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**Comparative response of tall fescue (*Lolium arundinacea*  
Schreb.) and perennial ryegrass (*Lolium perenne* L.)  
swards to variation in defoliation interval and height.**

A thesis

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## Abstract

New Zealand agricultural pastures are predominantly comprised of perennial ryegrass (*Lolium perenne* L.) with a minor component of white clover (*Trifolium repens* L.). However perennial ryegrass and white clover pasture is often limited by poor growth and low feed quality during warm dry conditions. Tall fescue (*Festuca arundinacea* Schreb.) can be used as an alternative permanent pasture to perennial ryegrass. However, the optimal grazing management of tall fescue is not yet clear.

The main objectives of this research were to compare the dry matter (DM) yields, herbage nutritive value, tiller density and botanical composition of tall fescue and perennial ryegrass to develop grazing management guidelines for tall fescue. Tall fescue and perennial ryegrass were sown with white clover and arranged in 36 plots, laid out in a randomised complete block design with three replications. The experiment was established in November 2012. There were three defoliation treatments for both tall fescue and perennial ryegrass. Tall fescue was defoliated at either the 1-leaf, 2-leaf or 4-leaf stage of regrowth and perennial ryegrass was defoliated at either the 1-leaf, 2-leaf or 3-leaf stage of regrowth. The present study provides evidence that tall fescue requires a longer defoliation interval than perennial ryegrass in order to achieve high DM yields and maintain adequate botanical composition (a high density of sown species). Tall fescue out-yielded perennial ryegrass over the 13 month treatment period, due to higher growth rates from spring, summer and autumn; however this was only achieved under the longest defoliation interval (4-leaf stage of regrowth). Dry matter yields, growth rates, botanical compositions and tiller densities of both species were all greater at the longest defoliation intervals (4-leaf stage of regrowth for tall fescue, 3-leaf stage of regrowth for perennial ryegrass), and while perennial ryegrass tolerated the moderately fast defoliation treatment (2-leaf stage of regrowth), tall fescue DM yields and botanical composition were both significantly reduced. The fastest defoliation interval (1-leaf stage of regrowth) was detrimental to yield, tillering and botanical composition both species. While the highest DM yields were recorded for tall fescue under a 4-leaf defoliation interval, this consistently resulted in the poorest quality herbage. Overall, results from the current study indicated that only under a longer regrowth interval (at the 4-leaf stage of regrowth) was tall fescue able to maintain adequate DM yields, pasture growth rates and tiller survival. In fact, under this defoliation regime, tall fescue was able to out-yield perennial ryegrass, especially in the drier and warmer parts of the year. However, the decline in herbage quality under this longer rotation would have compromised animal production for some parts of the

year. While repeated defoliation at the 2-leaf stage of regrowth resulted in generally adequate herbage quality of tall fescue, it also resulted in inadequate pasture composition and tiller density. The current study highlights that under field conditions, the 2-leaf stage of regrowth may be too short, and the 4-leaf stage of regrowth too long, for an adequate compromise between pasture growth and survival on the one hand, and herbage quality on the other. Therefore, additional research is required to explore defoliation options between the 2-leaf stage of regrowth and 4-leaf stage of regrowth of tall fescue.

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# 1 Introduction

New Zealand agricultural pastures are predominantly sown to a mix of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). However perennial ryegrass and white clover are often limited by low growth and poor quality of herbage when soil moisture is low and temperatures are high, which causes a summer feed deficit (Woodfield & Caradus, 1996; Minneé *et al.*, 2013), and these species are also susceptible to insect attack (MacFarlane, 1990). Tall fescue (*Festuca arundinacea* Schreb.) is a perennial grass adapted to a range of environments (Easton *et al.*, 1994; Milne & Johnson, 1997), and is considered as an alternative to perennial ryegrass for permanent pasture. Tall fescue is widely naturalised in New Zealand, and its use in pastoral agriculture has increased with the development of suitable cultivars (Easton *et al.*, 1994).

The advantages of tall fescue over perennial ryegrass are greatest in environments with warm - hot summers. For example, compared with perennial ryegrass, tall fescue displays greater tolerance to drought and heat (McCallum *et al.*, 1992, Milne *et al.*, 1993; Reed 1996), insects (Prestidge *et al.*, 1986; McCallum *et al.*, 1990), and moderately salty and wet soils (Easton *et al.*, 1994; Reed, 1996). Tall fescue is compatible with white clover (Exton *et al.*, 1996; Milne *et al.*, 1998), can grow well through summer (Reed, 1996) and thus can be more productive in some circumstances than perennial ryegrass over both the summer and autumn periods (30 - 40 % higher dry matter (DM) yields), as well as annually (McCallum *et al.*, 1992). Tall fescue has the potential to improve animal production (Milne *et al.*, 1998), but successful use depends on establishment and management techniques.

However, tall fescue is slow to establish compared to perennial ryegrass (Anderson, 1982; Brock, 1983), more expensive to establish due to the higher cost of seed (Pottinger *et al.*, 1987), a poor competitor with many other pasture species and weeds (Brock, 1983; Milne & Johnson, 1997), not tolerant of frequent grazing and can have poor persistence (Allo & Southon, 1967; Brock 1983; Lancashire & Brock, 1983; Miller, 1984).

Proper management is probably the most important factor in maintaining a dense, productive and persistent sward of tall fescue, in particular defoliation intervals (how often a pasture is grazed) and defoliation heights (how hard or close a pasture is grazed) (Matches, 1979). A number of studies have investigated the regrowth of tall fescue following defoliation at various heights (Hart *et al.*, 1971; Virkajarvi, 2003), intervals (Donaghy *et al.*, 2008) and a combination of defoliation intervals and defoliation heights (Kemp, 2004). Hart *et al.* (1971)

suggested that defoliating tall fescue to a height of 5 cm resulted in greater DM yields of herbage, and Cowan (1962) recommended that tall fescue should not be defoliated below 5 cm during the hot and dry summer period because the resulting slow regrowth provided an opportunity for weeds to invade (Wolf *et al.*, 1979). These recommendations of a defoliation height of 5 cm for tall fescue are in good agreement with a number of studies with ryegrass (Wilson & Robson, 1970; Simons *et al.*, 1972; Fulkerson *et al.*, 1994).

Previous studies investigating defoliation interval have used a range of methods or ‘triggers’ of when to graze including pre-grazing height (Brougham, 1959, 1960, 1970; Jameson, 1963; Davidson, 1968; Tainton, 1974; L’Huillier, 1987; Kerrisk & Thomson, 1990), days since last defoliation (Wade, 1979; Korte *et al.*, 1985; Kerrisk & Thomson, 1990; Judd *et al.*, 1990; Fulkerson *et al.*, 1994), and plant-based indicators such as leaf regrowth stage (number of fully emerged leaves per tiller; Fulkerson & Donaghy, 2001; Donaghy *et al.*, 2008). Grazing management guidelines for tall fescue have been developed using pasture mass and days since last grazing to set grazing interval (Milne & Johnson, 1997). The optimum grazing interval for perennial ryegrass has been clearly defined as between the 2-leaf and 3-leaf stages of regrowth. This has been shown to increase herbage DM yields (Fulkerson *et al.*, 1993; Fulkerson & Slack, 1995; Donaghy & Fulkerson, 1997, 1998; Donaghy *et al.*, 1997; Donaghy, 1998), plant persistence (Fulkerson *et al.*, 1993; Donaghy *et al.*, 1997; Donaghy, 1998) and herbage quality (Fulkerson *et al.*, 1998). However, little comparable research has been evaluated for tall fescue to determine whether a plant-based indicator such as leaf regrowth stage might consistently reflect high DM yields, herbage quality and persistence.

Results from a glasshouse study by Donaghy *et al.* (2008) found that repeated infrequent defoliation of tall fescue when 4 leaves/tiller had fully emerged (the ‘4-leaf stage’) maximised the accumulation of water-soluble carbohydrate (WSC) reserves and resulted in a subsequent increase in the regrowth of leaves, stubble and roots. In contrast, repeated frequent defoliation when only 1 leaf/tiller had fully emerged (the ‘1-leaf stage’) resulted in higher herbage quality, but delayed regrowth and threatened plant persistence through reducing tiller emergence and increasing tiller death. However, it is unclear whether this same approach would work as well in a field situation.

## **1.1 Aim and thesis structure**

The main objectives of the current study are to:

- (i) Compare the performance/production of tall fescue with perennial ryegrass, during the establishment year (year from time of sowing), in the lower North Island of New Zealand. Cultivars will represent industry 'standard' (most widely-sown) cultivars at the time of sowing.
- (ii) Explore interactions between defoliation interval (based on leaf regrowth stage) and defoliation height on the DM yields, tiller density, botanical composition and herbage quality of tall fescue compared with perennial ryegrass.



## **2 Literature review**

This chapter will review the literature on:

- (i) The performance of tall fescue against the more widely-sown perennial ryegrass; and
- (ii) The defoliation management, in terms of both defoliation interval and defoliation height, for both tall fescue and perennial ryegrass.

### **2.1 Perennial ryegrass**

#### ***2.1.1 Origin and adaptation***

Perennial ryegrass is a cool season grass that performs best in cool and moist environments (Romani *et al.*, 2002) and is native to Europe, temperate Asia and North Africa (Lamp *et al.*, 2001). Perennial ryegrass is now used for forage and turf purposes (Lamp *et al.*, 2001) as well as for livestock farming systems (Charlton & Stewart, 1999) and is the most widely-used grass throughout the temperate regions of the world including North and South America, South Africa, Australia and New Zealand (Lamp *et al.*, 2001).

