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# **Root Biomass under Range of Pasture Swards -Implications for Soil Carbon Stocks**

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of the requirements for the degree

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by

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# Abstract

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Soil carbon (C) is the largest terrestrial store of carbon, greater than all other pools combined. Root biomass is recognised as an important contributor to the accumulation of soil C and recent studies have suggested that a higher diversity of plant species with higher root biomass may increase soil C content. Maintenance of soil C stocks is important as losses can contribute to increased greenhouse gas emissions. Furthermore soil C is important for maintaining soil quality. Much of New Zealand agricultural land is under pastoral grazing and is the greatest contributor to national greenhouse gas emissions from land. The potential for storing additional soil C in pasture soils is poorly understood. This study has assessed root biomass and carbon contents of soils under a range of pasture diversities and species composition to determine whether (i) there is greater root biomass under increasing plant diversity, (ii) changes in root properties between diversity treatments are evident and (iii) there is variation in root biomass between seasons.

Soil samples were collected from an existing small plot trial managed by DairyNZ and Landcare Research containing 14 different mixtures of pasture species (three replicates per treatment). From each plot, fifteen soil cores were taken to a depth of 60cm, and bulked by 10cm depth increments. Root characteristics were determined after removing soil via scanning and analysing with WinRHIZO<sup>®</sup>, and subsequently root biomass determined following oven drying and weighing. A sub-sample of soil was also taken for C and nitrogen (N) analysis by combustion furnace.

While there were no significant differences in root biomass with individual treatments, plots which had a presence of herb species chicory and plantain, resulted in a lesser root biomass when compared with plots without herb species. This would imply that while the use of herb species is desirable for above-ground production and drought tolerance, they provide limited potential for increasing C input to soil. Root characteristics determined that the use of tall fescue as a base grass resulted in a reduced root length density (RLD, root length per volume of soil to 60 cm), specific root length (SRL) and an increased average diameter compared with ryegrass based pastures. These characteristics promote increased root longevity in soil.



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# Chapter One. Introduction

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## 1.1 Background

Increased concentrations of carbon dioxide (CO<sub>2</sub>) in the atmosphere from anthropogenic sources during the last century pose a significant threat to the earth's climate and natural ecosystems (Adams et al., 1998; Ministry for the Environment, 2013; Paustian et al., 2000; Smith et al., 2008). Because of this trend, it is important to identify approaches to decrease atmospheric CO<sub>2</sub> concentrations and prevent further emissions on a long-term basis. Soil is the largest terrestrial pool of carbon (C), greater than the atmosphere and above-ground biomass combined (Jobbagy & Jackson, 2000; Post & Kwon, 2000). Soil also has potential to sequester additional C, which would reduce atmospheric CO<sub>2</sub> levels (Smith et al., 2008), and many management practices on agricultural land have been proposed to increase soil C content. Smith et al. (2008) established three overarching methods for mitigating greenhouse gas emissions from land uses, broadly defined these were (i) reducing emissions e.g. through the more specific addition of nitrogen fertilisers to reduce nitrous oxide emissions (N<sub>2</sub>O), (ii) enhancing removal of atmospheric CO<sub>2</sub> by increasing C input and stabilisation to soils, and (iii) avoiding (or displacing) emissions through utilisation of crop residues as a source of fuel which decreases burning of fossil fuels. One specific approach suggested to increase soil C was increasing plant diversity in grassland ecosystems, where increased root biomass may lead to increased C inputs and long-term storage of C in soil, (along with co-benefits of enhancing other ecosystem services) (Fornara & Tilman, 2008).

An increase in plant species diversity has been shown to have numerous benefits within grassland ecosystems (Tilman et al., 1997). Several grassland experiments have been conducted over periods up to a decade to determine the effect diversity has on ecosystem stability, nutrient availability and productivity (Cardinale et al., 2007; De Deyn et al., 2011; Sanderson et al., 2007; Tilman et al., 2006). While the majority of these experiments have shown a positive effect of higher diversity, the mechanisms have been debated. It is most widely suggested that this positive

effect is mainly attributable to different niches being accessed by plants with different growth types i.e. C<sub>3</sub> grasses, C<sub>4</sub> grasses, legume or non-legume forbs that can occupy different above-and below-ground niches (Tilman et al., 2006). Consequently, it has been argued that increased diversity itself may be less important than ensuring a variety of different traits of species are present. For example, Fornara and Tilman (2008) found that the joint presence of C<sub>4</sub> grass and legume species resulted in a greater soil C accumulation in both higher and lower diversity plant assemblages. This increase in soil C with increasing diversity has mainly been observed in natural grasslands. However, Polley et al. (2013) suggested that there may be the potential for increased soil C with combinations of C<sub>4</sub> grasses and legumes in planted and grazed pastures.

While increased C inputs are important to further soil C sequestration it is also critical that the soil has the capacity to stabilise added C for long periods of time. Recently, the capacity of New Zealand soils to stabilise more C has been explored (Beare et al., 2014), and revealed that the fine particle fraction (e.g. silt and clay) was an important determinant of a soils capacity to stabilise C (due to their large surface area). However, this is not necessarily the complete story as Percival et al. (2000) found that the clay fraction of a soil had little impact on soil C content and concentration whereas the presence of allophane helps explain much of the variance. Much of New Zealands agricultural land is located on mineral soils with relatively high surface areas and some with high extractable Al, and therefore Beare et al. (2014) suggested there was potential for increasing C stocks in soil.

The agricultural industry has substantial importance around the world and specifically in New Zealand. New Zealand's agricultural industry accounts for around 16% of the country's gross domestic product and over half of their product exported product (New Zealand Ministry of Foreign Affairs & Trade, 2011). As soil underpins agricultural production, establishing the relationship between plant growth traits and soil C accumulation is important for more sustainable agricultural systems long-term. Increasing root biomass as a result of increased species diversity for the potential to sequester additional soil C is an emerging field of interest because of its potential to reduce greenhouse gas emissions as well as improve production and sustainability. Thus far there is limited data on the

amount of root biomass in New Zealand pastures and how biomass might vary with different sward compositions (Dodd et al., 2011; Saggar & Hedley, 2001).

The overarching goal of this research was to determine the root biomass of pasture with different mixes of species and to determine whether sward composition was an important regulator of total root biomass. Identifying sward mixes that increase root biomass and potential C inputs may be an important first step to identifying approaches to increase soil C stocks in New Zealand pastures. Increased C in soil would be beneficial to ecosystem services such as water quality, nutrient retention, a resistance to erosion and reduced atmospheric CO<sub>2</sub> (Schmidt et al., 2011; Tate et al., 2005). Root attributes, such as, surface area and length were also investigated as contact between soil and roots are important for C stabilisation (Jones et al., 2009).

## **1.2 Aims and objectives**

The main objective of this research was to determine whether differences in sward mixes and root morphology increased root biomass. Furthermore the aim was to determine, whether increases were dependent on a specific combination of pasture species or presence of a particular species. Root biomass was determined across 14 treatments at an existing field trial (Scott Farm, DairyNZ) which included various combinations of pasture species for example, ryegrass, tall fescue, clover, plantain, chicory and timothy.

## **1.3 Thesis layout**

Following this introduction the thesis consists of an additional four chapters and appendices.

Chapter 2 reviews literature to date on the importance of C in soils for structural stability and increased production. It also establishes the role of root biomass in stabilising soil C and the potential for increasing C stocks through the use of different pasture species mixes.

## CHAPTER ONE: INTRODUCTION

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Chapter 3 describes the full methods used for sampling an existing small plot pasture diversity trial, laboratory analysis, and statistical analysis undertaken for this research.

Chapter 4 contains the main experimental material for this thesis. This chapter is written in the format of a paper that may be submitted to a journal. Consequently, there is some repetition of the introduction, literature review and methods. It presents the data obtained during the course of the study and discusses the differences in root biomass and root characteristics between various combinations of pasture species.

Chapter 5 contains a summary and conclusions for the study and recommendations for potential future research.

The appendices contain the following information:

- Appendix A: Root biomass raw data from each of the four samplings. This includes individual sample dry matter values and values extrapolated to a per hectare scale.
- Appendix B: Scanning data –including root length density, specific root length, average diameter, surface area and volume.
- Appendix C: Bulk density and moisture content data. These were collected for use in C/N analysis which was not completed in this study due to time and resource constraints.

# Chapter Two. Literature Review

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## 2.1 Introduction

Greenhouse gases (GHG) such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) are increasing in the Earth's atmosphere and are considered to be the main contributors to increased global temperatures (IPCC, 2007). The International Panel on Climate Change (IPCC) predict that global emissions will continue at current or increased rates, resulting in a further warming and ongoing changes in global climate. In 2007, the IPCC attributed the majority of these emissions to anthropogenic sources, specifically fossil fuel, burning and land-use change. An update from the IPCC indicates that anthropogenic GHG emissions have risen more rapidly in the last decade compared with the previous three despite efforts to reduce further emissions (IPCC, 2014). New Zealand contributes a relatively small portion of total global greenhouse gas emissions (0.14%), however, on a per capita basis, in 2010, New Zealand ranked fifth among 40 countries (16.4 t CO<sub>2</sub>-e per person) (IPCC, 2007).

The Kyoto Protocol was an international agreement developed to address global greenhouse gas emissions in an effort to delay climate change. The protocol aimed to reduce emissions of developed countries to 5 percent below 1990 levels. This has now been implemented in New Zealand and altering land use practices in agriculture has been identified as an area which can be improved to reduce net GHG production (Ministry for the Environment, 2013). However, in New Zealand agriculture, CH<sub>4</sub> emissions have increased by 5.7% compared with 1990 levels mainly due to increases in enteric fermentation processes resulting from increased animal stock numbers (Ministry for the Environment, 2013). N<sub>2</sub>O emissions have also risen by 28.8% due to farming intensification and increased nitrogen inputs (5 fold in the last 45 years) (IPCC, 2007; Ministry for the Environment, 2013). While most mitigation research is focused on reducing CH<sub>4</sub> and N<sub>2</sub>O emissions which total almost half the country's GHG emissions, it is important that these mitigation approaches do not adversely affect soil C stocks (Metherell, 2003).

## CHAPTER TWO: LITERATURE REVIEW

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Furthermore, opportunities for storing more CO<sub>2</sub> as soil C in agricultural systems need to be explored (Beare et al., 2014; Paustian et al., 2000).

Agriculture lands occupy approximately 40-50% of the Earth's un-iced land and accounts for around 10-12% of global anthropogenic greenhouse gas emissions. While as a whole agriculture contributes a relatively small amount to global emissions (10-12% of total global anthropogenic emissions of GHG), agriculture is responsible for about 60% of N<sub>2</sub>O and 50% of CH<sub>4</sub> of global emissions which have a much higher global warming potential (IPCC, 2007). Total emissions from agriculture in most developed countries are 10-12%, however, in New Zealand, due to the large percentage of farmed land and the intensity of pastoral systems the GHG contribution is 48% (Pinares-Patino et al., 2009).

**Table 2.1 Summary of New Zealand's greenhouse gas emissions for land use, land-use change and forestry by land-use category in 1990 and 2011. Adapted from Ministry for the Environment (2013).**

<b>Land-use category</b>	<b>1990</b>	<b>2011</b>	<b>Difference</b>	<b>% Change</b>
	<b>Emissions (Gg CO<sub>2</sub>-e)</b>		<b>1990-2011</b>	<b>1990-2011</b>
<b>Forest land</b>	-27717.3	-17741.2	9976.1	36.0
<b>Cropland</b>	568.3	390.8	-177.5	-31.2
<b>Grassland</b>	-1233.1	3753.3	4986.5	404.4
<b>Wetlands</b>	167.3	20.9	-146.4	-87.5
<b>Settlements</b>	97.6	34.70	-62.9	-64.4
<b>Other land</b>	4.5	1.3	-3.2	-70.9

**Note: Negative values indicate a net removal. Columns may not add due to rounding.**

Changes in GHG emissions from 1990 to 2011 in New Zealand indicated that grassland ecosystems have increased GHG emissions by 400% in contrast to other land uses (except forests) which have decreased (Table 2.1). This indicates the importance and potential for managing these systems to reduce GHG emissions.

There is also a need to maintain and increase food security with a growing global population. This puts pressure on agricultural systems to increase production on a per hectare basis but prospects for continued land expansion are constrained

(Robertson, 2010). While this production growth is necessary, there is a very real threat of increased duration, severity and frequency of drought in agricultural lands, associated with anthropogenic impacts and climate change. In New Zealand and Australia, intensification of farming systems has progressed during the last few decades. Intensification of these systems, however, can be limited by nutrient and water availability. The use of water irrigation and nutrient addition (e.g. nitrogen fertilisers) can be used to lift production but can result in degradation of the environment. Recently, a model applied to New Zealand pastoral farming predicted that years 2030 and 2080 will receive harsh drought periods resulting in half the long-term production averages being realised for dairy, sheep and beef systems (Palmer, 2009). This decline in production due to drought is happening globally and is predicted to worsen. Research has been increasingly aimed at reducing vulnerability to global change by increasing food production, food distribution, and economic access to food (Gregory et al., 2005).

One of the other consequences of intensive farming is the alteration of ecosystem C cycling e.g. increased inputs via photosynthesis and increased outputs through soil and plant respiration and product removal. Changes in C storage in soils is dependent on the C balance which consists of i) inputs, e.g. photosynthesis, organic matter accumulation, and sediment re-deposition, and ii) outputs, e.g. ecosystem respiration, product removal, leaching and erosion (Parfitt et al., 2013; Schipper et al., 2010). The management of this balance can result in increased or decreases in profile C storage.

Historically, the method of increasing C stocks in agricultural soils has been through increased return of above ground crop residues to soil and hence a greater emphasis on the contribution of above-ground biomass to soil C. However, a long term residue trial reported that 30 years of residue incorporation did not always alter the C content of the soils (Campbell et al., 1991). It is now accepted that roots are likely a larger contributor of C to soil than above-ground plant material (Schmidt et al., 2011). Rasse et al. (2005) summarised root vs. shoot contribution to soil organic carbon (SOC) datasets and found that the relative contribution of roots to SOC was a factor of 2 higher than shoot contribution.

There has been increasing interest in the use of diverse pastures to both increase production in pastoral systems as well as potential for soil C storage and water use efficiency (Cransberg & McFarlane, 1994; De Deyn et al., 2009; Dodd et al., 2011). There is evidence that increased plant diversity in grasslands can increase root biomass, which is thought to be due to a wider range of root traits exploiting resources within the soil profile (Mueller et al., 2013b). Skinner et al. (2006) found that an increase in diversity from 2 species to 11 there was a 30-62% greater root biomass with a greater proportion of roots deeper in the profile. However, in the 11 species mix lower C levels were present. This is similar to a study in Germany which found that root biomass increased with increasing diversity, however, this was only evident after the trial was four years post-establishment (Ravenek et al., 2014). Root biomass with time may be sequestered into soil C, thus removing CO<sub>2</sub> from the atmosphere, and could also improve several chemical and physical properties of the soil, potentially supporting increased production and stability of pastoral ecosystems.

The objective of this literature review was to:

- a) Overview the importance of C in soils and describe changes in C associated with changes in land use and management, with specific focus on New Zealand pasture-based agriculture.
- b) Explore the effects of root biomass as the largest contributor of C to soil organic matter.
- c) Summarise and discuss existing evidence that diverse pastures of differing mixes may support greater root biomass.

## **2.2 Soil Carbon**

### **2.2.1 Importance of soil carbon**

Soil is the largest pool of terrestrial C, containing more than above-ground biomass and atmospheric C combined. It is both influenced by and influences vegetation growth and plays a major role in natural soil fertility (Condon et al., 2012; Jobbagy & Jackson, 2000; Meersmans et al., 2009; Schmidt et al., 2011). Soil organic matter (SOM) is affected by plant production and is a key controller

of soil fertility and stability. Carbon can either be stabilised in soil onto mineral surfaces or as plant fragments (Jobbagy & Jackson, 2000; Schmidt et al., 2011). In a pastoral context, soil C content is partly dependent on herbage utilisation, root production, litter quality, soil fertility and soil moisture status all of which can be managed intensively in New Zealand (Metherell, 2003). The presence of soil C has many physical and chemical benefits including water retention, high cation exchange capacity, a greater buffering capacity against pH change nutrient retention and numerous others (Sparling et al., 2006).

The persistence of SOM is dependent on chemical and biological interactions, which cycle organic matter and promote its integration into the soil profile (Rasse et al., 2005; Schmidt et al., 2011). All organic C added to soils is originally derived from photosynthesis, then through internal cycling is eventually returned to the atmosphere in the form of carbon dioxide (CO<sub>2</sub>) as an end product of microbial processes. Using elemental and isotopic composition of SOM, Schmidt et al. (2011) reviewed the literature and argued that most of the organic compounds stored in soil were microbial products of originally added plant biomass.

While the presence of organic C in soils has important benefits, it is also necessary to recognise detrimental soil and environmental quality issues can arise when soil is in C deficit. Liu et al. (2006) argue that soil organic C can reduce negative environmental impacts (e.g., nitrogen (N) leaching) and improve soil stability and nutrient availability. A lack of organic C reduces aggregate stability, moisture availability and microbial activity (Schmidt et al., 2011; Six et al., 2000c). Improving soil quality and stability has flow-on effects that influence the filtration of soil contaminants and effect soil and water quality over a larger scale. The absence of adequate soil quality can create a negative feedback loop which further reduces soil organic C and soil quality (Ghani et al., 2010; Sparling et al., 2006). Soil organic C loss does not only affect adjacent land; the lack of C can result in leaching of nutrients into groundwater which is a large problem especially in dairy-grazed pastures and has the potential to threaten water quality (Di & Cameron, 2000). Organic C in soil can bind nutrients for the support of plant production, thus reducing their availability for leaching through the soil

profile. Therefore the absence of organic matter leaves ground water sources vulnerable to contamination.

## **2.3 Factors that control C storage**

A number of factors regulate the amount of C stored in soil including soil edaphic factors (e.g. structure and mineralogy) as well as i) land use e.g. forestry, cropping, pasture, and ii) management practices e.g. plant species, grazing intensity and cultivation extent and frequency.

### **2.3.1 Soil Edaphic Factors**

Soil edaphic factors are the physical characteristics of the soil, e.g. structure and mineralogy, which determine soil drainage and ability to retain nutrients. Soil structure is the shape, size and aggregation development of primary soil particles which mediates many physical and biological processes in soils. Soil structure is important to maintain as it improves infiltration of water and filtration of contaminants, sequestration of C and regulates losses of nitrogen gases and therefore is an important regulator of the environmental footprint of agricultural farming. Mineralogy describes the composition of the primary particles derived from parent material and its subsequent weathering (McLaren & Cameron, 1996; Six et al., 2000b).

Mineralogy is an important determinant of a soil's capacity to sequester C due to how it affects chemical and physical processes within the soil. Typically there have been negative correlations between grain size and organic C content in soils due to the associations between mineral and organic surfaces. These associations are predominantly provided by very small particles (<2  $\mu\text{m}$ ) which constitute the clay fraction (Kögel-Knabner et al., 2008) that strongly bind organic molecules. In this clay fraction, there are a mixture of several chemically distinct colloids, such as phyllosilicates (e.g. halloysite, kaolinite, illite), oxides, hydroxides and short-range order minerals like allophane. Each of these colloids bind organic C in different ways (Kögel-Knabner et al., 2008). In the past, phyllosilicates were considered the best for providing mineral surfaces for organo-mineral associations, however, more recently the total mineral surface has been shown to

be a better predictor for a soil's ability to stabilise organic matter (Kögel-Knabner et al., 2008).

Volcanic soils are characterised as having a high organic content due to the abundance of fine textured non-crystalline minerals such as allophane, providing large surface areas for organo-mineral interactions but is also influenced by its ability to maintain hydration and having a net positive charge which enables interactions with negatively charged SOM (Rasmussen et al., 2006; Torn et al., 1997). These minerals and therefore soils are considered to be metastable and fairly easily disaggregated. With time they dehydrate to form crystalline clays including halloysite and kaolinite which have a lower surface area and therefore a lower affinity for soil organic matter (Six et al., 2000b; Torn et al., 1997). Beare et al. (2014) demonstrated that surface area of New Zealand soils, was of greater importance than other measures using a large dataset from the National Soils Database. When divided into allophanic and non-allophanic Beare et al. showed that allophanic soils have a lower soil organic C saturation deficit than non-allophanic soils. Percival et al. (2000) suggested that this increased C storage in allophanic soil was due to the presence of Al.

Aggregation is the formation of stable aggregates consisting of particulate organic material (POM) derived from plant residues, microbial products root material and exudates, and primary soil particles (Six et al., 2000a). The formation of aggregates is not only important for the protection of soil organic matter (SOM) but it is also known to influence the microbial community structure, regulate water diffusion, regulate nutrient adsorption and desorption and reduce run-off and erosion (Six et al., 2004). The way in which aggregates are formed has been under considerable debate since the mid 1900's along with the influence of land management. The formation of aggregates occurs in two stages, first via the formation of macroaggregates then smaller microaggregates. Macroaggregates occur when plant roots and fungal hyphae hold together mineral soil particles. As roots and hyphae are made of organic matter, they decompose into fragments with time. These fragments, covered 'sticky' mucilages become encased in clay particles, resulting in microaggregates forming within macroaggregates (Six et al.,

2004). The organic C is then stabilised in microaggregates, making aggregate formation key for sequestration of C in soils.

## **2.4 Land use and Management**

Land use and its management are well known to influence soil C stocks, especially with conversion between land uses (Poeplau et al., 2011). Land conversion globally has resulted in losses and gains of C due to the land use change and the process of conversion i.e. removal of trees or tillage events stimulating microbial respiration and emitting large quantities of C (Smith et al., 2010). How these C stocks change is dependent on the nature of the conversion. In a meta-analysis, Poeplau et al. (2011) demonstrated that in general, soil C stocks decline with conversion from native forest to crop (-31.4%), and pasture to crop (-36.1%), however, stocks increase with conversion from crop to forest (+16%) and crop to pasture (+39.8%). These trends were also observed in an analysis by Guo and Gifford (2000) on a smaller dataset. Over 2000 sites analysed by McNeill et al. (2014) showed that on average when compared to a low intensity grassland, seven of the 8 classes of land analysed showed a loss of C. Notably, high-producing grasslands lost 0.216 t C ha<sup>-1</sup>, cropland lost 19.5 t C ha<sup>-1</sup> and wetlands gained 38.9 t C ha<sup>-1</sup>.

In New Zealand land use changes have been more recent on a landscape that was initially low in nutrients. In recent years, intensification required application of phosphorus and N fertilisers for increased production. With the removal of agricultural subsidies in mid-1980, land use change and intensification of farming practices increased immensely. Sheep farming gave way to plantation forests and dairy cattle increased from around 2.96 million in 1980 to 5.32 million by 2002. The long term impacts of this intensification (e.g. increased stocking rates and fertiliser use) and the other associated impacts from intensive pastoral land management are only beginning to be understood (Sparling & Schipper, 2004; Tate et al., 2005). In New Zealand, land conversion has resulted in large changes in soil C. Under indigenous forest and grasslands, soils typically contain 44 to 268 Mg C ha<sup>-1</sup> whereas pastoral agricultural systems contain 70 to 130 Mg C ha<sup>-1</sup>

(Sparling et al., 2006). In New Zealand, the past millennium saw more than 26 million hectares being subjected to land use change, the large majority of this was due to deforestation by Polynesian and subsequently European settlers, contributing to C losses of 3.4 Pg (Tate et al., 2005).

There has been a specific focus on changes in soil C stocks of grazed pastures in New Zealand because of the contribution of agriculture to New Zealand economy (Schipper et al., 2014). This revealed that on average, soil profiles lost C ( $-2.1 \text{ kg C m}^{-2}$ ) compared with historical samplings about 30 years earlier. The data did not show a difference between dairy and sheep/beef land uses. These annual C losses were found to be similar to those of Bellamy *et al.*, (2005) (around  $0.6 \text{ g kg}^{-1} \text{ yr}^{-1}$ ) across over 2000 sites in England and Wales. However, the authors were not in agreement over the mechanism, where Bellamy et al. (2005) attributed the losses to climate driven increases in organic matter mineralisation, Schipper et al. (2007) suggests a more realistic mechanism of the C losses could also include increases in leaching of dissolved organic matter and transport via erosion. A follow up study by Schipper et al. (2014) suggested that much of the observed losses in pastoral soils was dependent on soil type. Allophanic and Gley soils had the greatest losses with no detectable change in soil C for the other soil types. Schipper et al. (2014) suggested that changes in Allophanic soils were due large pools of C and changes in Gley soils were due to drainage of these characteristically poorly drained soils.

Long-term research facilities enable a more intricate understanding of cycling of water and nutrients within an ecosystem. They also provide a dataset which is less affected by extreme weather events and other random influences on the soil. Winchmore, South Island, New Zealand is a sixty year old research farm which explores many different projects including the seasonal irrigation effects on C storage in soils beneath pasture grazed by sheep (Kelliher et al., 2012), response of pasture root C turnover to superphosphate addition (Scott et al., 2012) and others. Kelliher et al. (2012) showed that with flood irrigation (when the soil was at a water deficit of 20%) there was a significant decrease in C storage of the soil compared with that of the un-irrigated land. McDowell and Condron (2012) also

looked at effects of phosphorus (P) addition over a long period at Winchmore and discovered that after an initial rapid accumulation of organic P in the soil, subsequent added P was accumulated as inorganic P. Pasture production closely paralleled the accumulated P, i.e. with increased accumulated P production increased, however, organic C concentrations were no different (Condon et al., 2012; Schipper et al., 2013).

Tillage has been found to indirectly decrease the proportion of C-rich macroaggregates and increase proportions of C-poor microaggregates (Six et al., 2000a). Numerous studies have supported the idea that reduced aggregation occurs in conventional tillage (CT) sites compared with no-tillage (NT) (Paustian et al., 2000). Tillage exposes subsurface soils which are then exposed to wet-dry and freeze-thaw cycles as well as rain impact, increasing aggregate susceptibility to damage (Six et al., 2000c). Tillage also alters the soil conditions such as temperature, moisture and aeration which due to the concentration of microbial biomass in the top 10cm of soil (over 80%), increases SOM decomposition rates (Sparling et al., 2000). Consequently, tilled soils generally have lower C stocks (Poeplau et al., 2011).

## **2.5 Diverse pasture swards**

There is considerable interest in whether soils C stocks under pastures can be increased using new or alternative land management practices (Smith et al., 2008). There are a wide range of management practices of pastures that alter C inputs and losses. Since pastoral agriculture has been developed in New Zealand the focus has been on ryegrass/clover dominated swards but recently there has been increasing interest in the use of more diverse swards (Nobilly et al., 2013). This has largely been driven by a desire for increased pasture production to support greater milk and meat exports. Plant species diversity is a function of both the species richness (the number of species present in a community) and the species evenness (an estimate of the distribution of species in that community) (Sanderson et al., 2004). In New Zealand, there has been increased use of swards containing lucerne, plantain, chicory and tall fescue.

Plant diversity for increasing biomass production is by no means a new concept, Darwin (1859) stated that “It has been experimentally proved, that if a plot of ground be sown with one species of grass, and a similar plot sown with several distinct genera of grasses, a greater number and greater weight of dry herbage can be raised in the latter than in the former case.” There has been much research since on species diversity, primarily in grassland ecology which has shown the positive correlation between species diversity and biomass production (Cardinale et al., 2007; Mueller et al., 2013b; Tilman et al., 2006). However, there is some question as to the applicability of this theory to grazing agriculture where high yields occur in systems with relatively low diversity that rely on high inputs of fertilisers (Sanderson et al., 2007; Sanderson et al., 2004). The effect of biodiversity in grazed pastures was tested using two-, six- and nine-species plots with varying mixes of grasses, legumes and chicory (Sanderson et al., 2007). This experiment was conducted during a dry year (2002) and showed higher production and less weed invasion with the higher diversity plots (six- and nine-species) compared with the low diversity. The authors concluded that the use of higher species diversity can be used as a method for reducing the effects of drought and loss of production via weed invasion. Similar experiments on diverse pasture swards and their effect on increased production have also shown an increase in dry matter production (Skinner et al., 2006).

The positive production effects seen to be caused by diversity have been observed in many studies, however, the mechanisms for such effects are still debated (Cardinale et al., 2007; Tilman et al., 1997). Cardinale et al. (2007) argues that increases in production from diversity results from both a species effect (the presence of a particular species dominating the plot and being the highest producer) and species complementarity (where the presence of a species promotes the increased production of another or partitioning of resources enabling species to coexist). An example of complementarity is the interaction between nitrogen-fixing legumes and other plants. The presence of legumes has shown to improve the production of other plants presumably by increasing overall site nitrogen availability (Loreau & Hector, 2001).

## CHAPTER TWO: LITERATURE REVIEW

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There are also suggestions of wider environmental benefits of diverse pastures including their control of nutrient cycling and retention (Hooper & Vitousek, 1998). However, increased intensification of pastoral systems is often supported by higher inputs of mineral fertilisers that can also lead to greater risk of nutrient losses (Monaghan et al., 2005). A study at Lincoln University examined the N uptake capacities and leaching losses of 13 different individual pasture grasses (Moir et al., 2012). These authors showed that under different N loading rates of dairy cows urine, *Lolium multiflorum* (Italian ryegrass) had higher N uptake compared with traditionally used species such as *L. Perenne* (perennial ryegrass). This increased uptake in N was strongly correlated with increased root biomass. The nutrient efficiencies of individual species can be used in the design of vegetation composition experiments to determine the benefits of specific combinations of plant functional groups i.e. grasses and legumes, and their effects on soil C and N storage (De Deyn et al., 2009).

Table 2.2 Summary of root biomass studies conducted in New Zealand

Reference	Pasture type	MAP (mm)	Location	Landscape type	Method used	Soil depth (m)	Root biomass (kg DM ha <sup>-1</sup> )
<b>Saggar et al. (1997)</b>	Brown top ( <i>Agrostis capillaris</i> ) base –Low fertility grass	1200	Palmerston North	Hill country	Soil coring	0.1	13670
	Ryegrass ( <i>Lolium perenne</i> ) base + legumes –High fertility grass	1200	Palmerston North	Hill country	Soil coring	0.1	17630
	Brown top base + legumes – Medium fertility	1200	Palmerston North	Hill country	Soil coring	0.1	24060
<b>Saggar et al. (1999)</b>	Ryegrass/Clover	1200	Palmerston North	Hill country –low slope	Soil coring	0.1	11330
	Ryegrass/Clover	1200	Palmerston North	Hill country – medium slope	Soil coring	0.1	13310
	Ryegrass/Clover	1200	Palmerston North	Hill country – steep slope	Soil coring	0.1	12210

Table 2.2 *continued*

Reference	Pasture type	MAP (mm)	Location	Landscape type	Method used	Soil depth (m)	Root biomass (kg DM ha <sup>-1</sup> )
<b>Metherell (2003)</b>	Ryegrass/Clover -Dryland	740	Canterbury	Flat	-	-	7700
	Ryegrass/Clover Irrigated (20% soil moisture)	740	Canterbury	Flat	-	-	6000
	Ryegrass/Clover –No fertiliser	740	Canterbury	Flat	-	-	7000
	Ryegrass/Clover – Superphosphate (376 kg/ha/yr)	740	Canterbury	Flat	-	-	5900
<b>Saggar and Hedley (2001)</b>	Ryegrass/Clover	864.5	Palmerston North	Flat	Soil coring	0.1	17050
<b>Dodd and Mackay (2011)</b>	Ryegrass/Clover – Low P	940	Manawatu	-	Soil coring	0.16	1310
	Ryegrass/Clover –High P	940	Manawatu	-	Soil coring	0.16	1380
<b>Dodd et al. (2011)</b>		1210	Manawatu	Hill country	Soil coring	0.075	1125
<b>Scott et al. (2012)</b>	Ryegrass/Clover	741	Canterbury	Flat	Soil coring	0.2	6925
<b>McNally et al. (2014)</b>	Ryegrass/Clover	-	Waikato	Flat	Soil coring	0.3	2672
	Mixed sward	-	Waikato	Flat	Soil coring	0.3	5411

Mueller et al. (2013b) established from a combination of other studies that there are four factors which enhance water and nutrient acquisition in diverse pastures: 1) the presence of N fixing legumes facilitating plant growth, 2) positive feedbacks from plant productivity and nutrient concentrations to soil nutrients, 3) high root biomass and root activity for increasing soil C, and 4) niche differentiation with regard to obtaining resources in the community. The inclusion of species from differing functional groups such as grasses, herbs and legumes, hopes to utilise these different resource pools for increasing pastures resilience to weather events (e.g. drought tolerance) and increase production in grazed systems.

While there is plenty of evidence for the benefits of diverse pastures in natural grassland ecosystems (Cardinale et al., 2007; Sanderson et al., 2004; Tilman et al., 2006), there is far less research looking at intensively managed pastoral systems as in agriculture. There is even less known about root biomass and the influence of different pasture swards on a New Zealand scale (Table 2.2). There is much variation in the data obtained across different swards, with high variation ranging from 1310 to 17000 kg DM ha<sup>-1</sup>. From the summary of the previous work done, we can see that there really is no consensus about what goes on in the “hidden fraction” of biomass production. This leaves great potential for diverse pasture research which could increase production as well as have environmental benefits.

## 2.6 Root biomass –contribution to soil carbon

Root biomass, its turnover and subsequent assimilation to soil C is an important component of the global C budget as well as cycling of nutrients (Eissenstat et al., 2000). There is a large body of research that indicates that plant species diversity and functional trait diversity results in a higher productivity, in part due to a greater root biomass (Cardinale et al., 2007; Mueller et al., 2013a; Sanderson et al., 2004; Tilman et al., 1997). Increased root biomass could also lead to greater soil C sequestration, and thus mitigation of greenhouse gas emissions (Dodd et al., 2011; Mueller et al., 2013b).

Several studies summarised by Rasse et al. (2005), demonstrate the contribution of root biomass to soil C. These studies were divided first by method i.e. whether the roots were grown *in situ*, or a known quantity was added to soil at the beginning of the experiment using litter bags or mixing of plant residues into the soil surface. In all cases, across several species of plant including, maize (*Zea mays*), alfalfa (*Medicago sativa*), Barley (*Hordeum vulgare*), Ryegrass (*Lolium sp*) roots contributed a significantly higher proportion of C to the accumulation of soil C than above-ground biomass (Rasse et al., 2005). This relationship was expressed as a ratio: (root-derived soil C/total C input) / (shoot-derived soil C/total shoot-C input) and ranged from 0.77 to 3.30 i.e. root derived C contributed up to 3.30 times the C from shoot inputs. On average this ratio was 1.29.

Root traits are ways in which a plant's rooting habit adapts to a given environment, without which, plant persistence would not be possible. These functional traits include root length, tissue density, ratio of coarse and fine roots, root placement in the soil and rate of turnover (Craine et al., 2002; Eissenstat et al., 2000). Allocation of C to either fine roots or tap roots is a function of the growth habit of the species (Jackson et al., 1997). Jackson *et al.* (1997) estimated that as much as a third of global annual primary productivity was derived from the turnover of fine root biomass and therefore contributes considerably to soil C. Plants which have a high turnover of fine roots allocate less C to root growth and have a high

above-ground biomass production, whereas plants with low fine root turnover allocate more C to the establishment of roots (Jackson et al., 1997).

### **2.6.1 Root depth and diameter (fine vs. coarse)**

Three main features of root structure determine a plants success in a given environment these being; root size (fine or coarse), root turnover rate and root depth in the soil profile (Eissenstat et al., 2000). Plants adapt to their natural environment both from a resource access perspective as well as competition. The use of diverse pastures may exploits these root traits, to optimise resource use (e.g. water and nutrients) and thus produce a more stable and productive system (Mueller et al., 2013b).

Roots vary in their length and diameter in response to different strategies to explore available soil niches. Rooting depth and root diameter are correlated with an increase in cell wall thickness to account for increases in mechanical pressures (Crush & Nichols, 2010). Generally in dry climates, drought resistance is characterised by plants with deeper roots which enables access to ground water at depth as well as a significant portion of fine roots for the quick uptake of water when a rainfall event occurs (Bell, 2005; Markesteijn & Poorter, 2009; Skinner, 2008). In dry areas, such as Australia, plants adaptations for water acquisition are important both for access to groundwater stores and uptake of rainfall (Murphy & Lodge, 2006). Deep tap-rooted systems have a more concentrated water uptake zone directly adjacent to the taproot compared with plants with fine root (or fibrous) morphology (Doussan et al., 2006).

The differences between tap roots and fibrous root growth habits are easily distinguished. Tap rooting plants have one central root, which is usually of significantly greater diameter (often > 5 mm) compared with all other roots of the plant, whereas for fibrous rooted plants all roots have consistently finer diameters (Tufekcioglu et al., 1999). Fibrous root systems generally have associations with fungal hyphae which greatly increase the area which is accessible to the plant for water and nutrient uptake.

Grass species such as rye grass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*) have fibrous root systems which consist of many branching roots with small diameters (Gentile et al., 2003). This is in contrast to species such as herbs (chicory and plantain) which have a taprooted system (Skinner, 2008). Gentile et al. (2003) characterised the root systems of three forage species; tall fescue, alfalfa (or lucerne) (*Medicago sativa*) and chicory (*Cichorium intybus*). The author used a ratio of root biomass and root count to determine the nature of a species root system. The results showed that tall fescue had a higher total biomass ( $1.7 \text{ kg m}^{-2}$ ) and fibrous nature with fine root diameter. This was in contrast to chicory which had a reduced total biomass ( $1.1 \text{ kg m}^{-2}$ ), much larger diameter (based on the root biomass/root count ratio) and was relatively consistent through the profile (Skinner, 2008).

### **2.6.2 Root turnover**

Root turnover is a critical contributor to soil C stores from a global C budget perspective as well as for nutrient cycling within an ecosystem (Rasse et al., 2005). Root longevity varies greatly between species; it can range from a few weeks to a few years (Eissenstat et al., 2000). Longevity can also vary within species depending on the individuals environment and external factors, such as the presence of root pathogens (Eissenstat et al., 2000). Root longevity also varies depending on root morphology, root order, root diameter and tissue among others (Eissenstat et al., 2000). In longer lived species, such as sugar-maple, roots which were unbranched and less than 0.25 mm in diameter typically had life spans of less than 300 days, whereas roots greater than 0.25 mm had live spans as high as 600 days (Eissenstat et al., 2000). Root length, diameter and tissue density are all positively correlated with root life span i.e. increased C allocated to the size and strength of roots results in longer persistence of the root (Craine et al., 2001). Primarily tissue density was found to be the main contributor to root longevity as opposed to specific root length (Eissenstat et al., 2000). Tissue density also has implications for resistance to mechanical stress i.e. lignification of root tissue preventing damage from pathogens and extreme water stresses or frost (Craine et al., 2001).

In pastoral systems, root turnover has been measured by isotope labelling of  $^{13}\text{C}/^{14}\text{C}$ . The biomass production can be determined from the inverse of the decline in the label present in the root mass (Scott et al., 2012). New Zealand pasture experiments have compared root turnover in irrigated and non-irrigated systems and measured the turnover times of roots to be approximately 1.3 years (Metherell, 2003; Scott et al., 2012). In contrast, Saggar and Hedley (2001) measured turnover values of 90-130 days which they recognised was significantly lower than other studies. An irrigation trial at Winchmore, New Zealand an average of 35% of annual production was allocated to roots (Scott et al., 2012). The fine root turnover is the largest contributor to soil C in pastures; the utilisation of species with differing allocation to fine roots can enable a system which can be resilient to weather events while maintaining adequate above-ground biomass production.

