 hour	10	5.850	0.001	0.014	0.001	0.148	6.014	97.3	0.0	0.2	0.0	2.5
	control	11	4.810	0.021	0.015	0.018	0.322	5.186	92.7	0.4	0.3	0.3	6.2
	9 hour	12	5.240	0.118	0.055	0.083	0.183	5.679	92.3	2.1	1.0	1.5	3.2
20 weeks	control	1	2.140	0.079	0.001	0.005	0.496	2.721	78.6	2.9	0.0	0.2	18.2
26/11/99	3 hour	2	2.080	0.208	0.026	0.000	0.554	2.868	72.5	7.3	0.9	0.0	19.3
	24 hour	3	2.850	0.261	0.228	0.000	0.633	3.972	71.8	6.6	5.7	0.0	15.9
	3 hour	4	2.380	0.179	0.000	0.049	0.457	3.065	77.7	5.8	0.0	1.6	14.9
	9 hour	5	3.750	0.077	0.035	0.026	0.585	4.473	83.8	1.7	0.8	0.6	13.1
	control	6	2.280	0.327	0.038	0.000	0.647	3.292	69.3	9.9	1.2	0.0	19.7
	9 hour	7	3.660	0.011	0.000	0.014	0.557	4.242	86.3	0.3	0.0	0.3	13.1
	3 hour	8	4.910	0.022	0.000	0.423	0.591	5.946	82.6	0.4	0.0	7.1	9.9
	24 hour	9	3.250	0.020	0.000	0.000	0.549	3.819	85.1	0.5	0.0	0.0	14.4
	24 hour	10	2.870	0.008	0.036	0.000	0.366	3.280	87.5	0.2	1.1	0.0	11.2
	control	11	3.280	0.176	0.000	0.000	0.662	4.118	79.7	4.3	0.0	0.0	16.1
	9 hour	12	2.910	0.040	0.051	0.012	0.516	3.529	82.5	1.1	1.4	0.3	14.6

Note: Other grasses were predominantly Indian doab (*Cynodon dactylon* L.) with some poa (*Poa annua* L.), summer grass (*Digitaria sanguinalis* (L.) Scop) and meadow foxtail (*Alopecurus pratensis* L.). Weeds were a mix of yarrow (*Achillea millefolium* L.), dandelion (*Taraxacum officinale* Weber), and hydrocotyle (*Hydrocotyle Americana* L.), with some broad-leafed dock (*Rumex obtusifolius* L.) and creeping buttercup (*Ranunculus repens* L.).

XI.2.2 The 71% GSM Experiment

Time	Treatment	Plot #	Dry matter weight (g)					DM weight of sample (g)	Botanical Composition (%)				
			Rye grass	Other Grass-es	Clover	Weeds	Dead		Rye grass	Other Grass-es	Clover	Weeds	Dead
Before	9 hour	1	2.440	0.304	0.000	0.533	0.515	3.792	64.3	8.0	0.0	14.1	13.6
25/8/00	control	2	2.890	0.153	0.010	0.527	0.523	4.103	70.4	3.7	0.2	12.8	12.7
	24 hour	3	2.240	0.197	0.019	0.322	0.639	3.417	65.6	5.8	0.6	9.4	18.7
	3 hour	4	3.740	0.385	0.019	0.330	0.241	4.715	79.3	8.2	0.4	7.0	5.1
	9 hour	5	2.470	0.171	0.012	0.597	0.453	3.703	66.7	4.6	0.3	16.1	12.2
	3 hour	6	1.930	0.727	0.000	0.918	0.302	3.877	49.8	18.8	0.0	23.7	7.8
	24 hour	7	3.000	0.364	0.160	0.226	0.491	4.241	70.7	8.6	3.8	5.3	11.6
	control	8	1.880	0.254	0.076	0.825	0.610	3.645	51.6	7.0	2.1	22.6	16.7
	9 hour	9	2.450	0.934	0.000	0.259	0.515	4.158	58.9	22.5	0.0	6.2	12.4
	24 hour	10	2.150	0.563	0.009	1.022	0.890	4.634	46.4	12.1	0.2	22.1	19.2
	3 hour	11	3.260	0.291	0.000	0.208	0.713	4.472	72.9	6.5	0.0	4.7	15.9
	control	12	2.220	0.629	0.000	0.396	0.711	3.956	56.1	15.9	0.0	10.0	18.0
6 weeks	9 hour	1	1.570	0.270	0.000	0.250	0.260	2.350	66.8	11.5	0.0	10.6	11.1
26/10/00	control	2	2.310	0.640	0.030	0.670	0.280	3.930	58.8	16.3	0.8	17.0	7.1
	24 hour	3	2.630	0.210	0.010	0.660	0.090	3.600	73.1	5.8	0.3	18.3	2.5
	3 hour	4	3.070	0.310	0.020	0.550	0.770	4.720	65.0	6.6	0.4	11.7	16.3
	9 hour	5	2.860	0.240	0.040	0.820	0.180	4.140	69.1	5.8	1.0	19.8	4.3
	3 hour	6	2.620	0.350	0.010	0.250	0.190	3.420	76.6	10.2	0.3	7.3	5.6
	24 hour	7	3.350	0.210	0.040	0.260	0.090	3.950	84.8	5.3	1.0	6.6	2.3
	control	8	1.990	0.410	0.020	0.130	0.210	2.760	72.1	14.9	0.7	4.7	7.6
	9 hour	9	3.410	0.290	0.080	0.170	0.190	4.140	82.4	7.0	1.9	4.1	4.6
	24 hour	10	2.760	0.230	0.040	0.630	0.110	3.770	73.2	6.1	1.1	16.7	2.9
	3 hour	11	1.930	0.290	0.000	0.120	0.170	2.510	76.9	11.6	0.0	4.8	6.8
	control	12	2.200	0.260	0.000	0.090	0.140	2.690	81.8	9.7	0.0	3.3	5.2
21 weeks	9 hour	1	2.117	0.101	0.026	0.733	0.666	3.643	58.1	2.8	0.7	20.1	18.3
20/1/01	control	2	2.423	0.000	0.104	0.561	0.338	3.426	70.7	0.0	3.0	16.4	9.9
	24 hour	3	3.634	0.143	0.044	0.625	0.221	4.667	77.9	3.1	0.9	13.4	4.7
	3 hour	4	4.391	0.044	0.050	0.260	0.553	5.298	82.9	0.8	0.9	4.9	10.4
	9 hour	5	3.766	0.033	0.066	0.192	0.325	4.382	85.9	0.8	1.5	4.4	7.4
	3 hour	6	2.942	0.105	0.065	0.480	0.797	4.389	67.0	2.4	1.5	10.9	18.2
	24 hour	7	3.100	0.003	0.113	1.130	0.233	4.579	67.7	0.1	2.5	24.7	5.1
	control	8	2.851	0.182	0.005	0.507	0.912	4.457	59.4	3.8	0.1	17.7	19.0
	9 hour	9	2.804	0.000	0.061	0.607	0.466	3.938	71.2	0.0	1.5	15.4	11.8
	24 hour	10	0.061	0.078	0.079	0.641	0.490	1.349	67.9	1.9	2.0	16.0	12.2
	3 hour	11	2.889	0.019	0.417	0.759	0.922	5.006	57.7	0.4	8.3	15.2	18.4
	control	12	3.504	0.035	0.011	0.519	1.004	5.073	69.1	0.7	0.2	10.2	19.8
34 weeks	9 hour	1	1.242	0.084	0.078	2.092	0.207	3.703	33.5	2.3	2.1	56.5	5.6
23/4/01	control	2	1.895	0.031	0.027	0.511	0.069	2.533	74.8	1.2	1.1	20.2	2.7
	24 hour	3	1.316	0.055	0.017	1.393	0.031	2.812	46.8	2.0	0.6	49.5	1.1
	3 hour	4	1.767	0.005	0.159	0.968	0.066	2.965	59.6	0.2	5.4	32.6	2.2
	9 hour	5	1.656	0.000	0.030	1.052	0.035	2.773	59.7	0.0	1.1	37.9	1.3
	3 hour	6	3.011	0.000	0.000	1.016	0.130	4.157	72.4	0.0	0.0	24.4	3.1
	24 hour	7	2.825	0.041	0.047	2.105	0.063	5.081	55.6	0.8	0.9	41.4	1.2
	control	8	3.320	0.148	0.053	0.900	0.224	4.645	71.5	3.2	1.1	19.4	4.8
	9 hour	9	3.660	0.160	0.042	2.086	0.226	6.174	59.3	2.6	0.7	33.8	3.7
	24 hour	10	2.424	0.000	0.065	2.363	0.277	5.129	47.3	0.0	1.3	46.1	5.4
	3 hour	11	3.192	0.000	0.180	0.521	0.243	4.136	77.2	0.0	4.4	12.6	5.9
	control	12	4.345	0.000	0.029	1.783	0.279	6.436	67.5	0.0	0.5	27.7	4.3

Note: Other grasses were poa (*Poa annua* L.), prairie grass (*Bromus willdenowii* Kunth.) and summer grass (*Digitaria sanguinalis* (L.) Scop). Weeds were predominantly broad-leaved plantain (*Plantago major* L.) – particularly at week 34, with some dandelion (*Taraxacum officinale* Weber), broad-leafed dock (*Rumex obtusifolius* L.), yarrow (*Achillea millefolium* L.), creeping buttercup (*Ranunculus repens* L.) and daisy (*Bellis perennis* L.).