Perennial ryegrass is one of the most important forage species in temperate regions, due to its high herbage yield and nutritional value (Smith *et al.*, 2005). This species is best adapted to a rainfall of greater than 450 mm per annum (Thorogood, 2003). Perennial ryegrass grows well within the temperature range 5°C to 25°C, reaching optimum growth rates at 18 - 20°C (Murata & Iyama, 1963; Kemp *et al.*, 2002; Mitchell, 1956).

#### ***2.1.2 Morphology***

Perennial ryegrass is a densely tillering, perennial bunchgrass with an erect growth habit (Langer, 1990; Thorogood, 2003). Perennial ryegrass has shiny dark green hairless leaves, which emerge from the base of tillers and contain a rib in the upper leaf surface (Langer, 1990). Young leaves emerge folded, but leaves developing on reproductive tillers may be rolled (Lamp *et al.*, 2001) (Figure 2-1). Perennial ryegrass can form stolons, which are prostrate stems that bear nodes from which independent plants can develop (Langer, 1990). The root system is relatively shallow with approximately 80 % of roots in the top 15 cm of soil (Bolinder *et al.*, 2002; Crush *et al.*, 2005), resulting in low water extraction and reduced persistence in the sward under hot and/or dry conditions (Mayfield & Neilson, 1996). Perennial ryegrass occurs naturally as a diploid, with a standard set of 14 chromosomes (Charlton & Stewart, 2006), but has also been bred as a tetraploid with double the number of chromosomes (Nair, 2004; Charlton & Stewart, 2006).

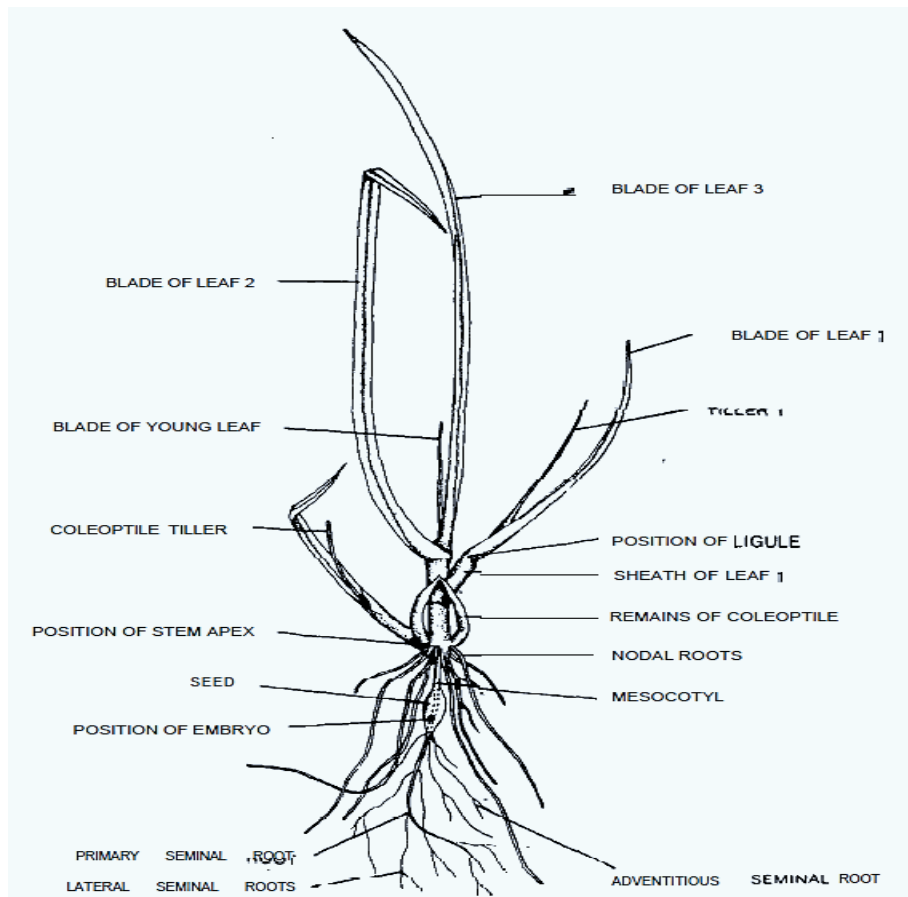


Figure 2-1. Perennial ryegrass plant. Source: Soper & Mitchell (1956), page2.

### 2.1.3 Soil requirements

Perennial ryegrass performs best on fertile, well-drained soil and will tolerate both acidic and alkaline soil conditions (pH range 5.2 - 8.0) but greatest DM yields occur when soil pH ranges from 5.5 - 7.5 (Hannaway *et al.*, 1999b). Perennial ryegrass responds well to applications of both nitrogen (N) and phosphorus (P) (Waller & Sale, 2001). Lambert *et al.* (1986) found that grazed pastures respond well to superphosphate (9 % P) with DM yields increasing by 1.6 to 2 t DM/ha with application rates between 11 - 57 kg P/ha/year.

### 2.1.4 Establishment

The objective in pasture establishment is to ensure that sufficient plants survive from sowing through to the end of the first summer (Bellotti & Blair, 1985), the period during which the greatest loss of seedlings occurs (Campbell & Swain, 1973). Perennial ryegrass is regarded as easy to establish (Moot *et al.*, 2000) and is also used to over-sow existing pasture (Wedderburn *et al.*, 1996).

#### **2.1.4.1 Effect of temperature**

Temperature is one of the physical components of the seed's microclimate which regulates germination. Temperature within the range of 5 - 30°C does not limit the germination of most temperate grasses (McWilliam *et al.*, 1970), but does affect the rate of germination (McWilliam *et al.*, 1970; Culleton & McCarthy, 1983; Charlton *et al.*, 1986; Hill *et al.*, 1985), although the value of germination rate as a factor in the establishment of perennial ryegrass appears to be variable (McWilliam *et al.*, 1970). Under conditions of low soil moisture, both germination and emergence can be delayed considerably, and seeds will either be exposed to fungal attack and/or seedlings which subsequently emerge may be exposed to low moisture conditions. This eventually leads to poor establishment.

#### **2.1.4.2 Weed competition**

Tozer *et al.* (2011) suggested that the poor persistence of sown grass species and subsequent weed invasion was of concern to farmers. For example, perennial ryegrass tends to lack persistence under dry/hot conditions (McKenzie, 1994) and this is often characterised by the invasion of weeds into the pasture (Fulkerson *et al.*, 1993). Harrington *et al.* (2008) suggested that a dense sward of perennial ryegrass helped to prevent the ingress of weeds in established pastures.

#### **2.1.5 Root system and drought tolerance**

Drought tolerance is defined as the presence of physiological and biochemical adaptations that enable plant tissues to cope with water deficit (Clarke & Durley, 1981). Mechanisms of drought tolerance include reducing water loss or maintaining water uptake to delay dehydration (e.g. increased stomatal resistance and/or increased root density and depth), and maintenance of turgor in order to tolerate dehydration (e.g. by osmotic adjustment) (Turner, 1986).

Perennial ryegrass is not drought tolerant and DM yield declines under even mild soil moisture deficits (Garwood & Sinclair, 1979). Although studies have reported a depth of between 80 - 130 cm for soil water extraction by perennial ryegrass root systems (Evans, 1978; Garwood & Sinclair, 1979), around 80 % of the root mass is in the top 15 cm of soil (Bolinder *et al.*, 2002; Crush *et al.*, 2005). Under hot/dry conditions, the low temperature ceiling and shallow rooting depth of perennial ryegrass means it is unable to produce significant DM yields (Mitchell, 1956; Silsbury, 1969; Nie *et al.*, 2004; Minneé *et al.*, 2013).

### **2.1.6 Pest tolerance**

Invertebrate pests can significantly affect sown grass species and lead to a reduction in DM yields (Allen, 1987). Endophyte-free perennial ryegrass is found to be susceptible to pasture pests such as grass grub (*Costelytra zealandica*), black beetle (*Heteronychus arator*) and Argentine stem weevil (*Listronotus bonariensis*), which can result in significant damage (Prestidge *et al.*, 1982). Grass grub larvae feed on the roots of perennial ryegrass (Radcliffe, 1970), making the plant even more susceptible to drought, and increasing the amount of plants physically pulled from the soil by grazing animals, resulting in reduced DM yields and survival (Popay & Baltus, 2001). Prestidge *et al.* (1985) showed that the endophyte-free ryegrass content of new pasture surveyed in the Waikato region of New Zealand decreased from over 90 % to 35 % in 3 years. However, the use of pesticides to control pasture pests is becoming less desirable, and the availability of suitable chemicals is becoming increasingly restricted (Donaghy, 1998). The majority of perennial ryegrass sown in New Zealand contains endophyte (Latch & Christensen, 1982) which confers protection from a range of pests.

### **2.1.7 Dry matter yields from perennial ryegrass pastures**

#### **2.1.7.1 Annual dry matter yields**

Annual DM yield is mainly determined by winter temperatures, summer rainfall and soil fertility (O'Connor *et al.*, 1968), and these may be considered the major limiting factors to perennial ryegrass growth in New Zealand. Although annual DM yield sets the upper limit for animal production from pasture, it is the seasonal supply of pasture, and how well this is matched to animal requirements, which determines the efficiency of the agricultural pastures (Valentine & Kemp, 2007). In a two year trial conducted at Hamilton New Zealand, Minneé *et al.* (2013) investigated the herbage production from five grazeable forages. They found that the total annual DM yields were greatest from perennial ryegrass in both years, ranging from 18.3 to 20.6 t DM/ha, resulting from superior cool season growth (Minneé *et al.*, 2013). A three year trial in Canterbury New Zealand also found perennial ryegrass had the greatest annual DM yield in all years of the study when compared to other sown species (yielding 15.9, 8.2 and 10.2 t DM/ha in years 1, 2 and 3 respectively) (Minneé *et al.*, 2010).