### **2.6.3 Root biomass and soil aggregation**

Roots contribute to the formation of soil aggregates for many reasons (Six et al., 2004). In a physical sense, they have two opposing effects on soil aggregation in both a formative and destructive manner. Root penetration in the soil causes compaction of the adjacent soil by up to 35% compared with the bulk soil, this decreases soil porosity and stimulates microaggregate formation by the re-orientation of clay particles (Six et al., 2004). In contrast, after plant growth, root penetration breaks down macroaggregates, stimulating turnover which is important for the stabilisation of C in the soil. Chemically, roots exude polysaccharide compounds known as mucilage which is used to lubricate movement through soil. As mucilage is a “sticky” C rich compound, this alters the immediate environment adjacent to the root surface and immediately acts as an adhesive for primary soil particles to bind together. This effect is termed rhizodeposition which is broadly defined as the release of organic C from roots and the rhizosphere (Jones et al., 2009). Rhizodeposition therefore includes C inputs from mucilage, root cap and border cell loss, root cells (i.e. cortex and root hairs), gaseous losses and root exudates (Jones et al., 2009). Roots also support mycorrhizae that along with fine roots help stabilise macroaggregates (Graf & Frei, 2013).

## **2.7 Root sampling methods**

Recently, models are being developed to predict the way in which anthropogenic activity is affecting global C cycles, however there are large gaps remaining in these models due to incomplete information on root biomass and turnover (IPCC, 2007). Especially in agricultural ecosystems, root biomass dynamics are largely unknown due to the difficulties of sampling. There are several methods used for sampling of root biomass, these can be either direct or indirect (Vogt et al., 1998). Primarily, root biomass is estimated based on above ground percentage cover, however, in the literature, the way in which this estimation can be calculated is debated (Park et al., 2007; Subedi et al., 2006; Vogt et al., 1998). Problems in estimation also arise from the variable nature of a plant's below-ground C allocation, for example, trees can vary from 4-69% of total plant C allocated to fine root biomass (Vogt et al., 1998). Soil coring and subsequent root washing is a destructive, direct method of sampling root biomass which has been used in a limited fashion due to its time consuming nature and therefore limits the frequency of sampling (Vogt et al., 1998).

As roots are the 'hidden half' of ecosystems, accessing roots has limited our ability to study their dynamics especially whole plant systems (Maeght et al., 2013; Taylor et al., 2014). Often, methods for sampling roots have to be developed with little knowledge of root distribution or characteristics. It should also be recognised that by itself, root biomass does not give information on the impact of roots on biological and chemical cycling.

Broadly, there are four categories by which roots are sampled; i) excavations, soil coring, ingrowth cores, trenches and ii) minirhizotron (Maeght et al., 2013; Majdi, 1996). Manual coring is by far the most popular technique and has been used for several decades (Maeght et al., 2013). Techniques such as minirhizotron and similar imaging methods are a relatively new method and enable repeat measurements without disturbance of the roots (post installation) (Majdi, 1996). Minirhizotron tubes are installed adjacent to a plants root system and take images of the root structure which can be used to obtain quantitative information on root length, density and dynamics without disturbance (Taylor et al., 2014).

### **2.7.1 Soil Coring**

The method employed in this thesis is soil coring, which is the most common direct root biomass sampling technique (Pierret et al., 2005). Soil coring, along with other excavation techniques have been employed for the last five decades with little change in the basic approach of removal of roots from soil through wet sieving (Maeght et al., 2013). Soil coring also provides a method to obtain vertical information of root distribution through the soil profile and once taken, the root samples can be used for further analysis such as C and N content. The only limitations with the technique are its requirement for large numbers of samples and its destructive nature; this limits collection of root information through time.

### **2.7.2 Root washing**

Root washing as a method for extraction of root biomass from soil samples is one which has been used since the 1970's. Lauenroth and Whitman (1970) established a washing procedure which uses several passes through a large (0.5 mm mesh) and small sieve (420  $\mu\text{m}$  mesh) by washing or decanting the roots out of a large bucket. The wide adoption of this technique comes from the optimal trade-off between speed, cost and accuracy as opposed to absolute accuracy and reproducibility (Pierret et al., 2005). While some fine root material may be lost during this process it is still considered to be one of the best methods to date.

## **2.8 Conclusions**

There is considerable interest in finding approaches to increase soil C in agricultural settings to offset greenhouse gas emissions (Smith et al., 2008). Root derived C is considered to be the main contributor to soil C (Rasse et al., 2005). The use of diverse pastures for increasing root biomass in soils has attracted much interest, however quantitatively, little is known about biomass of different pasture swards (Mueller et al., 2013b; Nobilly et al., 2013; Tilman et al., 2006). Even less is known about root morphology or characteristics of a wide range of more commonly used sward mixes that are being increasingly trialled in New Zealand.

It is important to be able to quantify these effects as the results have the potential to change management techniques for increasing soil C stores and mitigating greenhouse gas accumulation.

# Chapter Three. Methodology

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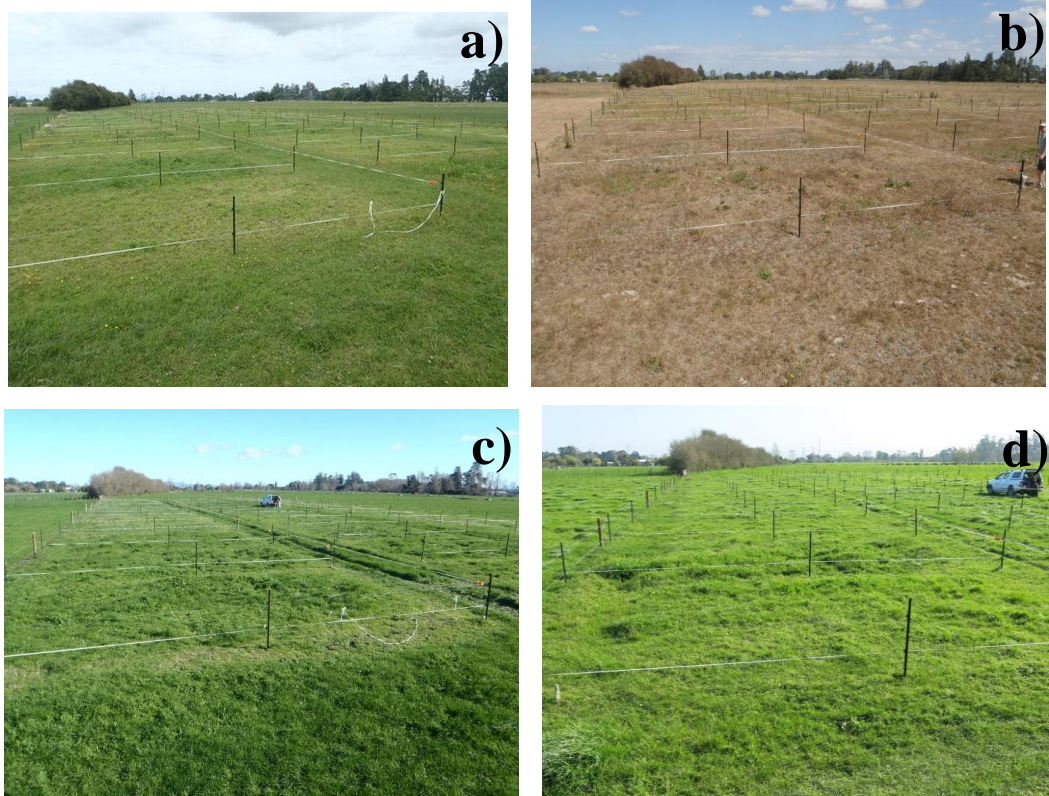
## 3.1 Introduction

The focus of this study was to determine whether different mixes of pasture species will result in greater root biomass. This study took advantage of an established field trial that examined different mixes of pasture species. This trial was designed to determine above- and below-ground productivity of the various mixes. The general approach was to:

- Determine the number of soil cores needed within each combination of plant species replicate to obtain representative soil and root sample from within the plot (Section 3.3.1).
- Using the sampling methodology described in Section 3.3, collect soil cores and analyse these for root biomass.
- Calculate root biomass per hectare for each plot and determine which combination of species had the highest biomass per unit area.
- Using WinRhizo© to determine root characteristics including length, average diameter, specific root length and establish how these affect root input to soil C.

## 3.2 Site

Soil and root sampling was conducted at a small plot trial initiated by DairyNZ and Landcare research on DairyNZ's Scott farm, Newstead, Hamilton (Figure 3.2). At this site above- and below ground traits of diverse pastures are to be determined collectively by the University of Waikato and Landcare Research. The area received a total of 980 mm of rain in 2013 and 1022 mm in 2014, where a drought was evident during the April (autumn) sampling (Figure 3.1). The trial was located on sandy and silt loams, which received an average of 100 kg N ha<sup>-1</sup> year<sup>-1</sup> of nitrogen fertiliser.



**Figure 3.1** Example of sample site at the time of each sampling where; a) December 2013 (summer), b) April 2014 (autumn), c) July 2014 (winter) and d) September 2014 (spring). Photos courtesy of Paul Mudge.



**Figure 3.2** Example of soil coring taking place at DairyNZ's Scott Farm, Newstead.

**Table 3.1 Species composition of 14 treatments applied in small plot trial at Scott Farm.**

Trt no.	Trt name	Abbrev	Species sown							
1	Ryegrass standard	<b>RGST</b>	Ryegrass	White clover						
2	Ryegrass standard + legumes A	<b>RGLA</b>	Ryegrass	White clover	Red clover					
3	Ryegrass standard + legumes B	<b>RGLB</b>	Ryegrass	White clover	Lucerne					
4	Ryegrass standard + herbs	<b>RGHB</b>	Ryegrass	White clover	Plantain	Chicory				
5	Ryegrass standard + grasses	<b>RGGR</b>	Ryegrass	White clover	Prairie grass	Timothy				
6	Ryegrass complex	<b>RGCO</b>	Ryegrass	White clover	Red clover	Lucerne	Plantain	Chicory	Prairie grass	Timothy
7	Tall fescue standard	<b>TFST</b>	Tall fescue	White clover						
8	Tall fescue standard + legumes A	<b>TFLA</b>	Tall fescue	White clover	Red clover					
9	Tall fescue standard + legumes B	<b>TFLB</b>	Tall fescue	White clover	Lucerne					
10	Tall fescue standard + herbs	<b>TFHB</b>	Tall fescue	White clover	Plantain	Chicory				
11	Tall fescue standard + grasses	<b>TFGR</b>	Tall fescue	White clover	Prairie grass	Timothy				
12	Tall fescue complex	<b>TFCO</b>	Tall fescue	White clover	Red clover	Lucerne	Plantain	Chicory	Prairie grass	Timothy
13	Special A	<b>GRLH</b>	White clover	Red clover	Lucerne	Plantain	Chicory	Prairie grass		
14	Special B	<b>PGLU</b>	Lucerne	Prairie grass						

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Species composition for each of the 14 treatments at the time of sowing is outlined in Table 3.1. Changes in above-ground species composition were monitored by staff at Landcare Research, separate to this study. The composition of species at the beginning of the trial had diverged from initial sowing (Table 3.2).



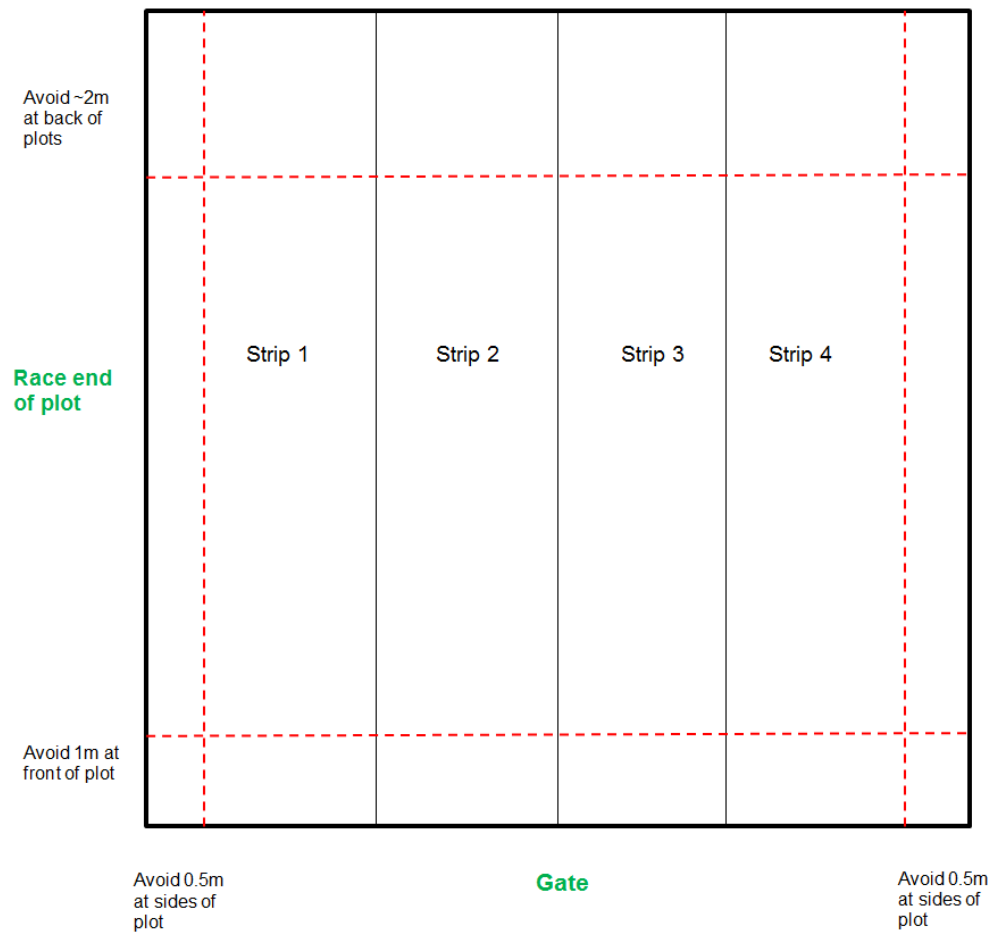
Figure 3.3 Diversity trial plot layout and treatment type at Scott Farm, Ruakura

The trial consisted of 42 plots distributed across three lines (Table 3.1, Figure 3.3). A line consists of one of 14 pasture species mixtures which vary in species richness and composition. These are replicated in random block order across the three lines. This trial has been in operation since March 2010 and has been maintained under conventional rotational grazing management i.e. 3 cows per plot, grazed for approx. two hours, for three years. Each plot is individually grazed approximately 11 times per year.

**Table 3.2 Visual estimate of botanical composition averaged from assessments at 30 cm x 30 cm quadrats at each of the 15 core locations per plot in December 2013. Data are % of total above ground biomass on dry weight basis. A few quadrats were harvested and dried to ‘calibrate’ the visual assessment. Visual assessment was carried out by staff at Landcare Research.**

Treatment	Rye	TF	WC	Chic	Pla	Luc	PG	Tim	RC	OG	Weeds
RGST	70.2	0.0	10.1	0.0	0.1	0.0	1.0	0.0	0.0	0.4	17.2
RGLA	66.3	0.0	13.4	0.0	1.2	0.0	0.0	0.0	0.0	0.3	18.8
RGLB	71.1	0.1	8.2	0.0	0.1	0.8	0.0	0.8	0.2	0.4	17.6
RGHB	61.9	0.1	9.6	4.9	7.6	0.0	0.0	0.0	0.0	0.4	15.4
RGGR	63.3	0.0	22.3	0.0	0.0	0.7	1.1	0.8	0.0	0.2	10.9
RGCO	60.3	0.0	11.5	2.3	8.2	1.2	0.7	2.1	0.2	0.2	13.0
TFST	33.3	30.1	16.4	0.0	0.3	0.0	0.2	0.0	0.0	1.1	18.4
TFLA	35.0	25.8	20.2	0.0	0.1	0.0	0.2	0.0	0.6	4.0	13.5
TFLB	29.6	28.1	18.2	0.0	0.5	3.3	1.4	0.0	0.0	0.1	19.0
TFHB	26.0	32.0	5.2	6.1	4.6	0.0	2.8	0.1	0.0	0.3	22.4
TFGR	23.9	20.3	25.3	0.0	0.9	0.0	3.5	3.8	0.0	0.2	20.3
TFCO	23.0	28.8	10.9	2.2	5.7	3.1	0.8	2.2	0.6	0.6	21.8
GRLH	36.8	0.2	12.3	6.6	7.9	5.5	3.9	8.4	0.7	0.7	16.8
PGLU	41.2	2.3	9.9	0.3	0.9	10.7	8.8	0.9	0.0	2.4	22.4

The sown area of each plot was 9m x 7m with a buffer zone of two metres from the back, 1 metre at the front and 0.5m on either side of the plots which were excluded from the sampling area to avoid edge effects (Figure 3.4). Each plot was divided into four sampling strips, three of which were sampled in this study while, the fourth is reserved for experiments conducted by AgResearch.



**Figure 3.4: Small plot layout of strips indicating included sampling area.**

### 3.3 Soil sampling

Sampling was undertaken every three months, commencing in early December 2013 and finishing September 2014 at the DairyNZ sample site. Each sampling was conducted in two weeks to minimise any effect of precise sampling day on the root biomass obtained.

From each plot, a total of fifteen randomly located soil cores (0.0254 m) were taken to a depth of 0.6m. The number of cores needed was determined in Section 3.3.1. Randomisation was achieved by producing 5 sets of random numbers which were plotted as x and y coordinates along the three sampled strips in a stratified random design, these were pegged and represent the sites from which the soil cores were taken. These cores were laid out on a board (Figure 3.5) and cut into

six 0.1m depth increments. Increments were then bulked by depth. Soil samples were transported to the laboratory and then refrigerated at 4°C until they could be processed.



**Figure 3.5** Example of 15 cores from plot 18 being laid out on a coring board before being divided into 10cm increments.

During sampling, photos were taken of the individual plots as well as the collected cores. These photos could be used to explain differences seen in the data, for example the differences seen with season are explained by the visual differences in moisture content and pasture production.

### **3.3.1 Number of cores**

The number of cores needed to capture spatial variability of roots was estimated using a power analysis conducted by Sam McNally (a doctoral candidate at the University of Waikato) on root data collected from an adjacent diverse pasture trial. This analysis determined that for a 0.05m diameter corer 12 cores was appropriate to take. Due to the smaller diameter of the corer used in this study (0.0254m), it was decided that 15 cores would adequately represent the small plots as any more would become impractical with collection and processing. The

smaller diameter corer was used in this study because samples were taken to 0.6 m compared with 0.3 m in the study of McNally, taking 0.05 m diameter cores to 0.6m would be physically too difficult for manual labour and would have caused too much disturbance of the small plots (i.e. could have affected yield measurements).

### **3.4 Laboratory analysis**

Soil cores were analysed for physical properties and root biomass and properties. Soil physical properties were only measured on the first sampling (December 2013).

Small pottles of soil from the first sampling were retained (approximately 45g of field moist soil), after sieving through 2mm screen and air-dried for archiving.

#### **3.4.1 Moisture factor**

To correct the field wet soil samples for use in dry bulk density, moisture factors were determined. Approximately 5 g of field wet soil was measured into a pre-weighed aluminium tray, which was then dried at 105°C for 24 hours then cooled in a desiccator to a constant weight, subsequently the samples were re-weighed. The moisture factor was determined using equation 1.

$$MF = \frac{M_t - M_c}{M_{t2} - M_c} \quad (\text{Eqn 1.})$$

Where  $M_t$  was the mass of the field wet soil plus the aluminium tray,  $M_c$  was the mass of the aluminium tray and  $M_{t2}$  was the mass of the oven-dried soil plus the aluminium tray.

This analysis was conducted to obtain data which were to be used for C/N analysis, however, due to time and resource constraints the C/N analysis could not be completed.

### 3.4.2 Soil dry bulk density

Bulk density (BD) was estimated from the bulked soil samples obtained in the field. While these cores were not carved in and so some compaction may have occurred, bulk densities here are the mass of soil to a specified depth (0-100mm). The volume of soil was calculated from the diameter of the corer (23mm) and the depth of the sample being 100mm as each 600mm core was divided into six equal depth increments, resulting in a volume of 41.55cm<sup>3</sup>. The bulk density was calculated using equation 2.

$$BD = \frac{M_s}{V_s} \quad (\text{Eqn 2.})$$

Where  $M_s$  was the oven dried soil mass and  $V_s$  was the soil volume of the 100mm increment.

This analysis was conducted to obtain data which were to be used for C/N analysis, however, due to time and resource constraints the C/N analysis could not be completed. The complete data for the December sampling is presented in Appendix C.

### 3.4.3 Root biomass

Root biomass was determined by washing soil cores and retaining the roots on a sieve. First, the soil was washed through a 2mm sieve where the large roots and stones were retained. The water-soil slurry then passed through a 250µm sieve to capture remaining fine root material. This root material was then rewashed and any non-root debris removed before being poured through the 250µm again. This final root sample was then removed from the sieve, excess water squeezed out and placed in an envelope and refrigerated at 4°C until scanning (see Section 3.4.4). Once scanning was complete root samples were dried at 60°C for 48h and weighed to obtain dry weight of root material for each depth.

#### **3.4.4 Root scanning**

Six of the 14 treatments were scanned for root characteristics, including Ryegrass standard (RGST), ryegrass complex (RGCO), ryegrass herb (RGHB), tall fescue standard (TFST), tall fescue complex (TFCO) and tall fescue herb (TFHB). Each of these treatments had three replicate plots, totalling 18 plots scanned. These treatments were chosen based on their performance in previous studies on above-ground biomass and time constraints meant that all treatments were unable to be scanned.

Analysis was completed using the programme WinRHIZO which measured many parameters from root images obtained by an EPSOM computer scanner. The resulting output gave many different measures; however this study was constrained to three properties; root length, average diameter, and specific root length. Root samples were teased out into a tray of water on the scanner, ensuring the crossover of individual root strands was minimal. In the case of the 0-10cm samples, the root material was split into several separate scans to ensure that the density was reduced in order to obtain a more accurate scan. All debris (non-root material) was removed from the samples when scanning sampling two, three and four, to ensure that the scanned and subsequently weighed samples were a measure of true root mass.

Specific root properties such as specific root density, specific root length and specific surface area were calculated by dividing by the root dry matter, making the properties relative to the root biomass.

### **3.5 Data analysis**

During scanning the removal of debris from samples was conducted in samplings two, three and four, and not the first sampling. This resulted in a lower apparent biomass for the latter three samplings. To make root dry matter comparable to the first season and also the samples which were unscanned, a correction was made.

The amount of non-root material was calculated as a percentage of total sample mass from samplings two, three and four within each plot and depth increment.

These percentages were then averaged across the samplings for individual samples then this average percent was applied to the total root mass from the first sampling. This method gives the best estimate of the proportion of non-root debris in the first sampling and enables direct comparison between the four samplings.

### **3.5.1 Statistical analysis**

Data were analysed using a linear mixed effects model, using all possible combinations of depth, season, dominant grass species and presence or absence of herbs as fixed effects and plot identity as a random effect. This approach was chosen because of the presence of non-independence between data taken from the same plot in different seasons and at different depths.

Mixed effects models were fitted in the statistical programme R (R Core Team, Vienna, Austria) using the lmer function in the lme4 package. We used maximum likelihood tests to assess whether or not each of the fixed effects (and interactions between them) significantly increased model goodness of fit. We also used the Akaike information criterion (AIC) to identify the model giving the most parsimonious fit to the data. For the model with the lowest AIC values, we also applied a modified Tukey test to test for significant differences between treatment combinations using the lsmeans function from package lsmeans in R. Data are reported as averages  $\pm$  standard error.



# Chapter Four. Root biomass under a Range of Pasture Swards – implications for soil carbon stocks

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## 4.1 Abstract

There is increasing interest in the use of mixed sward pastures in New Zealand agriculture. While use of additional species is predominantly intended for increased above-ground production and greater resilience to drought conditions, there is scope for their use for increasing soil carbon (C). Root biomass is recognised as an important contributor to the accumulation of soil C and recent studies have suggested that a higher diversity of plant species with greater root biomass may increase soil C content.

To test the influence of different combinations of pasture species on root biomass, soil samples were collected seasonally to a depth of 0.6 m from an existing small plot trial managed by DairyNZ and Landcare Research, Hamilton. The trial consisted of 14 pasture mixes containing different combinations of species. Roots were washed to remove soil and characteristics (e.g. length, diameter) determined via scanning and analysing with WinRHIZO© software. Subsequently root biomass was determined by drying and weighing. The average total root biomass across treatments was  $3263 \pm 113 \text{ kg ha}^{-1}$ , and did not differ significantly between treatments. While there were no significant differences in root biomass between treatments and base grass, treatments with herbs had a lower root biomass ( $2657 \pm 120 \text{ kg DM ha}^{-1}$ ) than treatments without herbs ( $3601 \pm 154 \text{ kg DM ha}^{-1}$ ,  $P < 0.001$ ). This lower root biomass was in contrast to McNally et al. (2014), who found that mixed sward pastures had a greater biomass when compared to standard ryegrass/clover pastures. The difference between these two studies was thought to be due to greater lucerne abundance in the study of McNally et al. Maximum (summer) and minimum (winter) biomass values obtained in the study,

were used to estimate the contribution of root biomass and C to soil that might be stabilised as soil C.

Scanning a subset of treatments for root characteristics showed that plots with tall fescue as a base grass had lower total root length and specific root length (SRL) and an increased average diameter compared with ryegrass based plots. Root diameter and SRL are positively correlated with root longevity suggesting that tall fescue could potentially increase residence times of root biomass in soil. However, further work would need to be completed to more fully understand this effect and the potential implications for soil C. Differences between treatments were not all that clear, but differences between base grass, season and presence of herbs were observed.

## **4.2 Introduction**

Agriculture in New Zealand is of great importance providing around 16% of the country's gross domestic product (New Zealand Ministry of Foreign Affairs & Trade, 2011). While agriculture is a large contributor to New Zealand economy, it also contributes a large proportion of the countries' greenhouse gas emissions. With increased concentrations of CO<sub>2</sub> in the atmosphere, it is important to identify approaches to slow or even halt increases in greenhouse gases. Soil is the largest terrestrial pool of C and also has potential to store much more (Jobbagy & Jackson, 2000; Post & Kwon, 2000). Smith et al. (2008) established that there are three main methods for mitigating greenhouse gas emissions, these were; i) reducing emissions of nitrous oxide and CO<sub>2</sub> through more careful addition of nitrogen fertilisers, ii) enhancing removal of CO<sub>2</sub> e.g. by increasing C input to soil through root inputs and iii) displacing emissions through incorporating crop residues in to soil or decreasing fossil fuel burning. One specific method suggested for increasing soil C was the use of diverse pastures that increased root biomass inputs increasing C inputs and storage in soil (Fornara & Tilman, 2008).

Plant species diversity has been shown to have several benefits within grassland ecosystems (Tilman et al., 1997). Grassland experiments conducted over decadal periods determined the effect diversity has on ecosystem stability, nutrient

availability and productivity (Cardinale et al., 2007; Tilman et al., 2006). It is most widely suggested that a positive relationship between diversity and productivity is attributable to different niches being accessed by plants with different growth types i.e. C3 grasses, C4 grasses, legume or non-legume forbs occupy somewhat different niches (Tilman et al., 2006). It has been argued that increased diversity itself may be less important than ensuring a variety of different traits of species present (Tilman et al., 1997). Fornara and Tilman (2008) found that the joint presence of C4 grass and legume species resulted in a greater soil C accumulation in both higher and lower diversity plant assemblages. This increase in soil C with increasing diversity has mainly been observed in natural grasslands. However, Polley et al. (2013) suggested that there may be the potential for increased soil C with combinations of C4 grasses and legumes in planted and grazed pastures.

Root biomass is recognised as the largest contributor to soil C (Rasse et al., 2005), therefore, increasing root biomass and turnover has the potential for increasing the amount of C stored in soil. To date, there is limited data on the amount of root biomass in New Zealand pastures and how biomass might vary with different sward compositions (Dodd et al., 2011; Saggar & Hedley, 2001). This study aims to determine whether root biomass differs between 14 pasture mixes containing different combinations of species (9 species in total). Estimates of soil C inputs are also calculated from differences in root biomass between seasons. Rooting characteristics (e.g. length and diameter) were determined on a subset of treatments to provide information on the turnover of biomass in the soil.

### **4.3 Methods**

Root sampling was conducted during 2014 on an existing diverse pasture small plot trial at DairyNZ's Scott farm, Newstead, New Zealand. The trial was established in March 2010 and has had continuous above-ground measurements made every grazing by DairyNZ, Hamilton. In this study, root biomass, root traits and above-ground traits were measured seasonally to determine differences in treatments across the year. Full methods are given in Chapter 3, but a condensed version is provided here for completeness.

**Table 4.1 Species composition of 14 treatments applied in small plot trial at Scott Farm.**

Trt no.	Trt name	Abbrev	Species sown							
1	Ryegrass standard	<b>RGST</b>	Ryegrass	White clover						
2	Ryegrass standard + legumes A	<b>RGLA</b>	Ryegrass	White clover	Red clover					
3	Ryegrass standard + legumes B	<b>RGLB</b>	Ryegrass	White clover	Lucerne					
4	Ryegrass standard + herbs	<b>RGHB</b>	Ryegrass	White clover	Plantain	Chicory				
5	Ryegrass standard + grasses	<b>RGGR</b>	Ryegrass	White clover	Prairie grass	Timothy				
6	Ryegrass complex	<b>RGCO</b>	Ryegrass	White clover	Red clover	Lucerne	Plantain	Chicory	Prairie grass	Timothy
7	Tall fescue standard	<b>TFST</b>	Tall fescue	White clover						
8	Tall fescue standard + legumes A	<b>TFLA</b>	Tall fescue	White clover	Red clover					
9	Tall fescue standard + legumes B	<b>TFLB</b>	Tall fescue	White clover	Lucerne					
10	Tall fescue standard + herbs	<b>TFHB</b>	Tall fescue	White clover	Plantain	Chicory				
11	Tall fescue standard + grasses	<b>TFGR</b>	Tall fescue	White clover	Prairie grass	Timothy				
12	Tall fescue complex	<b>TFCO</b>	Tall fescue	White clover	Red clover	Lucerne	Plantain	Chicory	Prairie grass	Timothy
13	Special A	<b>GRLH</b>	White clover	Red clover	Lucerne	Plantain	Chicory	Prairie grass		
14	Special B	<b>PGLU</b>	Lucerne	Prairie grass						

The small plot trial consisted of a total of 42 plots (9 x 7 m) with 14 different pasture species mixes with 3 replicates of each combination in a random block design (Table 4.1). Above-ground abundance was monitored by staff at Landcare Research separate from the current study. Visual assessments of quadrats determined that the species composition had diverged since sowing (Table 3.2). Within the 9 x 7 m area, a buffering zone of 2 m at the back of the plot, 0.5 m either side and 1 m at the front were avoided to eliminate an edge effect in the species composition. The trial received an average of 100 kg N ha<sup>-1</sup> year<sup>-1</sup> of nitrogen fertiliser. Species included were; ryegrass, tall fescue, white clover, red clover, lucerne, plantain, chicory, prairie grass, timothy. The treatments had one of three base grasses (ryegrass, tall fescue or prairie grass) then had a variety of different species additions (Appendix A). The soil at the trial was mapped as the Matangi Silt Loam, and classified as a Typic Orthic Gley Soil (Stiles, 1998). The A horizon had a consistent loamy silt texture, while the subsoil was more variable, with differing proportions of silt and sand.

#### *Soil Sampling*

Soil samplings for root biomass and characteristics were conducted seasonally in December 2013, March, July and September 2014. At each sampling, fifteen soil cores (0.0254 m diameter) were taken at random locations within each plot to a depth of 0.6 m. The fifteen cores from each plot were divided into six 10 cm increments, bulked by depth, and subsequently processed individually. Bulked samples were stored in plastic bags at 4°C until processed (see below).

#### *Root biomass and scanning*

Roots were separated from the soil through multiple wet sieves using 2 mm and 250 µm sieves (Blouin et al., 2007). The collected root samples were dried at 60°C to constant weight, weighed and stored dry, in plastic bags for future analysis. It is recognised that very small roots may pass through the 250 µm sieve but this is estimated to be less than 5%.

Scanning was conducted on a subset (six) of treatments. These included, ryegrass standard (RGST), ryegrass complex (RGCO), ryegrass herbs (RGHB), tall fescue

## CHAPTER FOUR: ROOT BIOMASS UNDER A RANGE OF PASTURE SWARDS

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standard (TFST), tall fescue complex (TFCO) and tall fescue herbs (TFHB). Each individual sample was scanned using an Epson scanner and analysed for root length and average diameter using WinRHIZO software (Regent Instruments Inc., Montreal, Canada).

### **4.3.1 Statistical analysis**

Data were analysed using a linear mixed effects model in R, using all possible combinations of depth, season, dominant grass species and presence or absence of herbs as fixed effects and plot identity as a random effect. This approach was chosen because of the presence of non-independence between data taken from the same plot in different seasons and at different depths. Data are reported as averages  $\pm$  standard error of the mean.

Data are generally presented in box plots where the median is the central line within a box. The upper and lower bounds of the box are the upper (25<sup>th</sup> percentile) and lower (75<sup>th</sup> percentile) quartiles of the dataset, whiskers are the maximum and minimum values and open circles are outliers.

## 4.4 Results

### 4.4.1 Root biomass

The mean total root biomass reported as dry matter (DM) across the 14 treatments (42 plots, 4 seasons = n of 168) was  $3264 \pm 113$  kg DM ha<sup>-1</sup> to a depth of 60 cm (Figure 4.1). Root DM from individual plots ranged between 800 and 8000 kg ha<sup>-1</sup>. There are many interactions between different measured characteristics such as depth, base grass, presence of herbs and season which have been explored further below. The linear mixed effects model which showed the most parsimonious fit to the root biomass data was the interaction between herb presence season and depth ( $P < 0.0001$ ); these parameters will be explored below.

Where treatments are significantly different ( $P < 0.05$ ), different letters are given for each measure.

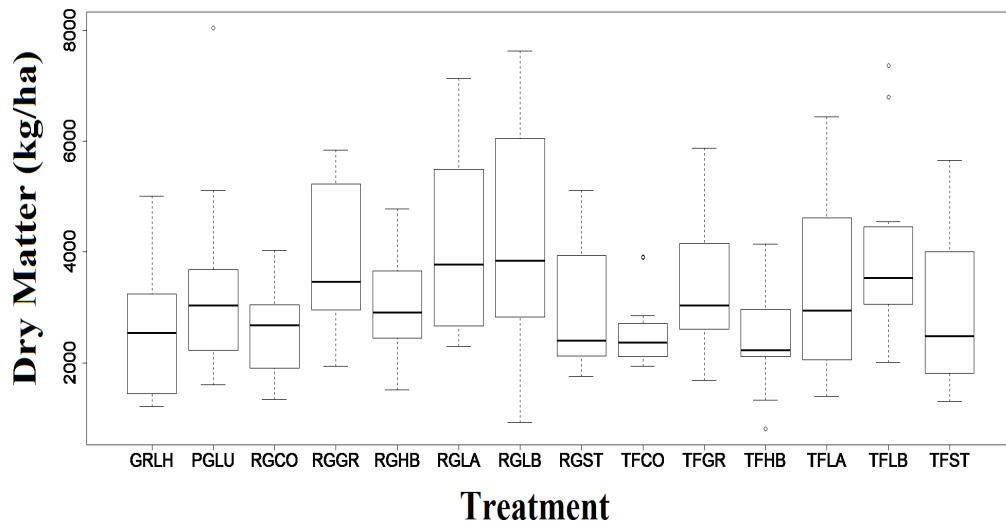


Figure 4.1 Total root dry matter (kg ha<sup>-1</sup>) across 14 treatments.

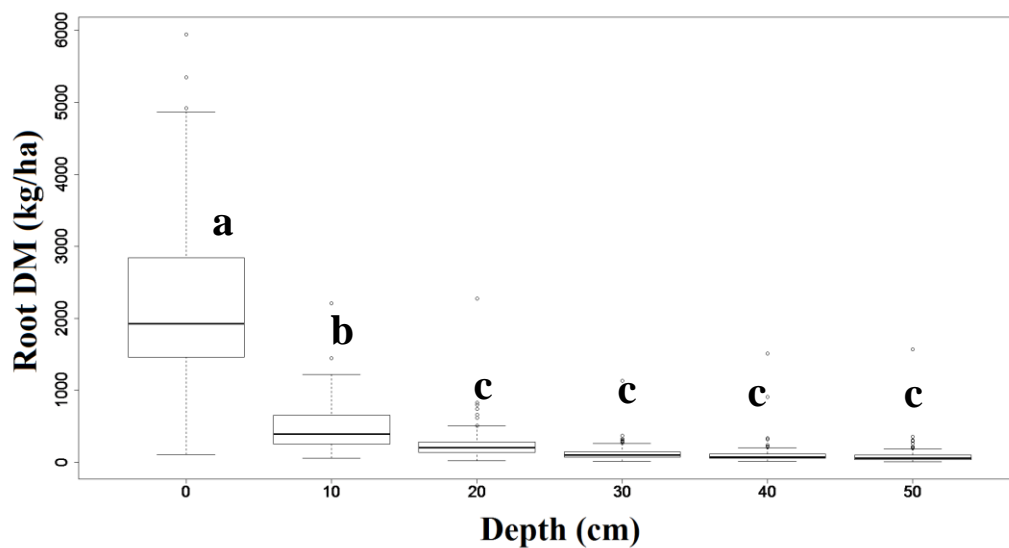
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*Biomass with Depth*

There was a large decline in root DM with depth ( $P < 0.0001$ , Figure 4.2), this relationship was consistent and not significantly different across all treatments and seasons. Depths 0-10 and 10-20 cm were significantly ( $P < 0.0001$  and  $P = 0.0002$  respectively) different from each other and the lower three depths, there were no significant differences in root biomass for depths below 20 cm.