XI.2.3 The 81% GSM Experiment

Time	Treatment	Plot #	Dry matter weight (g): Rye grass	Other Grass-es	Clover	Weeds	Dead	DM weight of sample (g)	Botanical Composition (%): Rye grass	Other Grass-es	Clover	Weeds	Dead
Before	9 hour	1	2.098	0.735	0.058	0.053	0.235	3.179	66.0	23.1	1.8	1.7	7.4
4/8/01	control	2	2.072	0.205	0.091	0.418	0.456	3.242	63.9	6.3	2.8	12.9	14.1
	24 hour	3	1.971	0.092	0.044	0.213	0.257	2.577	76.5	3.6	1.7	8.3	10.0
	control	4	2.669	0.606	0.042	0.077	0.534	3.928	67.9	15.4	1.1	2.0	13.6
	24 hour	5	2.402	0.925	0.072	0.000	0.224	3.623	66.3	25.5	2.0	0.0	6.2
	9 hour	6	1.976	0.495	0.005	0.000	0.045	2.521	78.4	19.6	0.2	0.0	1.8
	3 hour	7	2.166	0.412	0.020	0.000	0.331	2.929	74.0	14.1	0.7	0.0	11.3
	control	8	1.752	0.326	0.000	0.000	0.104	2.182	80.3	14.9	0.0	0.0	4.8
	9 hour	9	2.641	0.102	0.075	0.116	0.665	3.599	73.4	2.8	2.1	3.2	18.5
	3 hour	10	2.030	0.358	0.000	0.178	0.333	2.899	70.0	12.3	0.0	6.1	11.5
	24 hour	11	2.203	0.608	0.030	0.089	0.219	3.149	70.0	19.3	1.0	2.8	7.0
	3 hour	12	2.205	0.889	0.064	0.023	0.725	3.906	56.5	22.8	1.6	0.6	18.6
8 weeks	9 hour	1	1.521	0.281	0.375	0.403	0.129	2.709	56.1	10.4	13.8	14.9	4.8
5/10/01	control	2	1.974	0.359	0.471	0.154	0.476	3.434	57.5	10.5	13.7	4.5	13.9
	24 hour	3	3.144	0.768	0.067	0.138	0.021	4.138	76.0	18.6	1.6	3.3	0.5
	control	4	2.343	0.041	0.189	0.013	0.313	2.899	80.8	1.4	6.5	0.4	10.8
	24 hour	5	3.243	0.369	0.102	0.113	0.175	4.002	81.0	9.2	2.5	2.8	4.4
	9 hour	6	2.715	0.777	0.005	0.000	0.276	3.773	72.0	20.6	0.1	0.0	7.3
	3 hour	7	2.968	0.186	0.245	0.039	0.245	3.757	79.0	5.0	8.5	1.0	6.5
	control	8	2.757	0.204	0.060	0.000	0.219	3.240	85.1	6.3	1.9	0.0	6.8
	9 hour	9	3.255	0.227	0.092	0.053	0.159	3.786	86.0	6.0	2.4	1.4	4.2
	3 hour	10	2.806	0.540	0.072	0.164	0.251	3.833	73.2	14.1	1.9	4.3	6.5
	24 hour	11	3.146	0.085	0.190	0.138	0.080	3.639	86.5	2.3	5.2	3.8	2.2
	3 hour	12	1.504	0.244	0.611	0.755	0.180	3.294	45.7	7.4	18.5	22.9	5.5
18 weeks	9 hour	1	3.050	0.221	0.473	0.565	0.205	4.514	67.6	4.9	10.5	12.5	4.5
16/12/01	control	2	2.293	0.240	0.580	0.494	0.058	3.665	62.6	6.5	15.8	13.5	1.6
	24 hour	3	2.659	0.070	0.274	0.242	0.255	3.500	76.0	2.0	7.8	6.9	7.3
	control	4	2.390	0.223	0.527	0.233	0.356	3.729	64.1	6.0	14.1	6.2	9.5
	24 hour	5	2.926	0.200	0.222	0.412	0.267	4.027	72.7	5.0	5.5	10.2	6.6
	9 hour	6	3.063	0.322	0.071	0.000	0.227	3.683	83.2	8.7	1.9	0.0	6.2
	3 hour	7	2.646	0.140	0.197	0.021	0.162	3.166	83.6	4.4	6.2	0.7	5.1
	control	8	2.441	0.338	0.288	0.057	0.458	3.582	68.1	9.4	8.0	1.6	12.8
	9 hour	9	3.586	0.041	0.093	0.065	0.215	4.000	89.7	1.0	2.3	1.6	5.4
	3 hour	10	4.563	0.128	0.223	0.175	0.277	5.366	85.0	2.4	4.2	3.3	5.2
	24 hour	11	2.507	0.035	0.759	0.362	0.128	3.791	66.1	0.9	20.0	9.5	3.4
	3 hour	12	2.648	0.145	0.544	0.476	0.061	3.874	68.4	3.7	14.0	12.3	1.6

Note: Other grasses were poa (*Poa annua* L.), prairie grass (*Bromus willdenowii* Kunth.), and summer grass (*Digitaria sanguinalis* (L.) Scop). Weeds were broad-leaved plantain (*Plantago major* L.), dandelion (*Taraxacum officinale* Weber), broad-leafed dock (*Rumex obtusifolius* L.), creeping buttercup (*Ranunculus repens* L.), daisy (*Bellis perennis* L.), and yarrow (*Achillea millefolium* L.).

Appendix XII

Tiller Density

Appendix XII Tiller Density

XII.1 Treatment Means

	65% GSM Density of Ryegrass Tillers (tillers m^{-2})			
	Before	**6 weeks**	**21 weeks**	**28 weeks**
Control	2368	2973	3029	3406
3 hour	2609	1796	2682	2976
9 hour	2890	2096	2058	2790
24 hour	2526	1534	2149	3546
F.pr	0.767	0.001	0.040	0.522
e.s.e	353.0	260.2	270.3	394.4
s.e.d	499.3	368.0	382.3	557.8
l.s.d	1151.3	728.9	759.3	1286.3

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

	71% GSM Density of Ryegrass Tillers (tillers m^{-2})			
	Before	**6 weeks**	**19 weeks**	**30 weeks**
Control	1508	1935	3017	707
3 hour	1862	1501	3257	757
9 hour	1528	1062	3063	653
24 hour	1531	827	3414	5215
F.pr	0.755	0.006	0.775	0.670
e.s.e	278.7	162.8	278.7	140.9
s.e.d	394.1	230.2	394.1	199.3
l.s.d	908.8	530.8	908.8	395.8

	81% GSM Density of Ryegrass Tillers (tillers m^{-2})		
	Before	**6 weeks**	**19 weeks**
Control	1019	1641	1068
3 hour	840	1376	1173
9 hour	1081	761	11212
24 hour	1184	554	1008
F.pr	0.406	0.001	0.868
e.s.e	146.1	171.7	144.8
s.e.d	206.7	242.8	204.7
l.s.d	409.4	480.8	405.5

XII.2 Individual Results

XII.2.1 The 65% GSM Experiment

Time	Treatment	Plot #	Number of tillers per frame										Ryegrass tillers per m²
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
Before	control	1	50	35	29	22	37	24	24	69	35	23	3452
23/6/99	3 hour	2	15	62	30	69	11	35	0	6	12	33	2708
	24 hour	3	8	25	24	18	64	13	14	0	55	21	2401
	3 hour	4	48	12	15	18	15	33	45	54	20	34	2916
	9 hour	5	29	45	24	31	14	37	53	37	28	39	3343
	control	6	22	3	0	10	12	1	13	2	34	44	1399
	9 hour	7	15	55	28	17	35	28	23	27	34	22	2817
	3 hour	8	22	30	19	13	37	14	23	15	21	28	2202
	24 hour	9	38	10	36	15	16	65	44	27	26	17	2916
	24 hour	10	28	16	36	29	33	19	20	19	7	21	2262
	control	11	27	12	24	18	46	35	17	3	10	35	2252
	9 hour	12	46	36	38	26	24	13	12	23	17	18	2510
6 weeks	control	1	52	56	20	40	34	28	29	38	19	3	3164
6/8/99	3 hour	2	19	28	2	0	22	17	21	4	10	32	1538
	24 hour	3	13	31	18	12	47	6	20	8	7	0	1607
	3 hour	4	20	59	7	0	7	6	17	14	25	8	1617
	9 hour	5	43	17	13	11	28	9	82	0	9	24	2341
	control	6	33	21	7	27	13	38	21	18	13	26	2153
	9 hour	7	4	31	3	23	19	1	25	18	33	35	1905
	3 hour	8	30	20	37	13	1	20	33	27	19	25	2232
	24 hour	9	15	13	12	7	3	43	1	8	6	39	1458
	24 hour	10	10	23	9	39	12	0	17	29	7	9	1538
	control	11	42	57	42	29	24	26	62	29	5	47	3601
	9 hour	12	33	12	9	11	25	27	26	20	13	30	2043
20 weeks	control	1	21	23	28	20	33	20	20	33			2455
18/11/99	3 hour	2	56	15	15	18	34	26	47	40			3112
	24 hour	3	0	0	60	34	8	16	14	19			1872
	3 hour	4	13	20	27	32	17	21	21	21			2133
	9 hour	5	29	9	32	8	24	9	32	31			2158
	control	6	67	74	13	8	31	21	34	43			3608
	9 hour	7	21	13	19	4	24	37	34	41			2393
	3 hour	8	16	26	37	9	18	26	50	44			2802
	24 hour	9	19	43	14	33	22	22	25	20			2455
	24 hour	10	25	33	15	29	13	12	21	23			2120
	control	11	42	30	16	33	40	13	33	37			3025
	9 hour	12	22	0	23	34	14	17	20	1			1624
28 weeks	control	1	39	38	14	46	12	44	43	39			3410
9/1/2000	3 hour	2	24	20	22	49	26	12	33	33			2716
	24 hour	3	57	55	39	36	49	59	56	48			4947
	3 hour	4	33	35	17	19	26	28	54	18			2852
	9 hour	5	39	36	27	31	17	14	51	21			2926
	control	6	46	35	32	43	43	13	34	35			3484
	9 hour	7	28	39	16	30	45	5	17	19			2468
	3 hour	8	23	76	33	11	21	27	43	37			3360
	24 hour	9	37	49	42	10	10	17	18	11			2406
	24 hour	10	20	40	41	25	23	43	52	21			3286
	control	11	45	40	31	27	36	17	48	24			3323
	9 hour	12	45	24	39	2	15	44	32	39			2976

Note: Tiller frame was (0.010081297 m²)