#### **2.1.7.2 Seasonal dry matter yields**

In New Zealand, pasture growth rates peak during spring and exceed animal demands due to increasing temperatures and high soil moisture availability (Judd *et al.*, 1990). By contrast, the herbage growth rates over the summer frequently fall below stock requirements

(Brougham, 1970), probably due to moisture stress (Judd *et al.*, 1990) and a limiting supply of plant nutrients such as N (Brougham, 1957). In autumn, a combination of reducing evapotranspiration demand and soil moisture recovery, coupled with decreased animal demand, often leads to pasture surpluses in this period also. Pasture growth during winter is low as temperatures reduce and may not be sufficient to meet animal demands (Brougham, 1970). Dry matter yields from perennial ryegrass and tall fescue from a three year trial in Canterbury New Zealand under irrigation found that perennial ryegrass produced greater DM yield in spring, summer and autumn in all years of the study (Minneé *et al.* 2010).

### **2.1.7.3 Effect of irrigation on dry matter yields**

The shallow rooting of perennial ryegrass, along with the variability of rainfall events and often high temperatures in the summer months, necessitates the application of relatively frequent irrigation to maximise productivity of perennial ryegrass (Milne, 2011). In a study in Palmerston North New Zealand, perennial ryegrass DM yields in February (late summer) were greater from irrigated than from non-irrigated plots (1,067 vs. 109 kg DM/ha) (Barker *et al.*, 1985). Irrigation has been reported to increase the annual DM yields of perennial ryegrass from between 1 - 2 t DM/ha in the Waikato region (Thom *et al.* 2001), while in the drier Canterbury region, irrigation increased summer DM yields of perennial ryegrass by 3 - 4 t DM/ha (Minneé *et al.*, 2010).

### **2.1.8 Herbage quality**

Herbage quality can be defined in terms of nutritive value. The nutritive value of the herbage is determined by measuring the chemical composition of the herbage and using this to estimate the energy content and digestibility (Burns, 2009). There are three main indicators of herbage quality: metabolisable energy (ME) content, crude protein (CP) content and fibre content (measured in two ways, as acid detergent fibre (ADF) and neutral detergent fibre (NDF)). The ME content of herbage is defined as the amount of energy available to the ruminant for maintenance and production (Charlton & Stewart, 2006) and is expressed in units of megajoules (MJ) per kg of DM. The amount of ME herbage contains is often the primary limitation to production of grazing animals (Waghorn *et al.*, 2007). High quality herbages are defined as those that contain above 11.5 MJ/kg DM (Kolver, 2000). Reported ME values for perennial ryegrass range from 10 - 12 MJ/kg DM (Milne *et al.*, 1997; Burke *et al.*, 2000). However, actual ME values of the herbage consumed may vary from these estimates because of the effects of such factors as: level of feeding, interactions between

feeds, animal selectivity, feed deterioration, and contamination of ingested herbage with soil (de Ruiter *et al.*, 2007).

Herbage quality is not constant, and is influenced by physiology, season, plant maturity and management (Burns, 2009). When pastures mature, cell walls strengthen to support the growing leaves, and in spring, highly fibrous reproductive stem develops and the subsequent digestibility of maturing pastures declines (Hunt & Easton, 1989; Kemp *et al.*, 2002; Litherland & Lambert, 2007; Valentine & Kemp, 2007). Comparative studies between young leafy and mature perennial ryegrass herbage show that CP and digestibility (along with ME) of pasture declines, while fibre increases as pasture matures (Bell, 1985; Waghorn & Barry, 1987; Chaves *et al.*, 2006). Tetraploid cultivars of perennial ryegrass have larger cell size than diploid cultivars which results in lower cell wall content, and enhances digestibility (Jensen *et al.*, 2007).

### **2.1.9 Milk production from perennial ryegrass pastures**

Milk production in agricultural pastures is dependent on three main feed-related factors: i) total annual pasture DM yield, ii) the seasonal accumulation of pasture DM yield, and iii) the nutritive quality of pasture herbage (Minneé, 2011). A simulation model used by Barker *et al.* (1998) determined that annual pasture DM yield is the most important factor affecting milk production, with little effect from seasonal pasture growth. However, other research conflicts with this finding, stating that increases in herbage DM yield are not always the main cause of an increase in milk production (Callow *et al.*, 2003).

### **2.1.10 Grazing management**

Supplying high quality herbage is important to ensure the efficient conversion of grass to animal product (Mayne *et al.*, 2000). The key criteria of grazing management are interval (time between grazing), height (closeness of grazing) and their timing relative to key events such as flowering and seedling establishment (Fulkerson & Donaghy, 2001). These criteria can be based on day rotations (interval), sward surface height (interval or height) and herbage mass (interval or height). These have been developed based on stocking rate, size of paddock, and feed allocation principles for grazing stock (Fulkerson & Donaghy, 2001). At a practical level, grazing management is generally focused on animal feed requirements rather than optimising plant growth patterns (Fulkerson & Donaghy, 2001).

### **2.1.10.1 Defoliation interval**

Defoliation interval is defined as the time between one defoliation event and the next (Donaghy *et al.*, 2008). In a study undertaken in subtropical Australia, Fulkerson *et al.* (1994) found that the effect of frequent (1-leaf/tiller) compared to infrequent (3-leaves/tiller) defoliation on perennial ryegrass was to suppress leaf DM regrowth by 80 - 95 %, stubble WSC by 81 - 89 % and root DM by 76 - 60 %.

A study undertaken by Judd *et al.* (1990) observed that under a 28 day defoliation interval, ryegrass produced 20 % higher DM yields than under a 14 day interval. Similarly, Fulkerson *et al.* (1993) showed that in ryegrass-white clover swards, defoliation at 4 weeks or before the onset of senescence vs. 2 weeks increased DM yield by 32 % and 59 % in years 1 and 2 respectively. Korte *et al.* (1985) found in a ryegrass sward that mowing at 95 % light interception compared with mowing every 3 weeks increased herbage mass accumulation. Additionally, Hodgson and Wade (1979) observed that defoliating ryegrass at intervals of less than 2 weeks reduced net herbage accumulation by up to 40 %. These authors concluded that grazing every 4 weeks consistently increased production by 15 % - 17 % compared with grazing at either 2 or 3 weeks, when the height of grazing was controlled.

### **2.1.10.2 Defoliation height**

Davies (1988) suggested that defoliation height varies between cutting and grazing management and according to animal type. The reduction in whole plant photosynthesis or daily carbon gain provides a good measure of defoliation height (Richards, 1993). A single close defoliation ( $\leq 3$  cm height) (Davidson & Milthorpe, 1966; Ryle & Powell, 1975; Jarvis & Macduff, 1989) through either cutting or grazing can result in decreased photosynthesis, respiration, nutrient uptake and root growth (David & Milthorpe, 1966; Clement *et al.*, 1978; Ludlow & Charles-Edwards, 1980; Parsons *et al.*, 1983), a reduction in tiller size and an increase in tiller senescence (Gastal & Saugier, 1986).

Evidence from several studies indicates that the productivity of pastures can be positively manipulated via grazing management. For example, Brougham (1959, 1960, 1970), Jameson (1963), Davidson (1968), Tainton (1974), and L'Huillier (1987) have observed that the rate of accumulation of herbage after grazing or cutting is faster following higher defoliation heights (a post-grazing residual of  $> 6$  cm height); however, defoliation around a 5 cm height increases herbage production and subsequently animal production (Hoogendoorn *et al.*, 1988), and therefore, 5 cm may be regarded as 'optimal' height post-defoliation. Brougham



(1960) showed that repeated overgrazing, particularly in the summer, can severely reduce herbage production. Close defoliation height reduces DM yield by decreasing both tiller population density and tiller weight and consequently decreases pasture growth through reductions in leaf area index, longevity of individual leaves, photosynthetic efficiency, and a shortage of WSC reserves (Tavakoli, 1993).

The fluctuations in the level of WSC reserves following defoliation has led to the belief that WSC have an important role in influencing pasture regrowth and persistence (Figure 2-2) (Sprague & Sullivan, 1950; Fulkerson, 1994; Fulkerson & Donaghy, 2001). Donaghy & Fulkerson (1998) found that perennial ryegrass plants need to grow a minimum of 2 new leaves/tiller before they have adequate photosynthetic capacity for growth and maintenance, with WSC replenishment and tillering resuming at this stage of regrowth.

Defoliation height may affect the WSC levels and persistence of the pasture. Repeated defoliation of most of the photosynthetic area would be detrimental to sustained production and persistence (Tavakoli, 1993). Close defoliation under both grazing and cutting (< 3 cm height) has been found to cause a reduction in WSC concentration, a reduced rate of leaf elongation by 2 mm/tiller/day after the first week and by 1 mm/tiller/day after 4 weeks of regrowth, and reduced total regrowth of perennial ryegrass (Grant *et al.*, 1981). However, defoliation to a height of 6 cm increased the senescence rate of leaf and caused a reduction in the number of tillers. A number of previous studies have found that defoliation to 5 cm was optimum for the growth and persistence of ryegrass pastures (Wilson & Robson, 1970; Simons *et al.*, 1972; Fulkerson *et al.*, 1994).