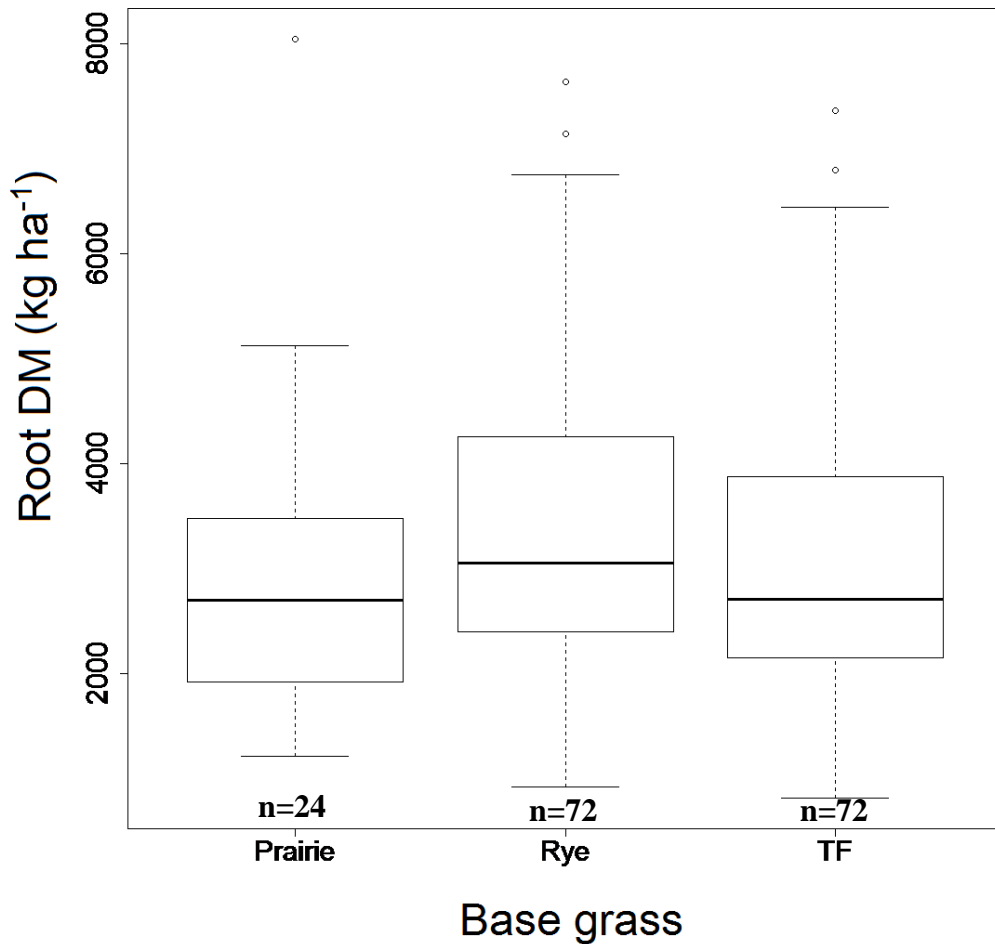
An average of 70% of the total biomass was found in the top 10 cm (across all plots and seasons).



**Figure 4.2** Root dry matter (kg/ha) with depth across all treatments and seasons. Depths on the x axis are the top of a 10 cm depth increment (i.e. 0 = 0-10 cm). Depths with the same letter were not significantly different ( $P > 0.05$ ).

*Biomass differences due to Base grass*

The mean biomass for the three base grasses varied slightly (Figure 4.3) but none of these differences were significant ( $P = 0.31$ ).



**Figure 4.3** Comparison of the influence of three base grasses on root biomass (across all seasons), no significant differences.

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*Biomass differences due to herb presence*

Plots containing herb species (chicory and plantain) had significantly lower root biomass (mean=  $2657 \pm 120$ , n=60) than plots without herbs (mean=  $3601 \pm 154$ , n=108) ( $P < 0.001$ , Figure 4.4). However, this herb effect was not consistent across all seasons and sampling depths. The herb effect was only significant for the 0-10cm depth samples collected in summer (herb root biomass =  $2240 \pm 149$  kg DM ha<sup>-1</sup>, n=15, and non-herb root biomass =  $3559 \pm 202$  kg DM ha<sup>-1</sup>, n=27,  $P < 0.0001$ ) and in spring (herb root biomass =  $1570 \pm 80$  kg DM ha<sup>-1</sup>, n=15 and non-herb root biomass =  $2102 \pm 129$  kg DM ha<sup>-1</sup>, n=27  $P = 0.01$ ).

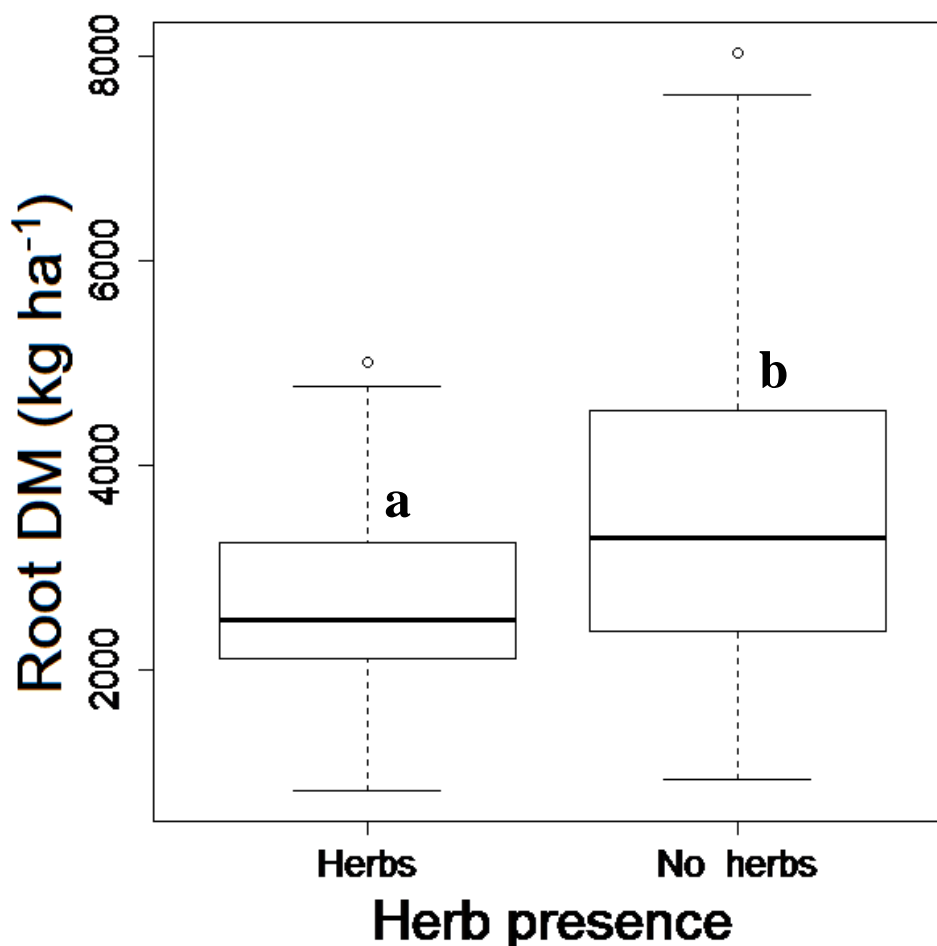


Figure 4.4 Significant differences in average of total root biomass (0-60 cm) in plots with or without herbs ( $P < 0.001$ ).

*Seasonal effect on biomass*

There was a significant difference in root biomass between seasonal samplings ( $P < 0.0001$ ). The summer biomass (mean =  $4496 \pm 219$  kg DM ha<sup>-1</sup>, n=42,  $P < 0.05$ ), was significantly higher than all other samplings with the exception of autumn, which is marginally not significant ( $P = 0.06$ ). The winter sampling had the lowest biomass for the year period with a mean of  $2326 \pm 179$  kg DM ha<sup>-1</sup>, n=42.

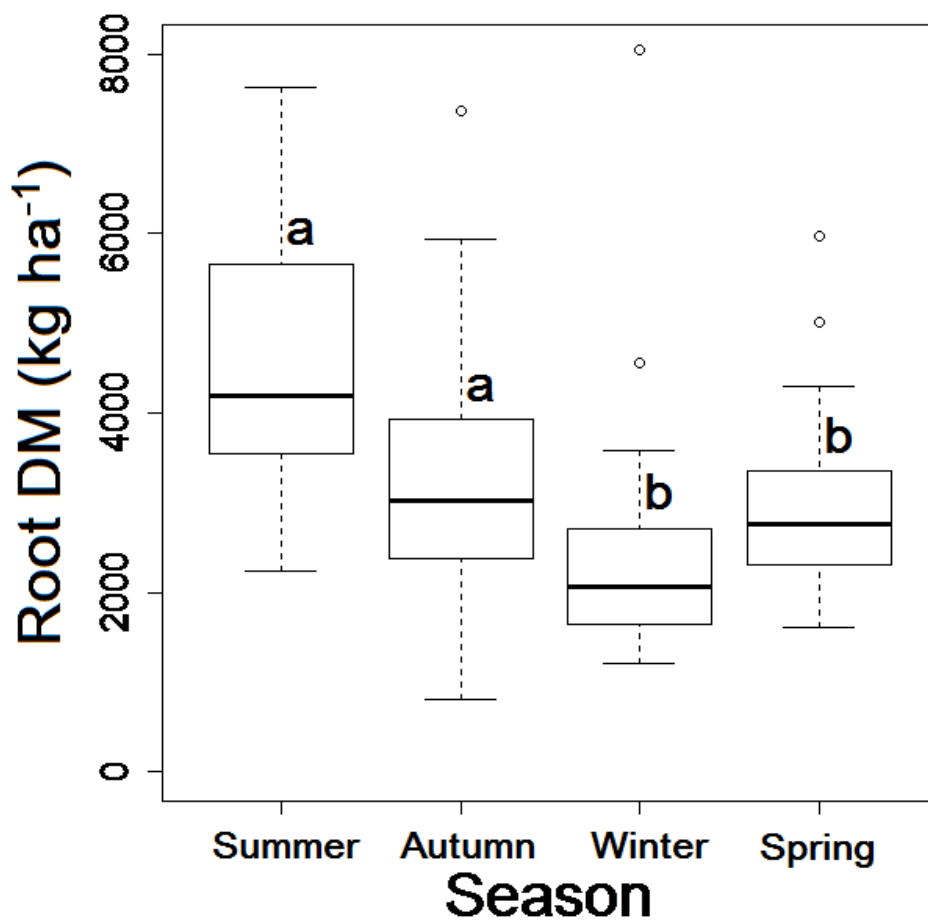


Figure 4.5 Root dry matter for all pasture treatments across four seasons. Boxes with different letters indicate significant difference at  $P < 0.05$ .

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*Input from root biomass to soil*

A rough estimate of the amount of C entering the soil in the form of dead roots can be made from the difference in root biomass between the maximum and minimum biomass between seasonal samplings (Table 4.2). Total C input to the soil can be calculated using a %C of dry matter of 40% (McNally et al., 2014). This is one measure of C input that is available for stabilisation in soil. Maximum root biomass occurred in summer and the minimum biomass in in winter, with the difference in biomass being greater in plots without herbs (Figure 4.6, Table 4.3). The inclusion of herb species results in a lowered dry matter input to soil mass by approximately 500 kg ha<sup>-1</sup> (Table 4.3).

**Table 4.2 Maximum and minimum season root biomass of 14 treatments. The difference between these values can be estimated as the biomass which is lost into the soil mass and is potentially available for stabilisation to soil C. Final column is the average root mass for the year. Values in parentheses are standard errors of the mean.**

Treatment name	Average DM (kg ha <sup>-1</sup> )		Difference (kg ha <sup>-1</sup> )	Contribution to soil C (kg ha <sup>-1</sup> C)*	Year average (kg ha <sup>-1</sup> )
	Max Summer	Min Winter			
RGST	4571	1833	2738	1095	2922 (101)
RGLA	5582	3131	2451	980	4153 (845)
RGLB	6851	2149	4702	1881	4215 (450)
RGHB	4177	2105	2072	829	3093 (176)
RGGR	5425	22490	2935	1174	3975 (298)
RGCO	3345	1599	1746	698	2604 (244)
TFST	4923	1807	3116	1247	2974 (482)
TFLA	5919	1666	4253	1701	3409 (272)
TFLB	5308	2499	2809	1124	3998 (614)
TFHB	3407	1439	1968	787	2427 (338)
TFGR	5258	2419	2839	1135	3401 (365)
TFCO†	3106	2149	1075	430	2572 (246)
GRLH	4101	1301	2800	1120	2588 (223)
PGLU§	4967	2234	2732	1093	3360 (854)
<b>Average</b>			2731 (143)	1092 (57)	3263 (167)

\* based on 40% C content of biomass from McNally, unpublished data.

†Biomass minimum occurred in spring.

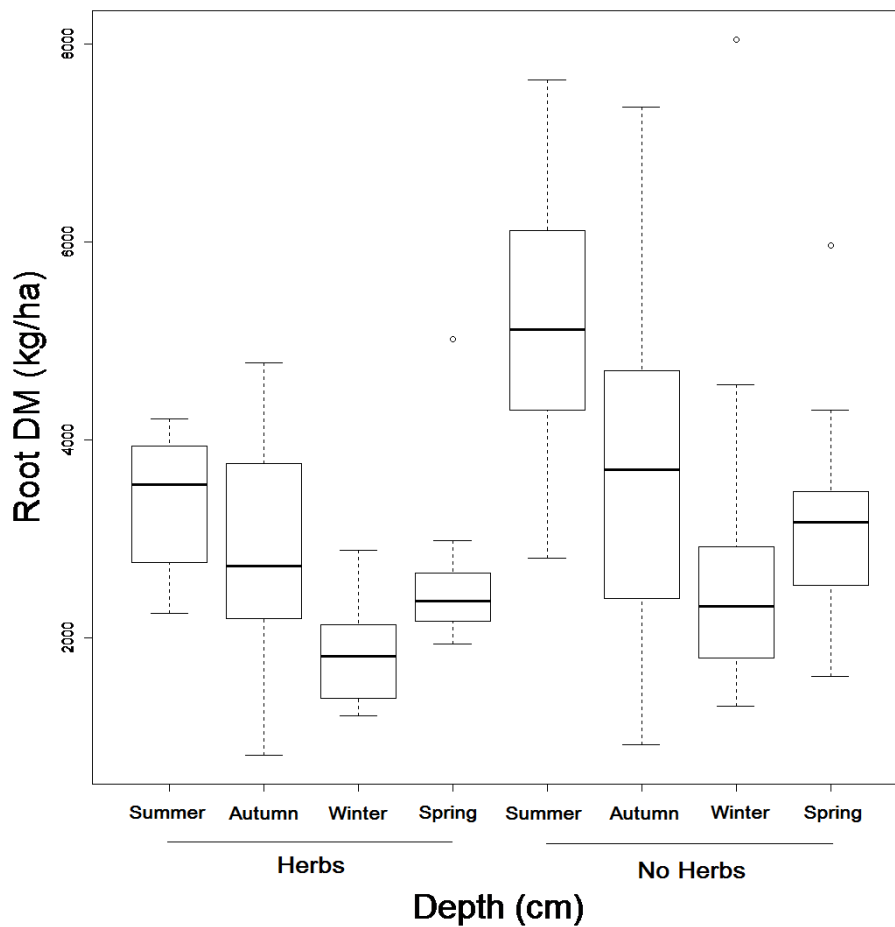
§Biomass maximum occurred in winter and minimum occurred in spring.

**Table 4.3 Mean maximum and minimum root biomass of 14 treatments separated into those with and without herbs. The difference between these values is an estimate of root biomass available for incorporation into soil organic matter. This is also converted to mass of C.**

	Average DM (kg/ha) per plot		Difference in DM (kg ha <sup>-1</sup> )	Difference in C (kg ha <sup>-1</sup> )*
	Max	Min		
<b>Herbs</b>	3627	1695	1932 (224)	773 (114)
<b>No Herbs</b>	5423	2248	3175 (212)	1270 (67)

\* based on 40% C content of biomass from McNally, unpublished data.

Values in parentheses are standard errors of the mean.



**Figure 4.6 Average root biomass for four seasonal samplings for plots with or without herbs present.**

#### 4.4.2 Root Length and Root Length Density (RLD)

Root length for a subset of samples was analysed using a scanner and analysis programme WinRHIZO. Total length describes the sum of the root lengths down the depth profile per volume of soil to a depth of 0.6 m; this can also be described as the average length per volume down the soil profile (root length density, RLD). Expressing root length as RLD allows for easier comparison between studies. Root length ranged from 1 to 10  $\text{cm cm}^{-3}$  for different treatments with an average of  $6.24 \text{ cm cm}^{-3}$  across all treatments. There was a great deal of variation in the total length (Figure 4.7) and total root length showed no significant differences between individual treatments ( $P > 0.05$ ). The model which best explained the variation in the root length data was the combination between treatment and season ( $P < 0.0001$ ). This relationship is therefore illustrated in the sections discussed below.

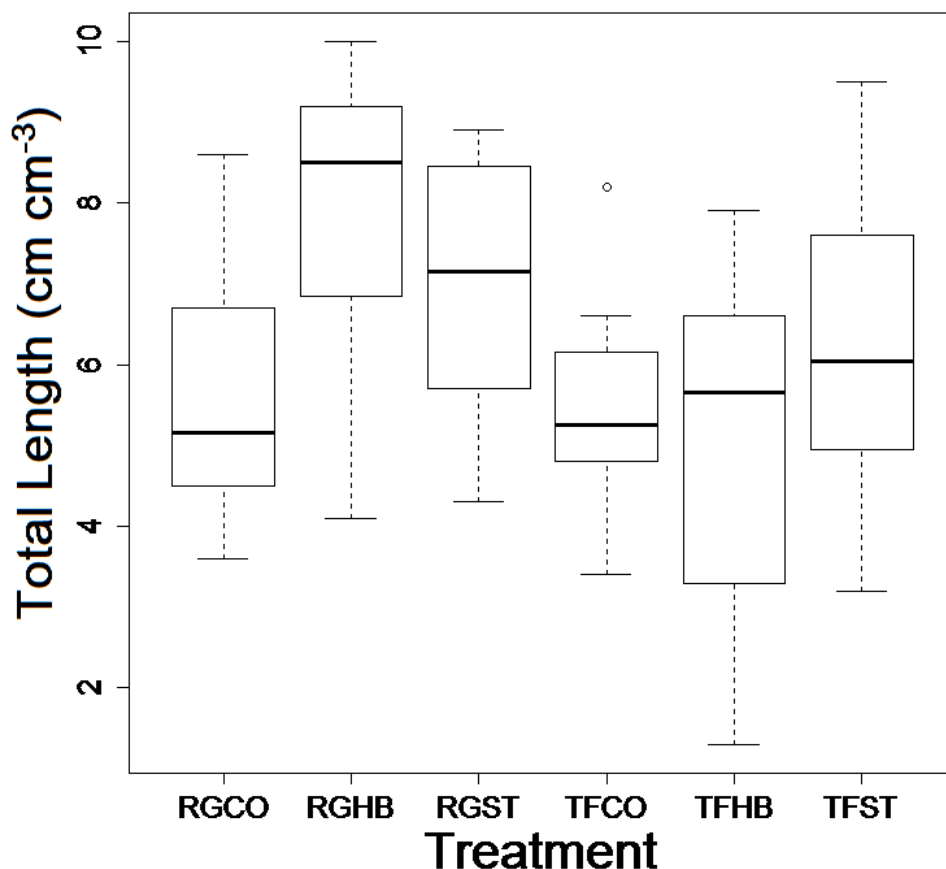


Figure 4.7 Total root length per volume of soil ( $\text{cm cm}^{-3}$ ) to a depth of 60 cm for each of six scanned treatments

As with biomass, total length declined significantly with depth ( $P < 0.0001$ , Figure 4.8). An average of 65.3% of the total length was present in the top 10 cm with an average of  $24.3 \pm 1.0 \text{ cm cm}^{-3}$  and the minimum occurring in the 50-60 cm sample ( $1.1 \pm 0.07 \text{ cm cm}^{-3}$ ). The significant differences were only occurred in the 0-10cm and 10-20cm samples ( $P < 0.0001$ ), the rest being statistically insignificant from one another. The significant differences in root length only occurred between the 0-10cm, 10-20cm, and 20-30cm (except 30-40 cm sample) samples ( $P < 0.0001$ ), with no differences below 30 cm.

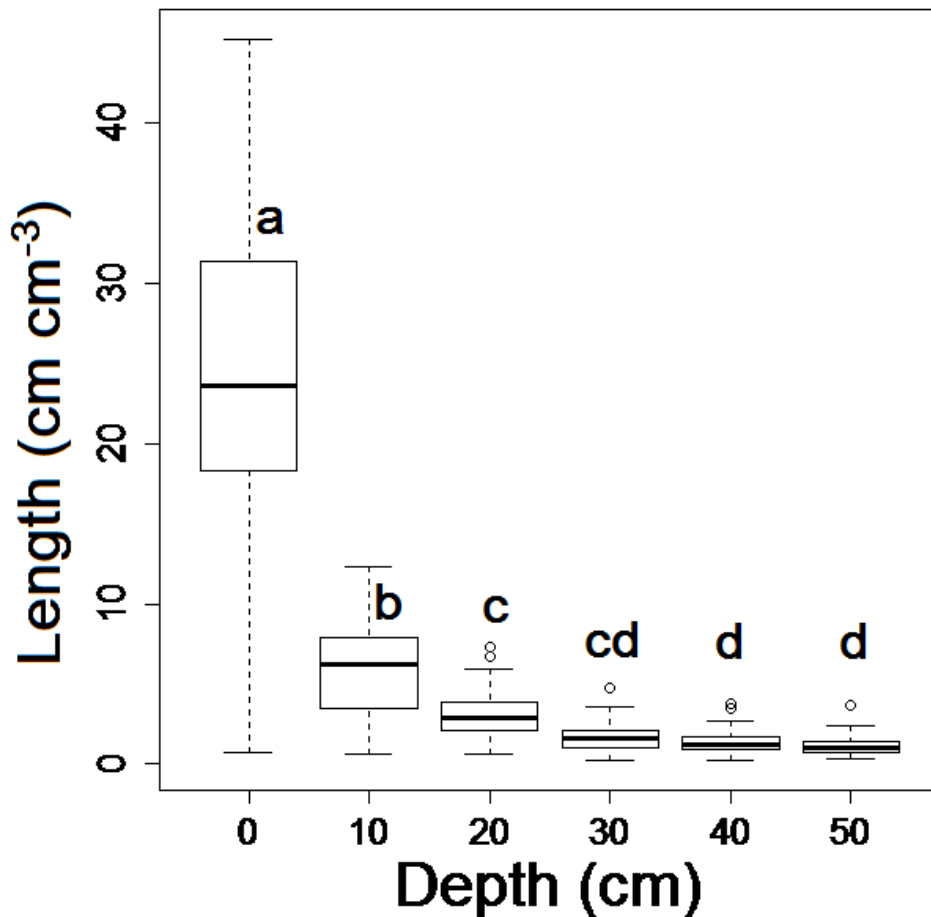


Figure 4.8 Decline of root length with depth (cm) for all scanned treatments.

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### *Base grass effect on root length*

Root length samples were summed to a depth of 0.6 m then further analysis was completed on these summed root length density (RLD) values ( $\text{cm cm}^{-3}$ ).

The importance of base grass on roots was examined in an attempt to explain variation seen between treatments (Figure 4.7). Tall fescue and rye grass were the two base species to which different combinations of species were added. Plots where tall fescue (abbreviated to TF for treatment names) was present, had significantly lower total length (mean =  $5.6 \pm 0.3 \text{ cm cm}^{-3}$ ,  $n=36$ ) compared with plots with a rye grass base (mean =  $6.9 \pm 0.3 \text{ cm cm}^{-3}$ ,  $n = 36$ ,  $P=0.039$ , Figure 4.9).

In contrast to the biomass data, there was no significant difference in RLD with and without the presence of herb species; chicory and plantain ( $P=0.41$ , Figure 4.10).

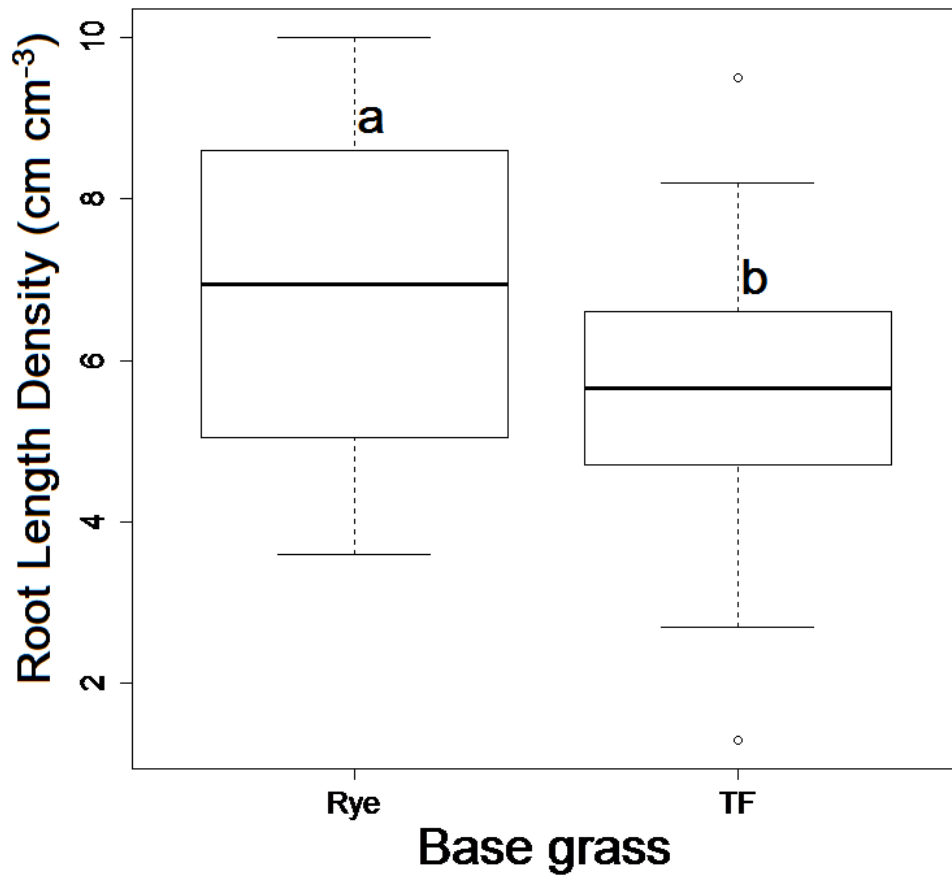


Figure 4.9 Significant difference in root length density to a depth of 60 cm ( $\text{cm cm}^{-3}$ ) in plots with different base grasses; ryegrass (Rye) and tall fescue (TF).

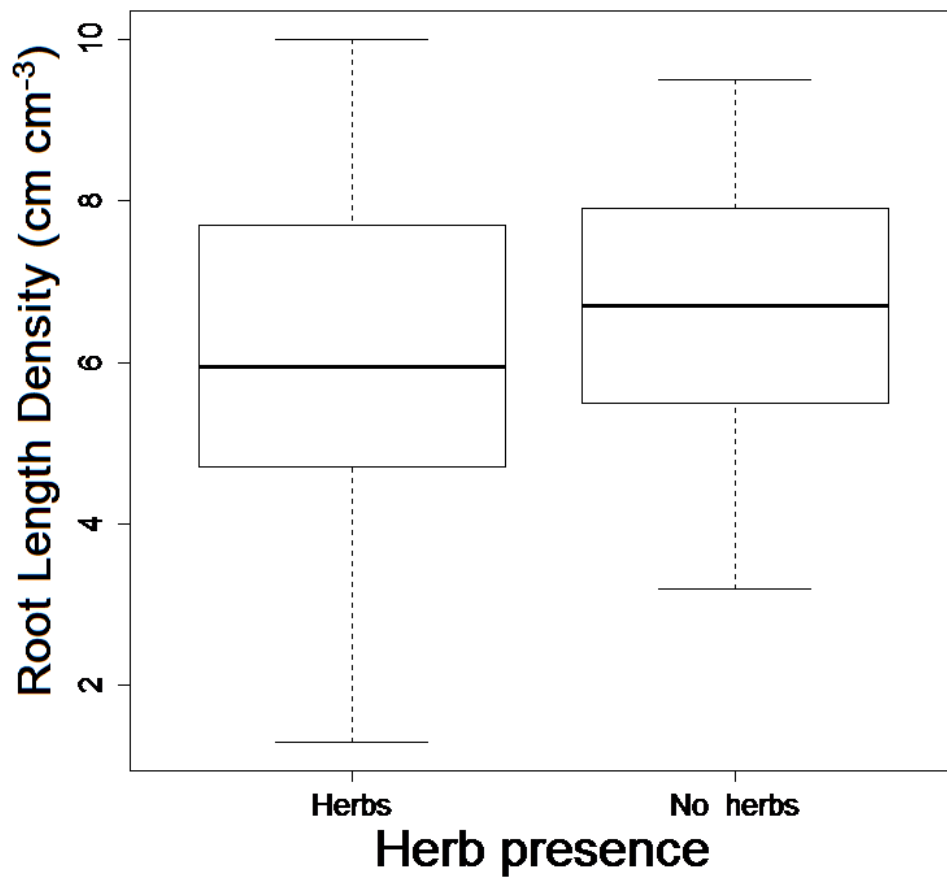
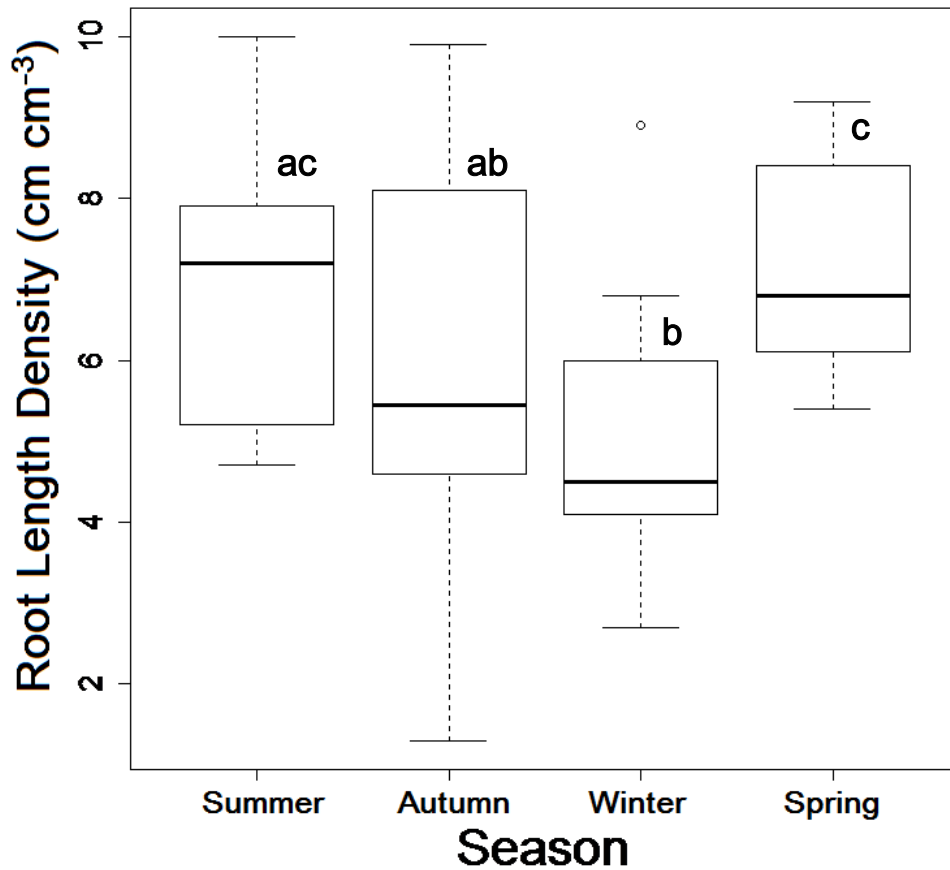


Figure 4.10 Root length density to 60 cm depth with the presence or absence of herb species were not significantly different from one another.

*Seasonal effect on root length*

Differences were observed in root length density (RLD) ( $\text{cm cm}^{-3}$ ) between seasons ( $P < 0.0001$ , Figure 4.11). The maximum RLD was observed in the early summer sampling (mean =  $6.82 \pm 0.39 \text{ cm cm}^{-3}$ ,  $n = 18$ ) and the minimum in winter (mean =  $4.91 \pm 0.37 \text{ cm cm}^{-3}$ ,  $n = 18$ ).



**Figure 4.11** Variation in root length density across all treatments between four seasonal samplings.

### 4.4.3 Average Root Diameter

Across the six scanned treatments there was no significant difference in average root diameter found between treatments ( $P>0.05$ , Figure 4.12). The model considering a combination of base grass, season and depth, explained the most variability in the dataset ( $P<0.0001$ ).

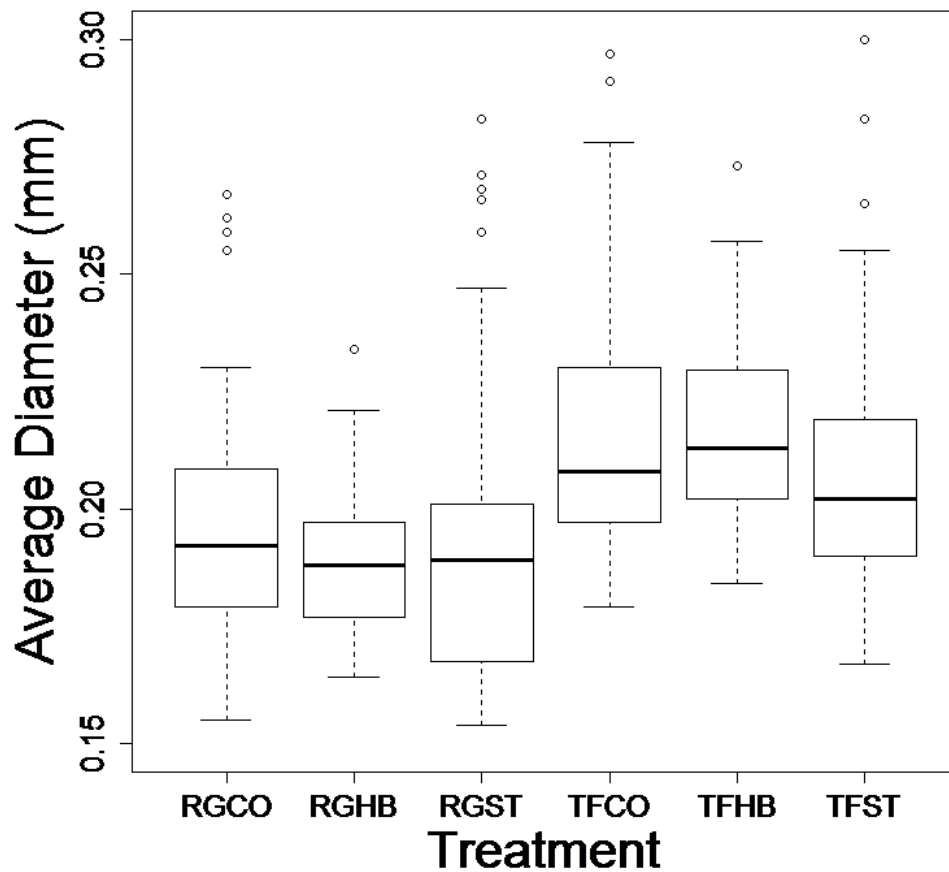


Figure 4.12 Average diameter (mm) for each of the six scanned treatments.

While there were significant differences in average root diameter between depths ( $P < 0.0001$ , Figure 4.13), these differences were only found between the 10-20 cm sample and the lower three depths (30-40 cm, 40-50 cm and 50-60 cm). There is no consistent trend with depth.

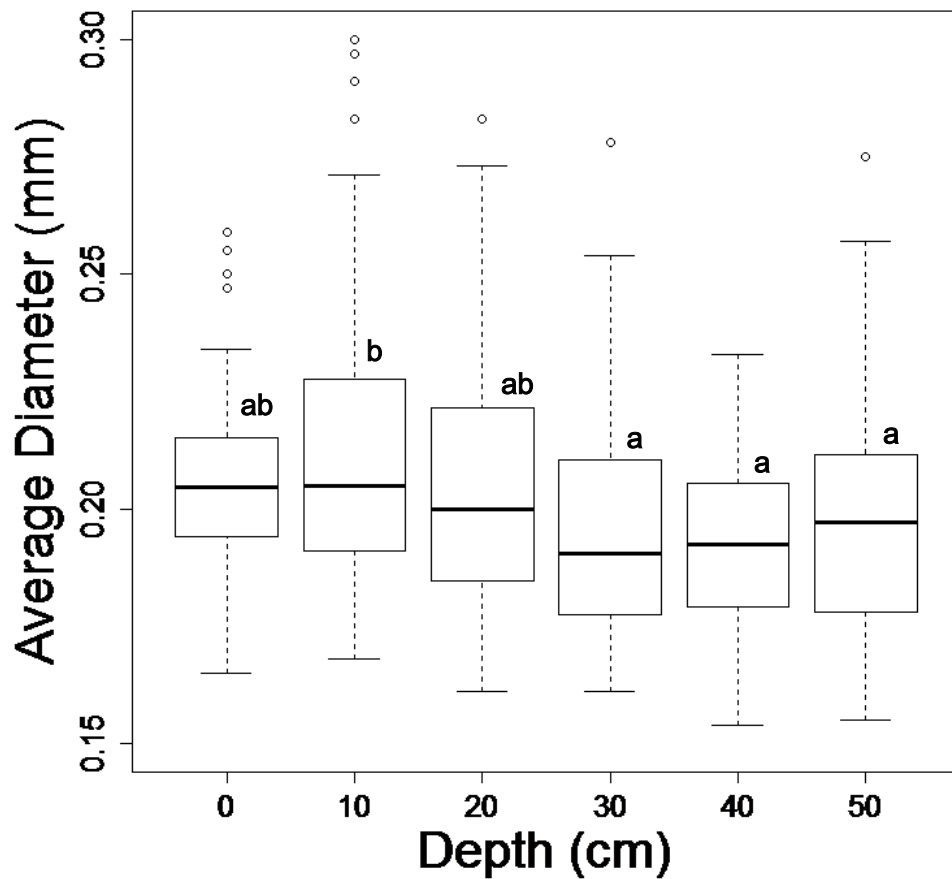


Figure 4.13 Average root diameter (mm) for the different depth increments (0-60 cm).

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*Base grass and herb effect on root diameter.*

Base grass had a strong influence on the average root diameter. Plots which had a base grass of tall fescue has a significantly larger diameter (mean= $0.22 \pm 0.004$  mm,  $n=36$ ) when compared with plots which had a rye grass base (mean= $0.19 \pm 0.023$  mm,  $n=36$ ,  $P=0.0001$ , Figure 4.14).

In contrast to base grass, presence or absence of chicory and plantain had no effect on average diameter of roots ( $P=0.52$ , Figure 4.15).

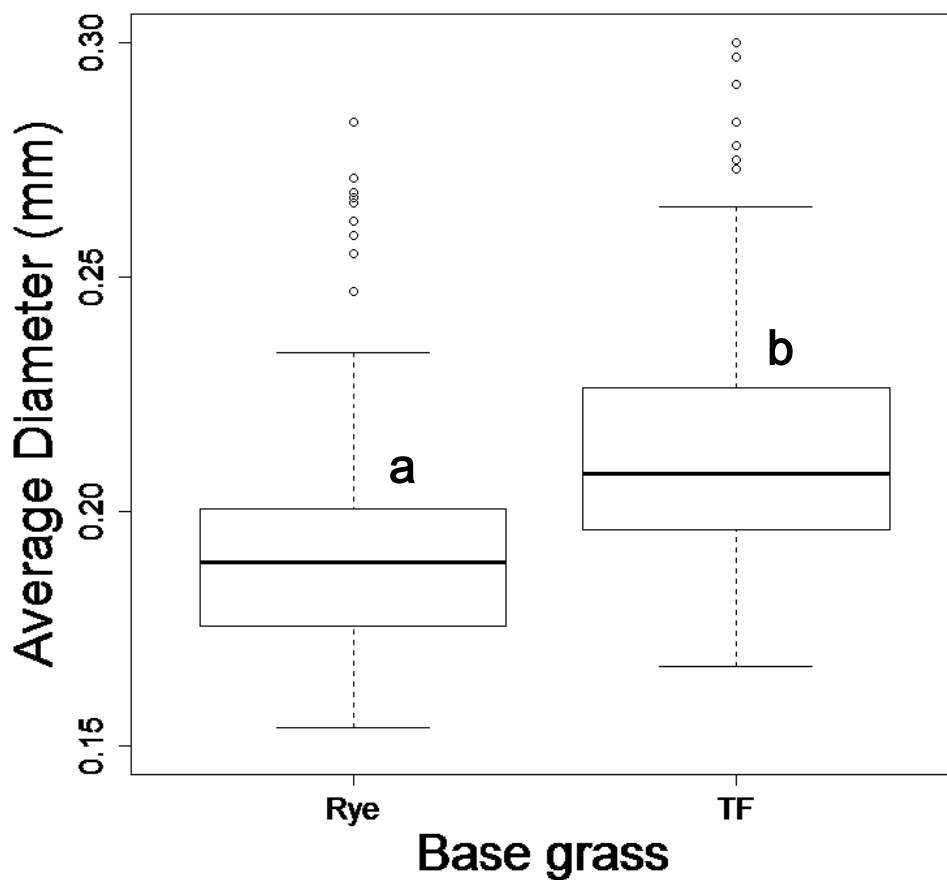


Figure 4.14 Difference in average root diameter of treatments with different base grasses; rye grass and tall fescue ( $P < 0.0001$ ).