XII.2.2 The 71% GSM Experiment

Time	Treatment	Plot #	Number of tillers per frame										Ryegrass tillers per m²
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	
Before	9 hour	1	0	23	19	16	0	7	4	10	10	44	1319
25/8/00	control	2	37	14	28	9	11	15	0	2	20	18	1528
	24 hour	3	26	28	9	9	19	13	12	6	28	29	1776
	3 hour	4	3	23	21	22	4	25	11	10	9	0	1270
	9 hour	5	18	19	7	14	0	25	22	9	21	3	1369
	3 hour	6	23	26	19	36	5	13	3	13	20	40	1964
	24 hour	7	15	41	13	15	20	23	13	10	42	13	2034
	control	8	15	9	0	32	10	20	15	15	0	4	1190
	9 hour	9	35	17	35	21	11	2	11	15	19	25	1895
	24 hour	10	2	8	15	13	5	10	13	0	5	8	784
	3 hour	11	26	33	24	21	58	29	37	9	0	0	2351
	control	12	17	36	7	29	26	21	18	2	6	20	1805
6 weeks	9 hour	1	25	0	17	3	10	30	9	1	0	17	1111
5/10/00	control	2	28	15	27	29	31	15	6	23	21	35	2282
	24 hour	3	10	3	7	27	21	3	4	2	0	6	823
	3 hour	4	13	2	18	6	17	33	11	9	7	18	1329
	9 hour	5	18	19	15	14	3	10	24	0	6	20	1280
	3 hour	6	9	12	15	15	17	23	19	6	14	27	1557
	24 hour	7	12	15	3	15	6	8	9	13	30	0	1101
	control	8	29	13	5	22	19	9	7	17	12	18	1498
	9 hour	9	13	9	15	3	8	4	16	3	0	9	794
	24 hour	10	3	4	9	16	11	0	0	0	10	3	556
	3 hour	11	16	29	18	8	0	24	15	15	23	15	1617
	control	12	20	18	14	27	10	20	20	42	13	20	2024
21 weeks	9 hour	1	39	38	14	46	48	44	43	39			3856
13/1/01	control	2	24	20	22	49	26	12	33	33			2716
	24 hour	3	57	55	39	36	49	19	56	48			4451
	3 hour	4	33	35	17	19	26	28	54	18			2852
	9 hour	5	39	36	27	31	17	14	51	21			2926
	3 hour	6	46	35	32	35	43	50	34	35			3844
	24 hour	7	28	39	16	30	5	48	17	19			2505
	control	8	23	76	33	11	21	27	43	37			3360
	9 hour	9	37	49	42	10	10	17	18	11			2406
	24 hour	10	20	40	41	25	23	43	52	21			3286
	3 hour	11	25	40	31	27	36	17	48	24			3075
	control	12	45	24	39	2	15	44	32	39			2976
30 weeks	9 hour	1	11	2	0	13	4	13	2	9			670
25/3/01	control	2	3	14	5	1	15	5	5	2			620
	24 hour	3	15	10	0	0	33	0	0	0			719
	3 hour	4	4	9	8	12	3	8	2	8			670
	9 hour	5	0	12	8	13	7	2	10	3			682
	3 hour	6	0	10	8	20	2	7	19	4			868
	24 hour	7	3	0	0	2	15	10	4	7			508
	control	8	0	14	13	0	8	5	3	9			645
	9 hour	9	2	0	13	7	5	16	6	0			608
	24 hour	10	2	0	0	0	0	0	0	25			335
	3 hour	11	0	2	0	17	23	7	10	0			732
	control	12	9	9	0	3	11	30	3	4			856

XII.2.3 The 81% GSM Experiment

Time	Treatment	Plot #	Number of tillers per frame Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Ryegrass tillers per m^2
Before	9 hour	1	13	6	8	0	11	16	0	2	9	23	873
4/8/01	control	2	9	17	5	8	9	0	16	0	15	11	893
	24 hour	3	20	0	3	0	0	9	19	20	0	29	992
	control	4	16	16	7	0	0	7	13	9	20	12	992
	24 hour	5	18	10	22	10	30	8	13	4	9	6	1290
	9 hour	6	9	8	7	32	12	7	12	10	0	9	1051
	3 hour	7	3	17	7	0	8	0	30	6	10	0	803
	control	8	4	0	17	13	10	13	3	16	28	14	1171
	9 hour	9	19	21	19	7	14	4	18	15	16	0	1319
	3 hour	10	13	9	0	12	3	9	17	12	5	9	883
	24 hour	11	3	0	8	39	18	16	8	0	17	19	1270
	3 hour	12	10	3	0	9	11	0	12	21	0	18	833
8 weeks	9 hour	1	4	0	0	0	5	10	12	9			496
16/9/01	control	2	12	8	19	25	14	32	27	0			1699
	24 hour	3	3	16	4	0	0	0	8	0			384
	control	4	17	33	13	24	9	17	16	24			1897
	24 hour	5	0	7	8	3	6	6	4	0			422
	9 hour	6	16	0	11	3	29	4	3	24			1116
	3 hour	7	14	3	31	12	13	13	14	0			1240
	control	8	0	0	0	8	21	35	16	27			1327
	9 hour	9	13	0	0	5	3	7	15	11			670
	3 hour	10	0	30	20	18	0	10	25	14			1451
	24 hour	11	31	0	0	4	8	9	13	4			856
	3 hour	12	6	9	21	40	23	4	0	13			1438
18 weeks	9 hour	1	12	10	18	0	15	19	5	7	12	18	1151
16/12/01	control	2	8	19	12	3	9	5	18	22	9	12	1161
	24 hour	3	20	5	8	0	21	0	18	0	15	0	863
	control	4	12	0	19	5	7	8	15	0	3	18	863
	24 hour	5	10	18	12	16	8	5	0	9	25	17	1190
	9 hour	6	5	16	3	19	15	7	9	12	19	25	1290
	3 hour	7	8	25	19	31	5	7	28	8	5	10	1448
	control	8	15	6	8	26	12	15	0	9	12	16	1180
	9 hour	9	5	0	9	29	5	0	0	31	5	9	923
	3 hour	10	0	5	24	16	5	3	19	8	6	8	932
	24 hour	11	15	3	19	24	3	0	14	7	6	7	972
	3 hour	12	14	15	7	0	18	31	12	5	6	7	1141

Appendix XIII

Herbage Accumulation

Appendix XIII Herbage Accumulation

XIII.1 Experimental Means

XIII.1.1 Herbage Accumulation (Per Time Interval)

65% GSM experiment Herbage accumulation per measurement time (kg DM ha^{-1})								
	Pre-tread	8.3 weeks	13.6 weeks	17.9 weeks	21.9 weeks	25.6 weeks	28.1 weeks	31.3 weeks
Control	309	1652	3108	1752	237	1743	735	881
3-hour	234	1365	3031	1817	398	1473	391	949
9-hour	340	1332	2904	1628	409	1296	478	864
24-hour	322	798	3418	1935	691	1531	247	1003
F. pr	0.569	0.038	0.089	0.840	0.161	0.628	0.220	0.287
e.s.e	54.8	166.6	124.1	242.9	125.8	236.1	151.8	52.1
s.e.d	77.6	235.6	175.6	343.5	177.9	333.9	214.6	73.7
l.s.d	178.9	543.3	404.9	792.0	410.3	769.9	495.0	169.9

Note: F.pr <0.05 indicates a significant difference has been observed, e.s.e. is the estimated standard error, s.e.d. is the standard error of the difference of the means, l.s.d. is the least significance difference of the means (5%).

71% GSM experiment Herbage accumulation per measurement time (kg DM ha^{-1})									
	Pre-tread	1.9 weeks	5.1 weeks	9.0 weeks	12.1 weeks	18.7 weeks	20.1 weeks	26.0 weeks	32.0 weeks
Control	473	279	1428	1279	229	1011	320	1415	2151
3-hour	500	294	1325	1523	182	1094	348	1466	2044
9-hour	467	133	928	963	70	941	405	1376	2148
24-hour	507	71	762	626	49	952	331	1372	2052
F. pr	0.920	0.014	0.002	0.001	0.047	0.672	0.125	0.917	0.967
e.s.e	49.5	42.3	85.4	98.6	56.4	95.9	37.6	107.9	203.9
s.e.d	70.0	59.8	120.7	139.5	79.8	135.6	53.0	152.6	288.3
l.s.d	161.4	137.9	278.4	321.6	173.9	312.8	122.2	351.9	664.9

81% GSM experiment											
Herbage accumulation per measurement time (kg DM ha^{-1})											
	Pre-tread	1 week	3.1 weeks	6.0 weeks	10.0 weeks	13.0 weeks	16.4 weeks	19.0 weeks	22.1 weeks	23.4 weeks	28.6 weeks
Control	443	199	383	1100	1931	1278	927	461	660	1765	1055
3-hour	327	88	376	981	1895	981	647	398	567	1796	1093
9-hour	358	123	199	853	1422	539	660	171	500	1837	1058
24-hour	343	239	214	210	936	352	423	209	413	1761	1013
F. pr	0.816	0.187	0.089	0.041	0.001	0.001	0.048	0.045	0.187	0.981	0.949
e.s.e	92.4	48.4	56.8	121.4	104.8	90.6	109.3	68.7	76.7	147.3	97.24
s.e.d	130.7	68.4	80.4	171.7	148.2	128.2	154.6	97.2	108.4	208.3	137.5
l.s.d	301.3	157.8	185.4	395.9	341.8	295.5	356.4	224.1	249.9	480.3	317.1

XIII.1.2 Herbage Accumulation (Cumulative)

65% GSM experiment							
Cumulative herbage accumulation (kg DM ha^{-1})							
	8.3 weeks	13.6 weeks	17.9 weeks	21.9 weeks	25.6 weeks	28.1 weeks	31.3 weeks
Control	1652	4759	6511	6749	8492	9226	10108
3-hour	1365	4396	6213	6611	8084	8475	9424
9-hour	1332	4236	5864	6273	7568	8046	8910
24-hour	798	4216	6150	6841	8372	8619	9621
F. pr	0.038	0.221	0.104	0.442	0.506	0.351	0.378
e.s.e	166.6	186.4	157.1	249.3	446.8	434.6	457.2
s.e.d	235.6	263.56	222.2	352.6	631.9	614.6	646.6
l.s.d	543.3	607.8	512.8	813.0	1457.1	1417.3	1491.0

71% GSM experiment Cumulative herbage accumulation (kg DM ha^{-1})								
	1.9 weeks	5.1 weeks	9.0 weeks	12.1 weeks	18.7 weeks	20.1 weeks	26.0 weeks	32.0 weeks
Control	279	1707	2986	3215	4226	4546	5960	8111
3-hour	294	1619	3141	3323	4417	4765	6232	8276
9-hour	133	1061	2024	2094	3035	3440	4816	6964
24-hour	71	833	1459	1508	2460	2791	4162	6214
F. pr	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.014
e.s.e	42.3	71.2	105.3	135.6	142.2	193.7	248.9	374.9
s.e.d	59.8	100.7	149.0	191.8	201.1	274.0	351.9	530.3
l.s.d	137.9	232.2	343.5	442.4	463.6	631.8	811.6	1222.8

81% GSM experiment Cumulative herbage accumulation (kg DM ha^{-1})										
	1 week	3.1 weeks	6.0 weeks	10.0 weeks	13.0 weeks	16.4 weeks	19.0 weeks	22.1 weeks	23.4 weeks	28.6 weeks
Control	199	583	1683	3613	4891	5819	6280	6940	8705	9760
3-hour	88	464	1445	3340	4321	4968	5366	4933	7729	8822
9-hour	123	323	1176	2598	3137	3798	3968	4469	6305	7363
24-hour	239	453	663	1600	1951	2375	2583	2996	4757	5770
F. pr	0.188	0.187	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
e.s.e	48.4	74.3	115.7	202.2	195.3	213.5	244.6	268.7	282.2	232.2
s.e.d	68.5	105.1	163.6	285.6	276.2	301.9	346.0	380.0	399.0	328.4
l.s.d	158.0	242.4	377.3	659.4	636.9	696.2	797.8	876.4	920.2	757.2

XIII.1.3 Herbage Accumulation (Relative to Controls)

65% GSM experiment

Proportional cumulative herbage accumulation
(% growth compared to controls)

	8.3 weeks	13.6 weeks	17.9 weeks	21.9 weeks	25.6 weeks	28.1 weeks	31.3 weeks
3 hour	82.6	92.4	95.4	98.0	95.2	91.9	93.2
9 hour	80.6	89.0	90.1	92.9	89.1	87.2	88.1
24 hour	48.3	88.6	94.5	101.4	98.6	93.4	95.2

Note: proportional herbage accumulation of treatment plots was the percent herbage accumulation compared to controls (i.e. herbage accumulation of treatments divided by controls).