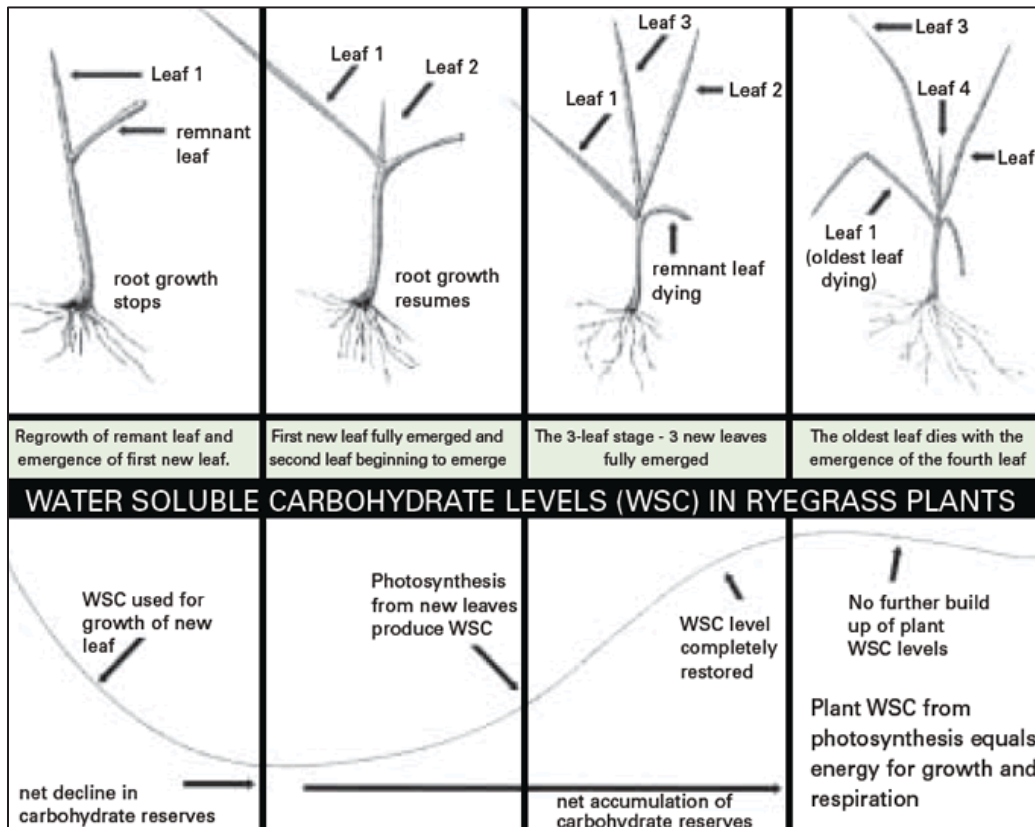


Figure 2-2. Regrowth of a perennial ryegrass tiller indicating the correlation between leaf number and levels of water soluble carbohydrate (WSC) stored in the tiller bases. Source: Donaghy & Fulkerson (1999), page 14.

### 2.1.10.3 Leaf regrowth stage

Leaf regrowth stage (number of fully expanded leaves per tiller) is an accurate measure of plant regrowth, and is driven by temperature and moisture availability. In a review, Fulkerson and Donaghy (2001) proposed that plant-based criteria such as leaf regrowth stage, be used as an effective system for determining grazing interval for ryegrass-based pastures, as it is applicable across cultivar types and varying levels of soil fertility. Glasshouse studies have shown leaf regrowth stage to be an accurate indicator of the optimum time for defoliation, reflecting plant energy levels (WSC) and the associated root growth, tillering, (Donaghy & Fulkerson, 1998), and changes in leaf nutrient concentrations during regrowth (Fulkerson *et al.*, 1998; Rawnsley *et al.*, 2002).

Leaf appearance interval is defined as the time taken for one new leaf per vegetative tiller to fully emerge following defoliation (Fulkerson & Donaghy, 2001). The leaf appearance interval is determined mainly by temperature and will therefore vary within and between years. In spring when the pasture is growing at its fastest, it can take around 9 days for a new

perennial ryegrass leaf to grow while in mid-winter when growth is slowest, it can take 20 to 30 days (Donaghy & Fulkerson, 2012).

Ryegrass plants maintain 3 live leaves per tiller (Davies, 1960; Hunt, 1965); the oldest leaves (first to emerge) beginning to senesce as the youngest fourth leaf emerges (Figure 2-3) (Alberda & Sibma, 1968; Davies & Calder, 1969). Previous studies on perennial ryegrass growth and utilisation indicated that maximum pasture yield and utilisation under rotational grazing or cutting was optimised by defoliating at the 3-leaf regrowth stage (Bircham & Hodgson, 1983; Fulkerson *et al.*, 1993, 2000; Fulkerson & Slack, 1994, 1995; Brougham, 1959, 1960, 1979; Slack *et al.*, 2000). This was shown to increase net accumulation of plant DM (Donaghy & Fulkerson, 1997), persistence (Fulkerson *et al.*, 1993; Donaghy & Fulkerson, 1998) and herbage quality (Fulkerson *et al.*, 1998). This is based on allowing plants enough time to build up their WSC levels and recover from the previous grazing (Fulkerson & Donaghy, 2001).

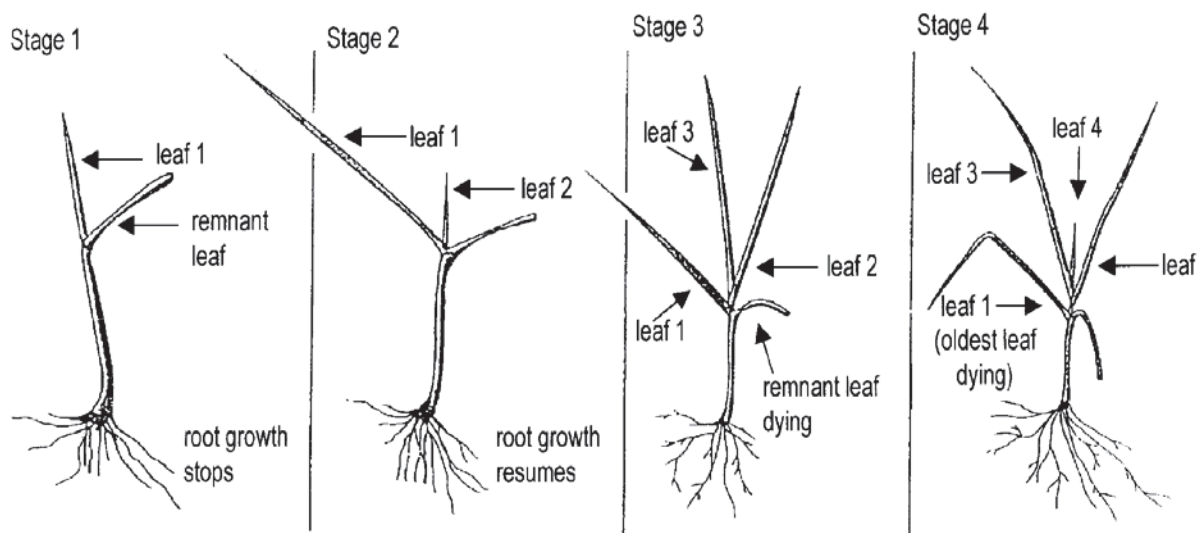


Figure 2-3. Regrowth of a ryegrass tiller following defoliation. Source: Donaghy (1998), page 25.

### ***2.1.11 Conclusions and limitations of perennial ryegrass***

Perennial ryegrass is the most common primary pasture species used for grazing dairy cattle worldwide (Barnard & Frankel, 1964), due to the high nutritive value of its herbage for most of the year under appropriate environmental and management conditions, its ability to tolerate grazing (Cunningham *et al.*, 1994) and its relatively easy establishment (Lamp *et al.*, 2001). Despite its widespread use, perennial ryegrass can have poor persistence (Quigley,

1991; Beattie, 1993; de Fegely, 1997), likely due to dry, hot summer periods (Reed, 1974; Anderson *et al.*, 1999). However, the reliance on perennial ryegrass as the sole pasture species to produce adequate herbage year round, especially through the dry summer period, is risky and may lead to a feed gap. Therefore alternatives to perennial ryegrass that are likely to persist and tolerate hot/drier periods will be valuable in agricultural pastures.

## **2.2 Tall fescue**

### **2.2.1 Origin and adaptation**

Tall fescue is native to Western Europe and North Africa (Buckner *et al.*, 1979; Sleper & West, 1996) and was introduced to New Zealand from Europe in the 1880's (Anderson, 1982; Brock, 1983) where it was proposed for use in waterlogged wasteland areas. Tall fescue is a widely adapted species and is found in sites from arid to very wet (Easton & Pennel, 1994). Temperature of below 5°C (Mitchell, 1956; McKenzie *et al.*, 1999) and rainfall below 450 mm/year can limit the growth and use of tall fescue (Buckner & Cowan, 1973).

Tall fescue is now widely distributed within Australia and New Zealand (Easton *et al.*, 1994). In New Zealand, the area of tall fescue sown has increased as farmers have become aware of its ability to tolerate difficult conditions (hot temperatures and either low or high soil moisture), and these farmers have gained confidence in their ability to establish and manage it (Craw, 1988; Martin & Moloney, 1988). Raeside *et al.* (2012) reported that tall fescue is used in zones with 650-700 mm in Australia. In New Zealand, Milne and Fraser (1990) have suggested that tall fescue is used in drier/warmer regions where soil moisture deficit limits the growth, persistence and yield of perennial ryegrass.