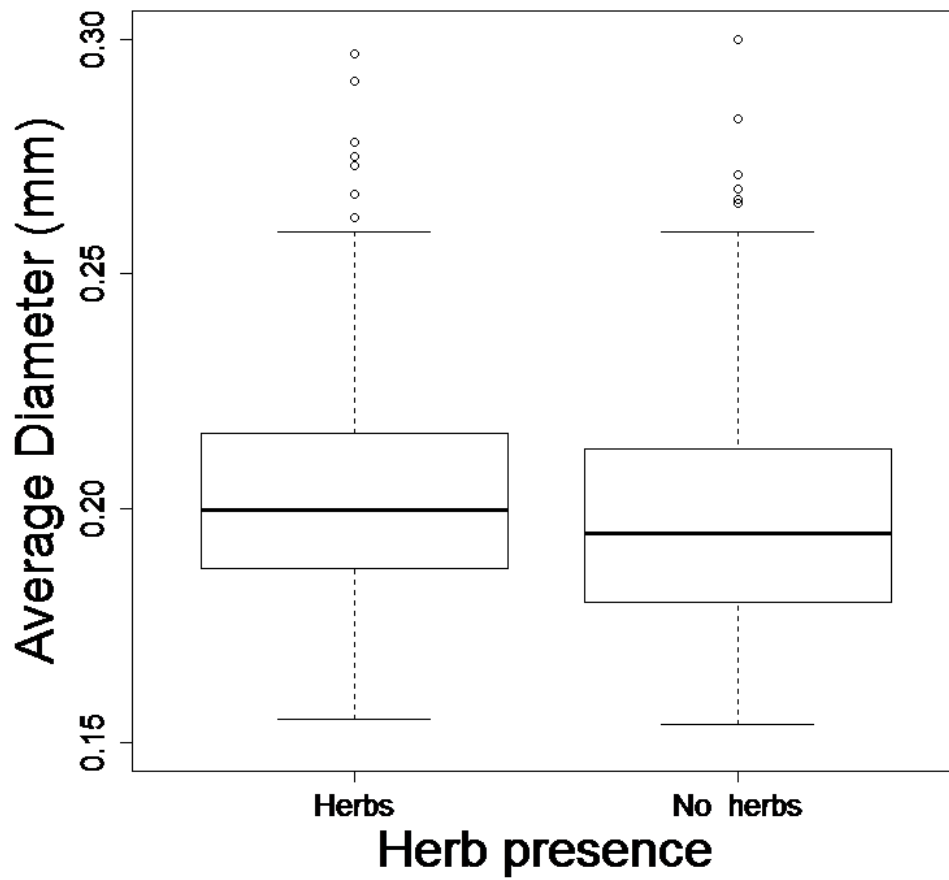


Figure 4.15 Presence of herbs shows no significant difference in average root diameter ( $P = 0.52$ ).

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*Seasonal effects on root diameter*

The average root diameter changed significantly over the year ( $P < 0.0001$ , Figure 4.16). The largest diameter roots were found in the summer sampling (mean =  $0.2 \pm 0.0055$  mm,  $n=18$ ) and the smallest in winter (mean =  $0.19 \pm 0.0027$  mm,  $n=18$ ).

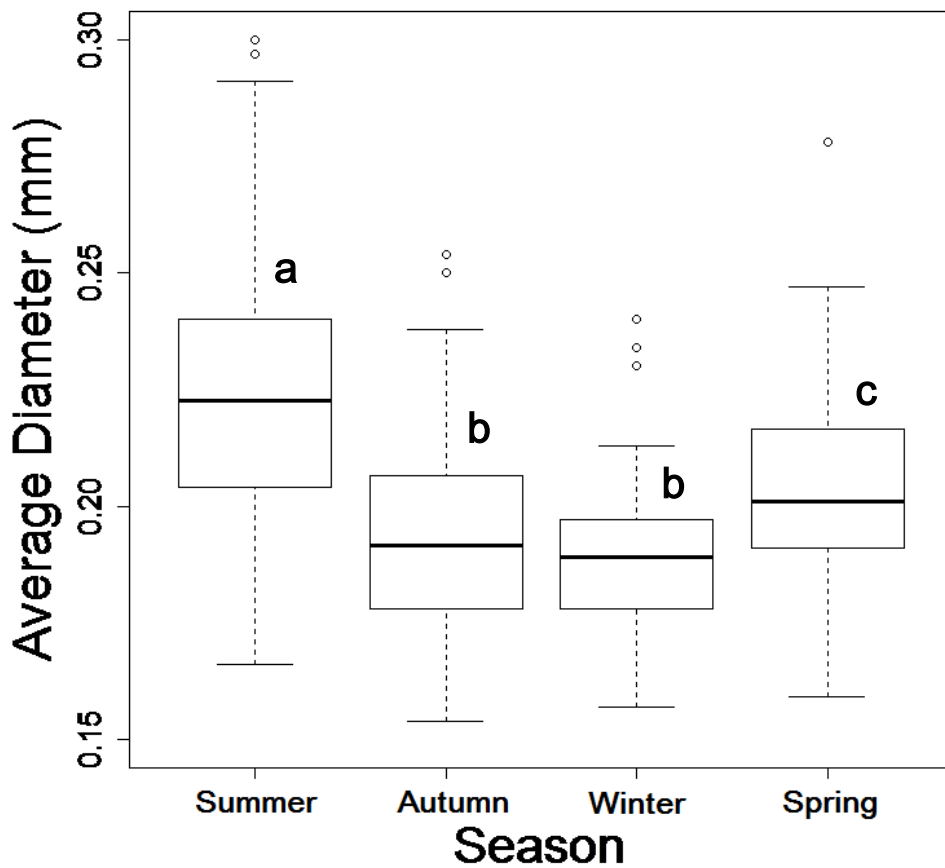


Figure 4.16 Seasonal changes in average root diameter (mm) across four samplings during the year.

#### 4.4.4 Specific Root Length

Specific root length (SRL) is calculated by dividing the total length of the sample (m) by the mass of the sample (g). Length was determined by root scanning (Section 3.4.4) and mass from weighing of samples (Section 3.4.3). Within the six treatments scanned and calculated for specific root length, there was an average SRL of  $170.7 \pm 2.8 \text{ m g}^{-1}$  and a significant treatment effect ( $P < 0.0001$ , Figure 4.17). There appeared to be a difference in base grass with ryegrass on average having higher SRL than those with a tall fescue base. These differences are explored further below. A linear mixed effects model considering a combination of base grass, season and depth gave the most parsimonious fit to the specific root length dataset.

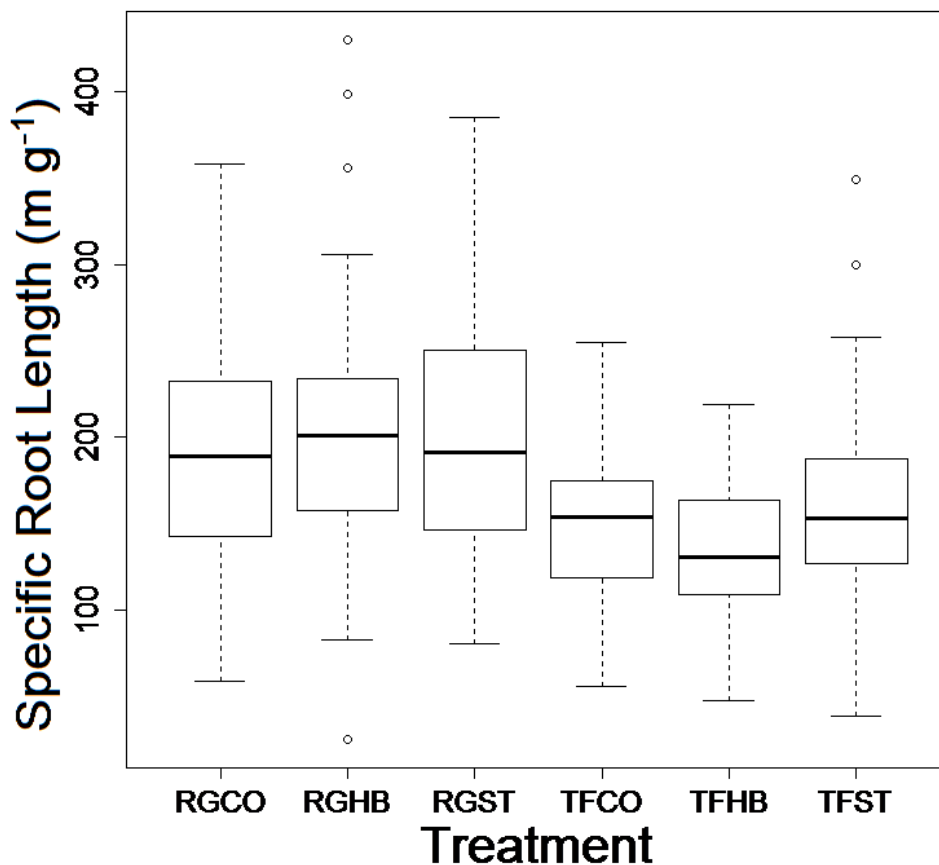


Figure 4.17 Specific root length (m) response to six different treatments. It appears that there is a base grass effect where ryegrass plots have higher SRL compared with tall fescue plots, however, this is explored further below.

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*Specific root length with depth*

Specific root length generally increased significantly with depth ( $P < 0.0001$ , Figure 4.18). The 0-10 cm samples had an average SRL of  $134.6 \pm 5.4 \text{ m g}^{-1}$ , in contrast to the 50-60 cm samples averaging  $192.4 \pm 8.4 \text{ m g}^{-1}$ . Specific root length did not change significantly past the depth of 30 cm.

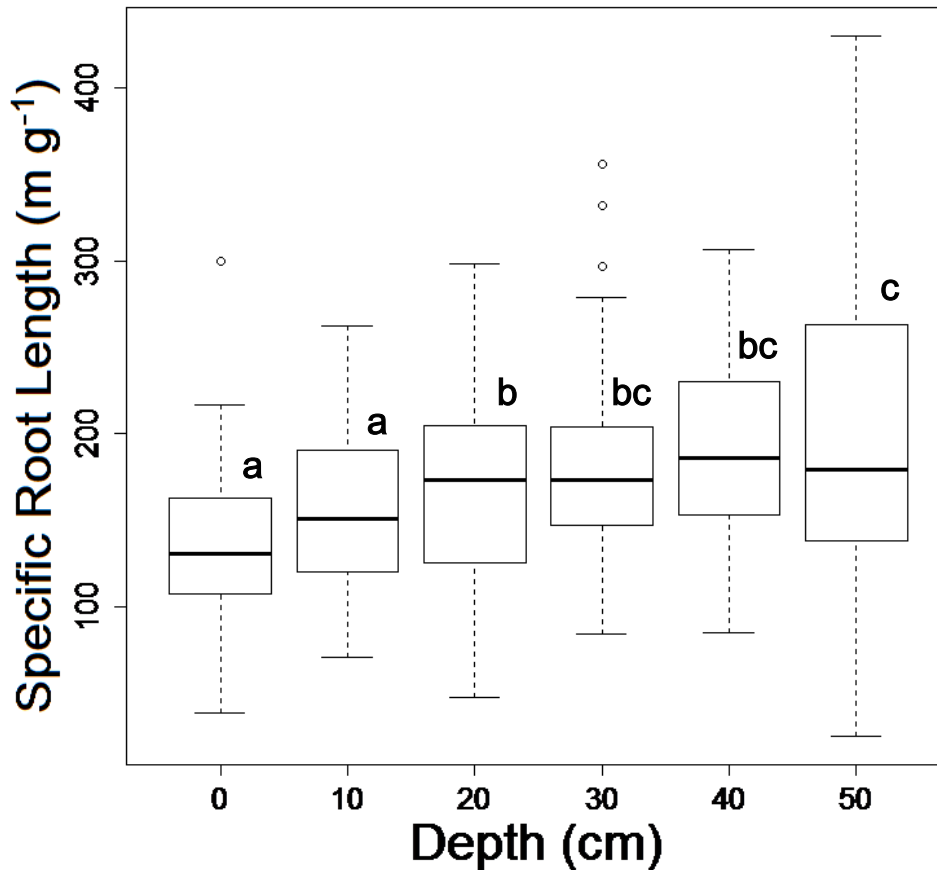
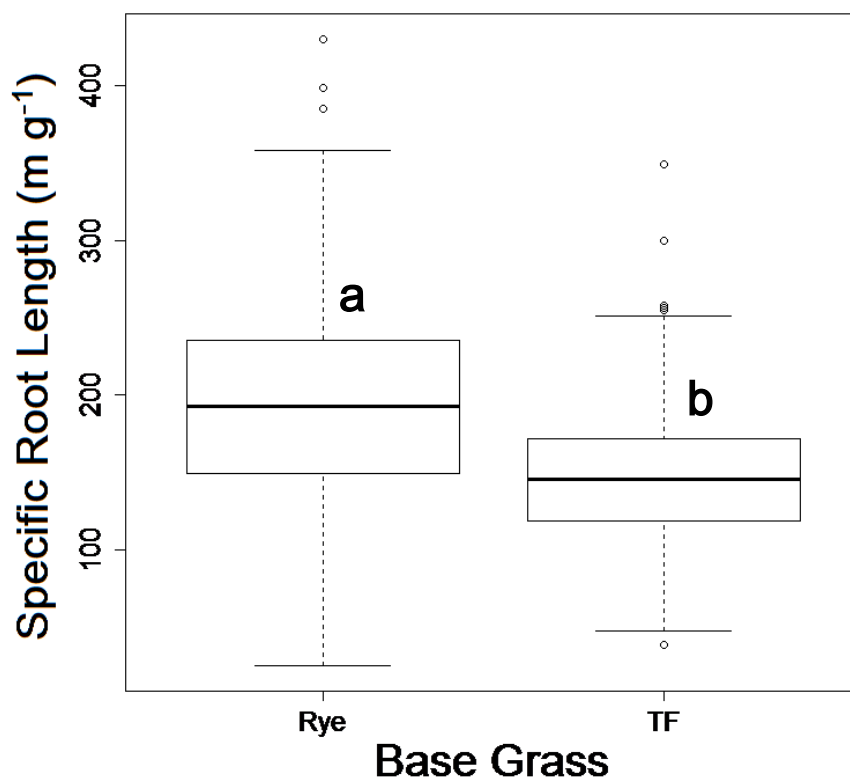


Figure 4.18 Specific root length ( $\text{m g}^{-1}$ ) by depth for all scanned treatments.

*Effect of base grass and herb presence on specific root length*

Plots containing tall fescue had significantly lower specific root length ( $146.3 \pm 2.9 \text{ m g}^{-1}$ ) compared with a base grass of ryegrass (mean =  $195.1 \pm 4.2 \text{ m g}^{-1}$ ) ( $P = <0.0001$ , Figure 4.19).

In contrast to root biomass, there was no difference in specific root length with the presence or absence of herb species ( $P > 0.05$ , Figure 4.20). This was consistent for each of the four seasons sampled.



**Figure 4.19** Significant difference in specific root length for treatments with different base grasses.

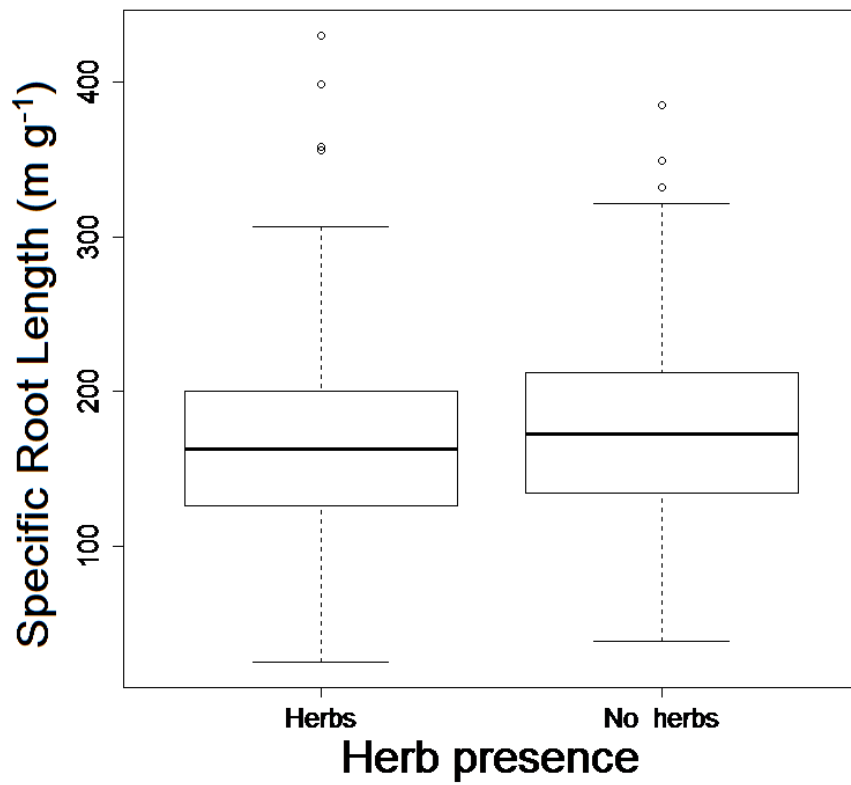


Figure 4.20 No significant difference in specific root length with the presence of absence of herb species.

*Seasonal effect on specific root length*

There was a highly significant influence of season on specific root length ( $P < 0.0001$ , Figure 4.21). There was a great deal of variation within these values; each season was significantly different from the others with exception of summer and autumn. The maximum specific root length occurred in spring (mean =  $204.3 \pm 9.2 \text{ m g}^{-1}$ ) and minimum in summer (mean =  $141.4 \pm 5.8 \text{ m g}^{-1}$ ). There is a steady incline evident across the year i.e. specific root length increased from summer through to spring.

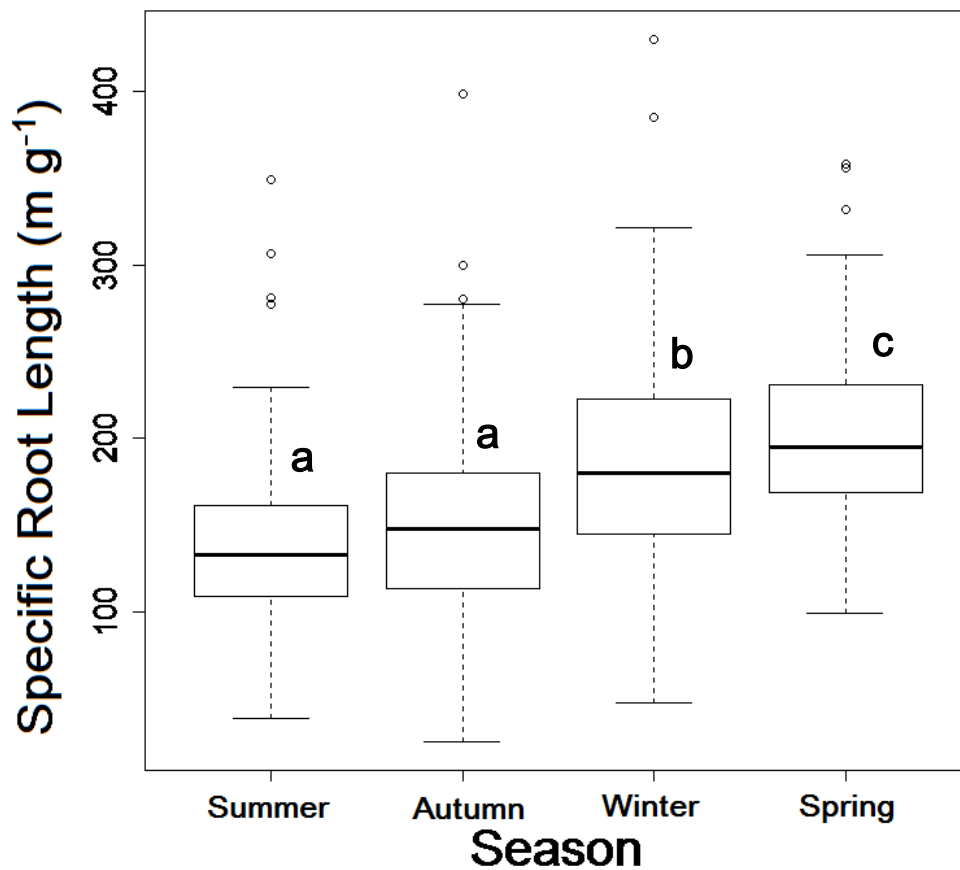


Figure 4.21 Seasonal variation of specific root length for all scanned treatments.

## 4.5 Discussion

### 4.5.1 Root Biomass

In New Zealand, studies focusing on pasture dominated by ryegrass/clover have shown a large variation in root biomass ranging from as little as 1100 kg DM ha<sup>-1</sup> to as much as 24000 kg DM ha<sup>-1</sup> (Table 2.2). Here, root cores to a depth of 0.6 m, were taken seasonally during a year. Using a linear mixed effects model to determine the most parsimonious fit to the data, the combination of herb presence, season and depth explains most of the variation seen in the data. The effects creating this model are further discussed below. Across the four samplings, root biomass ranged between 800 and 8000 kg DM ha<sup>-1</sup> with an average of 3264 ± 113 kg DM ha<sup>-1</sup> (average ± standard error). At the treatment scale, there were no detectable significant differences in root biomass due to high variation. Compared with previous work at Winchmore, at a fertiliser and irrigation trial (Metherell, 2003), the root biomass was low. At Winchmore, irrigated plots that had superphosphate applied at 376 kg ha<sup>-1</sup> yr<sup>-1</sup>, root biomass was 5900 kg DM ha<sup>-1</sup> less than dryland with 7700 kg DM ha<sup>-1</sup> (Metherell, 2003). Metherell et al. suggested that allocation to root biomass was reduced when water and nutrients are plentiful. At the Scott farm trial, the site had received annual fertiliser loading during previous trials and 100 kg N ha<sup>-1</sup> during the current trial and the soil was likely much more fertile than at Winchmore, potentially explaining lower biomass than in the current trial. Saggar et al. (1997) also attributed high root biomass values for a ryegrass/clover pasture (around 11000 kg DM ha<sup>-1</sup>) to low fertility at a hill country research station with three different slopes. Saggar et al., concluded that high root biomass was due to low fertility at the site.

Across all treatments and seasons, biomass declined significantly with depth ( $P < 0.001$ , Figure 4.2) with an average of 70% total biomass found in the top 0.1 m and 90% in the top 0.3 m. This depth distribution was consistent with many reported root mass data sets which have measured biomass in both standard ryegrass/clover systems and pastures of varying diversity (Dodd & Mackay, 2011; Gentile et al., 2003; McKenzie et al., 1990; McNally et al., 2014; Mueller et al.,

2013b). A higher root biomass in top soil is presumably due to pastures predominantly accessing water and nutrients at the surface.

While there was no detectable significant effect on total root biomass observed at the treatment scale, further analysis detected trends attributable to presence or absence of specific functional groups. The most significant effect was the reduction in total root biomass in plots containing the herb species chicory and plantain ( $P < 0.0001$ , Figure 4.4), despite herbs only making up a relatively small proportion of the sward by the time sampling occurred (Table 3.2). Herbs were present in five of the 14 treatments, all of which had a lower root biomass than treatments with no herbs. No-herb treatments had an average total root biomass of  $3560 \pm 200 \text{ kg DM ha}^{-1}$ , while plots with herbs had an average of  $2240 \pm 150 \text{ kg DM ha}^{-1}$ . When examining the reasons for differences in root biomass between herb and no-herb treatments, sampling depth was important. The difference between herb and no-herb plots was only significant in the top 0.1 m ( $P < 0.0001$ ), with no difference in biomass for all other depths.

The lower biomass caused by the addition of herbs to the sward mix was in contrast to other biomass studies where increasing species richness was positively correlated with root biomass, such as, increases of 18% in 8-species mixes above the average of monocultures of the same species (Cong et al., 2014). McNally et al. (2014) also measured the influence of mixed sward pastures also containing herbs on root biomass at an adjacent large plot trial at Scott farm. In contrast to the current findings, these authors showed that the more diverse pastures had a greater total biomass (average  $1770 \text{ kg ha}^{-1}$  higher than ryegrass clover). This greater biomass was partly attributed to the presence of lucerne, a taprooted plant with high root density ( $0.22 \text{ g cm}^{-3}$ ), compared with ryegrass ( $0.13 \text{ g cm}^{-3}$ ) (Gentile et al., 2003; McNally et al., 2014). Lucerne was present in higher abundance in plots sampled by McNally et al. than the current study, which would increase the probability of intercepting a lucerne taproot when taking soil cores. The lower total root biomass for plots with herbs in the current study may also have been due to sampling method. A 0.0254 m diameter sampling corer was used (15 replicates per plot) and this diameter may have been insufficient to adequately sample taprooting habit of chicory and plantain. In contrast to the herb effect, base

grass showed no significant effect on root biomass. While there was a trend for greater biomass in ryegrass plots than tall fescue, this trend was not significant.

#### **4.5.2 Seasonal Turnover and Carbon Input**

There was a significant difference in root biomass across the four seasons ( $P < 0.0001$ , Figure 4.5) with biomass ranging from  $4496 \pm 219$  kg DM ha<sup>-1</sup> in early summer to a minimum of  $2326 \pm 180$  kg DM ha<sup>-1</sup> in winter. A summer maximum and winter minimum root biomass has been commonly observed in biomass data sets both in New Zealand and in other regions for conventional ryegrass/clover and more diverse pastures (Dodd & Mackay, 2011; Gentile et al., 2003; McGranahan et al., 2014; McNally et al., 2014; Saggar & Hedley, 2001).

As root biomass is the main contributor to soil C, it is important to know how much of this biomass might be available for potential C sequestration in soil (Rasse et al., 2005). Net primary productivity (NPP) is the photosynthetic gain of vegetation per unit ground area after respiration and is one approach for estimating the amount of C gain from plant photosynthesis (Scurlock et al., 2002) but this does not partition C gains between above and below ground. There are many methods of estimating NPP of a system, some of which exclude below-ground productivity due to the difficulty of accurate prediction without direct sampling (Scurlock et al., 2002). A conservative estimate of below-ground NPP can be made by calculating the difference between the maximum and minimum root biomass. This biomass difference is a conservative because it does not account for C inputs from mycorrhizal activity around the roots and/or root exudation. There was an average difference in root biomass between seasons of  $2731 \pm 182$  kg DM ha<sup>-1</sup> (Table 4.2). Calculated differences ranged from 1070 to 4700 kg DM ha<sup>-1</sup> for different treatments. Using a percentage root C content of 40% (McNally et al., 2014) an estimate of the amount of C available in the soil for stabilisation was calculated (Table 4.2) ranged between 430 and 1880 C kg ha<sup>-1</sup> during the year.

The main treatment effect on biomass found was the difference between herbs and the absence of herbs. On average, plots without herbs had a significantly higher input of C soil of 1033 C kg ha<sup>-1</sup> than plots with herbs which had an estimated

average C input of 773 C kg ha<sup>-1</sup> (P = 0.047, Table 4.3). It is important to note that this estimate calculated from differences in root biomass is an underestimate of C entering the soil, as root exudates are excluded. The data of the current study indicated that the presence of chicory and plantain reduced the amount of C entering the soil and being potentially available for stabilisation. It was not possible to separate the effects of chicory and plantain because both were always sown and present in the same plots. The reasons for the influence of herbs were not clear and warrant further examination. Only a proportion of this C input to soil will be sequestered. The proportion of this C input that is sequestered to soil C is dependent on many external factors including the existing soil C and whether the soil is near its C saturation level (Beare et al., 2014).

### **4.5.3 Scanned root characteristics**

Root length, average diameter and specific root length are highly correlated and can be used to describe root longevity and turnover in a soil (Mueller et al., 2013b). Plants with larger diameter roots have comparatively greater longevity due to an increased C allocation resulting in greater lignin and cellulose concentrations (Bardgett et al., 2014). A subset of treatments (six treatments) was scanned to determine root characteristics such as root length, average diameter and specific root length. Measurements were made for different depths, seasons, base grass and herb presence to determine information about root longevity and turnover. The treatments scanned included ryegrass standard, ryegrass complex, ryegrass herbs, tall fescue standard, tall fescue complex and tall fescue herbs. The standard treatments were chosen because are most commonly used in New Zealand agriculture, herb treatments increasingly and complex treatments because they provided the most contrast to the standard treatments.

Root length and root length density

Root length is the sum of all the roots present in a specified sample volume of soil. Linear mixed effects models were used to determine the most parsimonious fit to the dataset. It was determined that a combination of treatment and seasonal effects explained the variation the best. Total root length for each plot varied between 1 and 10 cm cm<sup>-3</sup> to 60 cm depth and there was high variation between

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treatments. Consistent with high variation there was no observable significant differences between treatments ( $P > 0.05$ , Figure 4.7). Prathapar et al. (1989) reported an average of  $16 \text{ cm cm}^{-2}$  for a pasture, however, this was an irrigated system located in Australia. Similar to the current study, Kumar et al. (2010) reported root length densities ranging from 0.1 to  $1.7 \text{ cm cm}^{-3}$ . While this is relatively low, these values are average values down the depth profile compared with sum totals down to 0.6m in the current study.

As expected, there was a significant decline in root length with depth ( $P < 0.0001$ , Figure 4.8), as observed for the root biomass data (Section 4.4.1) and this decline is also generally reported in literature (Barker et al., 1988; Greenwood & Hutchinson, 1998; Kumar et al., 2010). The main differences in root length were between the 0-10 cm and 10-20 cm samples and below these depths there was no further significant declines in root length. Seasonal trends in root length were similar to changes in total root biomass data (Figure 4.9). Maximum root length was measured in early summer and the minimum measured in winter. Root length increased after the winter sampling suggesting a seasonal cycle may occur.

A root length density average of  $6.24 \text{ cm cm}^{-3}$  was measured in this study. In the literature, there is a large amount of variation seen in root length density (RLD) (Table 4.4). Barker et al. (1988) found a considerably higher RLD ( $150 \text{ cm cm}^{-3}$ ) than this study and others summarised in Table 4.4. This very high RLD reported by Barker et al., was for the top 5 cm of hill country pastures which can support thick turf mats i.e. thick dense mat of root material concentrated in only the top few centimetres. At the Scott Farm trial, there was no obvious comparable turf mat and perhaps it was unsurprising that root length in top soils was substantially less than reported by Barker et al. It is also important to note that RLD reports the density across the whole profile, therefore, if the samples are shallow such as (Barker et al., 1988), the density will be much higher than the current study and others (Prathapar et al., 1989; Ridley & Simpson, 1994).

The main effect observed in the root length data was the importance of tall fescue as a base grass in treatments, despite tall fescue only making up a relatively small proportion of the sward at the time of root sampling (Table 3.2). When compared

to ryegrass-based pastures, a base of tall fescue had a lower root length ( $P = 0.039$ , Figure 4.9). Tall fescue is regarded as a drought tolerant grass species, which can allocate more C to root than shoot biomass, and has a deeper rooting depth (Karcher et al., 2008). In contrast to the importance of base grass on root length, there was no detectable difference in root length in treatments with or without herbs. No other studies were found in the literature comparing root length of swards with different base grasses but this may deserve further investigation, particularly as there is increasing interest in use of tall fescue.

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**Table 4.4 Summary of root length density (RLD) for different pasture swards.**

Pasture mix	Site description	Location	Root Length Density (cm cm <sup>-3</sup> )	Sample depth (cm)	Source
<b>Mixes of tall fescue and ryegrass pastures</b>	High fertility, grazed by cattle	New Zealand	6	0-60	Current study
			24	0-10	
			1	50-60	
<b>Pasture (<i>Agrostis capillaris</i>, <i>Cynosurus cristatus</i>, <i>Holcus lanatus</i>, <i>T.repens</i> and <i>Lolium perenne</i>)</b>	Low fertility, grazed by sheep	New Zealand	150	0-10	Barker et al. (1988)
<b>Pasture (mainly <i>Phalaris aquatic</i> and <i>Trifolium</i> spp.)</b>	High fertility, grazed by sheep	NSW, Australia	24	0-75	Greenwood and Hutchinson (1998)
			90	0-5	
			4	65-75	
<b>Annual ryegrass (<i>L. rigidum</i>)</b>	High fertility, ungrazed	Victoria, Australia	4	0-110	Ridley and Simpson (1994)
<b>Annual pasture (<i>Hordeum leporinum</i> and <i>Lolium</i> spp.)</b>	Low fertility, ungrazed	NSW, Australia	3	0-55	(Prathapar et al., 1989)

*Average root diameter*

Typically, roots with a smaller diameter have a faster turnover time due to a higher contact with the soil (Gill et al., 2002). This tight coupling between root diameter and longevity has been established predominantly in tree and shrub root systems (Gill et al., 2002), with much less known about grass systems. Gill et al. (2002) confirmed that in grass systems, roots with diameters >0.4 mm had a greater longevity compared with diameters <0.4 mm. They did not observe a difference in longevity between roots of diameter <0.2 mm and 0.2-0.4 mm.

Average root diameters ranged between 0.15 and 0.62 mm with a plot average of 0.21 mm. Most of the variation in the data can be explained by a linear mixed effects model considering base grass, season and depth which are further explored below. These values were similar to measurements made in a study on *Bouteloua*

*gracilis*, a perennial C<sub>4</sub> grass, which had a diameter range of 0.1-0.85 mm with the majority in the 0.15-0.25 mm range (Gill et al., 2002; Hill et al., 2006). Average diameter varied significantly between treatments ( $P = 0.0016$ , Figure 4.12), however, there were no differences between individual treatments. The significant treatment effect was due to associated with depth, base grass or herbs (see below).

Average diameter changed significantly with depth ( $P < 0.0001$ , Figure 4.13), differences between depth increments occurring between the maximum at 10-20 cm depth and the lower three depths (30-40, 40-50, 50-60 cm). Therefore, there was no consistent trend down the profile. This was similar to Gill et al. (2002) who concluded that depth was not a significant factor in determining root diameter and therefore, explaining the turnover rate of roots.

In plots where tall fescue as the base grass, there was a significantly greater average root diameter (mean =  $0.22 \pm 0.003$  mm) compared to plots with a ryegrass base (mean =  $0.19 \pm 0.003$  mm,  $P = 0.0001$ , Figure 4.14). While highly significant, the difference in diameter is actually very small (0.03 mm) and the ecological importance of such a small difference is unknown and possibly modest. However, based on the theory that root diameter and longevity are closely coupled, Gill et al. (2002) suggested that an increase in diameter of approximately 0.10 mm would reduce the likelihood of mortality by 6% of an individual root. In contrast, there was no significant difference in root diameter with the presence of herbs (chicory and plantain) ( $P = 0.52$ , Figure 4.15). Considering the suggestion of Gill et al., that tenths of a millimetre could potentially alter root longevity in soil, tall fescue may have an increased root longevity in soil. But whether the small increase in root diameter for tall fescue plots would have increased longevity cannot be determined here.

#### *Specific root length*

Specific root length (SRL) is the root length per dry mass of roots so that pastures with high root length and low diameter have high SRL compared to pastures with large taprooted species (low SRL). Large taproots have less surface area in contact with the soil matrix and interactions with soil biota strongly influence the

## CHAPTER FOUR: ROOT BIOMASS UNDER A RANGE OF PASTURE SWARDS

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longevity of a root in soil (Eissenstat et al., 2000). Across all treatments, SRL averaged  $171 \pm 3 \text{ m g}^{-1}$  with a range of 25-414  $\text{m g}^{-1}$ . Changes in SRL were most parsimoniously explained by a model considering base grass, season and depth; the individual effects of these parameters on SRL are explored further below. SRL increased significantly with depth ( $P < 0.0001$ , Figure 4.18). An increase in depth is generally related to an increase in diameter and root density due to increased mechanical pressures of soil lower in the profile (Crush & Nichols, 2010).

Similar to average diameter and root length, SRL was dependent on the presence of tall fescue ( $P < 0.0001$ , Figure 4.19). Plots with tall fescue as a base grass had a SRL with a mean of  $146 \pm 3 \text{ m g}^{-1}$ , which was less than ryegrass based plots (mean =  $195 \pm 4 \text{ m g}^{-1}$ ). Also consistent with average diameter and length, there was no significant difference in specific root length in plots with the presence or absence of herb species i.e. chicory and plantain ( $P = 0.63$ , Figure 4.20). There is limited data on grazed pastoral systems to compare to the current study. A study looking at the response of roots to different phosphorus and nitrogen additions to pastures found SRL's increased by up to 30% with low nutrient availability and reached up to  $400 \text{ m g}^{-1}$  with considerable variation (Hill et al., 2006). Lower SRL at Scott Farm might then be attributed to the higher fertility in this trial. Specific root length increased significantly with depth ( $P < 0.0001$ , Figure 4.19).

### *Overview of root characteristics*

When considering all measured root characteristics (Table 4.5), plots with tall fescue as a base grass had lower root length and specific root length and higher average diameter than plots dominated by ryegrass. These characteristics are likely to increase residence time of roots in soil (Bardgett et al., 2014; Gill et al., 2002). Lower RLD and higher average diameter indicate a higher allocation to root C than high RLD and diameter, which is a response expected of a drought tolerant plant such as tall fescue (Karcher et al., 2008). Increased mechanical pressures resulting from a larger diameter could lead to greater tissue density which is chemically more difficult to decompose due to higher lignin content and therefore will promote longer residence time in the soil (Bardgett et al., 2014).

**Table 4.5 Summary of scanned root characteristics for tall fescue and ryegrass base treatments. Values are averages for the full profile (0- 0.6 m)**

	Tall Fescue base	Ryegrass base	P-value
<b>Root length density</b> (cm cm <sup>-3</sup> )	5.6 (0.3)	6.9 (0.3)	0.039
<b>Average diameter</b> (mm)	0.22 (0.003)	0.19 (0.003)	0.0001
<b>SRL (m g<sup>-1</sup> of roots)</b>	146.3 (2.9)	195.1 (4.2)	<0.0001

\* Numbers in parentheses are the standard error of the mean.