71% GSM experiment

Proportional cumulative herbage accumulation
(% growth compared to controls)

	1.9 weeks	5.1 weeks	9.0 weeks	12.1 weeks	18.7 weeks	20.1 weeks	26.0 weeks	32.0 weeks
3 hour	105.4	94.8	105.2	103.4	104.5	104.8	104.6	102.0
9 hour	47.5	62.1	67.8	65.1	71.8	75.7	80.8	85.9
24 hour	25.4	48.8	48.9	46.9	58.2	61.4	69.8	76.6

Note: a number greater than 100 indicates a gain compared to controls.

81% GSM experiment

Proportional cumulative herbage accumulation
(% growth compared to controls)

	1 week	3.1 weeks	6.0 weeks	10.0 weeks	13.0 weeks	16.4 weeks	19.0 weeks	22.1 weeks	23.4 weeks	28.6 weeks
3 hour	44.3	79.7	85.9	92.4	88.3	85.4	85.3	85.5	88.8	90.4
9 hour	61.9	55.4	69.9	71.9	64.1	65.3	63.2	64.4	72.4	75.4
24 hour	120.1	77.8	39.4	44.3	39.9	40.8	41.1	43.2	54.6	59.1

XIII.1.4 Herbage Accumulation Loss (Cumulative)

65% GSM experiment

Cumulative herbage accumulation loss (kg DM ha^{-1})

	8.3 weeks	13.6 weeks	17.9 weeks	21.9 weeks	25.6 weeks	28.1 weeks	31.3 weeks
3 hour	287	363	298	138	407	751	684
9 hour	320	523	648	476	923	1181	1198
24 hour	854	543	361	92	120	608	487

Note: cumulative herbage loss of treatment plots was the loss (decline) compared to herbage accumulation in controls (i.e. herbage accumulation of controls minus herbage accumulation of treatment plots).

71% GSM experiment

Cumulative herbage accumulation loss (kg DM ha^{-1})

	1.9 weeks	5.1 weeks	9.0 weeks	12.1 weeks	18.7 weeks	20.1 weeks	26.0 weeks	32.0 weeks
3 hour	-15	88	-156	-109	-191	-220	-271	-165
9 hour	147	646	962	1121	1191	1106	1144	1146
24 hour	208	874	1527	1706	1766	1755	1798	1897

Note: a negative number indicates a gain (negative loss) compared to controls.

81% GSM experiment

Cumulative herbage accumulation loss (kg DM ha^{-1})

	1 week	3.1 weeks	6.0 weeks	10.0 weeks	13.0 weeks	16.4 weeks	19.0 weeks	22.1 weeks	23.4 weeks	28.6 weeks
3 hour	111	119	238	273	571	851	914	1008	976	938
9 hour	76	260	507	1015	1754	2021	2311	2472	2400	2397
24 hour	-40	129	1019	2014	2940	3444	3697	3944	3948	3990

XIII.1.5 Herbage Accumulation Loss (Percentage of Controls)

65% GSM experiment

Cumulative herbage accumulation loss (% loss compared to controls)

	8.3 weeks	13.6 weeks	17.9 weeks	21.9 weeks	25.6 weeks	28.1 weeks	31.3 weeks
3 hour	17.4	7.6	4.6	2.0	4.8	8.1	6.8
9 hour	19.4	11.0	9.9	7.1	10.9	12.8	11.9
24 hour	51.7	11.4	5.5	-1.4	1.4	6.6	4.8

Note: Proportional herbage loss is the percent loss (decline) compared to control herbage accumulation (e.g. cumulative herbage loss compared to controls, divided by controls).

71% GSM experiment

Cumulative herbage accumulation loss (% loss compared to controls)

	1.9 weeks	5.1 weeks	9.0 weeks	12.1 weeks	18.7 weeks	20.1 weeks	26.0 weeks	32.0 weeks
3 hour	-5.4	5.2	-5.2	-3.4	-4.5	-4.8	-4.6	-2.0
9 hour	52.5	37.9	32.2	34.9	28.2	24.3	19.2	14.1
24 hour	74.6	51.2	51.1	53.1	41.8	38.6	30.2	23.4

Note: a negative number indicates a gain (negative loss) compared to controls.

81% GSM experiment

Cumulative herbage accumulation loss (% loss compared to controls)

	1 week	3.1 weeks	6.0 weeks	10.0 weeks	13.0 weeks	16.4 weeks	19.0 weeks	22.1 weeks	23.4 weeks	28.6 weeks
3 hour	55.7	20.3	14.1	7.6	11.7	14.6	14.6	14.5	11.2	9.6
9 hour	38.1	44.6	30.1	28.1	35.9	34.7	36.8	35.6	27.6	24.6
24 hour	-20.1	22.2	60.6	55.7	60.1	59.2	58.9	56.8	45.4	40.9

XIII.2 Individual Herbage Accumulation Results

XIII.2.1 The 65% GSM Experiment

Date & comment	Plot #	Treatment	Plate readings		Herbage mass (kg DM ha^{-1})	Herbage accumulated between grazings (kg DM ha^{-1})
			Start	End		
	1	control	33019	33420	1642.5	
5-6-99	2	3 hour	33420	33779	1537.5	
	3	24 hour	33779	34175	1630.0	
After grazing	4	3 hour	34175	34598	1697.5	
	5	9 hour	34598	35015	1682.5	
125CMR+640	6	control	35015	35327	1420.0	
	7	9 hour	35327	35674	1507.5	
	8	3 hour	35674	36054	1590.0	
	9	24 hour	36054	36411	1532.5	
	10	24 hour	36411	36805	1625.0	
	11	control	36805	37220	1677.5	
	12	9 hour	37220	37583	1547.5	
	1	control	37910	38397	1857.5	215.0
23-6-99	2	3 hour	38397	38873	1830.0	292.5
	3	24 hour	38915	39399	1850.0	220.0
Before treading treatment	4	3 hour	39399	39888	1862.5	165.0
	5	9 hour	39888	40404	1930.0	247.5
	6	control	40404	40871	1807.5	387.5
125CMR+640	7	9 hour	40871	41397	1955.0	447.5
	8	3 hour	41397	41875	1835.0	245.0
	9	24 hour	41875	42349	1825.0	292.5
	10	24 hour	42369	42944	2077.5	452.5
	11	control	42944	43489	2002.5	325.0
	12	9 hour	43489	43982	1872.5	325.0
	1	control	46495	46784	1362.5	
26-6-99	2	3 hour	46784	47053	1312.5	
	3	24 hour	47053	47218	1052.5	
After treading treatment	4	3 hour	47218	47477	1287.5	
	5	9 hour	47477	47621	1000.0	
	6	control	47621	47923	1395.0	
125CMR+640	7	9 hour	47923	48054	967.5	
	8	3 hour	48054	48241	1107.5	
	9	24 hour	48241	48544	1397.5	
	10	24 hour	48544	48829	1352.5	
	11	control	48829	49161	1470.0	
	12	9 hour	49161	49277	930.0	
	1	control	25674	26561	2857.5	1495.0
22-8-99	2	3 hour	26582	27340	2535.0	1222.5
	3	24 hour	27340	27809	1812.5	760.0
Before grazing	4	3 hour	27809	28548	2487.5	1200.0
	5	9 hour	28548	29027	1837.5	837.5
125CMR+640	6	control	29065	30036	3067.5	1672.5
	7	9 hour	30036	30893	2782.5	1815.0
	8	3 hour	30893	31749	2780.0	1672.5
	9	24 hour	31749	32372	2197.5	800.0
	10	24 hour	32372	32990	2185.0	832.5
	11	control	32990	34037	3257.5	1787.5
	12	9 hour	34047	34700	2272.5	1342.5
	1	control	58542	58884	1495.0	
23-8-99	2	3 hour	59345	59631	1355.0	
	3	24 hour	59631	59842	1167.5	
After grazing	4	3 hour	59842	60155	1422.5	
	5	9 hour	60155	60415	1290.0	
125CMR+640	6	control	60415	60750	1477.5	
	7	9 hour	60792	61162	1565.0	
	8	3 hour	61172	61479	1407.5	
	9	24 hour	61479	61773	1375.0	
	10	24 hour	61773	62039	1305.0	
	11	control	62039	62374	1477.5	
	12	9 hour	62488	62751	1297.5	