### **2.2.2 Morphology**

Tall fescue consists of flat leaves, which are dark green, erect and have a distinctive mid-rib (Figure 2-4). Tall fescue is a deep-rooted, perennial bunchgrass (Stephenson & Posler, 1988), but can form dense sods through a weakly rhizomatous growth habit that is productive (Charlton & Stewart, 2006) and adapted to a wide range of environments (Lazenby, 1997). Sub-surface growth consists of a dense fibrous root system (Burch & Johns, 1978; Gibson, 2001) that has the ability to extend greater than 100 cm into the soil profile for water extraction (Garwood & Sinclair, 1979; Ball *et al.*, 2002). This property is thought to provide tall fescue with a degree of drought tolerance (Garwood & Sinclair, 1979).

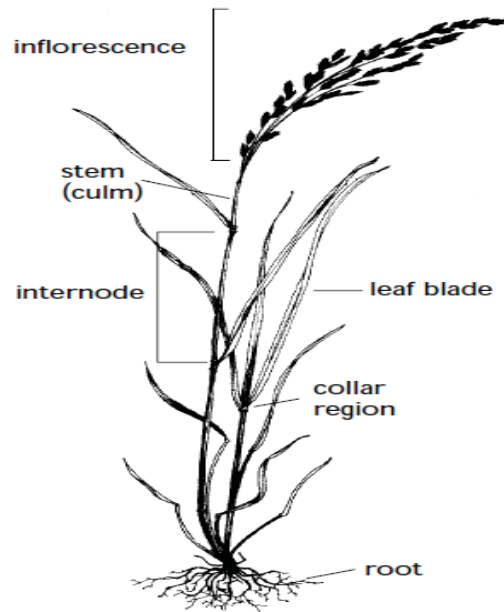


Figure 2-4. Tall fescue plant. Source: Hannaway *et al.* (1999a), page 1.

### 2.2.3 Soil requirements

Tall fescue is best suited to 'medium or heavy soil types' with high organic matter content (Buckner & Cowan, 1973). Tall fescue can grow within a pH range of 4.7 - 9.5, withstanding both acidic and alkaline soils (Cowan, 1962), but performs best within the pH range of 5.3 - 5.5 (Burns & Chamblee, 1979). Tall fescue can survive on low fertility soils, but has optimal performance on soils with high N fertility.

### 2.2.4 Establishment

Tall fescue is generally slower to germinate and establish compared to perennial ryegrass (Brock, 1983). This slow establishment is due to a poor mobilisation of seed reserves and slow root growth (Brock, 1983; Kemp *et al.*, 2002), and is one of the major constraints to the adoption of tall fescue in grazed pasture systems (Harkess, 1970; Brock, 1983). Rapid seedling establishment is important to ensure that weeds do not displace seedlings and to prevent seedling losses to desiccation or pest attack (Harkess, 1970). Tall fescue has slower root appearance and root elongation rate during establishment than that of perennial ryegrass, which results in slower shoot growth and tillering rates (Brock *et al.*, 1982). Slow establishment of tall fescue can result in reduced growth rate and herbage DM yield compared to perennial ryegrass (Praat, 1995; Callow *et al.*, 2003; Clark *et al.*, 2010). Several studies have shown that establishing tall fescue pastures had higher contents of weeds, white clover and subterranean clover (*Trifolium subterraneum* L.) and less dead matter, compared to perennial ryegrass pastures Goold & Hupkens van der Elst, 1980; Wright *et al.*, 1985).

Macfarlane (1990) stated that tall fescue sowing tended to be either great successes or great failures. Milne *et al.* (1997) concurred, suggesting that if establishment of tall fescue pastures is poor, then subsequent production will suffer as the pasture will not “thicken up” (i.e. produce enough tillers to form a dense sward).

#### 2.2.4.1 Effect of temperature

The germination and establishment of tall fescue are dependent on soil temperature (Milne & Johnson, 1997) (Figure 2-5). Temperature is the main factor determining the rate of seedling emergence (Hill *et al.*, 1985; Charles *et al.*, 1991); as temperature increases in the range of 3 to 30°C, the time taken for germination and emergence is reduced. Slower emergence increases the risk of seedlings succumbing to unfavourable moisture conditions, insect and disease attack (Campbell & Swain, 1973; Askin, 1990). Sowing tall fescue seed in cold soils (< 12°C) will delay emergence, reduce emergence percentage, and reduce the rate of seedling development (Charles *et al.*, 1991), thus allowing the invasion of weed species (Milne & Johnson, 1997). Charlton *et al.* (1986) found that at soil temperatures of 5°C, it took 65 days for 75 % of tall fescue seeds to germinate, whereas the same percentage of perennial ryegrass seeds had germinated within just 23 days. Research on tall fescue has shown that the rate of establishment and the percentage of sown seeds that finally emerge generally increase with a constant temperature of 12°C (Hill *et al.*, 1985; Charles *et al.*, 1991).

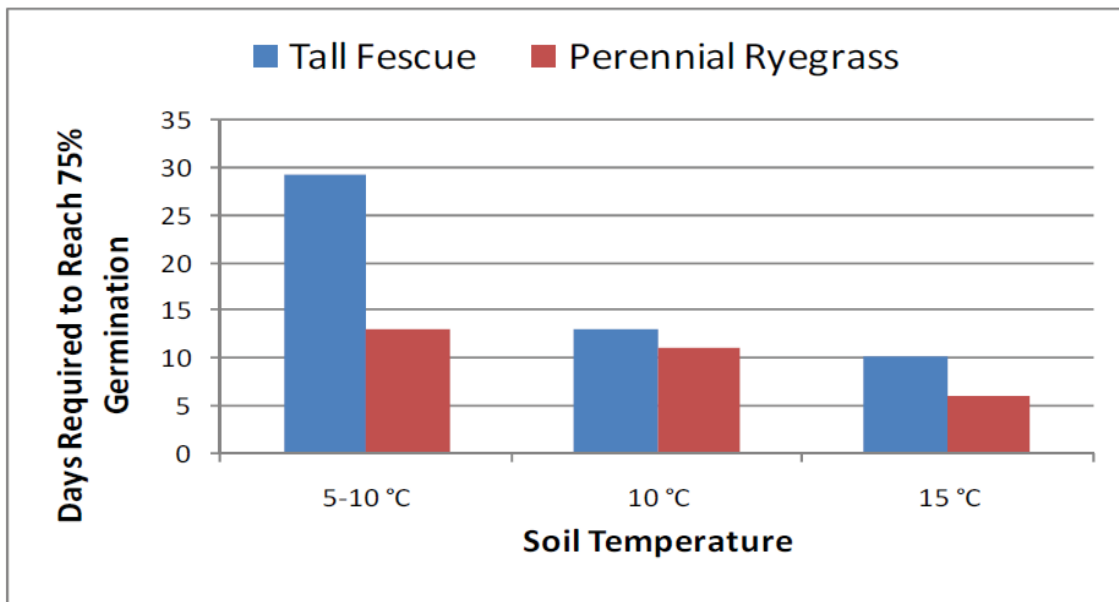


Figure 2-5. Days required for 75 % to reach germination of tall fescue and perennial ryegrass seeds at different soil temperatures. Source: DairyNZ (2010), page 2.

#### **2.2.4.2 Weed competition**

During establishment, tall fescue pastures can be exposed to greater weed invasion than perennial ryegrass pastures (Hamilton-Manns *et al.*, 1995) due to slower seedling emergence (Milne *et al.*, 1997). To achieve a dense sward of tall fescue, it is important to give the species an opportunity to develop in the absence of competition from weed species (Dowling & Robinson, 1976; Bellotti & Blair, 1989). Competition from weeds is reduced by preventing weed seed set in the year prior to sowing and by killing weeds immediately before sowing. Charles *et al.* (1991) found that pre-sowing herbicide treatment improved tall fescue seedling density by 63 %. Renovation of an existing pasture directly to new tall fescue will often fail as tall fescue is out-competed by faster growing weed species (Milne & Johnson, 1997).

Time of sowing of tall fescue can also affect weed contamination of new pastures. In New Zealand the timing of sowing is determined by the potential for weed ingress into the developing sward. Cross (1959) suggested that autumn sowing was more popular than spring sowing because of reduced weed competition and a more reliable moisture regime. The common method of sowing tall fescue in summer dry regions is to wait 2 weeks after an effective autumn break before final cultivation. Autumn sowing of tall fescue in dry conditions increases the risk of weed strike after sowing (Milne & Johnson, 1997). Milne and Johnson (1997) suggest that weed control is one of the most important tasks in site preparation and in many cases, will make the difference between success and failure.

#### **2.2.5 Root system and drought tolerance**

Tall fescue displays greater tolerance compared with perennial ryegrass to drought and heat (McCallum *et al.*, 1992, Milne *et al.*, 1993; Reed 1996), however there is no research that fully explains why tall fescue is more heat tolerant than perennial ryegrass. Perennial grasses grow well between the temperature ranges 5°C - 25°C, with an optimum temperature for growth around 18°C (Murata & Iyama, 1963; Kemp *et al.*, 2002), however tall fescue can tolerate higher temperatures than perennial ryegrass, sustaining growth and plant density at 30 - 35°C provided that sufficient moisture is available (Lowe & Bowdler, 1995; Greenwood *et al.*, 2006; Anon, 2008). Consequently tall fescue is used as an alternative species in areas of New Zealand where hot and dry conditions may limit the production and persistence of perennial ryegrass (Mitchell, 1956; Silsbury, 1969; Brock *et al.*, 1982; Brock, 1983; Judd *et al.*, 1990; McCallum *et al.*, 1992). The use of tall fescue in New Zealand has increased after droughts in the early 1980's highlighting its potential to produce more green herbage for



longer under moisture stress than perennial ryegrass (Figure 2-6) (Brock 1983; Charlton & Belgrave, 1992; Kemp *et al.*, 2002).