#### 4.5.4 Implications for increased C stocks

While inputs of C from roots can be estimated from differences in root biomass with season, estimating potential for C stabilisation in soil is difficult. Measuring rates of C stabilisation in soils is difficult due to relatively small changes that might occur against a large background of total C. Currently most of the literature is based on the modelling or indirect measures of soil organic matter stabilisation in soil (Rasse et al., 2005; Six et al., 2002). SOM stabilisation is dependent on many properties including the nature of the C source, climate and could vary between soil types due to different physical and chemical soil properties.

In the current study, root biomass and root characteristics were measured to determine the amount and nature of root biomass and therefore give an indication of how this C enters the soil. The current study ranged from 248 to 2334 kg C ha<sup>-1</sup> across all plots with a difference between herb and non-herb plots of 500 kg C ha<sup>-1</sup> in contrast to McNally et al., who reported a difference of 853 kg C ha<sup>-1</sup> between ryegrass/clover and the mixed sward. It is important to emphasise that this is not a measure of C stabilisation and rather the input of biomass into the soil. Much of this C will likely be mineralised to CO<sub>2</sub> and only a small portion stabilised in to soil C (Six et al., 2002).

Specific species combinations of species appeared to alter root biomass and inputs. Tall fescue as a base grass resulted in lower root length and SRL, while driving a higher average diameter and no influence on total root biomass (Table

4.5). This was in contrast to ryegrass-based plots which had a higher root length and SRL and a lower average diameter, therefore, ryegrass reduces root biomass residence time in soil and promoting decomposition, enabling root C to be available for storage in soil. The strongest species effect was the influence of herb species, chicory and plantain, on root biomass. Herb treatments had significantly lower root biomass compared with treatments without herbs and the reason for this difference was not clear. This herb effect may also reflect a lower probability of sampling tap roots compared with fine rooted grasses given the sampling procedure used here.

While herb species are selected for their high above-ground production fast establishment and drought tolerance (Powell et al., 2007), in this study, it appeared that they provide less potential for increasing C inputs in to soils compared with tall fescue and ryegrass based clover mixed pastures. This was in contrast to findings by McNally et al. (2014) who did find greater inputs to soils in plots with herbs and other pasture species including lucerne. The relative importance of different pasture species to below ground C inputs needs further attention. Additionally, studies using larger coring approaches and pastures with higher abundance of herbs and lucerne could be conducted to test this hypothesis to ensure results reported here were not confounded by inadequate sampling methodology.

## **4.6 Conclusions**

Root biomass and root characteristics were determined for 14 different species mixes in a grazed small plot trial. Differing species mixes were chosen to potentially increase the below-ground productivity i.e. increase root biomass. Highly significant declines in root biomass with depth were present in all treatments and biomass maximum was in early summer (similar to Gentile et al. (2003), McNally et al. (2014), Mueller et al. (2013b)). From season maximum and minimum values, seasonal turnover estimated the amount of root C available for potential stabilisation in soil. This study showed that there was a significant difference in seasonal root biomass and therefore available C with the presence of herb species, chicory and plantain. Herb presence resulted in a lower root biomass

compared with treatments without herbs, while there was no effect of base grass. This effect was in contrast to McNally et al. (2014) who found that an increase in diversity (including herbs) resulted in an increased root biomass. McNally et al. (2014) attributed this increased root biomass to higher abundance of lucerne. Lucerne was in low abundance in the current trial.

Root characteristics of six of the 14 treatments were also determined. Plots with tall fescue as a base grass had significantly lower total root length, specific root length and had a higher average diameter compared to plots with ryegrass as a base grass. This suggests that tall fescue will have a greater residence time in soil due to an increased C allocation to roots by the plant. A plant will produce roots of greater diameter and lower SRL if it is in an environment which is resource deficient, because of this the lignin and cellulose content in the root material will be higher therefore making it more difficult to decompose (Bardgett et al., 2014).

While herb species have been used for their benefits in above-ground production, the current results call into question their potential for increasing soil C via increased root biomass inputs. However sampling methodology i.e. small diameter cores may have under estimated the root biomass present. Presence of herb species reduced the amount of biomass in soil compared with plots without herbs, however there were no differences in root characteristics suggesting little difference in turn over. The use of tall fescue as a base grass resulted in no difference in root biomass but significant differences in root characteristics. While in some cases small differences in characteristics, it is suggested that tall fescue will potentially increase the residence time of root biomass in soil when compared with ryegrass based pastures.



# Chapter Five. Conclusions and Future Research

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## 5.1 Conclusions

Recently, there has been interest in the use of diverse pastures for increasing production and root inputs that could enhance soil C stocks (Steinbeiss et al., 2008). Roots are considered to be the main contributor to soil C and therefore grassland research has focused on methods for increasing below-ground productivity (Rasse et al., 2005). As root biomass is considered the ‘hidden half’ of ecosystems, accessing root biomass has limited our ability to obtain adequate datasets for determining below-ground structure and functioning. Destructive root sampling techniques such as digging of pits and coring have been used since the 1970’s, however; these methods are limited to analysis of standing biomass and rooting characteristics.

Much root biomass research has been focused on natural grassland ecosystems, with much less information about agricultural grazed pastures. Pastoral agriculture in New Zealand has traditionally been based on a ryegrass/clover mix with a more recent adoption of mixed/diverse swards in parts of farms to provide feed during dry periods (Woodward et al., 2013). Whether these new sward types have more or less root biomass and greater turnover is poorly known. The main objective of this research was to determine whether different sward mixes had increased root biomass. Root biomass was measured seasonally at a grazed trial of 14 mixes of different pasture species. While differences in root biomass between specific combinations were difficult to determine, the main finding was that where herb species, (chicory and plantain), were present in treatments, root biomass was significantly lower ( $2657 \pm 120 \text{ kg DM ha}^{-1}$ ) than treatments without herbs ( $3600 \pm 154 \text{ kg DM ha}^{-1}$ ,  $P < 0.001$ ). These differences were only constrained to the topsoil (0-10 cm) samples. This difference in herb biomass was in contrast to McNally et al. (2014) who sampled an adjacent large plot trial at Scott Farm, and compared a mixed sward (including herbs) and a standard ryegrass/clover pasture.

## CHAPTER FIVE: CONCLUSIONS AND FUTURE RESEARCH

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McNally et al. (2014) found that the mixed sward pasture had a higher root biomass compared with the standard ryegrass/clover pasture. The lower biomass in the herb species treatments in the current study was in contrast to McNally et al. who found greater biomass in the mixed sward, this is thought to be driven by the greater abundance of lucerne in the McNally et al. study which was largely absent in the current study. Additionally, in the current study a smaller sampling corer (0.0254 m) was used than the study by McNally et al. who used a 0.05 m corer. This smaller corer may have underestimated tap roots of lucerne (see section 5.2).

The second objective was to determine rooting characteristics of a subset of the 14 treatments measuring root length density, average diameter and specific root length (SRL). Six treatments were assessed including: ryegrass standard, ryegrass complex, ryegrass herbs, tall fescue standard, tall fescue complex and tall fescue herbs. Significant differences in root characteristics occurred between treatments with different base grasses. When tall fescue was the base grass there was a lower root length density, SRL and a larger average diameter compared with plots which had ryegrass as a base species (summarised in Table 4.5). Larger roots along with low SRL are considered to have increased longevity in soil, (Eissenstat et al., 2000). While significant differences in average diameter were only 0.03 mm between tall fescue and ryegrass plots, Gill et al. (2002), suggested that differences of only a few tenths of a millimetre in diameter could change the longevity of an individual root. These results suggest that the use of tall fescue as a base grass in pastures may promote the increased longevity of root biomass in soils and therefore lower turnover.

An estimate of the annual root biomass turnover can be made by calculating the difference between the maximum and minimum root biomass across the year. Maximum generally occurred in summer and minimum was measured in winter. Then, using a 40% C content of root biomass from McNally et al. (2014), an estimate of the mass of C being made available for stabilisation was calculated. Average root C input for each treatment ranged from 430 and 1880 C kg ha<sup>-1</sup>. The main treatment effect observed was that there was a lower root C when herb species were present compared with plots without herbs ( $P < 0.001$ ). There are

very few studies which measure soil C inputs from root biomass and further research would be required to confirm the observed species effects.

## 5.2 Future research

### *Reflections on current research*

The main trend in biomass found in this research was a lower biomass in plots with chicory and plantain present. Due to the experimental design, it was not possible to determine the mechanism for this effect. A possible reason was due to a decreased probability of adequately sampling taproots of the herb species due to use of a relatively small corer (0.0254 m). To improve sampling, a larger diameter corer could be used to capture large taproots more representatively. An alternative could be to increase the number of cores sampled per plot. However, increasing the number of cores in such a small area could be practically difficult both because of the physical effort and increasing the potential to intercept old core holes in subsequent samplings. Increasing sampling intensity was limited by available resources; in the current study more than 2500 cores were taken to 60 cm, representing nearly 1 m<sup>3</sup> of soil for subsequent root washing and analysis.

Toward the end of the trial there was obvious visual invasion of weed species and it was evident that the sown species were not in the same abundance as at the initiation of the trial. Management to maintain the intended species composition would make the resulting root biomass and root characteristic data more representative of initial treatments imposed. Alternatively, measures of above-ground abundance taken at each sampling could be correlated with root biomass obtained in the current study to determine whether the root biomass present was a direct result of the sown species.

### *Broader perspectives*

Root biomass in treatments including herbs was lower than those without herbs. This is in contrast to McNally et al. (2014) who found a mixed sward had a greater root biomass compared with standard ryegrass/clover pastures. This difference in biomass was predominantly attributed to the abundance of lucerne.

## CHAPTER FIVE: CONCLUSIONS AND FUTURE RESEARCH

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The trial studied by McNally et al. had a much higher abundance of lucerne in the sward than the current trial. Further research could involve determining the direct effect of lucerne in grazed pasture on total root biomass.

While root biomass sampling is not a complex process, it is time consuming to measure and has limited ability to describe the turnover of roots in soil. Methods such as minirhizotron can be used to measure growth and turnover of roots without disturbing the roots (Taylor et al., 2014). There are also limitations in the accuracy of the conversion of root biomass to soil C using the assumption that 40% of the biomass is C. This proportion will vary with individual species and therefore an average value is useful for estimations but C/N analyses of individual species would strengthen estimation of C stocks and turnover.

There continues to be debate in the grassland ecosystem literature about the drivers of increased above- and below-ground production with increasing species richness (Darwin, 1859; Fornara & Tilman, 2008; Tilman et al., 2006). While some authors attribute increased root production purely to an increase in diversity, others argue that it is more a result of functional group presence and therefore niche complementarity (Fornara & Tilman, 2008). Little work of the same nature has been completed in intensively grazed pastures common in New Zealand agriculture. The potential benefits of using mixed sward pastures is being explored by farmers and include possible increased production during different seasons and potential mitigation of greenhouse gas emissions. However, the precise nature and mechanisms by which these benefits might occur is largely unknown. Limited prospects for expansion into new land, growing populations and threats of climate change will require solutions such as these to be investigated.

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# Appendices

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# Appendix A: Root biomass raw data

Table A.1. Raw root biomass data including all sample identifiers and dry matter in g/sample (0.0076m<sup>2</sup>) for sample depth and kg ha<sup>-1</sup>.

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	1	RGHB	0-10	Rye	Herbs	2.11	2770
2013	December	1	1	RGHB	10-20	Rye	Herbs	0.41	543
2013	December	1	1	RGHB	20-30	Rye	Herbs	0.09	116
2013	December	1	1	RGHB	30-40	Rye	Herbs	0.07	96
2013	December	1	1	RGHB	40-50	Rye	Herbs	0.05	68
2013	December	1	1	RGHB	50-60	Rye	Herbs	0.04	50
2013	December	1	2	PGLU	0-10	Prairie	No_herbs	1.33	1753
2013	December	1	2	PGLU	10-20	Prairie	No_herbs	0.70	924
2013	December	1	2	PGLU	20-30	Prairie	No_herbs	0.36	477
2013	December	1	2	PGLU	30-40	Prairie	No_herbs	0.23	297
2013	December	1	2	PGLU	40-50	Prairie	No_herbs	0.15	199
2013	December	1	2	PGLU	50-60	Prairie	No_herbs	0.08	102
2013	December	1	3	RGLA	0-10	Rye	No_herbs	3.70	4870
2013	December	1	3	RGLA	10-20	Rye	No_herbs	1.10	1448
2013	December	1	3	RGLA	20-30	Rye	No_herbs	0.35	461
2013	December	1	3	RGLA	30-40	Rye	No_herbs	0.18	239

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	3	RGLA	40-50	Rye	No_herbs	0.09	114
2013	December	1	3	RGLA	50-60	Rye	No_herbs	0.01	9
2013	December	1	4	TFLB	0-10	TF	No_herbs	3.58	4709
2013	December	1	4	TFLB	10-20	TF	No_herbs	0.84	1110
2013	December	1	4	TFLB	20-30	TF	No_herbs	0.29	381
2013	December	1	4	TFLB	30-40	TF	No_herbs	0.16	204
2013	December	1	4	TFLB	40-50	TF	No_herbs	0.15	201
2013	December	1	4	TFLB	50-60	TF	No_herbs	0.14	190
2013	December	1	5	RGST	0-10	Rye	No_herbs	2.40	3161
2013	December	1	5	RGST	10-20	Rye	No_herbs	0.61	800
2013	December	1	5	RGST	20-30	Rye	No_herbs	0.18	238
2013	December	1	5	RGST	30-40	Rye	No_herbs	0.06	77
2013	December	1	5	RGST	40-50	Rye	No_herbs	0.06	78
2013	December	1	5	RGST	50-60	Rye	No_herbs	0.06	77
2013	December	1	6	TFGR	0-10	TF	No_herbs	2.28	2994
2013	December	1	6	TFGR	10-20	TF	No_herbs	0.64	843

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	6	TFGR	20-30	TF	No_herbs	0.23	298
2013	December	1	6	TFGR	30-40	TF	No_herbs	0.14	179
2013	December	1	6	TFGR	40-50	TF	No_herbs	0.12	154
2013	December	1	6	TFGR	50-60	TF	No_herbs	0.04	49
2013	December	1	7	TFCO	0-10	TF	Herbs	2.05	2698
2013	December	1	7	TFCO	10-20	TF	Herbs	0.50	652
2013	December	1	7	TFCO	20-30	TF	Herbs	0.19	255
2013	December	1	7	TFCO	30-40	TF	Herbs	0.13	174
2013	December	1	7	TFCO	40-50	TF	Herbs	0.05	63
2013	December	1	7	TFCO	50-60	TF	Herbs	0.06	77
2013	December	1	8	TFHB	0-10	TF	Herbs	1.52	1997
2013	December	1	8	TFHB	10-20	TF	Herbs	0.56	738
2013	December	1	8	TFHB	20-30	TF	Herbs	0.20	262
2013	December	1	8	TFHB	30-40	TF	Herbs	0.20	267
2013	December	1	8	TFHB	40-50	TF	Herbs	0.16	211
2013	December	1	8	TFHB	50-60	TF	Herbs	0.10	131

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	9	TFST	0-10	TF	No_herbs	2.29	3018
2013	December	1	9	TFST	10-20	TF	No_herbs	0.57	751
2013	December	1	9	TFST	20-30	TF	No_herbs	0.28	366
2013	December	1	9	TFST	30-40	TF	No_herbs	0.11	148
2013	December	1	9	TFST	40-50	TF	No_herbs	0.09	117
2013	December	1	9	TFST	50-60	TF	No_herbs	0.08	106
2013	December	1	10	RGLB	0-10	Rye	No_herbs	3.32	4370
2013	December	1	10	RGLB	10-20	Rye	No_herbs	0.61	804
2013	December	1	10	RGLB	20-30	Rye	No_herbs	0.36	479
2013	December	1	10	RGLB	30-40	Rye	No_herbs	0.20	264
2013	December	1	10	RGLB	40-50	Rye	No_herbs	0.11	140
2013	December	1	10	RGLB	50-60	Rye	No_herbs	0.08	108
2013	December	1	11	GRLH	0-10	Prairie	Herbs	1.44	1897
2013	December	1	11	GRLH	10-20	Prairie	Herbs	0.54	712
2013	December	1	11	GRLH	20-30	Prairie	Herbs	0.12	157
2013	December	1	11	GRLH	30-40	Prairie	Herbs	0.07	96

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	11	GRLH	40-50	Prairie	Herbs	0.05	71
2013	December	1	11	GRLH	50-60	Prairie	Herbs	0.06	83
2013	December	1	12	RGGR	0-10	Rye	No_herbs	2.91	3834
2013	December	1	12	RGGR	10-20	Rye	No_herbs	0.56	738
2013	December	1	12	RGGR	20-30	Rye	No_herbs	0.23	303
2013	December	1	12	RGGR	30-40	Rye	No_herbs	0.14	179
2013	December	1	12	RGGR	40-50	Rye	No_herbs	0.13	171
2013	December	1	12	RGGR	50-60	Rye	No_herbs	0.11	143
2013	December	1	13	RGCO	0-10	Rye	Herbs	2.33	3071
2013	December	1	13	RGCO	10-20	Rye	Herbs	0.39	507
2013	December	1	13	RGCO	20-30	Rye	Herbs	0.14	189
2013	December	1	13	RGCO	30-40	Rye	Herbs	0.11	144
2013	December	1	13	RGCO	40-50	Rye	Herbs	0.05	66
2013	December	1	13	RGCO	50-60	Rye	Herbs	0.04	58
2013	December	1	14	TFLA	0-10	TF	No_herbs	2.57	3375
2013	December	1	14	TFLA	10-20	TF	No_herbs	0.23	296

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	14	TFLA	20-30	TF	No_herbs	1.73	2275
2013	December	1	14	TFLA	30-40	TF	No_herbs	0.12	161
2013	December	1	14	TFLA	40-50	TF	No_herbs	0.14	188
2013	December	1	14	TFLA	50-60	TF	No_herbs	0.11	149
2013	December	1	15	RGST	0-10	Rye	No_herbs	2.31	3039
2013	December	1	15	RGST	10-20	Rye	No_herbs	0.50	664
2013	December	1	15	RGST	20-30	Rye	No_herbs	0.19	248
2013	December	1	15	RGST	30-40	Rye	No_herbs	0.09	124
2013	December	1	15	RGST	40-50	Rye	No_herbs	0.05	61
2013	December	1	15	RGST	50-60	Rye	No_herbs	0.03	34
2013	December	1	16	TFST	0-10	TF	No_herbs	1.98	2603
2013	December	1	16	TFST	10-20	TF	No_herbs	0.44	585
2013	December	1	16	TFST	20-30	TF	No_herbs	0.13	174
2013	December	1	16	TFST	30-40	TF	No_herbs	0.05	70
2013	December	1	16	TFST	40-50	TF	No_herbs	0.04	47
2013	December	1	16	TFST	50-60	TF	No_herbs	0.01	18

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	17	PGLU	0-10	Prairie	No_herbs	1.78	2345
2013	December	1	17	PGLU	10-20	Prairie	No_herbs	0.54	717
2013	December	1	17	PGLU	20-30	Prairie	No_herbs	0.15	198
2013	December	1	17	PGLU	30-40	Prairie	No_herbs	0.13	165
2013	December	1	17	PGLU	40-50	Prairie	No_herbs	0.07	87
2013	December	1	17	PGLU	50-60	Prairie	No_herbs	0.08	100
2013	December	1	18	TFHB	0-10	TF	Herbs	2.01	2645
2013	December	1	18	TFHB	10-20	TF	Herbs	0.62	818
2013	December	1	18	TFHB	20-30	TF	Herbs	0.20	266
2013	December	1	18	TFHB	30-40	TF	Herbs	0.07	87
2013	December	1	18	TFHB	40-50	TF	Herbs	0.13	167
2013	December	1	18	TFHB	50-60	TF	Herbs	0.12	159
2013	December	1	19	RGLA	0-10	Rye	No_herbs	3.41	4481
2013	December	1	19	RGLA	10-20	Rye	No_herbs	0.64	847
2013	December	1	19	RGLA	20-30	Rye	No_herbs	0.16	214
2013	December	1	19	RGLA	30-40	Rye	No_herbs	0.20	260

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	19	RGLA	40-50	Rye	No_herbs	0.12	159
2013	December	1	19	RGLA	50-60	Rye	No_herbs	0.08	99
2013	December	1	20	RGLB	0-10	Rye	No_herbs	4.52	5945
2013	December	1	20	RGLB	10-20	Rye	No_herbs	0.56	737
2013	December	1	20	RGLB	20-30	Rye	No_herbs	0.38	494
2013	December	1	20	RGLB	30-40	Rye	No_herbs	0.24	314
2013	December	1	20	RGLB	40-50	Rye	No_herbs	0.06	84
2013	December	1	20	RGLB	50-60	Rye	No_herbs	0.05	59
2013	December	1	21	RGHB	0-10	Rye	Herbs	2.17	2857
2013	December	1	21	RGHB	10-20	Rye	Herbs	0.44	579
2013	December	1	21	RGHB	20-30	Rye	Herbs	0.32	426
2013	December	1	21	RGHB	30-40	Rye	Herbs	0.10	135
2013	December	1	21	RGHB	40-50	Rye	Herbs	0.08	101
2013	December	1	21	RGHB	50-60	Rye	Herbs	0.08	110
2013	December	1	22	TFLA	0-10	TF	No_herbs	3.26	4284
2013	December	1	22	TFLA	10-20	TF	No_herbs	0.76	995

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	22	TFLA	20-30	TF	No_herbs	0.33	430
2013	December	1	22	TFLA	30-40	TF	No_herbs	0.17	221
2013	December	1	22	TFLA	40-50	TF	No_herbs	0.16	217
2013	December	1	22	TFLA	50-60	TF	No_herbs	0.13	166
2013	December	1	23	TFLB	0-10	TF	No_herbs	2.30	3027
2013	December	1	23	TFLB	10-20	TF	No_herbs	0.54	707
2013	December	1	23	TFLB	20-30	TF	No_herbs	0.23	307
2013	December	1	23	TFLB	30-40	TF	No_herbs	0.20	259
2013	December	1	23	TFLB	40-50	TF	No_herbs	0.12	159
2013	December	1	23	TFLB	50-60	TF	No_herbs	0.07	92
2013	December	1	24	RGCO	0-10	Rye	Herbs	1.46	1923
2013	December	1	24	RGCO	10-20	Rye	Herbs	0.51	667
2013	December	1	24	RGCO	20-30	Rye	Herbs	0.12	162
2013	December	1	24	RGCO	30-40	Rye	Herbs	0.04	47
2013	December	1	24	RGCO	40-50	Rye	Herbs	0.04	58
2013	December	1	24	RGCO	50-60	Rye	Herbs	0.03	45

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	25	TFCO	0-10	TF	Herbs	0.98	1292
2013	December	1	25	TFCO	10-20	TF	Herbs	0.68	898
2013	December	1	25	TFCO	20-30	TF	Herbs	0.17	225
2013	December	1	25	TFCO	30-40	TF	Herbs	0.05	66
2013	December	1	25	TFCO	40-50	TF	Herbs	0.04	53
2013	December	1	25	TFCO	50-60	TF	Herbs	0.04	47
2013	December	1	26	TFGR	0-10	TF	No_herbs	2.85	3751
2013	December	1	26	TFGR	10-20	TF	No_herbs	0.69	912
2013	December	1	26	TFGR	20-30	TF	No_herbs	0.20	266
2013	December	1	26	TFGR	30-40	TF	No_herbs	0.14	190
2013	December	1	26	TFGR	40-50	TF	No_herbs	0.09	117
2013	December	1	26	TFGR	50-60	TF	No_herbs	0.11	143
2013	December	1	27	RGGR	0-10	Rye	No_herbs	2.99	3937
2013	December	1	27	RGGR	10-20	Rye	No_herbs	0.93	1219
2013	December	1	27	RGGR	20-30	Rye	No_herbs	0.27	352
2013	December	1	27	RGGR	30-40	Rye	No_herbs	0.12	157

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	27	RGGR	40-50	Rye	No_herbs	0.09	116
2013	December	1	27	RGGR	50-60	Rye	No_herbs	0.05	65
2013	December	1	28	GRLH	0-10	Prairie	Herbs	1.44	1896
2013	December	1	28	GRLH	10-20	Prairie	Herbs	0.51	667
2013	December	1	28	GRLH	20-30	Prairie	Herbs	0.31	406
2013	December	1	28	GRLH	30-40	Prairie	Herbs	0.05	68
2013	December	1	28	GRLH	40-50	Prairie	Herbs	0.06	73
2013	December	1	28	GRLH	50-60	Prairie	Herbs	0.03	42
2013	December	1	29	TFHB	0-10	TF	Herbs	1.25	1645
2013	December	1	29	TFHB	10-20	TF	Herbs	0.23	299
2013	December	1	29	TFHB	20-30	TF	Herbs	0.10	130
2013	December	1	29	TFHB	30-40	TF	Herbs	0.04	47
2013	December	1	29	TFHB	40-50	TF	Herbs	0.05	61
2013	December	1	29	TFHB	50-60	TF	Herbs	0.05	63
2013	December	1	30	RGLB	0-10	Rye	No_herbs	3.48	4573
2013	December	1	30	RGLB	10-20	Rye	No_herbs	0.61	800

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	30	RGLB	20-30	Rye	No_herbs	0.63	827
2013	December	1	30	RGLB	30-40	Rye	No_herbs	0.17	223
2013	December	1	30	RGLB	40-50	Rye	No_herbs	0.10	137
2013	December	1	30	RGLB	50-60	Rye	No_herbs	0.15	193
2013	December	1	31	RGST	0-10	Rye	No_herbs	2.77	3648
2013	December	1	31	RGST	10-20	Rye	No_herbs	0.74	972
2013	December	1	31	RGST	20-30	Rye	No_herbs	0.17	230
2013	December	1	31	RGST	30-40	Rye	No_herbs	0.08	109
2013	December	1	31	RGST	40-50	Rye	No_herbs	0.06	74
2013	December	1	31	RGST	50-60	Rye	No_herbs	0.06	82
2013	December	1	32	TFST	0-10	TF	No_herbs	3.37	4431
2013	December	1	32	TFST	10-20	TF	No_herbs	0.63	828
2013	December	1	32	TFST	20-30	TF	No_herbs	0.15	203
2013	December	1	32	TFST	30-40	TF	No_herbs	0.06	78
2013	December	1	32	TFST	40-50	TF	No_herbs	0.05	61
2013	December	1	32	TFST	50-60	TF	No_herbs	0.05	60

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	33	TFLA	0-10	TF	No_herbs	2.45	3227
2013	December	1	33	TFLA	10-20	TF	No_herbs	0.75	982
2013	December	1	33	TFLA	20-30	TF	No_herbs	0.27	357
2013	December	1	33	TFLA	30-40	TF	No_herbs	0.15	197
2013	December	1	33	TFLA	40-50	TF	No_herbs	0.12	158
2013	December	1	33	TFLA	50-60	TF	No_herbs	0.06	81
2013	December	1	34	PGLU	0-10	Prairie	No_herbs	1.34	1767
2013	December	1	34	PGLU	10-20	Prairie	No_herbs	0.43	560
2013	December	1	34	PGLU	20-30	Prairie	No_herbs	0.21	280
2013	December	1	34	PGLU	30-40	Prairie	No_herbs	0.09	120
2013	December	1	34	PGLU	40-50	Prairie	No_herbs	0.04	58
2013	December	1	34	PGLU	50-60	Prairie	No_herbs	0.04	48
2013	December	1	35	GRLH	0-10	Prairie	Herbs	2.19	2881
2013	December	1	35	GRLH	10-20	Prairie	Herbs	0.40	526
2013	December	1	35	GRLH	20-30	Prairie	Herbs	0.14	182
2013	December	1	35	GRLH	30-40	Prairie	Herbs	0.12	161

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	35	GRLH	40-50	Prairie	Herbs	0.06	81
2013	December	1	35	GRLH	50-60	Prairie	Herbs	0.09	115
2013	December	1	36	RGLA	0-10	Rye	No_herbs	1.46	1924
2013	December	1	36	RGLA	10-20	Rye	No_herbs	0.33	437
2013	December	1	36	RGLA	20-30	Rye	No_herbs	0.14	181
2013	December	1	36	RGLA	30-40	Rye	No_herbs	0.06	84
2013	December	1	36	RGLA	40-50	Rye	No_herbs	0.07	95
2013	December	1	36	RGLA	50-60	Rye	No_herbs	0.06	83
2013	December	1	37	RGCO	0-10	Rye	Herbs	1.40	1839
2013	December	1	37	RGCO	10-20	Rye	Herbs	0.24	321
2013	December	1	37	RGCO	20-30	Rye	Herbs	0.22	285
2013	December	1	37	RGCO	30-40	Rye	Herbs	0.07	97
2013	December	1	37	RGCO	40-50	Rye	Herbs	0.03	38
2013	December	1	37	RGCO	50-60	Rye	Herbs	0.02	28
2013	December	1	38	RGGR	0-10	Rye	No_herbs	2.62	3444
2013	December	1	38	RGGR	10-20	Rye	No_herbs	0.58	760

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	38	RGGR	20-30	Rye	No_herbs	0.32	416
2013	December	1	38	RGGR	30-40	Rye	No_herbs	0.16	208
2013	December	1	38	RGGR	40-50	Rye	No_herbs	0.11	138
2013	December	1	38	RGGR	50-60	Rye	No_herbs	0.07	97
2013	December	1	39	TFCO	0-10	TF	Herbs	1.16	1527
2013	December	1	39	TFCO	10-20	TF	Herbs	0.36	474
2013	December	1	39	TFCO	20-30	TF	Herbs	0.13	169
2013	December	1	39	TFCO	30-40	TF	Herbs	0.06	74
2013	December	1	39	TFCO	40-50	TF	Herbs	0.05	60
2013	December	1	39	TFCO	50-60	TF	Herbs	0.05	59
2013	December	1	40	TFGR	0-10	TF	No_herbs	3.74	4919
2013	December	1	40	TFGR	10-20	TF	No_herbs	0.35	457
2013	December	1	40	TFGR	20-30	TF	No_herbs	0.19	253
2013	December	1	40	TFGR	30-40	TF	No_herbs	0.06	77
2013	December	1	40	TFGR	40-50	TF	No_herbs	0.05	72
2013	December	1	40	TFGR	50-60	TF	No_herbs	0.08	100

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2013	December	1	41	RGHB	0-10	Rye	Herbs	2.03	2666
2013	December	1	41	RGHB	10-20	Rye	Herbs	0.36	472
2013	December	1	41	RGHB	20-30	Rye	Herbs	0.14	182
2013	December	1	41	RGHB	30-40	Rye	Herbs	0.06	83
2013	December	1	41	RGHB	40-50	Rye	Herbs	0.08	105
2013	December	1	41	RGHB	50-60	Rye	Herbs	0.03	37
2013	December	1	42	TFLB	0-10	TF	No_herbs	2.02	2660
2013	December	1	42	TFLB	10-20	TF	No_herbs	0.29	385
2013	December	1	42	TFLB	20-30	TF	No_herbs	0.16	206
2013	December	1	42	TFLB	30-40	TF	No_herbs	0.06	73
2013	December	1	42	TFLB	40-50	TF	No_herbs	0.10	125
2013	December	1	42	TFLB	50-60	TF	No_herbs	0.14	180
2014	April	2	1	RGHB	0-10	Rye	Herbs	2.12	2792
2014	April	2	1	RGHB	10-20	Rye	Herbs	0.68	900
2014	April	2	1	RGHB	20-30	Rye	Herbs	0.39	509
2014	April	2	1	RGHB	30-40	Rye	Herbs	0.09	123

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	1	RGHB	40-50	Rye	Herbs	0.07	97
2014	April	2	1	RGHB	50-60	Rye	Herbs	0.27	357
2014	April	2	2	PGLU	0-10	Prairie	No_herbs	2.29	3013
2014	April	2	2	PGLU	10-20	Prairie	No_herbs	0.52	689
2014	April	2	2	PGLU	20-30	Prairie	No_herbs	0.56	742
2014	April	2	2	PGLU	30-40	Prairie	No_herbs	0.20	263
2014	April	2	2	PGLU	40-50	Prairie	No_herbs	0.26	335
2014	April	2	2	PGLU	50-60	Prairie	No_herbs	0.06	76
2014	April	2	3	RGLA	0-10	Rye	No_herbs	2.34	3081
2014	April	2	3	RGLA	10-20	Rye	No_herbs	0.59	780
2014	April	2	3	RGLA	20-30	Rye	No_herbs	0.47	619
2014	April	2	3	RGLA	30-40	Rye	No_herbs	0.25	328
2014	April	2	3	RGLA	40-50	Rye	No_herbs	0.12	162
2014	April	2	3	RGLA	50-60	Rye	No_herbs	0.04	50
2014	April	2	4	TFLB	0-10	TF	No_herbs	3.00	3945
2014	April	2	4	TFLB	10-20	TF	No_herbs	0.62	813

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	4	TFLB	20-30	TF	No_herbs	0.23	306
2014	April	2	4	TFLB	30-40	TF	No_herbs	0.86	1132
2014	April	2	4	TFLB	40-50	TF	No_herbs	0.69	905
2014	April	2	4	TFLB	50-60	TF	No_herbs	0.20	263
2014	April	2	5	RGST	0-10	Rye	No_herbs	2.07	2726
2014	April	2	5	RGST	10-20	Rye	No_herbs	0.38	496
2014	April	2	5	RGST	20-30	Rye	No_herbs	0.17	224
2014	April	2	5	RGST	30-40	Rye	No_herbs	0.11	149
2014	April	2	5	RGST	40-50	Rye	No_herbs	0.04	54
2014	April	2	5	RGST	50-60	Rye	No_herbs	0.05	63
2014	April	2	6	TFGR	0-10	TF	No_herbs	1.26	1652
2014	April	2	6	TFGR	10-20	TF	No_herbs	0.30	401
2014	April	2	6	TFGR	20-30	TF	No_herbs	0.11	148
2014	April	2	6	TFGR	30-40	TF	No_herbs	0.09	120
2014	April	2	6	TFGR	40-50	TF	No_herbs	0.09	123
2014	April	2	6	TFGR	50-60	TF	No_herbs	0.05	61

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	7	TFCO	0-10	TF	Herbs	1.88	2471
2014	April	2	7	TFCO	10-20	TF	Herbs	0.47	619
2014	April	2	7	TFCO	20-30	TF	Herbs	0.19	256
2014	April	2	7	TFCO	30-40	TF	Herbs	0.11	139
2014	April	2	7	TFCO	40-50	TF	Herbs	0.15	200
2014	April	2	7	TFCO	50-60	TF	Herbs	0.17	220
2014	April	2	8	TFHB	0-10	TF	Herbs	2.05	2694
2014	April	2	8	TFHB	10-20	TF	Herbs	0.46	601
2014	April	2	8	TFHB	20-30	TF	Herbs	0.20	268
2014	April	2	8	TFHB	30-40	TF	Herbs	0.08	104
2014	April	2	8	TFHB	40-50	TF	Herbs	0.05	61
2014	April	2	8	TFHB	50-60	TF	Herbs	0.08	106
2014	April	2	9	TFST	0-10	TF	No_herbs	3.05	4013
2014	April	2	9	TFST	10-20	TF	No_herbs	0.60	794
2014	April	2	9	TFST	20-30	TF	No_herbs	0.37	493
2014	April	2	9	TFST	30-40	TF	No_herbs	0.10	136

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	9	TFST	40-50	TF	No_herbs	0.05	59
2014	April	2	9	TFST	50-60	TF	No_herbs	0.09	116
2014	April	2	10	RGLB	0-10	Rye	No_herbs	3.31	4356
2014	April	2	10	RGLB	10-20	Rye	No_herbs	0.44	579
2014	April	2	10	RGLB	20-30	Rye	No_herbs	0.36	471
2014	April	2	10	RGLB	30-40	Rye	No_herbs	0.18	235
2014	April	2	10	RGLB	40-50	Rye	No_herbs	0.11	143
2014	April	2	10	RGLB	50-60	Rye	No_herbs	0.11	149
2014	April	2	11	GRLH	0-10	Prairie	Herbs	1.40	1837
2014	April	2	11	GRLH	10-20	Prairie	Herbs	0.71	938
2014	April	2	11	GRLH	20-30	Prairie	Herbs	0.20	265
2014	April	2	11	GRLH	30-40	Prairie	Herbs	0.08	106
2014	April	2	11	GRLH	40-50	Prairie	Herbs	0.09	125
2014	April	2	11	GRLH	50-60	Prairie	Herbs	0.05	70
2014	April	2	12	RGGR	0-10	Rye	No_herbs	3.03	3983
2014	April	2	12	RGGR	10-20	Rye	No_herbs	0.27	356

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	12	RGGR	20-30	Rye	No_herbs	0.25	326
2014	April	2	12	RGGR	30-40	Rye	No_herbs	0.16	212
2014	April	2	12	RGGR	40-50	Rye	No_herbs	0.07	98
2014	April	2	12	RGGR	50-60	Rye	No_herbs	0.09	118
2014	April	2	13	RGCO	0-10	Rye	Herbs	2.34	3082
2014	April	2	13	RGCO	10-20	Rye	Herbs	0.23	299
2014	April	2	13	RGCO	20-30	Rye	Herbs	0.22	293
2014	April	2	13	RGCO	30-40	Rye	Herbs	0.03	43
2014	April	2	13	RGCO	40-50	Rye	Herbs	0.05	65
2014	April	2	13	RGCO	50-60	Rye	Herbs	0.08	111
2014	April	2	14	TFLA	0-10	TF	No_herbs	2.20	2893
2014	April	2	14	TFLA	10-20	TF	No_herbs	0.30	390
2014	April	2	14	TFLA	20-30	TF	No_herbs	0.10	134
2014	April	2	14	TFLA	30-40	TF	No_herbs	0.04	56
2014	April	2	14	TFLA	40-50	TF	No_herbs	0.09	117
2014	April	2	14	TFLA	50-60	TF	No_herbs	0.08	105

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	15	RGST	0-10	Rye	No_herbs	1.37	1797
2014	April	2	15	RGST	10-20	Rye	No_herbs	0.08	107
2014	April	2	15	RGST	20-30	Rye	No_herbs	0.04	49
2014	April	2	15	RGST	30-40	Rye	No_herbs	0.06	85
2014	April	2	15	RGST	40-50	Rye	No_herbs	0.14	183
2014	April	2	15	RGST	50-60	Rye	No_herbs	0.11	147
2014	April	2	16	TFST	0-10	TF	No_herbs	0.76	999
2014	April	2	16	TFST	10-20	TF	No_herbs	0.62	810
2014	April	2	16	TFST	20-30	TF	No_herbs	0.27	352
2014	April	2	16	TFST	30-40	TF	No_herbs	0.09	121
2014	April	2	16	TFST	40-50	TF	No_herbs	0.05	64
2014	April	2	16	TFST	50-60	TF	No_herbs	0.05	71
2014	April	2	17	PGLU	0-10	Prairie	No_herbs	1.31	1724
2014	April	2	17	PGLU	10-20	Prairie	No_herbs	0.05	62
2014	April	2	17	PGLU	20-30	Prairie	No_herbs	0.29	377
2014	April	2	17	PGLU	30-40	Prairie	No_herbs	0.03	39