	1	control	82076	83582	4405.0	2910.0
29-9-99	2	3 hour	83583	85144	4542.5	3187.5
	3	24 hour	85144	86618	4325.0	3157.5
Before grazing	4	3 hour	86619	88093	4325.0	2902.5
	5	9 hour	88093	89549	4280.0	2990.0
125CMR+640	6	control	89550	91237	4857.5	3380.0
	7	9 hour	91239	92691	4270.0	2705.0
	8	3 hour	92691	94199	4410.0	3002.5
	9	24 hour	94202	95854	4770.0	3395.0
	10	24 hour	95857	97604	5007.5	3702.5
	11	control	97610	99158	4510.0	3032.5
	12	9 hour	99160	100630	4315.0	3017.5
	1	control	93125	93314	1667.2	
30-9-99	2	3 hour	93314	93488	1585.7	
	3	24 hour	93488	93673	1645.4	
After grazing	4	3 hour	93673	93865	1683.5	
	5	9 hour	93865	94034	1558.5	
125CMR+640	6	control	94034	94226	1683.5	
	7	9 hour	94226	94436	1781.3	
	8	3 hour	94436	94594	1498.7	
	9	24 hour	94594	94741	1438.9	
	10	24 hour	94742	94885	1417.2	
From mow strip	11	control	94886	95066	1618.3	
n=23	12	9 hour	95066	95266	1727.0	
	1	control	30460	31001	3695.0	2027.8
30-10-99	2	3 hour	31001	31534	3655.0	2069.3
	3	24 hour	31534	32127	3955.0	2309.6
Before grazing	4	3 hour	32127	32623	3470.0	1786.5
	5	9 hour	32623	33223	3990.0	2431.5
130CMR+990	6	control	33223	33693	3340.0	1656.5
	7	9 hour	33696	34103	3020.0	1238.7
	8	3 hour	34103	34524	3095.0	1596.3
	9	24 hour	34524	34954	3140.0	1701.1
	10	24 hour	34955	35399	3210.0	1792.8
From mow strip	11	control	35399	35839	3190.0	1571.7
n=26	12	9 hour	35840	36230	2940.0	1213.0
	1	control	5329	5662	1855.8	
4-11-99	2	3 hour	5662	5931	1689.4	
	3	24 hour	5933	6201	1686.8	
After grazing	4	3 hour	6201	6499	1764.8	
	5	9 hour	6503	6787	1728.4	
130CMR+990	6	control	6787	7099	1801.2	
	7	9 hour	7099	7370	1694.6	
	8	3 hour	7370	7622	1645.2	
	9	24 hour	7625	7915	1744.0	
	10	24 hour	7915	8184	1689.4	
	11	control	8184	8476	1749.2	
	12	9 hour	8477	8752	1705.0	
	1	control	72381	72829	2154.8	299.0
27-11-99	2	3 hour	72829	73389	2446.0	756.6
	3	24 hour	73389	73952	2453.8	767.0
Before grazing	4	3 hour	73952	74322	1952.0	187.2
	5	9 hour	74322	74763	2136.6	408.2
130CMR+990	6	control	74763	75165	2035.2	234.0
	7	9 hour	75165	75550	1991.0	296.4
	8	3 hour	75552	75900	1894.8	249.6
	9	24 hour	75900	76338	2128.8	384.8
	10	24 hour	76338	76961	2609.8	920.4
	11	control	76961	77322	1928.6	179.4
	12	9 hour	77322	77798	2227.6	522.6
	1	control	99362	99783	2084.6	
28-11-99	2	3 hour	99783	100237	2170.4	
	3	24 hour	237	688	2162.6	
After grazing	4	3 hour	688	1101	2063.8	
	5	9 hour	1104	1558	2170.4	
130CMR+990	6	control	1558	1999	2136.6	
	7	9 hour	2000	2426	2097.6	
	8	3 hour	2426	2839	2063.8	

	9	24 hour	2839	3251	2061.2	
	10	24 hour	3251	3664	2063.8	
	11	control	3664	4060	2019.6	
	12	9 hour	4065	4482	2074.2	
23-12-99 Before grazing 130CMR+990	1	control	43787	44966	4055.4	1970.8
	2	3 hour	44968	46279	4398.6	2228.2
	3	24 hour	46282	47342	3746.0	1583.4
	4	3 hour	47344	48093	2937.4	873.6
	5	9 hour	48093	49140	3712.2	1541.8
	6	control	49140	50279	3951.4	1814.8
	7	9 hour	50281	51258	3530.2	1432.6
	8	3 hour	51258	52178	3382.0	1318.2
	9	24 hour	52178	53182	3600.4	1539.2
	10	24 hour	53185	54163	3532.8	1469.0
	11	control	54164	55115	3462.6	1443.0
	12	9 hour	55117	55885	2986.8	912.6
24-12-99 After grazing 130CMR+990	1	control	58454	58981	2360.2	
	2	3 hour	58981	59600	2599.4	
	3	24 hour	59600	60207	2568.2	
	4	3 hour	60211	60763	2425.2	
	5	9 hour	60763	61343	2498.0	
	6	control	61343	61891	2414.8	
	7	9 hour	61891	62493	2555.2	
	8	3 hour	62493	63037	2404.4	
	9	24 hour	63038	63611	2479.8	
	10	24 hour	63611	64241	2628.0	
	11	control	64241	64643	2035.2	
	12	9 hour	64644	65176	2373.2	
10-1-00 Before grazing 130CMR+990	1	control	10979	11838	3223.4	863.2
	2	3 hour	11838	12660	3127.2	527.8
	3	24 hour	12660	13363	2817.8	249.6
	4	3 hour	13363	14082	2859.4	434.2
	5	9 hour	14082	14765	2765.8	267.8
	6	control	14765	15522	2958.2	543.4
	7	9 hour	15522	16192	2732.0	176.8
	8	3 hour	16192	16817	2615.0	210.6
	9	24 hour	16817	17545	2882.8	403.0
	10	24 hour	17546	18210	2716.4	88.4
	11	control	18210	18919	2833.4	798.2
	12	9 hour	18919	19831	3361.2	988.0
11-1-00 After grazing 130CMR+990	1	control	71349	71736	1996.2	
	2	3 hour	71736	72187	2162.6	
	3	24 hour	72189	72597	2050.8	
	4	3 hour	72597	72982	1991.0	
	5	9 hour	72982	73402	2082.0	
	6	control	73402	73767	1939.0	
	7	9 hour	73767	74102	1861.0	
	8	3 hour	74102	74410	1790.8	
	9	24 hour	74415	74805	2004.0	
	10	24 hour	74805	75165	1926.0	
	11	control	75165	75490	1835.0	
	12	9 hour	75491	75810	1819.4	
2-2-00 Before grazing 130CMR+990	1	control	27542	28280	2908.8	912.6
	2	3 hour	28280	29107	3140.2	977.6
	3	24 hour	29107	29940	3155.8	1105.0
	4	3 hour	29940	30677	2906.2	915.2
	5	9 hour	30677	31430	2947.8	865.8
	6	control	31430	32184	2950.4	1011.4
	7	9 hour	32186	32863	2750.2	889.2
	8	3 hour	32863	33538	2745.0	954.2
	9	24 hour	33539	34282	2921.8	917.8
	10	24 hour	34282	35021	2911.4	985.4
	11	control	35021	35623	2555.2	720.2
	12	9 hour	35623	36264	2656.6	837.2

XIII.2.2 The 71% GSM Experiment

Date & comment	Plot #	Treatment	Plate readings		Herbage mass (kg DM ha^{-1})	Herbage accumulated between measurements (kg DM ha^{-1})
			Start	End		
2-08-2000 After grazing 125CMR+640	1	9 hour	72436	72841	1652.5	
	2	control	72841	73180	1487.5	
	3	24 hour	73180	73574	1625.0	
	4	3 hour	73574	73932	1535.0	
	5	9 hour	73932	74286	1525.0	
	6	3 hour	74286	74678	1620.0	
	7	24 hour	74678	75032	1525.0	
	8	control	75032	75493	1792.5	
	9	9 hour	75539	75907	1560.0	
	10	24 hour	76015	76385	1565.0	
	11	3 hour	76385	76749	1550.0	
	12	control	76785	77148	1547.5	
29-08-2000 Before treading treatment 125CMR+640	1	9 hour	57302	57909	2157.5	505.0
	2	control	57909	58446	1982.5	495.0
	3	24 hour	58446	59105	2287.5	662.5
	4	3 hour	59105	59672	2057.5	522.5
	5	9 hour	59672	60182	1915.0	390.0
	6	3 hour	60182	60752	2065.0	445.0
	7	24 hour	60752	61302	2015.0	490.0
	8	control	61302	61955	2272.5	480.0
	9	9 hour	61955	62525	2065.0	505.0
	10	24 hour	62525	63042	1932.5	367.5
	11	3 hour	63042	63619	2082.5	532.5
	12	control	63619	64159	1990.0	442.5
30-08-2000 After treading treatment 125CMR+640	1	9 hour	65951	66200	1262.5	
	2	control	66200	66479	1337.5	
	3	24 hour	66479	66664	1102.5	
	4	3 hour	66664	66952	1360.0	
	5	9 hour	66952	67147	1127.5	
	6	3 hour	67147	67431	1350.0	
	7	24 hour	67431	67607	1080.0	
	8	control	67607	67936	1462.5	
	9	9 hour	67959	68221	1295.0	
	10	24 hour	68221	68468	1257.5	
	11	3 hour	68468	68887	1687.5	
	12	control	68887	69198	1417.5	
12-09-2000 In-between grazings 125CMR+640	1	9 hour	11882	12217	1477.5	215.0
	2	control	12217	12642	1702.5	365.0
	3	24 hour	12642	12865	1197.5	95.0
	4	3 hour	12865	13266	1642.5	282.5
	5	9 hour	13266	13514	1260.0	132.5
	6	3 hour	13514	13917	1647.5	297.5
	7	24 hour	13917	14136	1187.5	107.5
	8	control	14136	14591	1777.5	315.0
	9	9 hour	14664	14946	1345.0	50.0
	10	24 hour	14946	15197	1267.5	10.0
	11	3 hour	15197	15737	1990.0	302.5
	12	control	15737	16111	1575.0	157.5
5-10-2000 Before grazing 125CMR+640	1	9 hour	70592	71229	2232.5	755.0
	2	control	71229	72164	2977.5	1275.0
	3	24 hour	72165	72727	2045.0	847.5
	4	3 hour	72727	73712	3102.5	1460.0
	5	9 hour	73718	74350	2220.0	960.0
	6	3 hour	74350	75293	2997.5	1350.0
	7	24 hour	75294	75754	1790.0	602.5
	8	control	75754	76833	3337.5	1560.0
	9	9 hour	76833	77543	2415.0	1070.0
	10	24 hour	77549	78134	2102.5	835.0
	11	3 hour	78134	79140	3155.0	1165.0
	12	control	79140	80094	3025.0	1450.0