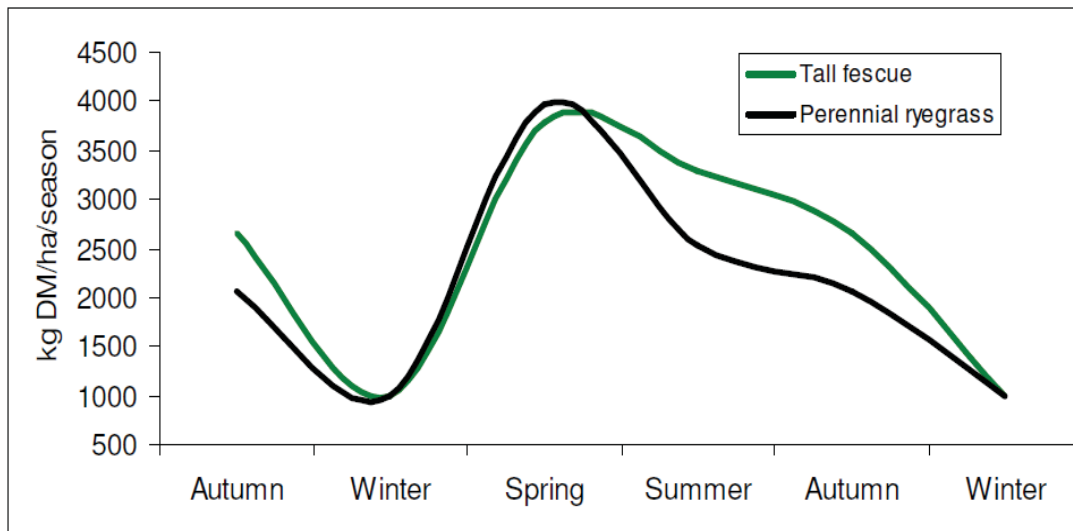


Figure 2-6. Pasture growth curves (kg dry matter (DM)/ha/season) for tall fescue and perennial ryegrass (growing in a summer dry environment). Source: DairyNZ (2010), page 1.

A greater proportion of root mass at deeper soil depths in response to decreased water availability in surface soil is considered an important trait for drought avoidance in many perennial grasses (Garwood *et al.*, 1979; Sheffer *et al.*, 1987; Tobert *et al.*, 1990; Hays *et al.*, 1991; Salaiz *et al.*, 1991; Marcum *et al.*, 1995; Wilman *et al.*, 1998). Rooting deeper into the soil where water is available for uptake allows the plant to avoid or delay tissue dehydration and maintain leaf water relations necessary for maintenance of physiological and metabolic function (Molyneux & Davies, 1983; Smucker & Aiken 1992; Carrow, 1996; Qian *et al.*, 1997). Greater root length densities of tall fescue can contribute to superior drought avoidance compared to perennial ryegrass (Qian *et al.*, 1997). Tall fescue has the ability to extract moisture from a depth below 100 cm to 200 cm in the soil profile compared to 80 cm to 130 cm effective depth of perennial ryegrass (Evans, 1978; Garwood *et al.*, 1979; Boschma *et al.*, 2003; Nie *et al.*, 2008). Furthermore, tall fescue had a greater number of roots and weight of root material at 50 - 100 cm soil depth than perennial ryegrass (Garwood *et al.*, 1979; Wilman *et al.*, 1998; Boschma *et al.*, 2003; Raeside *et al.*, 2012). Compared with perennial ryegrass and cocksfoot (*Dactylis glomerata* L.), tall fescue showed the greatest ability under moisture stress in cool temperate Tasmania Australia, to maintain productivity and display attributes that contribute to plant persistence (Turner *et al.*, 2012).

Factors or conditions that limit root growth decrease the potential for drought avoidance. For example, by constricting the root growth of tall fescue within small containers, the ability of the plants to maintain leaf water relations under drought stress was greatly diminished compared to that observed under field conditions (Volaire & Lelievre, 2001). Frequent defoliation of tall fescue also leads to a decline in the root system which affects its drought tolerance (Gibson, 2001).

### **2.2.6 Pest tolerance**

One of the main features of tall fescue is insect tolerance (Hay, 1987; Milne *et al.*, 1998) Tall fescue displays a greater degree of tolerance to the common pasture pests including grass grub, Argentine stem weevil and pathogens including crown rust (*Puccinia coronata*) that affect perennial ryegrass (Allo & Southon, 1967; Kain *et al.*, 1979; Prestidge *et al.*, 1986; Macfarlane, 1990; McCallum *et al.*, 1992; Judd *et al.*, 1990; Milne *et al.*, 1997; Popay *et al.*, 2005; Lowe *et al.*, 2008). These studies suggest that tall fescue may be a viable alternative to perennial ryegrass in regions where perennial ryegrass is susceptible to insect or fungal attack.

### **2.2.7 Dry matter yields from tall fescue pastures**

#### **2.2.7.1 Annual dry matter yields**

The DM yield results from studies of tall fescue and perennial ryegrass are variable, and results from a range of New Zealand studies are summarised in Table 2-1. Some studies have demonstrated greater DM yields of tall fescue (5 - 20 % more DM) (Allo & Southon, 1967; Goold & Hupkens van der Elst, 1980; Thomson *et al.*, 1988; Judd *et al.*, 1990) over perennial ryegrass. Others have shown that the annual DM yield from tall fescue is comparable to that from perennial ryegrass pastures (Allen & Cullen, 1975; Watkin, 1975; Milne *et al.*, 1997; Rollo *et al.*, 1998; White & Knight, 2007; Clark *et al.*, 2010). Conversely Hainsworth *et al.* (1991) found tall fescue produced 25 % less DM annually than perennial ryegrass.

#### **2.2.7.2 Seasonal dry matter yields**

Annual DM yield is driven by the seasonal response of pastures to temperature and rainfall. Tall fescue offers production advantages in the drier summer months compared to perennial ryegrass (Allo & Southon, 1967; Judd *et al.*, 1990; McCallum *et al.*, 1992; Rollo *et al.*, 1998). Tall fescue had greater DM yields (20 - 40 % more DM) and provided higher quality herbage in summer than perennial ryegrass (Lazenby & Lovett, 1975; Judd *et al.*, 1990;



McCallum *et al.*, 1992; Kemp *et al.*, 2002; Clark *et al.*, 2010). Tall fescue also has the ability to produce green herbage of 1 - 2 t DM/ha more quickly than ryegrass after summer rain (Lawson *et al.*, 2007; Nie *et al.*, 2008). For example, a study by Lawson *et al.* (2007) found that tall fescue produced green herbage for 4 - 6 weeks following 123 mm of rain in January 2007, while perennial ryegrass was only mildly responsive to this level of rainfall. Studies conducted over three years on a range of soil types in south-western Victoria, Australia, showed that the summer DM yields of tall fescue pastures was 1.3 t DM/ha more than perennial ryegrass pastures (Tharmaraj *et al.*, 2008).

Table 2-1. Summary of dry matter yields (t dry matter (DM)/ha/year) of tall fescue and perennial ryegrass pastures studies in New Zealand.  
 Source: Minneé (2011), page 42.

Author	Trial period	Tall fescue			Defoliation	Stock	Tall fescue cultivar	Endophyte	Region
		Ryegrass (non irrigated)	Ryegrass (non irrigated)	Tall fescue (irrigated)					
Allen & Cullen (1975)	1968-71	9	8.8		Cutting	-	S170	Nil	Southland - hill
		12.8	12.4		Cutting	-	S170	Nil	Southland - plain
Allo & Southon (1967)	1966-67	6.1	6.4		Cutting	-	S170	Nil	BOP
Clark et al. (2010)	2008-09	16.8	16.6		Grazing - rotational	Dairy	Advance	MaxP	Waikato
		13.9	12.2	18.3	Grazing - rotational	Dairy	Advance	MaxP	Waikato
Hainsworth et al. (1991)	1987-90	(6.9)	6.4		Grazing - rotational	Dairy	Roa	Nil	Taranaki
Hay et al. (1997)	1992-96	10.7			Grazing	Sheep	Advance	Nil	Manawatu
Judd et al. (1989)	1982-88	(14.5)	17.5		Grazing - rotational	Dairy	Roa	Nil	Taranaki
Martin et al. (2008)	2006-07			15	Cutting	-	Advance	MaxP	Canterbury
McCallum & Thomson (1992)	1986-87	(6.3)	8.7		Grazing - rotational	Dairy	Roa	Nil	Taranaki
Rollo et al. (1998)	1990-95	(9.9)	10.4		Grazing	Sheep	AU Triumph	Nil	Hawkes Bay
		(14.7)	17.0		Grazing	Dairy	Roa	Nil	Taranaki
	-	(8.0)	9.0	(14.0)			Roa	Nil	Canterbury
Thomson et al. (1988)	1983-86	(14.3)	16.9		Grazing - rotational	Dairy	Roa	Nil	Taranaki
Watkin (1975)	-	9.7	11.1		Grazing - rotational	Sheep	S170	Nil	Canterbury

### **2.2.7.3 Effect of irrigation on dry matter yields**

Tall fescue is highly responsive to irrigation (Lowe & Bowdler, 1995). A number of studies have shown that tall fescue produced more DM than perennial ryegrass when accompanied by irrigation during hot dry summers (Brock *et al.*, 1982; Macfarlane, 1990; Clark *et al.*, 2010), and tall fescue also generally has a greater efficiency in water use than perennial ryegrass swards (Minneé *et al.*, 2010). Yet, in a study by Parry *et al.* (1992) in Canterbury under mild summer temperatures, irrigated tall fescue did not outperform irrigated perennial ryegrass pastures; under those “low stress” conditions, the ryegrass was more water use efficient than tall fescue pastures (producing 22.3 vs. 21.9 kg DM/ha/mm water applied). These studies suggest that tall fescue and perennial ryegrass have differing ranges of optimal temperature for DM yield, and further to this tall fescue can exhibit a production advantage over ryegrass, but only when water or high temperatures are limiting ryegrass production.