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	17	PGLU	40-50	Prairie	No_herbs	0.11	142
2014	April	2	17	PGLU	50-60	Prairie	No_herbs	0.02	32
2014	April	2	18	TFHB	0-10	TF	Herbs	1.27	1667
2014	April	2	18	TFHB	10-20	TF	Herbs	0.11	143
2014	April	2	18	TFHB	20-30	TF	Herbs	0.04	47
2014	April	2	18	TFHB	30-40	TF	Herbs	0.09	118
2014	April	2	18	TFHB	40-50	TF	Herbs	0.06	76
2014	April	2	18	TFHB	50-60	TF	Herbs	0.11	146
2014	April	2	19	RGLA	0-10	Rye	No_herbs	2.46	3233
2014	April	2	19	RGLA	10-20	Rye	No_herbs	0.15	203
2014	April	2	19	RGLA	20-30	Rye	No_herbs	0.06	77
2014	April	2	19	RGLA	30-40	Rye	No_herbs	0.07	91
2014	April	2	19	RGLA	40-50	Rye	No_herbs	0.18	241
2014	April	2	19	RGLA	50-60	Rye	No_herbs	0.07	91
2014	April	2	20	RGLB	0-10	Rye	No_herbs	2.26	2974
2014	April	2	20	RGLB	10-20	Rye	No_herbs	0.17	225

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	20	RGLB	20-30	Rye	No_herbs	0.10	136
2014	April	2	20	RGLB	30-40	Rye	No_herbs	0.10	132
2014	April	2	20	RGLB	40-50	Rye	No_herbs	0.04	48
2014	April	2	20	RGLB	50-60	Rye	No_herbs	0.15	194
2014	April	2	21	RGHB	0-10	Rye	Herbs	2.33	3063
2014	April	2	21	RGHB	10-20	Rye	Herbs	0.12	163
2014	April	2	21	RGHB	20-30	Rye	Herbs	0.08	99
2014	April	2	21	RGHB	30-40	Rye	Herbs	0.15	198
2014	April	2	21	RGHB	40-50	Rye	Herbs	0.05	65
2014	April	2	21	RGHB	50-60	Rye	Herbs	0.07	89
2014	April	2	22	TFLA	0-10	TF	No_herbs	2.67	3512
2014	April	2	22	TFLA	10-20	TF	No_herbs	0.20	264
2014	April	2	22	TFLA	20-30	TF	No_herbs	0.10	131
2014	April	2	22	TFLA	30-40	TF	No_herbs	0.05	67
2014	April	2	22	TFLA	40-50	TF	No_herbs	0.08	104
2014	April	2	22	TFLA	50-60	TF	No_herbs	0.11	150

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	23	TFLB	0-10	TF	No_herbs	2.42	3187
2014	April	2	23	TFLB	10-20	TF	No_herbs	0.12	153
2014	April	2	23	TFLB	20-30	TF	No_herbs	0.14	180
2014	April	2	23	TFLB	30-40	TF	No_herbs	0.28	372
2014	April	2	23	TFLB	40-50	TF	No_herbs	0.13	174
2014	April	2	23	TFLB	50-60	TF	No_herbs	0.23	304
2014	April	2	24	RGCO	0-10	Rye	Herbs	1.48	1952
2014	April	2	24	RGCO	10-20	Rye	Herbs	0.08	100
2014	April	2	24	RGCO	20-30	Rye	Herbs	0.04	56
2014	April	2	24	RGCO	30-40	Rye	Herbs	0.02	24
2014	April	2	24	RGCO	40-50	Rye	Herbs	0.02	20
2014	April	2	24	RGCO	50-60	Rye	Herbs	0.03	42
2014	April	2	25	TFCO	0-10	TF	Herbs	1.33	1752
2014	April	2	25	TFCO	10-20	TF	Herbs	0.10	129
2014	April	2	25	TFCO	20-30	TF	Herbs	0.06	75
2014	April	2	25	TFCO	30-40	TF	Herbs	0.11	146

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	25	TFCO	40-50	TF	Herbs	0.01	16
2014	April	2	25	TFCO	50-60	TF	Herbs	0.03	38
2014	April	2	26	TFGR	0-10	TF	No_herbs	2.45	3217
2014	April	2	26	TFGR	10-20	TF	No_herbs	0.07	92
2014	April	2	26	TFGR	20-30	TF	No_herbs	0.06	82
2014	April	2	26	TFGR	30-40	TF	No_herbs	0.16	204
2014	April	2	26	TFGR	40-50	TF	No_herbs	0.05	69
2014	April	2	26	TFGR	50-60	TF	No_herbs	0.10	136
2014	April	2	27	RGGR	0-10	Rye	No_herbs	4.07	5350
2014	April	2	27	RGGR	10-20	Rye	No_herbs	0.10	125
2014	April	2	27	RGGR	20-30	Rye	No_herbs	0.08	108
2014	April	2	27	RGGR	30-40	Rye	No_herbs	0.04	58
2014	April	2	27	RGGR	40-50	Rye	No_herbs	0.03	39
2014	April	2	27	RGGR	50-60	Rye	No_herbs	0.06	82
2014	April	2	28	GRLH	0-10	Prairie	Herbs	1.66	2186
2014	April	2	28	GRLH	10-20	Prairie	Herbs	0.09	119

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	28	GRLH	20-30	Prairie	Herbs	0.02	20
2014	April	2	28	GRLH	30-40	Prairie	Herbs	0.06	73
2014	April	2	28	GRLH	40-50	Prairie	Herbs	0.05	60
2014	April	2	28	GRLH	50-60	Prairie	Herbs	0.03	44
2014	April	2	29	TFHB	0-10	TF	Herbs	0.08	108
2014	April	2	29	TFHB	10-20	TF	Herbs	0.31	403
2014	April	2	29	TFHB	20-30	TF	Herbs	0.14	189
2014	April	2	29	TFHB	30-40	TF	Herbs	0.01	13
2014	April	2	29	TFHB	40-50	TF	Herbs	0.05	63
2014	April	2	29	TFHB	50-60	TF	Herbs	0.03	35
2014	April	2	30	RGLB	0-10	Rye	No_herbs	0.29	378
2014	April	2	30	RGLB	10-20	Rye	No_herbs	0.09	120
2014	April	2	30	RGLB	20-30	Rye	No_herbs	0.04	53
2014	April	2	30	RGLB	30-40	Rye	No_herbs	0.04	59
2014	April	2	30	RGLB	40-50	Rye	No_herbs	0.12	164
2014	April	2	30	RGLB	50-60	Rye	No_herbs	0.11	144

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	31	RGST	0-10	Rye	No_herbs	1.49	1960
2014	April	2	31	RGST	10-20	Rye	No_herbs	0.09	118
2014	April	2	31	RGST	20-30	Rye	No_herbs	0.07	87
2014	April	2	31	RGST	30-40	Rye	No_herbs	0.11	141
2014	April	2	31	RGST	40-50	Rye	No_herbs	0.04	57
2014	April	2	31	RGST	50-60	Rye	No_herbs	0.05	67
2014	April	2	32	TFST	0-10	TF	No_herbs	0.89	1167
2014	April	2	32	TFST	10-20	TF	No_herbs	0.07	95
2014	April	2	32	TFST	20-30	TF	No_herbs	0.06	74
2014	April	2	32	TFST	30-40	TF	No_herbs	0.05	70
2014	April	2	32	TFST	40-50	TF	No_herbs	0.05	67
2014	April	2	32	TFST	50-60	TF	No_herbs	0.08	101
2014	April	2	33	TFLA	0-10	TF	No_herbs	1.08	1427
2014	April	2	33	TFLA	10-20	TF	No_herbs	0.07	95
2014	April	2	33	TFLA	20-30	TF	No_herbs	0.10	136
2014	April	2	33	TFLA	30-40	TF	No_herbs	0.06	78

Table B. Continued

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	33	TFLA	40-50	TF	No_herbs	0.03	35
2014	April	2	33	TFLA	50-60	TF	No_herbs	0.16	204
2014	April	2	34	PGLU	0-10	Prairie	No_herbs	1.23	1620
2014	April	2	34	PGLU	10-20	Prairie	No_herbs	0.09	120
2014	April	2	34	PGLU	20-30	Prairie	No_herbs	0.50	661
2014	April	2	34	PGLU	30-40	Prairie	No_herbs	0.03	46
2014	April	2	34	PGLU	40-50	Prairie	No_herbs	0.02	29
2014	April	2	34	PGLU	50-60	Prairie	No_herbs	0.06	73
2014	April	2	35	GRLH	0-10	Prairie	Herbs	0.88	1157
2014	April	2	35	GRLH	10-20	Prairie	Herbs	0.06	79
2014	April	2	35	GRLH	20-30	Prairie	Herbs	0.05	68
2014	April	2	35	GRLH	30-40	Prairie	Herbs	0.03	37
2014	April	2	35	GRLH	40-50	Prairie	Herbs	0.01	18
2014	April	2	35	GRLH	50-60	Prairie	Herbs	0.07	92
2014	April	2	36	RGLA	0-10	Rye	No_herbs	1.44	1892
2014	April	2	36	RGLA	10-20	Rye	No_herbs	0.07	94

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	36	RGLA	20-30	Rye	No_herbs	0.03	35
2014	April	2	36	RGLA	30-40	Rye	No_herbs	0.14	178
2014	April	2	36	RGLA	40-50	Rye	No_herbs	0.02	23
2014	April	2	36	RGLA	50-60	Rye	No_herbs	0.06	76
2014	April	2	37	RGCO	0-10	Rye	Herbs	2.14	2821
2014	April	2	37	RGCO	10-20	Rye	Herbs	0.05	70
2014	April	2	37	RGCO	20-30	Rye	Herbs	0.07	86
2014	April	2	37	RGCO	30-40	Rye	Herbs	0.03	45
2014	April	2	37	RGCO	40-50	Rye	Herbs	0.04	46
2014	April	2	37	RGCO	50-60	Rye	Herbs	0.02	30
2014	April	2	38	RGGR	0-10	Rye	No_herbs	1.49	1967
2014	April	2	38	RGGR	10-20	Rye	No_herbs	0.11	142
2014	April	2	38	RGGR	20-30	Rye	No_herbs	0.10	138
2014	April	2	38	RGGR	30-40	Rye	No_herbs	0.08	102
2014	April	2	38	RGGR	40-50	Rye	No_herbs	0.09	122
2014	April	2	38	RGGR	50-60	Rye	No_herbs	0.05	62

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	39	TFCO	0-10	TF	Herbs	1.52	1999
2014	April	2	39	TFCO	10-20	TF	Herbs	0.16	206
2014	April	2	39	TFCO	20-30	TF	Herbs	0.13	174
2014	April	2	39	TFCO	30-40	TF	Herbs	0.06	77
2014	April	2	39	TFCO	40-50	TF	Herbs	0.04	57
2014	April	2	39	TFCO	50-60	TF	Herbs	0.03	42
2014	April	2	40	TFGR	0-10	TF	No_herbs	1.62	2130
2014	April	2	40	TFGR	10-20	TF	No_herbs	0.23	308
2014	April	2	40	TFGR	20-30	TF	No_herbs	0.15	203
2014	April	2	40	TFGR	30-40	TF	No_herbs	0.09	120
2014	April	2	40	TFGR	40-50	TF	No_herbs	0.04	53
2014	April	2	40	TFGR	50-60	TF	No_herbs	0.11	141
2014	April	2	41	RGHB	0-10	Rye	Herbs	1.81	2383
2014	April	2	41	RGHB	10-20	Rye	Herbs	0.09	122
2014	April	2	41	RGHB	20-30	Rye	Herbs	0.08	101
2014	April	2	41	RGHB	30-40	Rye	Herbs	0.04	49

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	April	2	41	RGHB	40-50	Rye	Herbs	0.03	38
2014	April	2	41	RGHB	50-60	Rye	Herbs	0.02	31
2014	April	2	42	TFLB	0-10	TF	No_herbs	0.93	1228
2014	April	2	42	TFLB	10-20	TF	No_herbs	0.14	180
2014	April	2	42	TFLB	20-30	TF	No_herbs	0.24	312
2014	April	2	42	TFLB	30-40	TF	No_herbs	0.05	69
2014	April	2	42	TFLB	40-50	TF	No_herbs	0.10	128
2014	April	2	42	TFLB	50-60	TF	No_herbs	0.07	96
2014	July	3	1	RGHB	0-10	Rye	Herbs	1.65	2177
2014	July	3	1	RGHB	10-20	Rye	Herbs	0.30	391
2014	July	3	1	RGHB	20-30	Rye	Herbs	0.12	152
2014	July	3	1	RGHB	30-40	Rye	Herbs	0.07	87
2014	July	3	1	RGHB	40-50	Rye	Herbs	0.04	59
2014	July	3	1	RGHB	50-60	Rye	Herbs	0.01	19
2014	July	3	2	PGLU	0-10	Prairie	No_herbs	3.62	4759
2014	July	3	2	PGLU	10-20	Prairie	No_herbs	1.68	2206

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	2	PGLU	20-30	Prairie	No_herbs	0.61	797
2014	July	3	2	PGLU	30-40	Prairie	No_herbs	0.11	144
2014	July	3	2	PGLU	40-50	Prairie	No_herbs	0.08	111
2014	July	3	2	PGLU	50-60	Prairie	No_herbs	0.02	26
2014	July	3	3	RGLA	0-10	Rye	No_herbs	2.53	3327
2014	July	3	3	RGLA	10-20	Rye	No_herbs	0.54	710
2014	July	3	3	RGLA	20-30	Rye	No_herbs	0.18	233
2014	July	3	3	RGLA	30-40	Rye	No_herbs	0.14	181
2014	July	3	3	RGLA	40-50	Rye	No_herbs	0.07	98
2014	July	3	3	RGLA	50-60	Rye	No_herbs	0.01	9
2014	July	3	4	TFLB	0-10	TF	No_herbs	1.84	2418
2014	July	3	4	TFLB	10-20	TF	No_herbs	0.45	592
2014	July	3	4	TFLB	20-30	TF	No_herbs	0.15	200
2014	July	3	4	TFLB	30-40	TF	No_herbs	0.10	131
2014	July	3	4	TFLB	40-50	TF	No_herbs	0.04	56
2014	July	3	4	TFLB	50-60	TF	No_herbs	0.03	44

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	5	RGST	0-10	Rye	No_herbs	1.05	1382
2014	July	3	5	RGST	10-20	Rye	No_herbs	0.15	192
2014	July	3	5	RGST	20-30	Rye	No_herbs	0.13	168
2014	July	3	5	RGST	30-40	Rye	No_herbs	0.06	73
2014	July	3	5	RGST	40-50	Rye	No_herbs	0.05	65
2014	July	3	5	RGST	50-60	Rye	No_herbs	0.02	32
2014	July	3	6	TFGR	0-10	TF	No_herbs	0.91	1200
2014	July	3	6	TFGR	10-20	TF	No_herbs	0.11	150
2014	July	3	6	TFGR	20-30	TF	No_herbs	0.08	101
2014	July	3	6	TFGR	30-40	TF	No_herbs	0.07	96
2014	July	3	6	TFGR	40-50	TF	No_herbs	0.06	83
2014	July	3	6	TFGR	50-60	TF	No_herbs	0.04	49
2014	July	3	7	TFCO	0-10	TF	Herbs	1.00	1320
2014	July	3	7	TFCO	10-20	TF	Herbs	0.19	255
2014	July	3	7	TFCO	20-30	TF	Herbs	0.13	175
2014	July	3	7	TFCO	30-40	TF	Herbs	0.08	106

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	7	TFCO	40-50	TF	Herbs	0.07	97
2014	July	3	7	TFCO	50-60	TF	Herbs	0.05	61
2014	July	3	8	TFHB	0-10	TF	Herbs	1.17	1536
2014	July	3	8	TFHB	10-20	TF	Herbs	0.27	351
2014	July	3	8	TFHB	20-30	TF	Herbs	0.10	129
2014	July	3	8	TFHB	30-40	TF	Herbs	0.04	59
2014	July	3	8	TFHB	40-50	TF	Herbs	0.05	71
2014	July	3	8	TFHB	50-60	TF	Herbs	0.03	37
2014	July	3	9	TFST	0-10	TF	No_herbs	1.11	1462
2014	July	3	9	TFST	10-20	TF	No_herbs	0.38	505
2014	July	3	9	TFST	20-30	TF	No_herbs	0.21	276
2014	July	3	9	TFST	30-40	TF	No_herbs	0.13	167
2014	July	3	9	TFST	40-50	TF	No_herbs	0.07	93
2014	July	3	9	TFST	50-60	TF	No_herbs	0.03	41
2014	July	3	10	RGLB	0-10	Rye	No_herbs	0.90	1187
2014	July	3	10	RGLB	10-20	Rye	No_herbs	0.31	404

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	10	RGLB	20-30	Rye	No_herbs	0.14	190
2014	July	3	10	RGLB	30-40	Rye	No_herbs	0.07	96
2014	July	3	10	RGLB	40-50	Rye	No_herbs	0.03	39
2014	July	3	10	RGLB	50-60	Rye	No_herbs	0.02	29
2014	July	3	11	GRLH	0-10	Prairie	Herbs	0.47	618
2014	July	3	11	GRLH	10-20	Prairie	Herbs	0.05	59
2014	July	3	11	GRLH	20-30	Prairie	Herbs	0.04	49
2014	July	3	11	GRLH	30-40	Prairie	Herbs	0.14	184
2014	July	3	11	GRLH	40-50	Prairie	Herbs	0.24	319
2014	July	3	11	GRLH	50-60	Prairie	Herbs	0.03	35
2014	July	3	12	RGGR	0-10	Rye	No_herbs	0.96	1260
2014	July	3	12	RGGR	10-20	Rye	No_herbs	0.25	330
2014	July	3	12	RGGR	20-30	Rye	No_herbs	0.14	182
2014	July	3	12	RGGR	30-40	Rye	No_herbs	0.05	68
2014	July	3	12	RGGR	40-50	Rye	No_herbs	0.05	71
2014	July	3	12	RGGR	50-60	Rye	No_herbs	0.02	27

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	13	RGCO	0-10	Rye	Herbs	0.63	833
2014	July	3	13	RGCO	10-20	Rye	Herbs	0.19	249
2014	July	3	13	RGCO	20-30	Rye	Herbs	0.08	99
2014	July	3	13	RGCO	30-40	Rye	Herbs	0.07	87
2014	July	3	13	RGCO	40-50	Rye	Herbs	0.04	48
2014	July	3	13	RGCO	50-60	Rye	Herbs	0.02	21
2014	July	3	14	TFLA	0-10	TF	No_herbs	0.65	857
2014	July	3	14	TFLA	10-20	TF	No_herbs	0.19	253
2014	July	3	14	TFLA	20-30	TF	No_herbs	0.09	113
2014	July	3	14	TFLA	30-40	TF	No_herbs	0.04	53
2014	July	3	14	TFLA	40-50	TF	No_herbs	0.07	98
2014	July	3	14	TFLA	50-60	TF	No_herbs	0.02	24
2014	July	3	15	RGST	0-10	Rye	No_herbs	0.88	1160
2014	July	3	15	RGST	10-20	Rye	No_herbs	0.17	227
2014	July	3	15	RGST	20-30	Rye	No_herbs	0.10	133
2014	July	3	15	RGST	30-40	Rye	No_herbs	0.09	115

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	15	RGST	40-50	Rye	No_herbs	0.07	99
2014	July	3	15	RGST	50-60	Rye	No_herbs	0.01	18
2014	July	3	16	TFST	0-10	TF	No_herbs	0.66	873
2014	July	3	16	TFST	10-20	TF	No_herbs	0.15	199
2014	July	3	16	TFST	20-30	TF	No_herbs	0.06	75
2014	July	3	16	TFST	30-40	TF	No_herbs	0.05	65
2014	July	3	16	TFST	40-50	TF	No_herbs	0.04	59
2014	July	3	16	TFST	50-60	TF	No_herbs	0.02	31
2014	July	3	17	PGLU	0-10	Prairie	No_herbs	0.79	1043
2014	July	3	17	PGLU	10-20	Prairie	No_herbs	0.18	237
2014	July	3	17	PGLU	20-30	Prairie	No_herbs	0.10	136
2014	July	3	17	PGLU	30-40	Prairie	No_herbs	0.05	69
2014	July	3	17	PGLU	40-50	Prairie	No_herbs	0.06	79
2014	July	3	17	PGLU	50-60	Prairie	No_herbs	0.03	38
2014	July	3	18	TFHB	0-10	TF	Herbs	0.64	838
2014	July	3	18	TFHB	10-20	TF	Herbs	0.12	152

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	18	TFHB	20-30	TF	Herbs	0.12	151
2014	July	3	18	TFHB	30-40	TF	Herbs	0.05	61
2014	July	3	18	TFHB	40-50	TF	Herbs	0.06	74
2014	July	3	18	TFHB	50-60	TF	Herbs	0.04	47
2014	July	3	19	RGLA	0-10	Rye	No_herbs	1.39	1823
2014	July	3	19	RGLA	10-20	Rye	No_herbs	0.26	343
2014	July	3	19	RGLA	20-30	Rye	No_herbs	0.13	169
2014	July	3	19	RGLA	30-40	Rye	No_herbs	0.08	100
2014	July	3	19	RGLA	40-50	Rye	No_herbs	0.04	52
2014	July	3	19	RGLA	50-60	Rye	No_herbs	0.04	49
2014	July	3	20	RGLB	0-10	Rye	No_herbs	2.09	2745
2014	July	3	20	RGLB	10-20	Rye	No_herbs	0.23	309
2014	July	3	20	RGLB	20-30	Rye	No_herbs	0.18	238
2014	July	3	20	RGLB	30-40	Rye	No_herbs	0.11	142
2014	July	3	20	RGLB	40-50	Rye	No_herbs	0.09	123
2014	July	3	20	RGLB	50-60	Rye	No_herbs	0.02	27

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	21	RGHB	0-10	Rye	Herbs	0.76	1002
2014	July	3	21	RGHB	10-20	Rye	Herbs	0.13	177
2014	July	3	21	RGHB	20-30	Rye	Herbs	0.10	128
2014	July	3	21	RGHB	30-40	Rye	Herbs	0.06	77
2014	July	3	21	RGHB	40-50	Rye	Herbs	0.06	72
2014	July	3	21	RGHB	50-60	Rye	Herbs	0.05	59
2014	July	3	22	TFLA	0-10	TF	No_herbs	0.92	1216
2014	July	3	22	TFLA	10-20	TF	No_herbs	0.28	367
2014	July	3	22	TFLA	20-30	TF	No_herbs	0.15	191
2014	July	3	22	TFLA	30-40	TF	No_herbs	0.09	119
2014	July	3	22	TFLA	40-50	TF	No_herbs	0.10	130
2014	July	3	22	TFLA	50-60	TF	No_herbs	0.08	103
2014	July	3	23	TFLB	0-10	TF	No_herbs	1.15	1518
2014	July	3	23	TFLB	10-20	TF	No_herbs	0.31	407
2014	July	3	23	TFLB	20-30	TF	No_herbs	0.15	197
2014	July	3	23	TFLB	30-40	TF	No_herbs	0.06	79

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	23	TFLB	40-50	TF	No_herbs	0.05	69
2014	July	3	23	TFLB	50-60	TF	No_herbs	0.04	46
2014	July	3	24	RGCO	0-10	Rye	Herbs	1.06	1391
2014	July	3	24	RGCO	10-20	Rye	Herbs	0.16	209
2014	July	3	24	RGCO	20-30	Rye	Herbs	0.07	92
2014	July	3	24	RGCO	30-40	Rye	Herbs	0.04	57
2014	July	3	24	RGCO	40-50	Rye	Herbs	0.03	39
2014	July	3	24	RGCO	50-60	Rye	Herbs	0.02	28
2014	July	3	25	TFCO	0-10	TF	Herbs	1.83	2405
2014	July	3	25	TFCO	10-20	TF	Herbs	0.14	181
2014	July	3	25	TFCO	20-30	TF	Herbs	0.09	114
2014	July	3	25	TFCO	30-40	TF	Herbs	0.04	50
2014	July	3	25	TFCO	40-50	TF	Herbs	0.04	56
2014	July	3	25	TFCO	50-60	TF	Herbs	0.03	41
2014	July	3	26	TFGR	0-10	TF	No_herbs	1.42	1874
2014	July	3	26	TFGR	10-20	TF	No_herbs	0.33	440

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	26	TFGR	20-30	TF	No_herbs	0.14	189
2014	July	3	26	TFGR	30-40	TF	No_herbs	0.07	97
2014	July	3	26	TFGR	40-50	TF	No_herbs	0.05	69
2014	July	3	26	TFGR	50-60	TF	No_herbs	0.03	36
2014	July	3	27	RGGR	0-10	Rye	No_herbs	1.67	2204
2014	July	3	27	RGGR	10-20	Rye	No_herbs	0.30	388
2014	July	3	27	RGGR	20-30	Rye	No_herbs	0.17	221
2014	July	3	27	RGGR	30-40	Rye	No_herbs	0.09	118
2014	July	3	27	RGGR	40-50	Rye	No_herbs	0.05	60
2014	July	3	27	RGGR	50-60	Rye	No_herbs	0.01	9
2014	July	3	28	GRLH	0-10	Prairie	Herbs	0.62	819
2014	July	3	28	GRLH	10-20	Prairie	Herbs	0.28	362
2014	July	3	28	GRLH	20-30	Prairie	Herbs	0.10	132
2014	July	3	28	GRLH	30-40	Prairie	Herbs	0.04	54
2014	July	3	28	GRLH	40-50	Prairie	Herbs	0.03	38
2014	July	3	28	GRLH	50-60	Prairie	Herbs	0.02	25

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	29	TFHB	0-10	TF	Herbs	1.02	1342
2014	July	3	29	TFHB	10-20	TF	Herbs	0.11	140
2014	July	3	29	TFHB	20-30	TF	Herbs	0.33	433
2014	July	3	29	TFHB	30-40	TF	Herbs	0.03	41
2014	July	3	29	TFHB	40-50	TF	Herbs	0.04	54
2014	July	3	29	TFHB	50-60	TF	Herbs	0.03	41
2014	July	3	30	RGLB	0-10	Rye	No_herbs	1.30	1710
2014	July	3	30	RGLB	10-20	Rye	No_herbs	0.34	454
2014	July	3	30	RGLB	20-30	Rye	No_herbs	0.21	278
2014	July	3	30	RGLB	30-40	Rye	No_herbs	0.08	103
2014	July	3	30	RGLB	40-50	Rye	No_herbs	0.06	75
2014	July	3	30	RGLB	50-60	Rye	No_herbs	0.03	39
2014	July	3	31	RGST	0-10	Rye	No_herbs	0.80	1051
2014	July	3	31	RGST	10-20	Rye	No_herbs	0.21	278
2014	July	3	31	RGST	20-30	Rye	No_herbs	0.24	318
2014	July	3	31	RGST	30-40	Rye	No_herbs	0.07	97

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	31	RGST	40-50	Rye	No_herbs	0.04	55
2014	July	3	31	RGST	50-60	Rye	No_herbs	0.03	36
2014	July	3	32	TFST	0-10	TF	No_herbs	1.13	1490
2014	July	3	32	TFST	10-20	TF	No_herbs	0.20	259
2014	July	3	32	TFST	20-30	TF	No_herbs	0.11	150
2014	July	3	32	TFST	30-40	TF	No_herbs	0.05	64
2014	July	3	32	TFST	40-50	TF	No_herbs	0.04	50
2014	July	3	32	TFST	50-60	TF	No_herbs	0.12	153
2014	July	3	33	TFLA	0-10	TF	No_herbs	0.67	888
2014	July	3	33	TFLA	10-20	TF	No_herbs	0.22	295
2014	July	3	33	TFLA	20-30	TF	No_herbs	0.07	97
2014	July	3	33	TFLA	30-40	TF	No_herbs	0.05	63
2014	July	3	33	TFLA	40-50	TF	No_herbs	0.06	83
2014	July	3	33	TFLA	50-60	TF	No_herbs	0.04	47
2014	July	3	34	PGLU	0-10	Prairie	No_herbs	0.85	1113
2014	July	3	34	PGLU	10-20	Prairie	No_herbs	0.19	254

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	34	PGLU	20-30	Prairie	No_herbs	0.11	144
2014	July	3	34	PGLU	30-40	Prairie	No_herbs	0.10	133
2014	July	3	34	PGLU	40-50	Prairie	No_herbs	0.06	76
2014	July	3	34	PGLU	50-60	Prairie	No_herbs	0.02	32
2014	July	3	35	GRLH	0-10	Prairie	Herbs	0.55	725
2014	July	3	35	GRLH	10-20	Prairie	Herbs	0.15	202
2014	July	3	35	GRLH	20-30	Prairie	Herbs	0.09	120
2014	July	3	35	GRLH	30-40	Prairie	Herbs	0.09	113
2014	July	3	35	GRLH	40-50	Prairie	Herbs	0.02	27
2014	July	3	35	GRLH	50-60	Prairie	Herbs	0.02	22
2014	July	3	36	RGLA	0-10	Rye	No_herbs	1.22	1612
2014	July	3	36	RGLA	10-20	Rye	No_herbs	0.28	372
2014	July	3	36	RGLA	20-30	Rye	No_herbs	0.16	211
2014	July	3	36	RGLA	30-40	Rye	No_herbs	0.06	75
2014	July	3	36	RGLA	40-50	Rye	No_herbs	0.04	54
2014	July	3	36	RGLA	50-60	Rye	No_herbs	0.02	29

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	37	RGCO	0-10	Rye	Herbs	0.79	1040
2014	July	3	37	RGCO	10-20	Rye	Herbs	0.16	206
2014	July	3	37	RGCO	20-30	Rye	Herbs	0.13	167
2014	July	3	37	RGCO	30-40	Rye	Herbs	0.10	129
2014	July	3	37	RGCO	40-50	Rye	Herbs	0.04	56
2014	July	3	37	RGCO	50-60	Rye	Herbs	0.03	46
2014	July	3	38	RGGR	0-10	Rye	No_herbs	1.82	2390
2014	July	3	38	RGGR	10-20	Rye	No_herbs	0.31	404
2014	July	3	38	RGGR	20-30	Rye	No_herbs	0.18	233
2014	July	3	38	RGGR	30-40	Rye	No_herbs	0.08	104
2014	July	3	38	RGGR	40-50	Rye	No_herbs	0.08	107
2014	July	3	38	RGGR	50-60	Rye	No_herbs	0.03	39
2014	July	3	39	TFCO	0-10	TF	Herbs	1.09	1438
2014	July	3	39	TFCO	10-20	TF	Herbs	0.23	301
2014	July	3	39	TFCO	20-30	TF	Herbs	0.14	185
2014	July	3	39	TFCO	30-40	TF	Herbs	0.03	44

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	39	TFCO	40-50	TF	Herbs	0.04	56
2014	July	3	39	TFCO	50-60	TF	Herbs	0.05	60
2014	July	3	40	TFGR	0-10	TF	No_herbs	1.26	1656
2014	July	3	40	TFGR	10-20	TF	No_herbs	0.50	653
2014	July	3	40	TFGR	20-30	TF	No_herbs	0.25	332
2014	July	3	40	TFGR	30-40	TF	No_herbs	0.06	76
2014	July	3	40	TFGR	40-50	TF	No_herbs	0.06	83
2014	July	3	40	TFGR	50-60	TF	No_herbs	0.06	74
2014	July	3	41	RGHB	0-10	Rye	Herbs	1.30	1709
2014	July	3	41	RGHB	10-20	Rye	Herbs	0.22	287
2014	July	3	41	RGHB	20-30	Rye	Herbs	0.11	142
2014	July	3	41	RGHB	30-40	Rye	Herbs	0.07	94
2014	July	3	41	RGHB	40-50	Rye	Herbs	0.05	60
2014	July	3	41	RGHB	50-60	Rye	Herbs	0.03	44
2014	July	3	42	TFLB	0-10	TF	No_herbs	1.42	1867
2014	July	3	42	TFLB	10-20	TF	No_herbs	0.34	452

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	July	3	42	TFLB	20-30	TF	No_herbs	0.15	201
2014	July	3	42	TFLB	30-40	TF	No_herbs	0.09	112
2014	July	3	42	TFLB	40-50	TF	No_herbs	0.15	196
2014	July	3	42	TFLB	50-60	TF	No_herbs	0.10	132
2014	September	4	1	RGHB	0-10	Rye	Herbs	1.44	1897
2014	September	4	1	RGHB	10-20	Rye	Herbs	0.20	257
2014	September	4	1	RGHB	20-30	Rye	Herbs	0.11	149
2014	September	4	1	RGHB	30-40	Rye	Herbs	0.05	71
2014	September	4	1	RGHB	40-50	Rye	Herbs	0.04	51
2014	September	4	1	RGHB	50-60	Rye	Herbs	0.03	39
2014	September	4	2	PGLU	0-10	Prairie	No_herbs	1.45	1905
2014	September	4	2	PGLU	10-20	Prairie	No_herbs	0.50	664
2014	September	4	2	PGLU	20-30	Prairie	No_herbs	0.26	340
2014	September	4	2	PGLU	30-40	Prairie	No_herbs	0.22	294
2014	September	4	2	PGLU	40-50	Prairie	No_herbs	0.07	95
2014	September	4	2	PGLU	50-60	Prairie	No_herbs	0.04	49

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	3	RGLA	0-10	Rye	No_herbs	3.39	4458
2014	September	4	3	RGLA	10-20	Rye	No_herbs	0.80	1056
2014	September	4	3	RGLA	20-30	Rye	No_herbs	0.15	203
2014	September	4	3	RGLA	30-40	Rye	No_herbs	0.12	164
2014	September	4	3	RGLA	40-50	Rye	No_herbs	0.06	73
2014	September	4	3	RGLA	50-60	Rye	No_herbs	0.01	9
2014	September	4	4	TFLB	0-10	TF	No_herbs	1.82	2398
2014	September	4	4	TFLB	10-20	TF	No_herbs	0.23	296
2014	September	4	4	TFLB	20-30	TF	No_herbs	0.17	220
2014	September	4	4	TFLB	30-40	TF	No_herbs	0.08	100
2014	September	4	4	TFLB	40-50	TF	No_herbs	0.06	77
2014	September	4	4	TFLB	50-60	TF	No_herbs	0.06	76
2014	September	4	5	RGST	0-10	Rye	No_herbs	1.24	1626
2014	September	4	5	RGST	10-20	Rye	No_herbs	0.24	313
2014	September	4	5	RGST	20-30	Rye	No_herbs	0.16	213
2014	September	4	5	RGST	30-40	Rye	No_herbs	0.06	83

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	5	RGST	40-50	Rye	No_herbs	0.04	52
2014	September	4	5	RGST	50-60	Rye	No_herbs	0.03	38
2014	September	4	6	TFGR	0-10	TF	No_herbs	1.11	1462
2014	September	4	6	TFGR	10-20	TF	No_herbs	0.17	230
2014	September	4	6	TFGR	20-30	TF	No_herbs	0.09	116
2014	September	4	6	TFGR	30-40	TF	No_herbs	0.05	62
2014	September	4	6	TFGR	40-50	TF	No_herbs	0.07	98
2014	September	4	6	TFGR	50-60	TF	No_herbs	0.02	28
2014	September	4	7	TFCO	0-10	TF	Herbs	1.15	1512
2014	September	4	7	TFCO	10-20	TF	Herbs	0.26	348
2014	September	4	7	TFCO	20-30	TF	Herbs	0.15	193
2014	September	4	7	TFCO	30-40	TF	Herbs	0.08	104
2014	September	4	7	TFCO	40-50	TF	Herbs	0.08	104
2014	September	4	7	TFCO	50-60	TF	Herbs	0.08	106
2014	September	4	8	TFHB	0-10	TF	Herbs	1.00	1311
2014	September	4	8	TFHB	10-20	TF	Herbs	0.36	478

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	8	TFHB	20-30	TF	Herbs	0.15	196
2014	September	4	8	TFHB	30-40	TF	Herbs	0.10	125
2014	September	4	8	TFHB	40-50	TF	Herbs	0.10	128
2014	September	4	8	TFHB	50-60	TF	Herbs	0.06	77
2014	September	4	9	TFST	0-10	TF	No_herbs	1.41	1853
2014	September	4	9	TFST	10-20	TF	No_herbs	0.32	417
2014	September	4	9	TFST	20-30	TF	No_herbs	0.17	229
2014	September	4	9	TFST	30-40	TF	No_herbs	0.10	126
2014	September	4	9	TFST	40-50	TF	No_herbs	0.07	87
2014	September	4	9	TFST	50-60	TF	No_herbs	0.05	70
2014	September	4	10	RGLB	0-10	Rye	No_herbs	2.14	2818
2014	September	4	10	RGLB	10-20	Rye	No_herbs	0.43	560
2014	September	4	10	RGLB	20-30	Rye	No_herbs	0.21	282
2014	September	4	10	RGLB	30-40	Rye	No_herbs	0.13	171
2014	September	4	10	RGLB	40-50	Rye	No_herbs	0.08	109
2014	September	4	10	RGLB	50-60	Rye	No_herbs	0.04	48

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	11	GRLH	0-10	Prairie	Herbs	1.08	1421
2014	September	4	11	GRLH	10-20	Prairie	Herbs	0.29	385
2014	September	4	11	GRLH	20-30	Prairie	Herbs	0.12	154
2014	September	4	11	GRLH	30-40	Prairie	Herbs	0.05	67
2014	September	4	11	GRLH	40-50	Prairie	Herbs	0.05	67
2014	September	4	11	GRLH	50-60	Prairie	Herbs	0.05	67
2014	September	4	12	RGGR	0-10	Rye	No_herbs	1.96	2577
2014	September	4	12	RGGR	10-20	Rye	No_herbs	0.44	574
2014	September	4	12	RGGR	20-30	Rye	No_herbs	0.18	238
2014	September	4	12	RGGR	30-40	Rye	No_herbs	0.09	122
2014	September	4	12	RGGR	40-50	Rye	No_herbs	0.05	61
2014	September	4	12	RGGR	50-60	Rye	No_herbs	0.04	50
2014	September	4	13	RGCO	0-10	Rye	Herbs	1.60	2110
2014	September	4	13	RGCO	10-20	Rye	Herbs	0.40	524
2014	September	4	13	RGCO	20-30	Rye	Herbs	0.15	201
2014	September	4	13	RGCO	30-40	Rye	Herbs	0.06	74

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	13	RGCO	40-50	Rye	Herbs	0.03	36
2014	September	4	13	RGCO	50-60	Rye	Herbs	0.03	39
2014	September	4	14	TFLA	0-10	TF	No_herbs	1.03	1362
2014	September	4	14	TFLA	10-20	TF	No_herbs	0.41	542
2014	September	4	14	TFLA	20-30	TF	No_herbs	0.21	279
2014	September	4	14	TFLA	30-40	TF	No_herbs	0.07	93
2014	September	4	14	TFLA	40-50	TF	No_herbs	0.04	52
2014	September	4	14	TFLA	50-60	TF	No_herbs	0.03	44
2014	September	4	15	RGST	0-10	Rye	No_herbs	1.35	1780
2014	September	4	15	RGST	10-20	Rye	No_herbs	0.27	360
2014	September	4	15	RGST	20-30	Rye	No_herbs	0.23	298
2014	September	4	15	RGST	30-40	Rye	No_herbs	0.11	139
2014	September	4	15	RGST	40-50	Rye	No_herbs	0.05	67
2014	September	4	15	RGST	50-60	Rye	No_herbs	0.03	43
2014	September	4	16	TFST	0-10	TF	No_herbs	0.84	1111
2014	September	4	16	TFST	10-20	TF	No_herbs	0.19	246