6-10-2000 After grazing 125CMR+640	1	9 hour	90100	90531	1717.5	
	2	control	90531	90929	1635.0	
	3	24 hour	90929	91293	1550.0	
	4	3 hour	91293	91730	1732.5	
	5	9 hour	91730	92060	1465.0	
	6	3 hour	92060	92422	1545.0	
	7	24 hour	92422	92810	1610.0	
	8	control	92810	93296	1855.0	
	9	9 hour	93296	93691	1627.5	
	10	24 hour	93691	94142	1767.5	
	11	3 hour	94142	94642	1890.0	
	12	control	94642	94994	1520.0	
1-11-2000 Before grazing 130CMR+990	1	9 hour	865	1530	2719.0	1001.5
	2	control	1530	2306	3007.6	1372.6
	3	24 hour	2307	2846	2391.4	841.4
	4	3 hour	2846	3761	3369.0	1636.5
	5	9 hour	3762	4328	2461.6	996.6
	6	3 hour	4335	5077	2919.2	1374.2
	7	24 hour	5077	5566	2261.4	651.4
	8	control	5566	6300	2898.4	1043.4
	9	9 hour	6300	6888	2518.8	891.3
	10	24 hour	6890	7337	2152.2	384.7
	11	3 hour	7337	8282	3447.0	1557.0
	12	control	8285	9035	2940.0	1420.0
5-11-2000 After grazing 130CMR+990	1	9 hour	95177	95603	2097.6	
	2	control	95603	96092	2261.4	
	3	24 hour	96092	96552	2186.0	
	4	3 hour	96552	97037	2251.0	
	5	9 hour	97037	97512	2225.0	
	6	3 hour	97512	98035	2349.8	
	7	24 hour	98035	98487	2165.2	
	8	control	98487	99068	2500.6	
	9	9 hour	99068	99555	2256.2	
	10	24 hour	99555	99985	2108.0	
	11	3 hour	99985	100662	2750.2	
	12	control	662	1138	2227.6	
23-11-2000 Before grazing 130CMR+990	1	9 hour	1393	1866	2219.8	122.2
	2	control	1866	2452	2513.6	252.2
	3	24 hour	2452	2922	2212.0	26.0
	4	3 hour	2922	3553	2630.6	379.6
	5	9 hour	3553	4032	2235.4	10.4
	6	3 hour	4032	4608	2487.6	137.8
	7	24 hour	4610	5070	2186.0	20.8
	8	control	5070	5728	2700.8	200.2
	9	9 hour	5728	6245	2334.2	78.0
	10	24 hour	6245	6714	2209.4	101.4
	11	3 hour	6714	7402	2778.8	28.6
	12	control	7402	7968	2461.6	234.0
24-11-2000 After grazing 130CMR+990	1	9 hour	19894	20300	2045.6	
	2	control	20300	20623	1829.8	
	3	24 hour	20623	20971	1894.8	
	4	3 hour	20971	21358	1996.2	
	5	9 hour	21358	21694	1863.6	
	6	3 hour	21694	22084	2004.0	
	7	24 hour	22084	22452	1946.8	
	8	control	22452	22884	2113.2	
	9	9 hour	22884	23236	1905.2	
	10	24 hour	23236	23592	1915.6	
	11	3 hour	23592	24123	2370.6	
	12	control	24123	24488	1939.0	
9-01-2001 In-between grazings 130CMR+990	1	9 hour	12593	13230	2646.2	600.6
	2	control	13230	13962	2893.2	1063.4
	3	24 hour	13964	14664	2810.0	915.2
	4	3 hour	14664	15438	3002.4	1006.2
	5	9 hour	15439	16179	2914.0	1050.4
	6	3 hour	16179	16987	3090.8	1086.8
	7	24 hour	16989	17729	2914.0	967.2
	8	control	17760	18606	3189.6	1076.4
	9	9 hour	18606	19409	3077.8	1172.6

	10	24 hour	19409	20139	2888.0	972.4
	11	3 hour	20142	21130	3558.8	1188.2
	12	control	21130	21839	2833.4	894.4
	1	9 hour	4051	4561	3163.0	516.8
19-01-2001	2	control	4561	5084	3205.9	312.7
Before grazing	3	24 hour	5084	5624	3262.0	452.0
165CMR+1480	4	3 hour	5629	6278	3621.7	619.3
	5	9 hour	6278	6827	3291.7	377.7
	6	3 hour	6827	7370	3271.9	181.1
	7	24 hour	7372	7899	3219.1	305.1
	8	control	7899	8503	3473.2	283.6
	9	9 hour	8503	9084	3397.3	319.5
	10	24 hour	9084	9582	3123.4	235.4
	11	3 hour	9584	10288	3803.2	244.4
	12	control	10288	10808	3196.0	362.6
	1	9 hour	86694	87064	2701.0	
21-01-2001	2	control	87064	87382	2529.4	
After grazing	3	24 hour	87382	87702	2536.0	
165CMR+1480	4	3 hour	87702	88090	2760.4	
	5	9 hour	88090	88446	2654.8	
	6	3 hour	88446	88850	2813.2	
	7	24 hour	88850	89212	2674.6	
	8	control	89212	89595	2743.9	
	9	9 hour	89595	89948	2644.9	
	10	24 hour	89948	90311	2677.9	
	11	3 hour	90311	90761	2965.0	
	12	control	90761	91081	2536.0	
	1	9 hour	46624	47414	4087.0	1386.0
29-2-2001	2	control	47414	48078	3671.2	1141.8
Before grazing	3	24 hour	48078	48823	3938.5	1402.5
165CMR+1480	4	3 hour	48823	49707	4397.2	1636.8
	5	9 hour	49707	50499	4093.6	1438.8
	6	3 hour	50499	51336	4242.1	1428.9
	7	24 hour	51336	52159	4195.9	1521.3
	8	control	52159	52962	4129.9	1386.0
	9	9 hour	52962	53710	3948.4	1303.5
	10	24 hour	53710	54434	3869.2	1191.3
	11	3 hour	54434	55288	4298.2	1333.2
	12	control	55288	56128	4252.0	1716.0
	1	9 hour	56574	56936	2674.6	
29-2-2001	2	control	56936	57265	2565.7	
After grazing	3	24 hour	57265	57609	2615.2	
165CMR+1480	4	3 hour	57609	57958	2631.7	
	5	9 hour	57958	58288	2569.0	
	6	3 hour	58288	58652	2681.2	
	7	24 hour	58652	58999	2625.1	
	8	control	58999	59438	2928.7	
	9	9 hour	59438	59790	2641.6	
	10	24 hour	59790	60192	2806.6	
	11	3 hour	60192	60727	3245.5	
	12	control	60727	61017	2437.0	
	1	9 hour	20949	22038	5073.7	2399.1
11-04-2001	2	control	22038	23013	4697.5	2131.8
Before grazing	3	24 hour	23013	23919	4469.8	1854.6
165CMR+1480	4	3 hour	23919	25015	5096.8	2465.1
	5	9 hour	25015	26055	4912.0	2343.0
	6	3 hour	26055	27021	4667.8	1986.6
	7	24 hour	27021	27998	4704.1	2079.0
	8	control	27998	28971	4690.9	1762.2
	9	9 hour	28971	29839	4344.4	1702.8
	10	24 hour	29839	30914	5027.5	2220.9
	11	3 hour	30914	31958	4925.2	1679.7
	12	control	31958	33023	4994.5	2557.5

XIII.2.3 The 81% GSM Experiment

Date & comment	Plot #	Treatment	Plate readings Start	End	Herbage mass (kg DM ha^{-1})	Herbage accumulated between measurements (kg DM ha^{-1})
18-06-2001 After grazing 125CMR+640	1	9 hour	16088	16511	1697.5	
	2	control	16511	16962	1767.5	
	3	24 hour	16962	17505	1997.5	
	4	control	17588	18059	1817.5	
	5	24 hour	18059	18562	1897.5	
	6	9 hour	18562	19047	1852.5	
	7	3 hour	19047	19522	1827.5	
	8	control	19522	20031	1912.5	
	9	9 hour	20031	20509	1835.0	
	10	3 hour	20509	21001	1870.0	
	11	24 hour	21001	21352	1517.5	
	12	3 hour	21352	21757	1652.5	
6-08-2001 Before treading treatment 125CMR+640	1	9 hour	22366	22851	1852.5	155.0
	2	control	22851	23472	2192.5	425.0
	3	24 hour	23518	24193	2327.5	330.0
	4	control	24193	24882	2362.5	545.0
	5	24 hour	24882	25478	2130.0	232.5
	6	9 hour	25478	26093	2177.5	325.0
	7	3 hour	26093	26734	2242.5	415.0
	8	control	26734	27386	2270.0	357.5
	9	9 hour	27386	28102	2430.0	595.0
	10	3 hour	28102	28770	2310.0	440.0
	11	24 hour	28770	29307	1982.5	465.0
	12	3 hour	29307	29762	1777.5	125.0
8-08-2001 After treading treatment 125CMR+640	1	9 hour	29784	29942	1035.0	
	2	control	29942	30231	1362.5	
	3	24 hour	30231	30306	827.5	
	4	control	30306	30598	1370.0	
	5	24 hour	30598	30735	982.5	
	6	9 hour	30735	30966	1217.5	
	7	3 hour	30966	31342	1580.0	
	8	control	31342	31647	1402.5	
	9	9 hour	31647	31977	1465.0	
	10	3 hour	32017	32408	1618.0	
	11	24 hour	32408	32535	957.5	
	12	3 hour	32535	32813	1335.0	
13-08-2001 In-between grazings 125CMR+640	1	9 hour	33231	33477	1255.0	220.0
	2	control	33477	33785	1410.0	47.5
	3	24 hour	33785	33979	1125.0	297.5
	4	control	33979	34384	1652.5	282.5
	5	24 hour	34384	34600	1180.0	197.5
	6	9 hour	34600	34854	1275.0	57.5
	7	3 hour	34854	35278	1700.0	120.0
	8	control	35278	35690	1670.0	267.5
	9	9 hour	35690	36057	1557.5	92.5
	10	3 hour	36057	36474	1682.5	64.5
	11	24 hour	36474	36690	1180.0	222.5
	12	3 hour	36690	37000	1415.0	80.0
28-08-2001 In-between grazings 125CMR+640	1	9 hour	37187	37519	1470.0	215.0
	2	control	37519	37996	1832.5	422.5
	3	24 hour	37996	38305	1412.5	287.5
	4	control	38305	38850	2002.5	350.0
	5	24 hour	38850	39184	1475.0	295.0
	6	9 hour	39184	39551	1557.5	282.5
	7	3 hour	39551	40173	2195.0	495.0
	8	control	40173	40736	2047.5	377.5
	9	9 hour	40736	41143	1657.5	100.0
	10	3 hour	41143	41678	1977.5	295.0
	11	24 hour	41678	41918	1240.0	60.0
	12	3 hour	41918	42363	1752.5	337.5