### **2.2.8 Herbage quality**

The herbage quality of tall fescue herbage is comparable with perennial ryegrass, although as the plant matures, both digestibility and palatability decline (Easton *et al.*, 1994). Reported ME values for tall fescue are in a similar range to those of perennial ryegrass, of between 11 - 12 MJ/kg DM (Milne *et al.*, 1997), indicating that it is generally a high quality forage suitable for lactating dairy cows.

Tall fescue once had a reputation of being poorer quality than perennial ryegrass (Fulkerson *et al.*, 2000), probably because early cultivars of tall fescue were tough-leaved, containing a large amount of structural fibre (Milne, 2001), and also management guidelines specific to tall fescue weren't well developed until the mid-1990's (Minneé, 2011). Newer cultivars of tall fescue, such as 'Advance', are reportedly less fibrous and more palatable to cows than older cultivars such as 'Demeter', and management guidelines that are more specific to tall fescue have been developed (Milne *et al.*, 1997). Milne *et al.* (1997) reported similar levels of fibre and digestibility in tall fescue and perennial ryegrass pastures when both were kept in a vegetative state. However, several other studies have found that the increase in fibre and related decline in digestibility of tall fescue occurs more rapidly than observed in perennial ryegrass pastures (Callow *et al.*, 2003; Lowe *et al.*, 2009). Therefore the management of tall fescue and perennial ryegrass should be adjusted according to seasonal growth rate and particular care is needed to control stem and seed-head development in tall fescue pastures in spring (Easton *et al.*, 1994; Milne, 2001; Charlton & Stewart, 2006).

### **2.2.9 Milk production from tall fescue pastures**

Studies comparing milk production from tall fescue and perennial ryegrass have reported conflicting results. Evidence from commercial farms in the Waikato suggest that milksolids (MS) and milk yield production from well-managed tall fescue pastures is greater than from perennial ryegrass pastures (Milne *et al.*, 1997; Milne, 2001). Other studies reported similar total milk yields (Wilson, 1975) and MS yields (Wilson, 1975; Thomson *et al.*, 1988; Hainsworth & Thomson, 1997) from cows grazing tall fescue and perennial ryegrass pastures. However, evidence from a study in Australia indicated that milk production from tall fescue was lower than that from perennial ryegrass (Lowe *et al.*, 1999).

The discrepancies in results from these studies can be explained by differences in management of pastures and in the selection of cultivars. For example, Lowe *et al.* (2008) agree that once management of tall fescue pastures is optimised, milk production from both tall fescue and perennial ryegrass pastures is comparable. The slower establishment of tall fescue may also allow a higher content of legumes such as white clover, and this is likely to have enhanced milk yield in some studies (Johnson & Thomson, 1996; Harris *et al.*, 1997), as white clover has a higher average nutritive value (11.5 - 12.5 MJ/kg DM) compared with sown grasses. For example, in a study reported by Wilson (1975), tall fescue contained considerably higher proportions of white clover than the ryegrass pastures (35 % vs. 11 % of DM for the tall fescue and ryegrass pastures, respectively).

Advantages in MS production have also been observed during dry summer conditions. In an evaluation of pasture mixes and their effect on MS yield, Thom *et al.* (1998) showed that in a summer when soil moisture was not limited, the MS production from tall fescue and perennial ryegrass pastures were similar, but in the following year when a drought occurred, MS production from tall fescue pastures was greater than perennial ryegrass pastures (0.89 vs. 0.71 kg MS/cow/day, respectively). This trend was also noted by Thomson *et al.* (1988) where MS production from tall fescue pastures was below that of perennial ryegrass pastures in wetter years but was greater in drier years, resulting in no significant difference over the four years of the trial.

### **2.2.10 Grazing management**

#### **2.2.10.1 Defoliation interval**

A number of studies suggest that tall fescue is more productive under less frequent defoliation. For example, Schiller and Lazenby (1975) showed that the total DM yield of tall

fescue over 2 years decreased from the longest interval of 16 weeks, to the shortest interval of 2 weeks. Bell (1985) found that in a mixed sward, tall fescue contributed the greatest DM yield under a 63 day defoliation interval and the least yield under a 21 day defoliation interval, and Hart *et al.* (1971) found that tall fescue produced a greater DM yield when defoliated every month rather than every week. Contrary to results from these studies, Kerrisk and Thomson (1990) found that under dry conditions in spring and summer, frequent defoliation resulted in greater DM yield. In spring, yield of tall fescue was highest under a 15 day defoliation interval (compared to 10 and 30 days) while 30 days resulted in the highest DM yields from perennial ryegrass (Table 2-2). In summer, the 10 day defoliation interval resulted in greater growth rates in both tall fescue and perennial ryegrass than did the 15 day or 30 day intervals.

Table 2-2. Daily pasture growth rate (kg dry matter (DM)/ha/day) response to cutting frequency. Source: Kerrisk & Thomson (1990), page 137.

Year 1	Spring (dry)				Summer (wet)				Autumn (dry)				Winter (wet)			
	F	M	I	LSD*	F	M	I	LSD*	F	M	I	LSD*	F	M	I	LSD*
Ryegrass	57	66	73	8.9	54	56	47		31	25	23	4.0	15	16	14	ns
Fescue	45	59	43	7.2	69	74	65		41	41	30		24	24	26	
Year 2	Spring (wet)				Summer (dry)				Autumn (wet)				Winter (dry)			
	F	M	I	LSD*	F	M	I	LSD*	F	M	I	LSD*	F	M	I	LSD*
Ryegrass	78	89	88		20	20	16	2.5	50	51	43		30	36	30	
Fescue	95	107	110		35	28	27	6.0	65	64	65		29	33	30	

LSD\*  $P < 0.05$

F = Frequent cutting frequency (10 day defoliation interval)

M = Medium cutting frequency (15 day defoliation interval)

I = Infrequent cutting frequency (30 day defoliation interval)

Defoliation also affects herbage quality, with longer defoliation interval (when canopy height reached 31 cm) decreasing herbage quality (Burns *et al.*, 2002). Burns *et al.* (2002) made the point that grazing rotations must be sufficiently short (when canopy height reached 15 cm) to prevent losses in herbage quality associated with increased DM accumulation. However, in this study, the time taken to reach these canopy heights varied with season, and the regrowth stage of the tall fescue was not specified.

### 2.2.10.2 Defoliation height

There is evidence that close defoliation reduces herbage DM yields. Research by Kerrisk and Thomson (1990) found that if post-grazing residual was too low, it could be detrimental to

pasture regrowth rates under dry conditions, with a residual height of 4.5 - 5.5 cm resulting in 20 % greater DM yield in summer and autumn, and 30 % greater DM yield in spring, compared to a residual height of 3 - 4 cm. Kerrisk and Thomson (1990) also suggest that grazing to a height less than 5 cm during dry conditions could be detrimental to the persistence of tall fescue swards. It is also evident that defoliating tall fescue to heights above 5 cm does not optimise pasture production; a study undertaken by Hart *et al.* (1971) in Maryland USA, found that a defoliation height of 5 cm resulted in greater DM yields compared with longer stubble heights (10 or 15 cm).

Defoliation height has a major effect on the structure and characteristics of pasture swards. Research by Penning *et al.* (1991), working with four sward surface heights (3, 6, 9 and 12 cm) showed that defoliation height had a direct effect on the numbers of tillers, tiller mass and leaf area. During late spring, swards maintained at lower defoliation heights (3 and 6 cm) had a greater number of tillers and a lower proportion of reproductive tillers than the swards maintained at 9 and 12 cm. Furthermore, the taller swards became more open, sparsely tillered and stemmy. Brink *et al.* (2014) compared the effect of defoliation to 10 cm vs 5 cm on four temperate grasses (including meadow fescue (*Schedonorus pratensis* (Huds.)) and found that all grasses produced a greater number of tillers, herbage DM and root DM when defoliated to 10 cm compared to 5 cm height. In a field study conducted by Tavakoli (1993), tall fescue and perennial ryegrass were compared under continuous stocking with sheep to maintain defoliation heights of 9 - 10 cm (lax), 5 - 6 cm (medium), and 3 - 4 cm (hard). Results showed a reduction in tiller density, tiller weight and tiller numbers, leaf and root growth and DM yield for both tall fescue and perennial ryegrass under hard grazing management.

The response of tall fescue and perennial ryegrass to defoliation was compared by Kemp *et al.* (2001) under controlled environment conditions in both the vegetative and reproductive stages of growth. The oldest leaves were defoliated regularly to maintain 4 (control), 3 (lax), 2 (medium) or only 1 (hard) leaf/tiller for a duration of 7 leaf appearance intervals. Results indicated that the responses of tall fescue and perennial ryegrass to defoliation were generally similar, but tall fescue persistence was more affected than perennial ryegrass by the closest defoliation (maintaining 1 leaf/tiller). Furthermore when Kemp *et al.* (2001) compared tall fescue and perennial ryegrass under continuous defoliation at various residual heights (3 vs 6 cm), they found that the optimal sward surface height for continuously stocked tall fescue

swards was between 3 cm and 6 cm under rotational grazing and observed that tall fescue swards were not as persistent or productive as swards of perennial ryegrass when continuously defoliated to maintain a surface height of 3 - 4 cm. Sheath and Bircham (1983) indicated that the extremes of over-grazing (a post-grazing residual of < 3 cm height) and under-grazing (a post-grazing residual of > 6 cm height) should be avoided, because at the lower height insufficient pasture cover limits new growth and at the taller height insufficient utilisation of pasture results in wasted herbage.