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	16	TFST	20-30	TF	No_herbs	0.08	106
2014	September	4	16	TFST	30-40	TF	No_herbs	0.05	66
2014	September	4	16	TFST	40-50	TF	No_herbs	0.03	43
2014	September	4	16	TFST	50-60	TF	No_herbs	0.03	37
2014	September	4	17	PGLU	0-10	Prairie	No_herbs	1.14	1496
2014	September	4	17	PGLU	10-20	Prairie	No_herbs	0.30	389
2014	September	4	17	PGLU	20-30	Prairie	No_herbs	0.05	64
2014	September	4	17	PGLU	30-40	Prairie	No_herbs	0.04	53
2014	September	4	17	PGLU	40-50	Prairie	No_herbs	0.03	45
2014	September	4	17	PGLU	50-60	Prairie	No_herbs	0.03	39
2014	September	4	18	TFHB	0-10	TF	Herbs	1.16	1521
2014	September	4	18	TFHB	10-20	TF	Herbs	0.29	381
2014	September	4	18	TFHB	20-30	TF	Herbs	0.14	184
2014	September	4	18	TFHB	30-40	TF	Herbs	0.05	67
2014	September	4	18	TFHB	40-50	TF	Herbs	0.05	60
2014	September	4	18	TFHB	50-60	TF	Herbs	0.03	38

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	19	RGLA	0-10	Rye	No_herbs	1.90	2500
2014	September	4	19	RGLA	10-20	Rye	No_herbs	0.38	505
2014	September	4	19	RGLA	20-30	Rye	No_herbs	0.19	253
2014	September	4	19	RGLA	30-40	Rye	No_herbs	0.13	169
2014	September	4	19	RGLA	40-50	Rye	No_herbs	0.08	106
2014	September	4	19	RGLA	50-60	Rye	No_herbs	0.07	90
2014	September	4	20	RGLB	0-10	Rye	No_herbs	2.11	2777
2014	September	4	20	RGLB	10-20	Rye	No_herbs	0.60	785
2014	September	4	20	RGLB	20-30	Rye	No_herbs	0.31	406
2014	September	4	20	RGLB	30-40	Rye	No_herbs	0.13	177
2014	September	4	20	RGLB	40-50	Rye	No_herbs	0.08	99
2014	September	4	20	RGLB	50-60	Rye	No_herbs	0.04	55
2014	September	4	21	RGHB	0-10	Rye	Herbs	1.28	1681
2014	September	4	21	RGHB	10-20	Rye	Herbs	0.26	336
2014	September	4	21	RGHB	20-30	Rye	Herbs	0.13	174
2014	September	4	21	RGHB	30-40	Rye	Herbs	0.06	81

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	21	RGHB	40-50	Rye	Herbs	0.07	90
2014	September	4	21	RGHB	50-60	Rye	Herbs	0.04	56
2014	September	4	22	TFLA	0-10	TF	No_herbs	1.30	1706
2014	September	4	22	TFLA	10-20	TF	No_herbs	0.29	379
2014	September	4	22	TFLA	20-30	TF	No_herbs	0.16	212
2014	September	4	22	TFLA	30-40	TF	No_herbs	0.11	139
2014	September	4	22	TFLA	40-50	TF	No_herbs	0.10	125
2014	September	4	22	TFLA	50-60	TF	No_herbs	0.11	144
2014	September	4	23	TFLB	0-10	TF	No_herbs	1.81	2383
2014	September	4	23	TFLB	10-20	TF	No_herbs	0.30	394
2014	September	4	23	TFLB	20-30	TF	No_herbs	0.14	188
2014	September	4	23	TFLB	30-40	TF	No_herbs	0.11	150
2014	September	4	23	TFLB	40-50	TF	No_herbs	0.09	116
2014	September	4	23	TFLB	50-60	TF	No_herbs	0.09	124
2014	September	4	24	RGCO	0-10	Rye	Herbs	1.05	1380
2014	September	4	24	RGCO	10-20	Rye	Herbs	0.27	351

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	24	RGCO	20-30	Rye	Herbs	0.10	133
2014	September	4	24	RGCO	30-40	Rye	Herbs	0.04	51
2014	September	4	24	RGCO	40-50	Rye	Herbs	0.03	44
2014	September	4	24	RGCO	50-60	Rye	Herbs	0.03	38
2014	September	4	25	TFCO	0-10	TF	Herbs	1.05	1376
2014	September	4	25	TFCO	10-20	TF	Herbs	0.32	427
2014	September	4	25	TFCO	20-30	TF	Herbs	0.08	106
2014	September	4	25	TFCO	30-40	TF	Herbs	0.06	75
2014	September	4	25	TFCO	40-50	TF	Herbs	0.07	89
2014	September	4	25	TFCO	50-60	TF	Herbs	0.05	70
2014	September	4	26	TFGR	0-10	TF	No_herbs	1.80	2369
2014	September	4	26	TFGR	10-20	TF	No_herbs	0.36	474
2014	September	4	26	TFGR	20-30	TF	No_herbs	0.16	205
2014	September	4	26	TFGR	30-40	TF	No_herbs	0.09	113
2014	September	4	26	TFGR	40-50	TF	No_herbs	0.11	142
2014	September	4	26	TFGR	50-60	TF	No_herbs	0.08	105

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	27	RGGR	0-10	Rye	No_herbs	1.57	2071
2014	September	4	27	RGGR	10-20	Rye	No_herbs	0.60	787
2014	September	4	27	RGGR	20-30	Rye	No_herbs	0.19	248
2014	September	4	27	RGGR	30-40	Rye	No_herbs	0.08	100
2014	September	4	27	RGGR	40-50	Rye	No_herbs	0.04	57
2014	September	4	27	RGGR	50-60	Rye	No_herbs	0.02	32
2014	September	4	28	GRLH	0-10	Prairie	Herbs	0.96	1260
2014	September	4	28	GRLH	10-20	Prairie	Herbs	0.25	333
2014	September	4	28	GRLH	20-30	Prairie	Herbs	0.23	300
2014	September	4	28	GRLH	30-40	Prairie	Herbs	0.03	38
2014	September	4	28	GRLH	40-50	Prairie	Herbs	1.15	1511
2014	September	4	28	GRLH	50-60	Prairie	Herbs	1.20	1573
2014	September	4	29	TFHB	0-10	TF	Herbs	1.23	1621
2014	September	4	29	TFHB	10-20	TF	Herbs	0.19	248
2014	September	4	29	TFHB	20-30	TF	Herbs	0.11	138
2014	September	4	29	TFHB	30-40	TF	Herbs	0.05	66

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	29	TFHB	40-50	TF	Herbs	0.04	49
2014	September	4	29	TFHB	50-60	TF	Herbs	0.03	41
2014	September	4	30	RGLB	0-10	Rye	No_herbs	1.46	1921
2014	September	4	30	RGLB	10-20	Rye	No_herbs	0.41	534
2014	September	4	30	RGLB	20-30	Rye	No_herbs	0.22	293
2014	September	4	30	RGLB	30-40	Rye	No_herbs	0.07	97
2014	September	4	30	RGLB	40-50	Rye	No_herbs	0.06	79
2014	September	4	30	RGLB	50-60	Rye	No_herbs	0.05	71
2014	September	4	31	RGST	0-10	Rye	No_herbs	1.17	1544
2014	September	4	31	RGST	10-20	Rye	No_herbs	0.30	394
2014	September	4	31	RGST	20-30	Rye	No_herbs	0.13	176
2014	September	4	31	RGST	30-40	Rye	No_herbs	0.05	69
2014	September	4	31	RGST	40-50	Rye	No_herbs	0.06	73
2014	September	4	31	RGST	50-60	Rye	No_herbs	0.05	68
2014	September	4	32	TFST	0-10	TF	No_herbs	0.89	1169
2014	September	4	32	TFST	10-20	TF	No_herbs	0.34	445

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	32	TFST	20-30	TF	No_herbs	0.13	165
2014	September	4	32	TFST	30-40	TF	No_herbs	0.06	85
2014	September	4	32	TFST	40-50	TF	No_herbs	0.06	78
2014	September	4	32	TFST	50-60	TF	No_herbs	0.05	71
2014	September	4	33	TFLA	0-10	TF	No_herbs	1.65	2172
2014	September	4	33	TFLA	10-20	TF	No_herbs	0.36	480
2014	September	4	33	TFLA	20-30	TF	No_herbs	0.18	238
2014	September	4	33	TFLA	30-40	TF	No_herbs	0.08	111
2014	September	4	33	TFLA	40-50	TF	No_herbs	0.09	112
2014	September	4	33	TFLA	50-60	TF	No_herbs	0.05	71
2014	September	4	34	PGLU	0-10	Prairie	No_herbs	1.64	2158
2014	September	4	34	PGLU	10-20	Prairie	No_herbs	0.38	503
2014	September	4	34	PGLU	20-30	Prairie	No_herbs	0.23	305
2014	September	4	34	PGLU	30-40	Prairie	No_herbs	0.10	137
2014	September	4	34	PGLU	40-50	Prairie	No_herbs	0.08	104
2014	September	4	34	PGLU	50-60	Prairie	No_herbs	0.03	37

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	35	GRLH	0-10	Prairie	Herbs	0.89	1176
2014	September	4	35	GRLH	10-20	Prairie	Herbs	0.26	343
2014	September	4	35	GRLH	20-30	Prairie	Herbs	0.39	507
2014	September	4	35	GRLH	30-40	Prairie	Herbs	0.13	168
2014	September	4	35	GRLH	40-50	Prairie	Herbs	0.06	73
2014	September	4	35	GRLH	50-60	Prairie	Herbs	0.23	300
2014	September	4	36	RGLA	0-10	Rye	No_herbs	1.88	2475
2014	September	4	36	RGLA	10-20	Rye	No_herbs	0.35	466
2014	September	4	36	RGLA	20-30	Rye	No_herbs	0.22	286
2014	September	4	36	RGLA	30-40	Rye	No_herbs	0.12	156
2014	September	4	36	RGLA	40-50	Rye	No_herbs	0.06	79
2014	September	4	36	RGLA	50-60	Rye	No_herbs	0.06	84
2014	September	4	37	RGCO	0-10	Rye	Herbs	1.59	2093
2014	September	4	37	RGCO	10-20	Rye	Herbs	0.20	259
2014	September	4	37	RGCO	20-30	Rye	Herbs	0.13	170
2014	September	4	37	RGCO	30-40	Rye	Herbs	0.11	138

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	37	RGCO	40-50	Rye	Herbs	0.03	42
2014	September	4	37	RGCO	50-60	Rye	Herbs	0.03	40
2014	September	4	38	RGGR	0-10	Rye	No_herbs	1.60	2106
2014	September	4	38	RGGR	10-20	Rye	No_herbs	0.25	335
2014	September	4	38	RGGR	20-30	Rye	No_herbs	0.15	197
2014	September	4	38	RGGR	30-40	Rye	No_herbs	0.09	120
2014	September	4	38	RGGR	40-50	Rye	No_herbs	0.07	88
2014	September	4	38	RGGR	50-60	Rye	No_herbs	0.04	56
2014	September	4	39	TFCO	0-10	TF	Herbs	0.96	1268
2014	September	4	39	TFCO	10-20	TF	Herbs	0.28	371
2014	September	4	39	TFCO	20-30	TF	Herbs	0.13	170
2014	September	4	39	TFCO	30-40	TF	Herbs	0.04	56
2014	September	4	39	TFCO	40-50	TF	Herbs	0.03	36
2014	September	4	39	TFCO	50-60	TF	Herbs	0.03	33
2014	September	4	40	TFGR	0-10	TF	No_herbs	1.45	1908
2014	September	4	40	TFGR	10-20	TF	No_herbs	0.42	554

Table A. Continued

Year	Month	Sampling	Plot	Treatment	Depth (cm)	Base grass	Herbs	Total DM (g)	Root DM (kg ha <sup>-1</sup> )
2014	September	4	40	TFGR	20-30	TF	No_herbs	0.24	320
2014	September	4	40	TFGR	30-40	TF	No_herbs	0.09	124
2014	September	4	40	TFGR	40-50	TF	No_herbs	0.10	127
2014	September	4	40	TFGR	50-60	TF	No_herbs	0.07	88
2014	September	4	41	RGHB	0-10	Rye	Herbs	1.47	1929
2014	September	4	41	RGHB	10-20	Rye	Herbs	0.36	480
2014	September	4	41	RGHB	20-30	Rye	Herbs	0.18	236
2014	September	4	41	RGHB	30-40	Rye	Herbs	0.09	120
2014	September	4	41	RGHB	40-50	Rye	Herbs	0.06	73
2014	September	4	41	RGHB	50-60	Rye	Herbs	0.07	90
2014	September	4	42	TFLB	0-10	TF	No_herbs	2.02	2662
2014	September	4	42	TFLB	10-20	TF	No_herbs	0.59	781
2014	September	4	42	TFLB	20-30	TF	No_herbs	0.17	220
2014	September	4	42	TFLB	30-40	TF	No_herbs	0.12	157
2014	September	4	42	TFLB	40-50	TF	No_herbs	0.08	108
2014	September	4	42	TFLB	50-60	TF	No_herbs	0.06	81



# Appendix B: Scanning data

Table B. Raw scanning data obtained using WinRHIZO© for a subset of treatments across four seasons.

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2013	December	1	RGHB	Rye	Herbs	0-10	2.11	29337.77		139.35	0.21	1908.28	14.15
2013	December	1	RGHB	Rye	Herbs	10-20	0.41	4970.99		120.55	0.21	321.53	1.99
2013	December	1	RGHB	Rye	Herbs	20-30	0.09	2008.14		227.78	0.20	125.40	0.91
2013	December	1	RGHB	Rye	Herbs	30-40	0.07	1499.01		205.63	0.18	86.80	0.48
2013	December	1	RGHB	Rye	Herbs	40-50	0.05	720.54		138.57	0.20	44.89	0.27
2013	December	1	RGHB	Rye	Herbs	50-60	0.04	600.74	8.58	158.09	0.21	39.98	0.28
2013	December	5	RGST	Rye	No_herbs	0-10	2.40	25308.32		105.34	0.25	1927.86	18.74
2013	December	5	RGST	Rye	No_herbs	10-20	0.61	5474.84		90.04	0.27	460.20	5.79
2013	December	5	RGST	Rye	No_herbs	20-30	0.18	2553.73		141.12	0.22	179.87	1.40
2013	December	5	RGST	Rye	No_herbs	30-40	0.06	959.55		164.54	0.21	61.97	0.40
2013	December	5	RGST	Rye	No_herbs	40-50	0.06	1110.95		187.03	0.20	70.11	0.38
2013	December	5	RGST	Rye	No_herbs	50-60	0.06	1037.69	7.99	177.58	0.20	64.98	0.36
2013	December	7	TFCO	TF	Herbs	0-10	2.05	13509.32		65.88	0.32	1374.66	23.47
2013	December	7	TFCO	TF	Herbs	10-20	0.50	4320.00		87.13	0.29	395.54	4.47
2013	December	7	TFCO	TF	Herbs	20-30	0.19	2389.62		123.49	0.24	182.93	1.52
2013	December	7	TFCO	TF	Herbs	30-40	0.13	1890.05		143.21	0.23	139.41	1.06
2013	December	7	TFCO	TF	Herbs	40-50	0.05	590.21		123.73	0.23	42.09	0.33
2013	December	7	TFCO	TF	Herbs	50-60	0.06	745.27	5.14	127.74	0.27	64.29	0.58

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2013	December	8	TFHB	TF	Herbs	0-10	1.52	17148.28		113.00	0.23	1230.49	11.17
2013	December	8	TFHB	TF	Herbs	10-20	0.56	7404.13		131.96	0.24	563.99	4.39
2013	December	8	TFHB	TF	Herbs	20-30	0.20	1637.06		82.23	0.27	141.10	1.40
2013	December	8	TFHB	TF	Herbs	30-40	0.20	2573.40		126.88	0.23	185.69	1.33
2013	December	8	TFHB	TF	Herbs	40-50	0.16	2040.56		127.04	0.48	154.92	1.14
2013	December	8	TFHB	TF	Herbs	50-60	0.10	1085.26	6.99	108.85	0.25	86.67	0.69
2013	December	9	TFST	TF	No_herbs	0-10	2.29	24708.82		107.72	0.23	1828.90	15.22
2013	December	9	TFST	TF	No_herbs	10-20	0.57	4438.10		77.76	0.30	417.99	5.05
2013	December	9	TFST	TF	No_herbs	20-30	0.28	2215.05		79.52	0.28	196.64	2.15
2013	December	9	TFST	TF	No_herbs	30-40	0.11	1589.37		141.27	0.22	110.86	0.82
2013	December	9	TFST	TF	No_herbs	40-50	0.09	1411.39		158.41	0.21	94.37	0.60
2013	December	9	TFST	TF	No_herbs	50-60	0.08	1145.38	7.79	141.93	0.21	76.68	0.47
2013	December	13	RGCO	Rye	Herbs	0-10	2.33	13625.20		58.37	0.26	1110.10	12.86
2013	December	13	RGCO	Rye	Herbs	10-20	0.39	3643.45		94.63	0.26	299.63	3.66
2013	December	13	RGCO	Rye	Herbs	20-30	0.14	2627.92		183.24	0.22	183.00	1.24
2013	December	13	RGCO	Rye	Herbs	30-40	0.11	1791.95		163.65	0.23	129.55	0.86
2013	December	13	RGCO	Rye	Herbs	40-50	0.05	1003.43		201.49	0.19	60.61	0.33
2013	December	13	RGCO	Rye	Herbs	50-60	0.04	1109.69	5.22	252.20	0.18	63.02	0.30

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2013	December	15	RGST	Rye	No_herbs	0-10	2.31	25418.28		110.05	0.26	2102.00	23.61
2013	December	15	RGST	Rye	No_herbs	10-20	0.50	5444.61		107.94	0.27	463.81	5.28
2013	December	15	RGST	Rye	No_herbs	20-30	0.19	1949.19		103.62	0.27	162.86	1.33
2013	December	15	RGST	Rye	No_herbs	30-40	0.09	1577.16		167.10	0.22	108.38	0.67
2013	December	15	RGST	Rye	No_herbs	40-50	0.05	857.70		184.45	0.22	58.01	0.37
2013	December	15	RGST	Rye	No_herbs	50-60	0.03	352.83	7.81	137.90	0.20	22.57	0.13
2013	December	16	TFST	TF	No_herbs	0-10	1.98	24884.16		125.76	0.23	1831.25	15.61
2013	December	16	TFST	TF	No_herbs	10-20	0.44	4783.77		107.60	0.26	397.54	4.13
2013	December	16	TFST	TF	No_herbs	20-30	0.13	1970.43		148.90	0.22	136.58	0.96
2013	December	16	TFST	TF	No_herbs	30-40	0.05	789.82		149.16	0.22	55.59	0.41
2013	December	16	TFST	TF	No_herbs	40-50	0.04	778.31		217.40	0.22	52.92	0.40
2013	December	16	TFST	TF	No_herbs	50-60	0.01	348.94	7.36	252.85	0.24	25.95	0.32
2013	December	18	TFHB	TF	Herbs	0-10	2.01	23047.64		114.67	0.23	1703.13	14.54
2013	December	18	TFHB	TF	Herbs	10-20	0.62	7579.95		121.93	0.24	563.35	4.45
2013	December	18	TFHB	TF	Herbs	20-30	0.20	2174.61		107.45	0.25	172.41	1.39
2013	December	18	TFHB	TF	Herbs	30-40	0.07	745.08		112.27	0.23	52.93	0.39
2013	December	18	TFHB	TF	Herbs	40-50	0.13	1571.43		124.13	0.23	111.60	0.77
2013	December	18	TFHB	TF	Herbs	50-60	0.12	1087.94	7.94	89.99	0.26	88.31	0.74

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2013	December	21	RGHB	Rye	Herbs	0-10	2.17	28619.93		131.80	0.21	1912.08	14.56
2013	December	21	RGHB	Rye	Herbs	10-20	0.44	6634.48		150.80	0.21	438.30	2.60
2013	December	21	RGHB	Rye	Herbs	20-30	0.32	5105.17		157.80	0.22	351.23	2.49
2013	December	21	RGHB	Rye	Herbs	30-40	0.10	1752.97		170.85	0.19	104.82	0.52
2013	December	21	RGHB	Rye	Herbs	40-50	0.08	1837.62		238.65	0.17	97.01	0.41
2013	December	21	RGHB	Rye	Herbs	50-60	0.08	1679.46	10.01	200.65	0.19	99.63	0.53
2013	December	24	RGCO	Rye	Herbs	0-10	1.46	18633.77		127.46	0.22	1260.23	9.63
2013	December	24	RGCO	Rye	Herbs	10-20	0.51	5200.41		102.65	0.27	435.60	4.73
2013	December	24	RGCO	Rye	Herbs	20-30	0.12	2448.02		198.94	0.21	161.34	0.98
2013	December	24	RGCO	Rye	Herbs	30-40	0.04	693.86		194.36	0.19	40.87	0.23
2013	December	24	RGCO	Rye	Herbs	40-50	0.04	1226.72		278.17	0.20	76.14	0.39
2013	December	24	RGCO	Rye	Herbs	50-60	0.03	843.80	6.37	248.18	0.20	53.82	0.33
2013	December	25	TFCO	TF	Herbs	0-10	0.98	15599.10		158.90	0.20	982.10	6.80
2013	December	25	TFCO	TF	Herbs	10-20	0.68	4919.87		72.05	0.30	459.58	8.27
2013	December	25	TFCO	TF	Herbs	20-30	0.17	2277.27		133.25	0.23	166.74	1.29
2013	December	25	TFCO	TF	Herbs	30-40	0.05	794.86		158.44	0.23	57.41	0.43
2013	December	25	TFCO	TF	Herbs	40-50	0.04	607.67		151.54	0.23	44.51	0.31
2013	December	25	TFCO	TF	Herbs	50-60	0.04	506.35	5.42	141.46	0.24	38.57	0.32

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2013	December	29	TFHB	TF	Herbs	0-10	1.25	16368.13		130.94	0.21	1059.37	7.65
2013	December	29	TFHB	TF	Herbs	10-20	0.23	2502.51		110.27	0.22	175.51	1.35
2013	December	29	TFHB	TF	Herbs	20-30	0.10	1180.55		119.29	0.22	80.48	0.52
2013	December	29	TFHB	TF	Herbs	30-40	0.04	604.68		168.66	0.19	35.85	0.20
2013	December	29	TFHB	TF	Herbs	40-50	0.05	423.56		91.31	0.22	28.78	0.22
2013	December	29	TFHB	TF	Herbs	50-60	0.05	681.24	4.77	142.52	0.21	45.07	0.25
2013	December	31	RGST	Rye	No_herbs	0-10	2.77	27981.67		100.91	0.23	1981.40	19.90
2013	December	31	RGST	Rye	No_herbs	10-20	0.74	5934.59		80.35	0.28	526.71	6.43
2013	December	31	RGST	Rye	No_herbs	20-30	0.17	3027.84		173.06	0.22	207.43	1.38
2013	December	31	RGST	Rye	No_herbs	30-40	0.08	1462.10		176.57	0.20	92.40	0.56
2013	December	31	RGST	Rye	No_herbs	40-50	0.06	1285.90		229.22	0.19	76.59	0.39
2013	December	31	RGST	Rye	No_herbs	50-60	0.06	1038.42	8.93	167.44	0.20	66.48	0.45
2013	December	32	TFST	TF	No_herbs	0-10	3.37	13097.79		38.89	0.25	1046.28	12.04
2013	December	32	TFST	TF	No_herbs	10-20	0.63	8371.24		133.02	0.24	620.91	5.10
2013	December	32	TFST	TF	No_herbs	20-30	0.15	2045.56		132.79	0.24	153.82	1.18
2013	December	32	TFST	TF	No_herbs	30-40	0.06	726.60		122.00	0.24	54.47	0.39
2013	December	32	TFST	TF	No_herbs	40-50	0.05	642.13		138.39	0.21	42.86	0.31
2013	December	32	TFST	TF	No_herbs	50-60	0.05	619.08	5.59	136.66	0.22	42.54	0.35

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2013	December	37	RGCO	Rye	Herbs	0-10	1.40	12879.90		92.13	0.26	1033.21	10.38
2013	December	37	RGCO	Rye	Herbs	10-20	0.24	3140.69		128.55	0.23	222.16	1.73
2013	December	37	RGCO	Rye	Herbs	20-30	0.22	3348.80		154.41	0.22	234.91	1.74
2013	December	37	RGCO	Rye	Herbs	30-40	0.07	1025.14		139.29	0.21	67.57	0.46
2013	December	37	RGCO	Rye	Herbs	40-50	0.03	444.49		152.75	0.19	26.91	0.14
2013	December	37	RGCO	Rye	Herbs	50-60	0.02	365.04	4.65	173.01	0.19	21.96	0.16
2013	December	39	TFCO	TF	Herbs	0-10	1.16	13985.71		120.48	0.23	1016.53	8.28
2013	December	39	TFCO	TF	Herbs	10-20	0.36	4473.47		124.24	0.24	330.27	2.80
2013	December	39	TFCO	TF	Herbs	20-30	0.13	1285.97		100.00	0.24	96.55	0.79
2013	December	39	TFCO	TF	Herbs	30-40	0.06	517.21		91.58	0.24	39.20	0.34
2013	December	39	TFCO	TF	Herbs	40-50	0.05	528.17		116.59	0.20	33.94	0.19
2013	December	39	TFCO	TF	Herbs	50-60	0.05	675.44	4.71	149.77	0.20	42.49	0.26
2013	December	41	RGHB	Rye	Herbs	0-10	2.03	24061.51		118.77	0.20	1557.18	11.64
2013	December	41	RGHB	Rye	Herbs	10-20	0.36	5208.71		145.06	0.20	321.48	2.13
2013	December	41	RGHB	Rye	Herbs	20-30	0.14	2297.59		165.92	0.18	132.56	0.72
2013	December	41	RGHB	Rye	Herbs	30-40	0.06	1045.93		165.23	0.19	62.02	0.37
2013	December	41	RGHB	Rye	Herbs	40-50	0.08	1192.00		149.75	0.18	69.02	0.40
2013	December	41	RGHB	Rye	Herbs	50-60	0.03	598.50	7.54	212.23	0.17	31.99	0.15

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	April	1	RGHB	Rye	Herbs	0-10	2.12	23597.79		111.21	0.21	1538.96	11.69
2014	April	1	RGHB	Rye	Herbs	10-20	0.68	9366.71		137.00	0.20	587.81	4.12
2014	April	1	RGHB	Rye	Herbs	20-30	0.39	5530.47		142.91	0.20	345.34	2.40
2014	April	1	RGHB	Rye	Herbs	30-40	0.09	1507.53		161.58	0.19	90.68	0.61
2014	April	1	RGHB	Rye	Herbs	40-50	0.07	1229.31		167.03	0.19	72.69	0.45
2014	April	1	RGHB	Rye	Herbs	50-60	0.27	676.45	9.19	24.90	0.23	49.68	1.97
2014	April	5	RGST	Rye	No_herbs	0-10	2.07	16865.46		81.39	0.19	1022.49	6.30
2014	April	5	RGST	Rye	No_herbs	10-20	0.38	7445.38		197.33	0.17	393.38	1.78
2014	April	5	RGST	Rye	No_herbs	20-30	0.17	3615.27		212.54	0.16	182.51	0.75
2014	April	5	RGST	Rye	No_herbs	30-40	0.11	1619.48		143.06	0.16	82.45	0.42
2014	April	5	RGST	Rye	No_herbs	40-50	0.04	1088.62		264.23	0.15	52.86	0.20
2014	April	5	RGST	Rye	No_herbs	50-60	0.05	967.35	6.93	201.95	0.16	48.91	0.22
2014	April	7	TFCO	TF	Herbs	0-10	1.88	19197.69		102.21	0.21	1236.67	8.34
2014	April	7	TFCO	TF	Herbs	10-20	0.47	7278.41		154.79	0.20	458.69	2.65
2014	April	7	TFCO	TF	Herbs	20-30	0.19	3263.62		167.80	0.19	192.68	0.96
2014	April	7	TFCO	TF	Herbs	30-40	0.11	1903.58		180.43	0.18	109.57	0.53
2014	April	7	TFCO	TF	Herbs	40-50	0.15	2828.23		186.07	0.19	170.57	0.95
2014	April	7	TFCO	TF	Herbs	50-60	0.17	2781.71	8.17	166.07	0.20	172.00	0.94

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	April	8	TFHB	TF	Herbs	0-10	2.05	16490.22		80.54	0.23	1164.25	9.48
2014	April	8	TFHB	TF	Herbs	10-20	0.46	6674.38		146.14	0.20	422.23	2.69
2014	April	8	TFHB	TF	Herbs	20-30	0.20	3250.86		159.43	0.19	192.74	0.94
2014	April	8	TFHB	TF	Herbs	30-40	0.08	1440.32		181.86	0.19	84.61	0.41
2014	April	8	TFHB	TF	Herbs	40-50	0.05	847.26		181.81	0.21	54.72	0.36
2014	April	8	TFHB	TF	Herbs	50-60	0.08	1293.30	6.58	159.86	0.21	84.32	0.49
2014	April	9	TFST	TF	No_herbs	0-10	3.05	26380.75		86.49	0.22	1796.58	16.65
2014	April	9	TFST	TF	No_herbs	10-20	0.60	8161.32		135.17	0.19	493.04	2.78
2014	April	9	TFST	TF	No_herbs	20-30	0.37	5087.62		135.78	0.21	331.65	2.47
2014	April	9	TFST	TF	No_herbs	30-40	0.10	1454.39		140.39	0.21	92.01	0.57
2014	April	9	TFST	TF	No_herbs	40-50	0.05	795.33		175.96	0.19	48.42	0.29
2014	April	9	TFST	TF	No_herbs	50-60	0.09	1243.88	9.46	141.19	0.21	81.04	0.51
2014	April	13	RGCO	Rye	Herbs	0-10	2.34	25454.13		108.66	0.21	1678.17	11.47
2014	April	13	RGCO	Rye	Herbs	10-20	0.23	4021.01		176.67	0.19	240.34	1.57
2014	April	13	RGCO	Rye	Herbs	20-30	0.22	4388.09		196.86	0.18	253.18	1.33
2014	April	13	RGCO	Rye	Herbs	30-40	0.03	500.66		151.71	0.17	26.09	0.10
2014	April	13	RGCO	Rye	Herbs	40-50	0.05	947.34		191.00	0.19	55.23	0.34
2014	April	13	RGCO	Rye	Herbs	50-60	0.08	1775.13	8.13	210.57	0.18	99.37	0.46

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	April	15	RGST	Rye	No_herbs	0-10	1.37	15600.99		114.22	0.20	154.59	6.34
2014	April	15	RGST	Rye	No_herbs	10-20	0.08	1105.05		135.92	0.21	72.54	0.53
2014	April	15	RGST	Rye	No_herbs	20-30	0.04	645.83		175.02	0.18	35.84	0.19
2014	April	15	RGST	Rye	No_herbs	30-40	0.06	1516.80		234.44	0.18	83.69	0.37
2014	April	15	RGST	Rye	No_herbs	40-50	0.14	2662.15		191.25	0.20	163.42	0.85
2014	April	15	RGST	Rye	No_herbs	50-60	0.11	1467.95	5.04	131.18	0.19	89.05	0.52
2014	April	16	TFST	TF	No_herbs	0-10	0.76	6903.50		90.96	0.21	468.49	3.80
2014	April	16	TFST	TF	No_herbs	10-20	0.62	7401.33		120.23	0.19	444.20	2.33
2014	April	16	TFST	TF	No_herbs	20-30	0.27	3303.26		123.58	0.19	195.31	1.01
2014	April	16	TFST	TF	No_herbs	30-40	0.09	1396.41		151.78	0.18	79.47	0.44
2014	April	16	TFST	TF	No_herbs	40-50	0.05	803.02		166.26	0.18	45.40	0.26
2014	April	16	TFST	TF	No_herbs	50-60	0.05	883.37	4.54	164.81	0.18	49.98	0.25
2014	April	18	TFHB	TF	Herbs	0-10	1.27	13514.39		106.66	0.21	884.07	6.22
2014	April	18	TFHB	TF	Herbs	10-20	0.11	981.77		90.40	0.23	69.31	0.54
2014	April	18	TFHB	TF	Herbs	20-30	0.04	495.85		137.73	0.20	31.48	0.18
2014	April	18	TFHB	TF	Herbs	30-40	0.09	1077.44		120.52	0.20	67.29	0.39
2014	April	18	TFHB	TF	Herbs	40-50	0.06	546.09		95.14	0.22	37.06	0.24
2014	April	18	TFHB	TF	Herbs	50-60	0.11	793.88	3.82	71.33	0.20	49.06	0.55

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	April	21	RGHB	Rye	Herbs	0-10	2.33	34421.39		147.85	0.18	1990.38	11.31
2014	April	21	RGHB	Rye	Herbs	10-20	0.12	1873.31		151.44	0.19	112.15	0.59
2014	April	21	RGHB	Rye	Herbs	20-30	0.08	1404.72		187.30	0.17	75.99	0.32
2014	April	21	RGHB	Rye	Herbs	30-40	0.15	3639.33		241.82	0.17	191.53	0.79
2014	April	21	RGHB	Rye	Herbs	40-50	0.05	931.07		187.34	0.17	50.53	0.21
2014	April	21	RGHB	Rye	Herbs	50-60	0.07	2788.17	9.88	414.29	0.17	147.97	0.41
2014	April	24	RGCO	Rye	Herbs	0-10	1.48	19982.93		134.71	0.17	1048.60	5.51
2014	April	24	RGCO	Rye	Herbs	10-20	0.08	1006.33		132.59	0.19	58.66	0.32
2014	April	24	RGCO	Rye	Herbs	20-30	0.04	732.42		172.74	0.18	41.67	0.19
2014	April	24	RGCO	Rye	Herbs	30-40	0.02	358.45		199.14	0.16	18.23	0.07
2014	April	24	RGCO	Rye	Herbs	40-50	0.02	268.93		176.93	0.17	13.95	0.05
2014	April	24	RGCO	Rye	Herbs	50-60	0.03	832.84	5.08	262.72	0.16	40.62	0.16
2014	April	25	TFCO	TF	Herbs	0-10	1.33	18416.25		138.29	0.18	1060.64	5.82
2014	April	25	TFCO	TF	Herbs	10-20	0.10	963.08		98.37	0.21	63.70	0.44
2014	April	25	TFCO	TF	Herbs	20-30	0.06	702.24		123.85	0.20	43.68	0.26
2014	April	25	TFCO	TF	Herbs	30-40	0.11	1952.29		175.41	0.18	109.59	0.55
2014	April	25	TFCO	TF	Herbs	40-50	0.01	148.83		120.03	0.21	9.85	0.05
2014	April	25	TFCO	TF	Herbs	50-60	0.03	308.17	4.93	106.26	0.21	20.46	0.15

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	April	29	TFHB	TF	Herbs	0-10	0.08	509.24		61.95	0.25	40.04	0.37
2014	April	29	TFHB	TF	Herbs	10-20	0.31	2982.75		97.41	0.20	183.58	0.71
2014	April	29	TFHB	TF	Herbs	20-30	0.14	1707.10		119.13	0.20	105.24	0.57
2014	April	29	TFHB	TF	Herbs	30-40	0.01	165.90		164.25	0.22	11.23	0.06
2014	April	29	TFHB	TF	Herbs	40-50	0.05	476.76		99.33	0.19	28.91	0.16
2014	April	29	TFHB	TF	Herbs	50-60	0.03	238.69	1.33	89.07	0.21	15.45	0.08
2014	April	31	RGST	Rye	No_herbs	0-10	1.49	18863.28		126.64	0.18	1045.97	5.70
2014	April	31	RGST	Rye	No_herbs	10-20	0.09	1458.82		163.00	0.18	81.24	0.29
2014	April	31	RGST	Rye	No_herbs	20-30	0.07	1223.63		185.68	0.17	65.45	0.28
2014	April	31	RGST	Rye	No_herbs	30-40	0.11	2727.08		254.87	0.16	138.40	0.62
2014	April	31	RGST	Rye	No_herbs	40-50	0.04	1036.51		240.49	0.17	54.47	0.21
2014	April	31	RGST	Rye	No_herbs	50-60	0.05	1358.13	5.85	267.35	0.16	69.06	0.31
2014	April	32	TFST	TF	No_herbs	0-10	0.89	26667.46		300.72	0.19	1454.58	4.29
2014	April	32	TFST	TF	No_herbs	10-20	0.07	493.38		68.52	0.24	36.78	0.30
2014	April	32	TFST	TF	No_herbs	20-30	0.06	485.21		86.34	0.24	36.30	0.28
2014	April	32	TFST	TF	No_herbs	30-40	0.05	544.15		101.71	0.22	37.50	0.25
2014	April	32	TFST	TF	No_herbs	40-50	0.05	835.44		164.13	0.18	48.30	0.24
2014	April	32	TFST	TF	No_herbs	50-60	0.08	1160.17	6.62	150.48	0.18	67.02	0.36

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	April	37	RGCO	Rye	Herbs	0-10	2.14	13887.01		64.77	0.19	833.48	12.71
2014	April	37	RGCO	Rye	Herbs	10-20	0.05	576.16		107.89	0.21	38.75	0.23
2014	April	37	RGCO	Rye	Herbs	20-30	0.07	576.15		87.69	0.22	39.61	0.26
2014	April	37	RGCO	Rye	Herbs	30-40	0.03	628.68		184.36	0.19	36.76	0.18
2014	April	37	RGCO	Rye	Herbs	40-50	0.04	455.93		129.16	0.19	27.89	0.16
2014	April	37	RGCO	Rye	Herbs	50-60	0.02	479.35	3.64	210.24	0.17	25.54	0.11
2014	April	39	TFCO	TF	Herbs	0-10	1.52	17928.88		118.02	0.21	1155.81	8.04
2014	April	39	TFCO	TF	Herbs	10-20	0.16	1697.11		108.37	0.21	113.23	0.77
2014	April	39	TFCO	TF	Herbs	20-30	0.13	1464.54		110.78	0.22	102.90	0.72
2014	April	39	TFCO	TF	Herbs	30-40	0.06	503.28		86.03	0.25	40.14	0.33
2014	April	39	TFCO	TF	Herbs	40-50	0.04	476.20		109.72	0.21	31.73	0.20
2014	April	39	TFCO	TF	Herbs	50-60	0.03	447.42	4.94	141.14	0.20	28.61	0.16
2014	April	41	RGHB	Rye	Herbs	0-10	1.81	14919.55		82.37	0.19	879.91	7.63
2014	April	41	RGHB	Rye	Herbs	10-20	0.09	1951.95		210.11	0.19	115.26	0.60
2014	April	41	RGHB	Rye	Herbs	20-30	0.08	1855.43		240.65	0.18	102.07	0.48
2014	April	41	RGHB	Rye	Herbs	30-40	0.04	939.54		252.57	0.17	49.20	0.22
2014	April	41	RGHB	Rye	Herbs	40-50	0.03	746.79		260.21	0.16	38.63	0.19
2014	April	41	RGHB	Rye	Herbs	50-60	0.02	560.57	4.60	234.55	0.18	31.35	0.16