17-09-2001 Before grazing 125CMR+640	1	9 hour	49590	50152	2045.0	575.0
	2	control	50152	51055	2897.5	1065.0
	3	24 hour	51055	51379	1450.0	37.5
	4	control	51379	52287	2910.0	907.5
	5	24 hour	52287	52781	1875.0	400.0
	6	9 hour	52781	53467	2355.0	797.5
	7	3 hour	53467	54446	3087.5	892.5
	8	control	54446	55540	3375.0	1327.5
	9	9 hour	55540	56422	2845.0	1187.5
	10	3 hour	56422	57311	2862.5	885.0
	11	24 hour	57311	57628	1432.5	192.5
	12	3 hour	57628	58464	2730.0	977.5
19-09-2001 After grazing 125CMR+640	1	9 hour	59154	59498	1500.0	
	2	control	59498	59864	1555.0	
	3	24 hour	59864	60155	1367.5	
	4	control	60155	60570	1677.5	
	5	24 hour	60574	60917	1497.5	
	6	9 hour	60917	61302	1602.5	
	7	3 hour	61302	61828	1955.0	
	8	control	61828	62289	1792.5	
	9	9 hour	62289	62741	1770.0	
	10	3 hour	62741	63165	1700.0	
	11	24 hour	63165	63529	1550.0	
	12	3 hour	63529	63939	1665.0	
15-10-2001 Before grazing 130CMR+990	1	9 hour	70947	71612	2719.0	1219.0
	2	control	71612	72508	3319.6	1764.6
	3	24 hour	72508	73063	2433.0	1065.5
	4	control	73063	74042	3535.4	1857.9
	5	24 hour	74042	74593	2422.6	925.1
	6	9 hour	74593	75405	3101.2	1498.7
	7	3 hour	75405	76582	4050.2	2095.2
	8	control	76582	77725	3961.8	2169.3
	9	9 hour	77725	78621	3319.6	1549.6
	10	3 hour	78621	79622	3592.6	1892.6
	11	24 hour	79622	80152	2368.0	818.0
	12	3 hour	80152	81064	3361.2	1696.2
17-10-2001 After grazing 130CMR+990	1	9 hour	81068	81476	2050.8	
	2	control	81476	81815	1871.4	
	3	24 hour	81815	82255	2134.0	
	4	control	82791	83173	1983.2	
	5	24 hour	83173	83642	2209.4	
	6	9 hour	83642	84171	2365.4	
	7	3 hour	84171	84800	2625.4	
	8	control	84800	85362	2451.2	
	9	9 hour	85362	85890	2362.8	
	10	3 hour	85890	86365	2225.0	
	11	24 hour	86365	86851	2253.6	
	12	3 hour	86851	87249	2024.8	
5-11-2001 Before grazing 130CMR+990	1	9 hour	95845	96572	2880.2	829.4
	2	control	96572	97459	3296.2	1424.8
	3	24 hour	97459	98024	2459.0	325.0
	4	control	98024	98851	3140.2	1157.0
	5	24 hour	98851	99451	2550.0	340.6
	6	9 hour	99451	100110	2703.4	338.0
	7	3 hour	110	1166	3735.6	1110.2
	8	control	1166	2210	3704.4	1253.2
	9	9 hour	2210	2911	2812.6	449.8
	10	3 hour	2911	3734	3129.8	904.8
	11	24 hour	3734	4370	2643.6	390.0
	12	3 hour	4370	5125	2953.0	928.2
7-11-2001 After grazing 130CMR+990	1	9 hour	8277	8626	1897.4	
	2	control	8626	9009	1985.8	
	3	24 hour	9009	9349	1874.0	
	4	control	9349	9743	2014.4	
	5	24 hour	9743	10427	2768.4	
	6	9 hour	10427	10867	2134.0	
	7	3 hour	10867	11600	2895.8	

	8	control	11600	12195	2537.0	
	9	9 hour	12195	12641	2149.6	
	10	3 hour	12641	13123	2243.2	
	11	24 hour	13123	13576	2167.8	
	12	3 hour	13576	14010	2118.4	
29-11-2001 Before grazing 130CMR+990	1	9 hour	15641	16228	2516.2	618.8
	2	control	16228	16890	2711.2	725.4
	3	24 hour	16898	17454	2435.6	561.6
	4	control	17558	18381	3129.8	1115.4
	5	24 hour	18493	19224	2890.6	122.2
	6	9 hour	19226	19860	2638.4	504.4
	7	3 hour	19860	20835	3525.0	629.2
	8	control	20835	21792	3478.2	941.2
	9	9 hour	21792	22568	3007.6	858.0
	10	3 hour	22568	23328	2966.0	722.8
	11	24 hour	23328	24006	2752.8	585.0
	12	3 hour	24008	24669	2708.6	590.2
4-12-2001 After grazing 130CMR+990	1	9 hour	29816	30235	2079.4	
	2	control	30235	30581	1889.6	
	3	24 hour	30581	31174	2531.8	
	4	control	31174	31592	2076.8	
	5	24 hour	31592	32104	2321.2	
	6	9 hour	32104	32637	2375.8	
	7	3 hour	32637	33347	2836.0	
	8	control	33347	33884	2386.2	
	9	9 hour	33884	34466	2503.2	
	10	3 hour	34466	34955	2261.4	
	11	24 hour	34955	35352	2022.2	
	12	3 hour	35352	35859	2308.2	
17-12-2001 Before grazing 130CMR+990	1	9 hour	40093	40623	2368.0	288.6
	2	control	40623	41082	2183.4	293.8
	3	24 hour	41082	41698	2591.6	59.8
	4	control	41698	42318	2602.0	525.2
	5	24 hour	42319	42952	2635.8	314.6
	6	9 hour	42960	43529	2469.4	93.6
	7	3 hour	43529	44424	3317.0	481.0
	8	control	44424	45178	2950.4	564.2
	9	9 hour	45178	45810	2633.2	130.0
	10	3 hour	45816	46458	2659.2	397.8
	11	24 hour	46549	47043	2274.4	252.2
	12	3 hour	47043	47671	2622.8	314.6
20-12-2001 After grazing 130CMR+990	1	9 hour	35642	35901	1663.4	
	2	control	35901	36212	1798.6	
	3	24 hour	36212	36643	2110.6	
	4	control	36659	37072	2063.8	
	5	24 hour	37072	37494	2087.2	
	6	9 hour	37494	37924	2108.0	
	7	3 hour	37924	38477	2427.8	
	8	control	38477	38919	2139.2	
	9	9 hour	38919	39398	2235.4	
	10	3 hour	39398	39813	2069.0	
	11	24 hour	39813	40181	1946.8	
	12	3 hour	40181	40541	1926.0	
8-01-2002 In-between grazings 130CMR+990	1	9 hour	52991	53410	2079.4	416.0
	2	control	53410	54022	2581.2	782.6
	3	24 hour	54022	54618	2539.6	429.0
	4	control	54618	55207	2521.4	457.6
	5	24 hour	55207	55796	2521.4	434.2
	6	9 hour	55796	56454	2700.8	592.8
	7	3 hour	56454	57290	3163.6	735.8
	8	control	57290	58017	2880.2	741.0
	9	9 hour	58017	58685	2726.8	491.4
	10	3 hour	58685	59264	2495.4	426.4
	11	24 hour	59264	59776	2321.2	374.4
	12	3 hour	59776	60343	2464.2	538.2
	1	9 hour	36668	37518	4285.0	2205.6
17-01-2002	2	control	37518	38409	4420.3	1839.1

Before grazing 165CMR+1480	3	24 hour	38409	39296	4407.1	1867.5
	4	control	39296	40211	4499.5	1978.1
	5	24 hour	40211	41096	4400.5	1879.1
	6	9 hour	41096	41986	4417.0	1716.2
	7	3 hour	41986	43099	5152.9	1989.3
	8	control	43099	43971	4357.6	1477.4
	9	9 hour	43971	44830	4314.7	1587.9
	10	3 hour	44830	45608	4047.4	1552.0
	11	24 hour	45608	46329	3859.3	1538.1
	12	3 hour	46329	47187	4311.4	1847.2
18-01-2002 After grazing 165CMR+1480	1	9 hour	7115	7411	2456.8	
	2	control	7411	7769	2661.4	
	3	24 hour	7769	8212	2941.9	
	4	control	8212	8649	2922.1	
	5	24 hour	8649	9083	2912.2	
	6	9 hour	9083	9527	2945.2	
	7	3 hour	9527	10100	3370.9	
	8	control	10100	10579	3060.7	
	9	9 hour	10579	11027	2958.4	
	10	3 hour	11027	11437	2833.0	
	11	24 hour	11437	11876	2928.7	
	12	3 hour	11876	12309	2908.9	
22-02-2002 Before grazing 165CMR+1480	1	9 hour	4325	4960	3575.5	1118.7
	2	control	4960	5657	3780.1	1118.7
	3	24 hour	5657	6374	3846.1	904.2
	4	control	6374	7196	4192.6	1270.5
	5	24 hour	7197	7918	3859.3	947.1
	6	9 hour	7918	8706	4080.4	1135.2
	7	3 hour	8708	9577	4347.7	976.8
	8	control	9577	10291	3836.2	775.5
	9	9 hour	10292	11019	3879.1	920.7
	10	3 hour	11019	11767	3948.4	1115.4
	11	24 hour	11769	12568	4116.7	1188.0
	12	3 hour	12568	13361	4096.9	1188.0

Appendix XIV

Soil Moisture Content and AgResearch Penetrometer Results

Appendix XIV Soil Moisture Content and AgResearch Penetrometer Results

XIV.1 Experimental Means

Soil Moisture Content and AgResearch Penetrometer at Time of Treading Treatment

Experiment	Gravimetric Soil Moisture ($g\ g^{-1}$)	Volumetric Soil Moisture ($cm^3\ cm^{-3}$)	Degree of Saturation (%)	AgResearch Penetrometer (% ≥2cm depth penetration)
65% GSM	0.65 (0.0106)	0.52 (0.8227)	0.79 (1.444)	39 (3.580)
71% GSM	0.71 (0.0208)	0.51 (1.145)	0.73 (1.831)	40 (3.015)
81% GSM	0.81 (0.0284)	0.60 (2.220)	0.89 (3.506)	82 (7.470)

Note: number in bracket is the standard error.

XIV.2 Individual Results for Soil Moisture Content

Experiment	Treatment	Plot #	Container weight (g)	Container and wet soil (g)	Container and over dry soil (g)	Over dry weight (g)	Gravimetric soil moisture content (g g^{-1})	Volumetric soil moisture (cm^3 cm^{-3})	Degree of saturation (%)[a]
65% GSM	control	1	157.5	1033.0	697.92	540.42	0.62	50.47	77.74
25/6/99	3 hour	2	158.0	979.0	653.98	495.98	0.66	48.59	71.42
	24 hour	3	158.0	1019.0	673.70	515.70	0.67	56.97	89.96
	3 hour	4	158.0	1024.5	687.52	529.52	0.64	50.23	76.13
	9 hour	5	158.0	901.0	608.40	450.40	0.65	53.04	81.85
	control	6	158.0	964.0	638.58	480.58	0.68	53.31	80.69
	9 hour	7	158.5	1017.0	703.30	544.80	0.58	46.62	71.62
	3 hour	8	158.0	955.5	620.44	462.44	0.72	55.55	82.98
	24 hour	9	158.0	1052.0	698.94	540.94	0.65	51.46	77.96
	24 hour	10	158.0	1081.0	722.28	564.28	0.64	51.53	79.20
	control	11	158.0	968.5	651.32	493.32	0.64	50.69	76.78
	9 hour	12	158.0	940.0	621.60	463.60	0.69	53.20	79.88
71% GSM	9 hour	1	158.0	757.5	493.06	335.06	0.79	51.47	71.69
29/8/00	control	2	158.0	800.0	529.15	371.15	0.73	44.17	59.83
	24 hour	3	158.0	733.5	476.54	318.54	0.81	56.17	80.37
	3 hour	4	158.0	751.5	495.70	337.70	0.76	52.65	75.29
	9 hour	5	158.0	768.0	519.97	361.97	0.69	48.30	69.48
	3 hour	6	158.0	864.0	594.76	436.76	0.62	43.90	63.45
	24 hour	7	158.0	747.0	529.16	371.16	0.59	47.74	73.65
	control	8	158.0	807.5	560.73	402.73	0.61	49.44	75.95
	9 hour	9	158.0	723.0	485.66	327.66	0.72	51.83	75.06
	24 hour	10	158.0	819.0	535.23	377.23	0.75	54.73	79.86
	3 hour	11	158.0	738.5	492.11	334.11	0.74	51.28	73.34
	control	12	157.5	898.0	578.87	421.37	0.76	54.74	79.63
81% GSM	9 hour	1	157.62	826.50	536.01	378.39	0.77	55.07	80.06
6/8/01	control	2	158.16	852.92	496.52	338.36	1.05	74.48	107.57
	24 hour	3	158.17	882.32	550.69	392.52	0.84	67.85	104.30
	control	4	158.03	790.56	513.66	355.63	0.78	57.22	84.11
	24 hour	5	158.13	804.32	523.64	365.51	0.77	59.18	89.03
	9 hour	6	157.94	829.06	532.19	374.25	0.79	56.11	81.06
	3 hour	7	158.15	801.12	534.96	376.81	0.71	49.04	70.27
	control	8	158.15	936.74	619.60	461.45	0.69	51.09	75.53
	9 hour	9	157.96	780.48	512.10	354.14	0.76	57.10	84.94
	3 hour	10	158.11	893.98	566.88	408.77	0.80	58.01	84.74
	24 hour	11	158.05	805.42	502.50	344.45	0.88	64.89	95.58
	3 hour	12	158.17	960.60	580.80	422.63	0.90	69.78	105.39

[a] calculated using the pre-treatment mean total porosity (cm^3 cm^{-3}) at the 0-5 cm soil depth for each treatment plot.

XIV.3 Individual Results for AgResearch Penetrometer

Experiment	Treatment	Plot #	Depth penetration (mm)										Mean	Stdev	s.e.	% of readings ≥20 mm
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10				
65% GSM	control	1	0	0	0	5	0	25	10	7	0	0	4.7	8.015	2.534	40
25/6/99	3 hour	2	0	0	0	0	20	0	0	0	0	2	2.2	6.286	1.988	20
	24 hour	3	20	2	0	0	1	3	0	0	0	10	3.6	6.535	2.067	40
	3 hour	4	0	0	0	0	2	0	0	2	0	0	0.4	0.843	0.267	20
	9 hour	5	25	0	15	0	2	0	0	1	12	0	5.5	8.797	2.782	40
	control	6	0	0	2	5	4	3	10	0	0	1	2.5	3.206	1.014	50
	9 hour	7	5	0	0	0	10	3	3	0	5	0	2.6	3.340	1.056	50
	3 hour	8	0	1	1	10	0	1	5	8	0	10	3.6	4.248	1.343	40
	24 hour	9	0	0	5	5	5	0	5	0	20	5	4.5	5.986	1.893	60
	24 hour	10	5	0	0	0	10	3	2.5	0	5	0	2.55	3.337	1.055	50
	control	11	6	3	0	0	0	3	0	0	1	0	1.3	2.058	0.651	30
	9 hour	12	2	0	0	0	0	10	0	3	0	0	1.5	3.171	1.003	30
												Grand mean	2.91			39.17
												Stdev	5.169			12.401
												s.e.	0.472			3.580
71% GSM	9 hour	1	1	3	3	2	0	1	0.5	2	1	1	1.5	1.012	0.320	40
29/8/00	control	2	1	7	2	1	5	3	1	0	0	5	2.5	2.415	0.764	50
	24 hour	3	0.5	0.5	0.5	8	2	2	0.5	0	3	0	1.7	2.429	0.768	40
	3 hour	4	1.5	0	0	1	5	0.5	0	0.5	1	2.5	1.2	1.549	0.490	20
	9 hour	5	1	0	8	2	1	7	1	5	1	1.5	2.8	2.841	0.898	40
	3 hour	6	0.5	0.5	0.5	0.5	3	1	2.5	9	3	0	2.1	2.692	0.851	40
	24 hour	7	2	1	0.5	2.5	0.5	1	4	0	1.5	1.5	1.5	1.165	0.369	30
	control	8	0	1	1	1	1	4	3	3	2	3	1.9	1.287	0.407	50
	9 hour	9	0	2	2	0	2	2.5	6	2	0	1.5	1.8	1.767	0.559	60
	24 hour	10	4	3	1	1	1	1	3	1.5	4	1.5	2.1	1.265	0.400	40
	3 hour	11	0.5	0.5	1	2	2	3	1	2	0	1.5	1.4	0.914	0.289	40
	control	12	4	1	1.5	0	1	6.5	9	1	1	1.5	2.7	2.935	0.928	30
												Grand mean	1.908			40.00
												Stdev	1.963			10.445
												s.e.	0.179			3.015

81% GSM	9 hour	1	2	5	2	11	10	10	8	11	9	12	8.0	3.712	1.174	100
6/8/01	control	2	5	0	1	1	5	0	0	0	0	2	1.4	2.011	0.636	30
	24 hour	3	9	7	10	2	2	5	7	9	11	7	6.9	3.107	0.983	100
	control	4	2	1	4	3	1	0	2	4	3	4	2.4	1.430	0.452	70
	24 hour	5	6	4	4	7	5	8	7	6.5	4	9.5	6.1	1.868	0.591	100
	9 hour	6	3	5	5.5	6	3	1	4	7	6	12	5.3	2.974	0.941	90
	3 hour	7	3	3	3	8	2	3	4.5	9	5	5.5	4.6	2.331	0.737	100
	control	8	4	3	1	5	1	1	0	1	0	1	1.7	1.703	0.539	30
	9 hour	9	0	3	6	7.5	7	5	21	4	2	4	6.0	5.756	1.820	90
	3 hour	10	3	2	5	1	4.5	5	3	3.5	2	2.5	3.2	1.355	0.428	90
	24 hour	11	4	12	13	6.5	7	3	3	6.5	7.5	6	6.9	3.392	1.073	100
	3 hour	12	3	4	4	0	5	10	1	2	8	2	3.9	3.107	0.983	80
												Grand mean	4.683			81.67
												Stdev	3.528			25.879
												s.e.	0.322			7.470

XIV.4 Analyses of Depth Categories for the AgResearch Penetrometer

Experiment	Plot #	Depth categories - % of readings equal or exceeding given value of depth of penetration									
		≥ 10 mm	≥ 20 mm	≥ 30 mm	≥ 40 mm	≥ 50 mm	≥ 60 mm	≥ 70 mm	≥ 80 mm	≥ 90 mm	≥ 100 mm
65% GSM	1	40	40	40	40	40	30	30	20	20	20
	2	20	20	10	10	10	10	10	10	10	10
	3	50	40	30	20	20	20	20	20	20	20
	4	20	20	0	0	0	0	0	0	0	0
	5	50	40	30	30	30	30	30	30	30	30
	6	60	50	40	30	20	10	10	10	10	10
	7	50	50	50	30	30	10	10	10	10	10
	8	70	40	40	40	40	30	30	30	20	20
	9	60	60	60	60	60	10	10	10	10	10
	10	50	50	40	30	30	10	10	10	10	10
	11	40	30	30	10	10	10	0	0	0	0
	12	30	30	20	10	10	10	10	10	10	10
	Mean	45.00	39.17	32.50	25.83	25.00	15.00	14.17	13.33	12.50	12.50
	Stdev	15.667	12.401	16.583	16.765	16.787	10.000	10.836	9.847	8.660	8.660
	s.e.	4.523	3.580	4.787	4.840	4.846	2.887	3.128	2.843	2.500	2.500
	% failure [a]	16.7	16.7	25.0	41.7	50.0	75.0	75.0	83.3	91.7	91.7
	% success [b]	83.3	83.3	75.0	58.3	50.0	25.0	25.0	16.7	8.3	8.3
71% GSM	1	80	40	20	0	0	0	0	0	0	0
	2	80	50	40	30	30	10	10	0	0	0

	3	40	40	20	10	10	10	10	10	0	0
	4	50	20	10	10	10	0	0	0	0	0
	5	90	40	30	30	30	20	20	10	0	0
	6	50	40	30	10	10	10	10	10	10	0
	7	70	30	10	10	0	0	0	0	0	0
	8	90	50	40	10	0	0	0	0	0	0
	9	70	60	10	10	10	10	0	0	0	0
	10	100	40	40	20	0	0	0	0	0	0
	11	70	40	10	0	0	0	0	0	0	0
	12	90	30	30	30	20	20	10	10	10	0
Mean			73.33	40.00	24.17	14.17	10.00	6.67	5.00	3.33	1.67
Stdev			18.749	10.445	12.401	10.836	11.282	7.785	6.742	4.924	3.892
s.e.		5.412	3.015	3.580	3.128	3.257	2.247	1.946	1.421	1.124	na
% failure [a]		0.0	8.3	50.0	75.0	83.3	100.0	100.0	100.0	100.0	100.0
% success [b]		100.0	91.7	50.0	25.0	16.7	0.0	0.0	0.0	0.0	0.0
81% GSM	1	100	100	80	80	80	70	70	70	60	50
	2	50	30	20	20	20	0	0	0	0	0
	3	100	100	80	80	80	70	70	40	40	20
	4	90	70	50	30	0	0	0	0	0	0
	5	100	100	100	100	70	60	40	20	10	0
	6	100	90	90	70	60	40	20	10	10	10
	7	100	100	90	50	40	20	20	20	10	0
	8	80	30	30	20	10	0	0	0	0	0
	9	90	90	80	70	50	40	30	10	10	10
	10	100	90	60	30	20	0	0	0	0	0
	11	100	100	100	80	70	70	40	20	20	20
	12	90	80	60	50	30	20	20	20	10	10
Mean		91.67	81.67	70.00	56.67	44.17	32.50	25.83	17.50	14.17	10.00
Stdev		14.668	25.879	26.285	27.080	28.110	29.580	25.391	20.505	18.320	14.771
s.e.		4.234	7.470	7.588	7.817	8.115	8.539	7.330	5.919	5.288	4.264
% failure [a]		0.0	0.0	8.3	16.7	33.3	50.0	58.3	83.3	83.3	91.7
% success [b]		100.0	100.0	91.7	83.3	66.7	50.0	41.7	16.7	16.7	8.3

[a] percent failure was the percentage of treatment plots failing to register as susceptible to pugging damage (i.e. <30% of AgR Penetrometer readings exceeding the given depth category).
[b] percent success was the percentage of treatment plots accurately determined as susceptible to pugging damage (>30% of AgR Penetrometer readings exceeding the given depth category).