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	July	1	RGHB	Rye	Herbs	0-10	1.65	29269.81		176.90	0.19	1716.38	10.39
2014	July	1	RGHB	Rye	Herbs	10-20	0.30	6083.21		204.55	0.19	369.61	2.02
2014	July	1	RGHB	Rye	Herbs	20-30	0.12	2795.02		242.62	0.18	160.85	0.84
2014	July	1	RGHB	Rye	Herbs	30-40	0.07	1262.67		191.31	0.18	69.46	0.36
2014	July	1	RGHB	Rye	Herbs	40-50	0.04	889.65		198.58	0.18	49.71	0.28
2014	July	1	RGHB	Rye	Herbs	50-60	0.01	430.12	8.93	292.60	0.19	25.43	0.15
2014	July	5	RGST	Rye	No_herbs	0-10	1.05	21377.53		203.48	0.18	1205.82	6.54
2014	July	5	RGST	Rye	No_herbs	10-20	0.15	3502.96		240.26	0.17	188.50	0.93
2014	July	5	RGST	Rye	No_herbs	20-30	0.13	2904.90		227.48	0.17	156.16	0.80
2014	July	5	RGST	Rye	No_herbs	30-40	0.06	1414.53		253.50	0.16	72.27	0.31
2014	July	5	RGST	Rye	No_herbs	40-50	0.05	1291.03		261.87	0.16	65.22	0.27
2014	July	5	RGST	Rye	No_herbs	50-60	0.02	642.65	6.83	264.46	0.16	31.69	0.14
2014	July	7	TFCO	TF	Herbs	0-10	1.00	12947.24		129.02	0.20	823.40	5.73
2014	July	7	TFCO	TF	Herbs	10-20	0.19	3113.63		160.66	0.20	192.26	1.14
2014	July	7	TFCO	TF	Herbs	20-30	0.13	1960.88		147.10	0.20	120.99	0.72
2014	July	7	TFCO	TF	Herbs	30-40	0.08	1310.79		163.24	0.19	77.04	0.42
2014	July	7	TFCO	TF	Herbs	40-50	0.07	1323.88		178.66	0.18	74.27	0.37
2014	July	7	TFCO	TF	Herbs	50-60	0.05	689.52	4.68	147.65	0.20	42.61	0.26

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	July	8	TFHB	TF	Herbs	0-10	1.17	19787.17		169.54	0.20	1247.77	8.47
2014	July	8	TFHB	TF	Herbs	10-20	0.27	4760.67		178.57	0.21	309.17	1.97
2014	July	8	TFHB	TF	Herbs	20-30	0.10	2007.62		204.44	0.20	127.48	0.75
2014	July	8	TFHB	TF	Herbs	30-40	0.04	668.77		149.95	0.20	42.35	0.26
2014	July	8	TFHB	TF	Herbs	40-50	0.05	822.03		153.36	0.20	52.06	0.34
2014	July	8	TFHB	TF	Herbs	50-60	0.03	437.21	6.25	153.41	0.21	28.44	0.19
2014	July	9	TFST	TF	No_herbs	0-10	1.11	14991.57		134.91	0.21	1001.39	7.31
2014	July	9	TFST	TF	No_herbs	10-20	0.38	5552.25		144.74	0.20	339.95	2.36
2014	July	9	TFST	TF	No_herbs	20-30	0.21	1920.72		91.55	0.20	119.77	0.99
2014	July	9	TFST	TF	No_herbs	30-40	0.13	1874.96		147.75	0.19	114.75	0.74
2014	July	9	TFST	TF	No_herbs	40-50	0.07	1587.31		223.56	0.18	90.01	0.50
2014	July	9	TFST	TF	No_herbs	50-60	0.03	626.46	5.82	199.51	0.19	36.63	0.18
2014	July	13	RGCO	Rye	Herbs	0-10	0.63	12449.19		196.64	0.20	772.83	5.03
2014	July	13	RGCO	Rye	Herbs	10-20	0.19	3548.52		187.85	0.19	210.31	1.07
2014	July	13	RGCO	Rye	Herbs	20-30	0.08	1455.75		193.58	0.18	84.16	0.45
2014	July	13	RGCO	Rye	Herbs	30-40	0.07	914.54		138.78	0.18	51.21	0.30
2014	July	13	RGCO	Rye	Herbs	40-50	0.04	627.38		172.36	0.18	35.36	0.17
2014	July	13	RGCO	Rye	Herbs	50-60	0.02	480.25	4.27	303.96	0.18	27.37	0.17

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	July	15	RGST	Rye	No_herbs	0-10	0.88	11790.62		133.68	0.19	707.63	4.89
2014	July	15	RGST	Rye	No_herbs	10-20	0.17	2414.49		140.05	0.20	148.59	0.90
2014	July	15	RGST	Rye	No_herbs	20-30	0.10	1775.57		175.28	0.19	106.21	0.59
2014	July	15	RGST	Rye	No_herbs	30-40	0.09	1570.63		179.50	0.19	94.20	0.55
2014	July	15	RGST	Rye	No_herbs	40-50	0.07	1467.91		195.98	0.19	88.54	0.55
2014	July	15	RGST	Rye	No_herbs	50-60	0.01	385.16	4.26	275.11	0.16	19.04	0.08
2014	July	16	TFST	TF	No_herbs	0-10	0.66	8668.14		130.64	0.20	551.30	3.95
2014	July	16	TFST	TF	No_herbs	10-20	0.15	2687.63		177.87	0.19	160.97	0.97
2014	July	16	TFST	TF	No_herbs	20-30	0.06	943.80		165.29	0.18	54.21	0.28
2014	July	16	TFST	TF	No_herbs	30-40	0.05	988.89		199.78	0.18	54.45	0.25
2014	July	16	TFST	TF	No_herbs	40-50	0.04	802.88		179.21	0.18	46.13	0.25
2014	July	16	TFST	TF	No_herbs	50-60	0.02	516.06	3.20	216.83	0.17	27.07	0.12
2014	July	18	TFHB	TF	Herbs	0-10	0.64	7719.28		121.20	0.21	499.27	3.56
2014	July	18	TFHB	TF	Herbs	10-20	0.12	1614.66		139.92	0.19	96.74	0.51
2014	July	18	TFHB	TF	Herbs	20-30	0.12	1297.52		112.83	0.21	86.50	0.60
2014	July	18	TFHB	TF	Herbs	30-40	0.05	636.06		136.79	0.18	36.76	0.17
2014	July	18	TFHB	TF	Herbs	40-50	0.06	752.55		133.43	0.19	45.86	0.26
2014	July	18	TFHB	TF	Herbs	50-60	0.04	321.35	2.71	90.27	0.23	23.60	0.16

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	July	21	RGHB	Rye	Herbs	0-10	0.76	9604.63		126.08	0.19	578.36	3.63
2014	July	21	RGHB	Rye	Herbs	10-20	0.13	2405.65		179.26	0.18	134.67	0.69
2014	July	21	RGHB	Rye	Herbs	20-30	0.10	2201.32		226.94	0.18	121.98	0.61
2014	July	21	RGHB	Rye	Herbs	30-40	0.06	1671.69		286.25	0.17	88.33	0.44
2014	July	21	RGHB	Rye	Herbs	40-50	0.06	1449.79		263.60	0.17	77.56	0.37
2014	July	21	RGHB	Rye	Herbs	50-60	0.05	1339.64	4.09	297.70	0.16	69.13	0.34
2014	July	24	RGCO	Rye	Herbs	0-10	1.06	14656.81		138.64	0.19	869.63	5.45
2014	July	24	RGCO	Rye	Herbs	10-20	0.16	1839.65		115.92	0.19	109.61	0.95
2014	July	24	RGCO	Rye	Herbs	20-30	0.07	1475.99		212.07	0.18	82.56	0.42
2014	July	24	RGCO	Rye	Herbs	30-40	0.04	799.60		183.39	0.18	43.99	0.23
2014	July	24	RGCO	Rye	Herbs	40-50	0.03	783.46		266.48	0.17	42.17	0.22
2014	July	24	RGCO	Rye	Herbs	50-60	0.02	462.04	4.39	220.02	0.17	24.30	0.13
2014	July	25	TFCO	TF	Herbs	0-10	1.83	10149.21		55.52	0.20	638.23	5.88
2014	July	25	TFCO	TF	Herbs	10-20	0.14	1961.38		142.96	0.19	119.90	0.76
2014	July	25	TFCO	TF	Herbs	20-30	0.09	1590.87		183.70	0.19	93.79	0.54
2014	July	25	TFCO	TF	Herbs	30-40	0.04	650.81		172.63	0.19	38.69	0.19
2014	July	25	TFCO	TF	Herbs	40-50	0.04	682.90		161.83	0.19	41.72	0.22
2014	July	25	TFCO	TF	Herbs	50-60	0.03	527.43	3.41	167.44	0.19	31.13	0.16

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	July	29	TFHB	TF	Herbs	0-10	1.02	7673.68		75.21	0.21	505.55	6.63
2014	July	29	TFHB	TF	Herbs	10-20	0.11	1747.42		164.70	0.21	115.27	0.76
2014	July	29	TFHB	TF	Herbs	20-30	0.33	1570.76		47.69	0.23	113.63	3.08
2014	July	29	TFHB	TF	Herbs	30-40	0.03	518.06		164.99	0.20	31.80	0.19
2014	July	29	TFHB	TF	Herbs	40-50	0.04	682.23		165.99	0.20	42.85	0.24
2014	July	29	TFHB	TF	Herbs	50-60	0.03	480.10	2.78	154.37	0.20	30.07	0.16
2014	July	31	RGST	Rye	No_herbs	0-10	0.80	14472.13		181.20	0.19	862.29	5.42
2014	July	31	RGST	Rye	No_herbs	10-20	0.21	5329.23		252.45	0.18	298.21	1.56
2014	July	31	RGST	Rye	No_herbs	20-30	0.24	2454.96		101.61	0.19	146.52	1.31
2014	July	31	RGST	Rye	No_herbs	30-40	0.07	1326.71		180.50	0.16	67.26	0.35
2014	July	31	RGST	Rye	No_herbs	40-50	0.04	1151.46		273.51	0.16	59.20	0.26
2014	July	31	RGST	Rye	No_herbs	50-60	0.03	812.60	5.60	298.75	0.16	41.27	0.19
2014	July	32	TFST	TF	No_herbs	0-10	1.13	11739.37		103.63	0.20	736.92	6.54
2014	July	32	TFST	TF	No_herbs	10-20	0.20	3426.89		174.22	0.20	215.55	1.31
2014	July	32	TFST	TF	No_herbs	20-30	0.11	2502.68		219.34	0.18	142.09	0.76
2014	July	32	TFST	TF	No_herbs	30-40	0.05	925.79		189.71	0.18	52.65	0.27
2014	July	32	TFST	TF	No_herbs	40-50	0.04	724.52		190.66	0.19	42.63	0.23
2014	July	32	TFST	TF	No_herbs	50-60	0.12	566.09	4.36	48.68	0.24	42.71	0.49

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	July	37	RGCO	Rye	Herbs	0-10	0.79	12337.23		156.05	0.20	758.75	4.93
2014	July	37	RGCO	Rye	Herbs	10-20	0.16	2419.96		154.24	0.20	155.15	0.97
2014	July	37	RGCO	Rye	Herbs	20-30	0.13	2450.02		192.61	0.19	149.23	0.82
2014	July	37	RGCO	Rye	Herbs	30-40	0.10	2030.79		206.59	0.20	125.20	0.67
2014	July	37	RGCO	Rye	Herbs	40-50	0.04	996.38		233.34	0.17	54.71	0.28
2014	July	37	RGCO	Rye	Herbs	50-60	0.03	802.36	4.61	231.90	0.17	43.24	0.19
2014	July	39	TFCO	TF	Herbs	0-10	1.09	18113.72		165.77	0.19	1109.44	7.43
2014	July	39	TFCO	TF	Herbs	10-20	0.23	4352.05		190.30	0.20	276.42	1.60
2014	July	39	TFCO	TF	Herbs	20-30	0.14	2818.02		200.86	0.20	172.29	1.05
2014	July	39	TFCO	TF	Herbs	30-40	0.03	764.71		229.64	0.18	42.97	0.22
2014	July	39	TFCO	TF	Herbs	40-50	0.04	765.77		180.18	0.19	45.51	0.26
2014	July	39	TFCO	TF	Herbs	50-60	0.05	585.66	6.01	128.72	0.21	38.33	0.23
2014	July	41	RGHB	Rye	Herbs	0-10	1.30	16961.21		130.59	0.19	1017.06	8.63
2014	July	41	RGHB	Rye	Herbs	10-20	0.22	4745.10		217.17	0.19	279.97	1.60
2014	July	41	RGHB	Rye	Herbs	20-30	0.11	2840.37		262.27	0.18	160.08	0.90
2014	July	41	RGHB	Rye	Herbs	30-40	0.07	1582.64		222.28	0.18	87.85	0.45
2014	July	41	RGHB	Rye	Herbs	40-50	0.05	1339.90		295.13	0.17	69.63	0.32
2014	July	41	RGHB	Rye	Herbs	50-60	0.03	859.31	6.21	259.61	0.17	46.26	0.24

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	September	1	RGHB	Rye	Herbs	0-10	1.44	27848.20		193.19	0.19	1707.82	10.99
2014	September	1	RGHB	Rye	Herbs	10-20	0.20	4380.36		223.83	0.19	264.36	1.63
2014	September	1	RGHB	Rye	Herbs	20-30	0.11	2527.13		222.65	0.18	146.77	0.81
2014	September	1	RGHB	Rye	Herbs	30-40	0.05	1084.79		199.78	0.18	62.28	0.32
2014	September	1	RGHB	Rye	Herbs	40-50	0.04	884.29		226.74	0.16	45.43	0.21
2014	September	1	RGHB	Rye	Herbs	50-60	0.03	600.60	8.18	202.22	0.18	33.93	0.19
2014	September	5	RGST	Rye	No_herbs	0-10	1.24	26772.68		216.61	0.19	1587.60	9.80
2014	September	5	RGST	Rye	No_herbs	10-20	0.24	6165.53		258.95	0.19	370.19	2.11
2014	September	5	RGST	Rye	No_herbs	20-30	0.16	4424.04		272.92	0.18	257.34	1.44
2014	September	5	RGST	Rye	No_herbs	30-40	0.06	1175.14		187.12	0.17	62.40	0.31
2014	September	5	RGST	Rye	No_herbs	40-50	0.04	1072.67		271.56	0.16	54.43	0.25
2014	September	5	RGST	Rye	No_herbs	50-60	0.03	844.42	8.87	291.18	0.17	45.06	0.21
2014	September	7	TFCO	TF	Herbs	0-10	1.15	17710.27		154.11	0.22	1207.27	9.82
2014	September	7	TFCO	TF	Herbs	10-20	0.26	4721.08		178.56	0.22	332.70	2.60
2014	September	7	TFCO	TF	Herbs	20-30	0.15	2373.71		161.81	0.23	171.44	1.53
2014	September	7	TFCO	TF	Herbs	30-40	0.08	1366.55		172.33	0.21	90.66	0.72
2014	September	7	TFCO	TF	Herbs	40-50	0.08	1420.14		179.99	0.21	93.85	0.64
2014	September	7	TFCO	TF	Herbs	50-60	0.08	1306.12	6.34	162.65	0.22	92.29	0.72

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	September	8	TFHB	TF	Herbs	0-10	1.00	17052.87		171.09	0.21	1143.69	8.83
2014	September	8	TFHB	TF	Herbs	10-20	0.36	6549.35		180.42	0.21	437.17	3.01
2014	September	8	TFHB	TF	Herbs	20-30	0.15	2680.67		180.27	0.44	184.62	1.46
2014	September	8	TFHB	TF	Herbs	30-40	0.10	1236.15		129.98	0.22	87.05	0.71
2014	September	8	TFHB	TF	Herbs	40-50	0.10	1493.78		153.05	0.22	102.78	0.76
2014	September	8	TFHB	TF	Herbs	50-60	0.06	984.40	6.58	168.27	0.21	66.00	0.49
2014	September	9	TFST	TF	No_herbs	0-10	1.41	22357.86		158.75	0.21	1463.20	10.28
2014	September	9	TFST	TF	No_herbs	10-20	0.32	6713.11		211.57	0.60	423.89	2.57
2014	September	9	TFST	TF	No_herbs	20-30	0.17	3560.11		204.72	0.20	225.63	1.48
2014	September	9	TFST	TF	No_herbs	30-40	0.10	1431.47		149.74	0.21	92.97	0.65
2014	September	9	TFST	TF	No_herbs	40-50	0.07	1359.55		206.30	0.20	84.98	0.54
2014	September	9	TFST	TF	No_herbs	50-60	0.05	897.10	7.96	168.94	0.20	55.57	0.39
2014	September	13	RGCO	Rye	Herbs	0-10	1.60	25595.85		159.60	0.20	1647.78	11.45
2014	September	13	RGCO	Rye	Herbs	10-20	0.40	7789.18		195.66	0.21	506.88	3.23
2014	September	13	RGCO	Rye	Herbs	20-30	0.15	3219.90		210.73	0.21	211.94	1.41
2014	September	13	RGCO	Rye	Herbs	30-40	0.06	1327.84		237.11	0.20	83.96	0.54
2014	September	13	RGCO	Rye	Herbs	40-50	0.03	629.96		233.32	0.19	38.30	0.24
2014	September	13	RGCO	Rye	Herbs	50-60	0.03	720.04	8.61	244.91	0.20	44.49	0.30

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	September	15	RGST	Rye	No_herbs	0-10	1.35	19712.35		145.74	0.21	1277.23	9.13
2014	September	15	RGST	Rye	No_herbs	10-20	0.27	5263.26		192.23	0.20	325.90	2.15
2014	September	15	RGST	Rye	No_herbs	20-30	0.23	4516.60		199.32	0.20	284.13	1.81
2014	September	15	RGST	Rye	No_herbs	30-40	0.11	2345.23		221.25	0.19	138.48	0.91
2014	September	15	RGST	Rye	No_herbs	40-50	0.05	1104.19		215.24	0.19	66.09	0.48
2014	September	15	RGST	Rye	No_herbs	50-60	0.03	716.88	7.38	219.23	0.21	47.65	0.40
2014	September	16	TFST	TF	No_herbs	0-10	0.84	16183.24		191.63	0.20	1038.59	7.75
2014	September	16	TFST	TF	No_herbs	10-20	0.19	4779.61		256.14	0.19	289.00	1.84
2014	September	16	TFST	TF	No_herbs	20-30	0.08	1471.56		183.26	0.19	88.40	0.56
2014	September	16	TFST	TF	No_herbs	30-40	0.05	948.87		190.15	0.20	60.13	0.47
2014	September	16	TFST	TF	No_herbs	40-50	0.03	751.42		231.21	0.19	44.69	0.31
2014	September	16	TFST	TF	No_herbs	50-60	0.03	710.06	5.45	250.90	0.19	42.77	0.27
2014	September	18	TFHB	TF	Herbs	0-10	1.16	17952.77		155.30	0.21	1161.70	9.40
2014	September	18	TFHB	TF	Herbs	10-20	0.29	4243.14		146.42	0.23	304.14	2.68
2014	September	18	TFHB	TF	Herbs	20-30	0.14	1753.45		125.16	0.24	132.71	1.31
2014	September	18	TFHB	TF	Herbs	30-40	0.05	831.58		163.06	0.23	60.55	0.55
2014	September	18	TFHB	TF	Herbs	40-50	0.05	702.70		153.43	0.23	50.91	0.49
2014	September	18	TFHB	TF	Herbs	50-60	0.03	534.73	5.71	183.13	0.22	36.63	0.36

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	September	21	RGHB	Rye	Herbs	0-10	1.28	22148.50		173.35	0.19	1352.48	9.04
2014	September	21	RGHB	Rye	Herbs	10-20	0.26	6695.77		262.27	0.19	402.00	2.37
2014	September	21	RGHB	Rye	Herbs	20-30	0.13	3932.93		298.18	0.19	230.18	1.42
2014	September	21	RGHB	Rye	Herbs	30-40	0.06	2189.06		355.94	0.18	120.48	0.69
2014	September	21	RGHB	Rye	Herbs	40-50	0.07	1873.15		275.06	0.18	105.77	0.56
2014	September	21	RGHB	Rye	Herbs	50-60	0.04	1302.41	8.36	305.73	0.19	78.88	0.54
2014	September	24	RGCO	Rye	Herbs	0-10	1.05	20191.69		192.54	0.20	1257.64	8.58
2014	September	24	RGCO	Rye	Herbs	10-20	0.27	5871.21		220.14	0.19	359.64	2.32
2014	September	24	RGCO	Rye	Herbs	20-30	0.10	2530.13		249.77	0.18	143.06	0.88
2014	September	24	RGCO	Rye	Herbs	30-40	0.04	1140.01		296.88	0.17	62.05	0.40
2014	September	24	RGCO	Rye	Herbs	40-50	0.03	1019.51		301.63	0.17	55.82	0.38
2014	September	24	RGCO	Rye	Herbs	50-60	0.03	1034.71	6.97	358.03	0.18	57.49	0.36
2014	September	25	TFCO	TF	Herbs	0-10	1.05	19986.51		191.04	0.20	1253.54	9.02
2014	September	25	TFCO	TF	Herbs	10-20	0.32	4970.15		153.12	0.22	341.54	2.61
2014	September	25	TFCO	TF	Herbs	20-30	0.08	1857.59		229.90	0.20	118.25	0.81
2014	September	25	TFCO	TF	Herbs	30-40	0.06	1353.90		236.28	0.20	83.83	0.54
2014	September	25	TFCO	TF	Herbs	40-50	0.07	1298.47		192.08	0.21	84.78	0.61
2014	September	25	TFCO	TF	Herbs	50-60	0.05	813.72	6.64	153.82	0.22	57.40	0.51

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	September	29	TFHB	TF	Herbs	0-10	1.23	17627.29		143.03	0.21	1161.97	11.84
2014	September	29	TFHB	TF	Herbs	10-20	0.19	4116.55		218.62	0.22	278.66	2.06
2014	September	29	TFHB	TF	Herbs	20-30	0.11	2077.24		197.46	0.22	140.70	1.25
2014	September	29	TFHB	TF	Herbs	30-40	0.05	601.25		119.30	0.23	44.04	0.47
2014	September	29	TFHB	TF	Herbs	40-50	0.04	685.48		184.76	0.20	42.54	0.40
2014	September	29	TFHB	TF	Herbs	50-60	0.03	427.21	5.60	138.26	0.23	30.89	0.30
2014	September	31	RGST	Rye	No_herbs	0-10	1.17	24805.40		211.40	0.19	1516.41	10.23
2014	September	31	RGST	Rye	No_herbs	10-20	0.30	7726.03		258.14	0.19	457.16	2.60
2014	September	31	RGST	Rye	No_herbs	20-30	0.13	3626.44		271.24	0.17	196.35	1.11
2014	September	31	RGST	Rye	No_herbs	30-40	0.05	1731.51		332.34	0.17	90.97	0.41
2014	September	31	RGST	Rye	No_herbs	40-50	0.06	1587.99		285.10	0.16	79.20	0.38
2014	September	31	RGST	Rye	No_herbs	50-60	0.05	1080.46	8.89	209.80	0.17	56.77	0.27
2014	September	32	TFST	TF	No_herbs	0-10	0.89	18318.56		206.10	0.20	1152.19	8.52
2014	September	32	TFST	TF	No_herbs	10-20	0.34	5742.92		169.61	0.22	390.16	2.98
2014	September	32	TFST	TF	No_herbs	20-30	0.13	1726.20		137.88	0.21	110.95	0.70
2014	September	32	TFST	TF	No_herbs	30-40	0.06	845.21		130.43	0.20	53.80	0.35
2014	September	32	TFST	TF	No_herbs	40-50	0.06	982.89		165.75	0.19	58.78	0.34
2014	September	32	TFST	TF	No_herbs	50-60	0.05	930.52	6.26	171.37	0.20	57.23	0.39

Table B. Continued

Year	Month	Plot	Treatment	Basegrass	Herbs	Depth (cm)	Dry root mass per sample (g)	Length (cm)	RLD (to 60cm) (cm cm <sup>-3</sup> )	SRL (m g <sup>-1</sup> )	Average diameter (mm)	Surface area (cm <sup>2</sup> )	Volume (cm <sup>3</sup> )
2014	September	37	RGCO	Rye	Herbs	0-10	1.59	17306.35		108.80	0.22	1148.57	12.61
2014	September	37	RGCO	Rye	Herbs	10-20	0.20	3813.22		193.76	0.22	263.54	1.88
2014	September	37	RGCO	Rye	Herbs	20-30	0.13	2893.46		224.13	0.22	196.18	1.32
2014	September	37	RGCO	Rye	Herbs	30-40	0.11	2152.42		204.80	0.21	138.77	0.90
2014	September	37	RGCO	Rye	Herbs	40-50	0.03	765.97		238.62	0.18	43.89	0.25
2014	September	37	RGCO	Rye	Herbs	50-60	0.03	844.09	6.09	275.85	0.18	47.38	0.24
2014	September	39	TFCO	TF	Herbs	0-10	0.96	18256.96		189.41	0.21	1179.99	8.91
2014	September	39	TFCO	TF	Herbs	10-20	0.28	5447.05		192.95	0.23	394.75	3.08
2014	September	39	TFCO	TF	Herbs	20-30	0.13	1988.51		153.79	0.25	152.52	1.62
2014	September	39	TFCO	TF	Herbs	30-40	0.04	423.97		99.52	0.28	36.96	0.47
2014	September	39	TFCO	TF	Herbs	40-50	0.03	439.91		162.93	0.23	32.07	0.38
2014	September	39	TFCO	TF	Herbs	50-60	0.03	499.64	5.93	196.71	0.22	34.13	0.27
2014	September	41	RGHB	Rye	Herbs	0-10	1.47	26943.05		183.81	0.20	1682.68	11.63
2014	September	41	RGHB	Rye	Herbs	10-20	0.36	6509.54		178.59	0.62	418.84	2.96
2014	September	41	RGHB	Rye	Herbs	20-30	0.18	3457.80		192.63	0.22	238.76	1.86
2014	September	41	RGHB	Rye	Herbs	30-40	0.09	2050.02		225.28	0.20	126.98	0.80
2014	September	41	RGHB	Rye	Herbs	40-50	0.06	1367.31		247.25	0.20	86.04	0.60
2014	September	41	RGHB	Rye	Herbs	50-60	0.07	1573.34	9.19	231.03	0.19	95.71	0.61

## Appendix C: Bulk density and moisture content data

Table C: Moisture content, moisture factor and bulk density values obtained from a small plot trial at Scott Farm, Newstead in December 2013.

Plot	Depth (cm)	Oven-dry Sample mass (g)	Moisture content (g g <sup>-1</sup> )	Bulk density (g cm <sup>-3</sup> )
1	0-10	582.04	0.57	0.76
1	10-20	529.13	0.56	0.69
1	20-30	552.62	0.53	0.72
1	30-40	578.46	0.42	0.74
1	40-50	680.09	0.24	0.82
1	50-60	706.17	0.16	0.81
2	0-10	631.44	0.41	0.82
2	10-20	614.97	0.41	0.80
2	20-30	623.79	0.40	0.81
2	30-40	807.21	0.31	1.06
2	40-50	841.41	0.23	1.03
2	50-60	971.07	0.08	1.10
3	0-10	647.46	0.48	0.84
3	10-20	595.22	0.47	0.78
3	20-30	698.46	0.41	0.92
3	30-40	860.40	0.22	1.09
3	40-50	875.33	0.12	1.05
3	50-60	983.29	0.11	1.08
4	0-10	542.01	0.36	0.70
4	10-20	498.78	0.38	0.65
4	20-30	490.04	0.41	0.64
4	30-40	502.49	0.39	0.66
4	40-50	584.54	0.27	0.75
4	50-60	809.46	0.15	1.00
5	0-10	527.31	0.50	0.69
5	10-20	547.72	0.53	0.71
5	20-30	476.17	0.53	0.62
5	30-40	491.65	0.52	0.64
5	40-50	513.40	0.39	0.67
5	50-60	532.22	0.44	0.69
6	0-10	556.80	0.42	0.73
6	10-20	545.64	0.47	0.71
6	20-30	538.79	0.48	0.69

APPENDIX C:  
BULK DENSITY AND MOISTURE CONTENT

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*Table C. Continued.*

<b>Plot</b>	<b>Depth (cm)</b>	<b>Oven-dry Sample mass (g)</b>	<b>Moisture content (g g<sup>-1</sup>)</b>	<b>Bulk density (g cm<sup>-3</sup>)</b>
6	30-40	549.92	0.45	0.72
6	40-50	590.33	0.39	0.74
6	50-60	641.00	0.36	0.79
7	0-10	537.29	0.54	0.70
7	10-20	572.05	0.52	0.75
7	20-30	632.98	0.44	0.83
7	30-40	697.01	0.41	0.90
7	40-50	751.54	0.36	0.97
7	50-60	781.99	0.28	0.98
8	0-10	615.66	0.55	0.79
8	10-20	587.08	0.54	0.77
8	20-30	620.73	0.46	0.81
8	30-40	719.16	0.41	0.94
8	40-50	744.90	0.32	0.96
8	50-60	886.64	0.23	1.10
9	0-10	631.41	0.49	0.83
9	10-20	585.89	0.49	0.76
9	20-30	636.11	0.47	0.83
9	30-40	695.61	0.44	0.90
9	40-50	656.90	0.44	0.85
9	50-60	805.21	0.33	1.02
10	0-10	647.19	0.50	0.84
10	10-20	608.80	0.47	0.79
10	20-30	658.34	0.46	0.86
10	30-40	724.68	0.43	0.92
10	40-50	676.13	0.46	0.88
10	50-60	637.91	0.48	0.82
11	0-10	662.53	0.50	0.87
11	10-20	643.77	0.50	0.84
11	20-30	664.83	0.45	0.86
11	30-40	657.10	0.48	0.86
11	40-50	610.88	0.47	0.78
11	50-60	634.98	0.40	0.82
12	0-10	632.99	0.47	0.81
12	10-20	607.47	0.46	0.80
12	20-30	701.00	0.41	0.92
12	30-40	737.86	0.37	0.96
12	40-50	658.10	0.41	0.85
12	50-60	706.60	0.39	0.92

APPENDIX C:  
BULK DENSITY AND MOISTURE CONTENT

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*Table C. Continued.*

<b>Plot</b>	<b>Depth (cm)</b>	<b>Oven-dry Sample mass (g)</b>	<b>Moisture content (g g<sup>-1</sup>)</b>	<b>Bulk density (g cm<sup>-3</sup>)</b>
13	0-10	619.46	0.50	0.81
13	10-20	583.99	0.50	0.76
13	20-30	663.98	0.42	0.87
13	30-40	688.29	0.41	0.90
13	40-50	629.85	0.40	0.83
13	50-60	701.67	0.39	0.92
14	0-10	561.74	0.35	0.73
14	10-20	617.09	0.35	0.80
14	20-30	623.99	0.34	0.81
14	30-40	594.35	0.35	0.78
14	40-50	671.95	0.31	0.88
14	50-60	704.39	0.30	0.93
15	0-10	560.62	0.57	0.73
15	10-20	589.94	0.55	0.77
15	20-30	645.83	0.50	0.84
15	30-40	690.23	0.42	0.90
15	40-50	680.37	0.38	0.89
15	50-60	781.33	0.37	1.02
16	0-10	612.15	0.54	0.80
16	10-20	564.13	0.53	0.74
16	20-30	629.05	0.46	0.82
16	30-40	755.47	0.39	0.99
16	40-50	662.22	0.41	0.87
16	50-60	733.67	0.38	0.96
17	0-10	607.45	0.52	0.79
17	10-20	568.27	0.52	0.73
17	20-30	682.15	0.47	0.86
17	30-40	657.87	0.46	0.81
17	40-50	648.63	0.41	0.84
17	50-60	783.58	0.31	1.00
18	0-10	631.84	0.48	0.83
18	10-20	598.25	0.46	0.78
18	20-30	642.22	0.42	0.84
18	30-40	709.04	0.38	0.93
18	40-50	723.26	0.37	0.94
18	50-60	882.86	0.30	1.10
19	0-10	668.80	0.49	0.87
19	10-20	560.45	0.48	0.73
19	20-30	680.78	0.43	0.89

APPENDIX C:  
BULK DENSITY AND MOISTURE CONTENT

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Table C. Continued.

Plot	Depth (cm)	Oven-dry Sample mass (g)	Moisture content (g g <sup>-1</sup> )	Bulk density (g cm <sup>-3</sup> )
19	30-40	763.69	0.39	1.00
19	40-50	699.29	0.41	0.92
19	50-60	760.07	0.36	0.98
20	0-10	610.54	0.48	0.79
20	10-20	618.54	0.50	0.81
20	20-30	647.59	0.44	0.83
20	30-40	732.69	0.39	0.90
20	40-50	693.64	0.38	0.84
20	50-60	700.37	0.39	0.83
21	0-10	593.64	0.51	0.77
21	10-20	524.20	0.53	0.68
21	20-30	589.30	0.51	0.77
21	30-40	622.01	0.53	0.82
21	40-50	623.16	0.47	0.82
21	50-60	695.97	0.40	0.91
22	0-10	547.26	0.55	0.71
22	10-20	516.75	0.55	0.67
22	20-30	573.16	0.51	0.75
22	30-40	657.09	0.44	0.84
22	40-50	594.31	0.48	0.75
22	50-60	638.90	0.48	0.83
23	0-10	523.62	0.58	0.67
23	10-20	515.07	0.59	0.67
23	20-30	531.20	0.55	0.65
23	30-40	579.28	0.51	0.71
23	40-50	578.13	0.48	0.72
23	50-60	686.33	0.44	0.85
24	0-10	534.00	0.58	0.70
24	10-20	496.40	0.56	0.65
24	20-30	550.88	0.53	0.72
24	30-40	574.24	0.45	0.74
24	40-50	568.36	0.40	0.73
24	50-60	693.01	0.35	0.88
25	0-10	533.76	0.57	0.68
25	10-20	486.23	0.59	0.62
25	20-30	481.38	0.52	0.58
25	30-40	512.10	0.53	0.59
25	40-50	561.81	0.29	0.63
25	50-60	844.75	0.16	0.95

APPENDIX C:  
BULK DENSITY AND MOISTURE CONTENT

*Table C. Continued.*

Plot	Depth (cm)	Oven-dry Sample mass (g)	Moisture content (g g <sup>-1</sup> )	Bulk density (g cm <sup>-3</sup> )
26	0-10	515.16	0.35	0.66
26	10-20	545.57	0.38	0.70
26	20-30	567.99	0.38	0.73
26	30-40	573.32	0.37	0.72
26	40-50	577.53	0.25	0.67
26	50-60	709.56	0.15	0.81
27	0-10	492.68	0.34	0.64
27	10-20	533.76	0.37	0.69
27	20-30	516.25	0.38	0.67
27	30-40	611.80	0.27	0.77
27	40-50	720.09	0.15	0.83
27	50-60	938.30	0.11	1.03
28	0-10	544.71	0.50	0.69
28	10-20	572.68	0.46	0.72
28	20-30	623.26	0.38	0.78
28	30-40	656.98	0.32	0.82
28	40-50	719.48	0.26	0.87
28	50-60	949.85	0.12	1.09
29	0-10	547.39	0.61	0.70
29	10-20	518.38	0.61	0.67
29	20-30	521.87	0.58	0.66
29	30-40	519.00	0.51	0.65
29	40-50	497.46	0.43	0.64
29	50-60	618.26	0.38	0.77
30	0-10	462.17	0.35	0.59
30	10-20	444.04	0.36	0.57
30	20-30	470.43	0.37	0.60
30	30-40	527.91	0.31	0.67
30	40-50	555.48	0.26	0.68
30	50-60	827.77	0.16	0.95
31	0-10	484.39	0.37	0.62
31	10-20	494.84	0.37	0.63
31	20-30	470.03	0.43	0.60
31	30-40	473.87	0.39	0.59
31	40-50	521.45	0.25	0.61
31	50-60	790.11	0.17	0.90
32	0-10	525.82	0.55	0.68
32	10-20	483.50	0.55	0.62
32	20-30	495.95	0.51	0.62

APPENDIX C:  
BULK DENSITY AND MOISTURE CONTENT

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*Table C. Continued.*

<b>Plot</b>	<b>Depth (cm)</b>	<b>Oven-dry Sample mass (g)</b>	<b>Moisture content (g g<sup>-1</sup>)</b>	<b>Bulk density (g cm<sup>-3</sup>)</b>
32	20-30	503.76	0.40	0.62
32	30-40	592.58	0.29	0.70
32	40-50	769.20	0.16	0.89
33	50-60	476.29	0.40	0.62
33	0-10	556.16	0.41	0.73
33	10-20	492.55	0.46	0.64
33	20-30	501.91	0.42	0.64
33	30-40	629.75	0.25	0.77
33	40-50	730.98	0.18	0.88
34	50-60	546.16	0.53	0.71
34	0-10	525.58	0.51	0.68
34	10-20	549.43	0.51	0.72
34	20-30	594.28	0.42	0.77
34	30-40	751.43	0.31	0.98
34	40-50	814.64	0.24	1.06
35	50-60	572.04	0.53	0.74
35	0-10	554.74	0.50	0.72
35	10-20	543.16	0.48	0.71
35	20-30	637.85	0.46	0.83
35	30-40	600.75	0.44	0.78
35	40-50	683.19	0.48	0.87
36	50-60	631.34	0.44	0.79
36	0-10	686.66	0.40	0.86
36	10-20	605.54	0.48	0.79
36	20-30	649.38	0.47	0.85
36	30-40	699.93	0.39	0.91
36	40-50	668.49	0.37	0.87
37	50-60	621.85	0.52	0.78
37	0-10	600.72	0.49	0.76
37	10-20	621.54	0.49	0.80
37	20-30	610.40	0.50	0.80
37	30-40	709.43	0.40	0.93
34	40-50	882.12	0.16	1.13
38	0-10	582.51	0.48	0.76
38	10-20	567.29	0.50	0.73
38	20-30	665.59	0.43	0.86
38	30-40	731.31	0.39	0.96
38	40-50	722.39	0.35	0.94
38	0-10	754.76	0.28	0.96

APPENDIX C:  
BULK DENSITY AND MOISTURE CONTENT

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*Table C. Continued.*

<b>Plot</b>	<b>Depth (cm)</b>	<b>Oven-dry Sample mass (g)</b>	<b>Moisture content</b>	<b>Bulk density (g cm<sup>-3</sup>)</b>
39	0-10	647.15	0.45	0.84
39	10-20	604.21	0.44	0.78
39	20-30	713.44	0.34	0.91
39	30-40	770.02	0.29	0.96
39	40-50	776.75	0.28	0.98
39	50-60	793.78	0.28	1.00
40	0-10	646.55	0.52	0.84
40	10-20	578.31	0.51	0.76
40	20-30	732.62	0.43	0.96
40	30-40	772.82	0.36	1.01
40	40-50	731.15	0.34	0.95
40	50-60	737.12	0.31	0.93
41	0-10	590.39	0.48	0.77
41	10-20	635.66	0.45	0.83
41	20-30	677.16	0.39	0.88
41	30-40	744.15	0.35	0.98
41	40-50	708.87	0.36	0.93
41	50-60	743.12	0.30	0.96
42	0-10	505.62	0.55	0.66
42	10-20	530.17	0.55	0.69
42	20-30	568.64	0.49	0.75
42	30-40	629.24	0.43	0.82
42	40-50	618.89	0.44	0.81
42	50-60	722.62	0.35	0.95