### **2.2.10.3 Leaf regrowth stage**

Frequent defoliation diminishes WSC storage capacity and affects regrowth and persistence, while infrequent defoliation can result in the loss of DM through leaf senescence and reduced rates of tillering (Grant *et al.*, 1981; Fulkerson & Slack, 1995).

Donaghy *et al.* (2008) conducted a glasshouse study on tall fescue to investigate the effect of repeated defoliation at the 1-leaf, 2-leaf, and 4-leaf stages of regrowth on herbage quality, WSC energy reserves and the rate of subsequent plant regrowth. They found that the WSC concentration in the stubble and leaves of plants was greater with increasing number of leaves (1-leaf vs. 2-leaf vs. 4-leaf). Both the WSC content and the rate of replenishment throughout the regrowth cycle were shown to be greater in the stubble than in the leaves confirming that, as in ryegrass (Danckwerts & Gordon, 1987; Fulkerson & Slack, 1994), WSC are stored in the tiller base in tall fescue plants (Donaghy *et al.*, 2008).

Defoliating tall fescue at the 2-leaf regrowth stage has positive effects on herbage quality (Donaghy *et al.*, 2008) whereas defoliating at the 4-leaf stage optimises WSC, yield and persistence (Kemp *et al.*, 2001; Donaghy *et al.*, 2008; Raeside *et al.*, 2012). With perennial ryegrass, defoliating between the 2- and 3-leaf regrowth intervals has been shown to increase net accumulation of plant DM (Fulkerson *et al.*, 1993; Fulkerson and Slack 1995; Donaghy and Fulkerson 1997, 1998; Donaghy *et al.*, 1997; Donaghy 1998), persistence (Fulkerson *et al.*, 1993; Donaghy *et al.*, 1997; Donaghy 1998) and herbage quality (Fulkerson *et al.*, 1998). However these plant-based indicators have not yet been defined for tall fescue plants.

The replenishment of WSC reserves and onset of senescence - both defined by leaf regrowth stage - are appropriate criteria to demonstrate a guideline for an optimum defoliation plan for both tall fescue and perennial ryegrass (Fulkerson & Slack, 1995; Fulkerson & Donaghy, 2001). Grazing management based on these principles should optimise the use of the pasture

in terms of DM production, utilisation, persistence and herbage quality. Furthermore these criteria are a simple and practical means to determine the appropriate defoliation interval.

### **2.3 Summary and conclusion**

This literature review compared the performance and management of tall fescue and perennial ryegrass. Pasture production of ryegrass in New Zealand agricultural pastures is limited under dry and hot summer temperatures. Also, results from a number of experiments show that grazing management during spring and summer is the most critical factor in determining pasture density and herbage production.

Tall fescue is an alternative pasture grass species to perennial ryegrass, and has been shown to be more heat and drought tolerant and more productive under warmer and drier conditions. Therefore tall fescue shows potential for filling the summer feed deficit when perennial ryegrass pasture growth and herbage quality are reduced. However, its growth and persistence can be negatively affected by fast defoliation intervals and close post-grazing residuals.

Therefore this thesis sets out to investigate the effects of defoliation management based on defoliation heights (optimal at 5 cm and higher at 8 cm) and defoliation intervals based on different stages of leaf regrowth; 1-leaf, 2-leaf or 4-leaf in tall fescue compared to perennial ryegrass 1-leaf, 2-leaf or 3-leaf stage of regrowth, to better understand the optimum grazing management of tall fescue.



### 3 Methods

#### 3.1 Site

A small plot trial was conducted between November 2012 and November 2014 at paddock 16 on No. 4 dairy farm (41°18'5.61"S, 174°46'31.88"E) which is located adjacent to the Massey University campus, approximately 5 km south of Palmerston North, New Zealand. The soil chemistry profile from samples taken on 13 October 2012 from a 0 - 10 cm depth is given in Table 3-1. The soil at the site was a Tokomaru silt loam (Harmsworth, 2009). Monthly rainfall and ambient temperatures (Table 3-2) were recorded from an AgResearch weather station, approximately 2 km north of the trial site.

Table 3-1. Soil chemical and physical properties at the trial site prior to fertiliser application, from soil sampled to a depth of 100 mm.

Property	
pH *	7.4
Olsen phosphorus (mg/L)	30
Potassium (me/100g)	0.34
Calcium (me/100g)	28.9
Magnesium (me/100g)	0.66
Sodium (me/100g)	0.14
Cation exchange capacity (me/100g)	30
Total base saturation (%)	100
Volume weight (g/mL)	1.02
Sulphate sulphur (mg/kg)	7

\*pH calculated via water method

me = milliequivalent

The site was prepared by spraying with Roundup® Transorb (glyphosate 540 g active ingredient/L) on 16 October 2012 to remove the previous perennial ryegrass and white clover pasture. A fine, firm seedbed was prepared by ploughing with a power harrow and secondary cultivation with a Dutch harrow. Fertiliser (Cropmaster 15, 200 kg/ha; 15.2 % N, 10% P, 10 % potassium (K), 7.7 % sulphur (S)) was applied on the 15 November 2012 using an oscillating spout fertiliser spreader. The plots (1.2 m x 6 m) were sown on 16 November 2012 using a specialist plot seed drill. This sowing date ensured that establishment was not inhibited by low soil temperatures (< 12°C) (Hill *et al.*, 1985; Charles *et al.*, 1991) and that

the paddock was dry enough to be driven on. The site was sown with either a mix of tall fescue and white clover, or perennial ryegrass and white clover (Table 3-3). These plots were later sprayed (with Roundup® Transorb (glyphosate 540 g active ingredient/L)) back to 1.2 m x 5 m. All plots were cut to 8 cm prior to treatments starting on 23 January 2013 (two months after trial established).

Table 3-2. Monthly rainfall (mm) and average maximum and minimum air temperatures (°C) for the duration of the current study, along with the 10 year average. Source: AgResearch Weather Station, Palmerston North.

	Temperatures (°C)										Rainfall (mm)		
	2012		2013		2014		10 yr. av.			2012	2013	2014	10 yr. av.
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max			
<b>Jan</b>	12	21.2	11.7	23.3	5.7	24.5	12.7	22.5	87	29	52	52	
<b>Feb</b>	12.2	21.1	12.2	24.1	10.5	25.4	13.3	23.3	72	34	19	55	
<b>Mar</b>	10.8	19.7	11.1	23.6	9.7	22.2	11.9	21.7	57	37	9	60	
<b>Apr</b>	8.4	19.5	10.8	19.2	11	20.5	9.4	18.8	28	128	100	84	
<b>May</b>	3.9	15	6.7	16	7.2	16.7	6.5	16.2	62	50	85	102	
<b>Jun</b>	3.4	12.8	5.7	13.8	7	15.3	5.2	13.6	93	85	66	100	
<b>Jul</b>	4.2	13.1	6.4	13.4	3.7	12.8	4.4	12.9	109	37	16	91	
<b>Aug</b>	5.6	14.4	6.8	15.1	4.4	13.6	4.9	13.4	98	44	64	84	
<b>Sep</b>	5.7	15.2	7.5	15.3	7.3	16.0	7	15.4	59	108	66	87	
<b>Oct</b>	7.1	16.1	9.7	17.2	7.2	17.1	8.5	16.9	64	105	54	108	
<b>Nov</b>	7.8	17.6	11.5	20.3	9.2	17.4	9.5	17.9	20	54	80	100	
<b>Dec</b>	12.5	22.3	9.8	23.8	11.8	21.2	12.1	20.8	100	59	79	90	

### 3.2 Treatments and experimental design

Treatments were arranged in 36 plots, laid out in a randomised complete block design with three replications. Pasture species and equivalent sowing rates in kg/ha are presented in Table 3-3.

Table 3-3. Sowing rates (kg of seed/ha) of swards established in the current study.

Pasture species	Species and cultivars	Sowing rate (kg/ha)
<b>Perennial ryegrass &amp; white clover</b>	<i>Lolium perenne</i> L. (cv. Bealey)	28
	<i>Trifolium repens</i> L. (cv. Kopu II)	2
	<i>Trifolium repens</i> L.(cv. Tribute)	2
<b>Tall fescue &amp; white clover</b>	<i>Festuca arundinacea</i> (cv. Easton)	25
	<i>Trifolium repens</i> L. (cv. Kopu II)	2
	<i>Trifolium repens</i> L. (cv. Tribute)	2

### 3.3 Defoliation treatments

Defoliation treatments were based on interval defined by leaf emergence and residual height defined by cm above ground level. There were 3 defoliation interval treatments for both tall fescue and perennial ryegrass. Tall fescue was defoliated using a rotary mower at either the 1-leaf, 2-leaf or 4-leaf stages of regrowth, while perennial ryegrass was defoliated at either the 1-leaf, 2-leaf or 3-leaf stages of regrowth. The 4-leaf stage for tall fescue and the 3-leaf stage for perennial ryegrass represented the maximum number of live leaves/tiller. Two defoliation heights of 5 cm (optimum (O)) and 8 cm (high (H)) were imposed over each leaf stage interval treatment. Timing of harvest occurred according to the treatment cutting dates shown in Table 3-4.

Table 3-4. Pasture species treatment cuts for tall fescue (TF) and perennial ryegrass (PR) subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3), and 4-leaf stage (TF-4)) for the experimental period 4 October 2013 - 7 November 2014.

		Cutting dates for tall fescue and perennial ryegrass treatments									
<b>TF-1</b>	6/10/13	<b>1</b>	8/11/13	15/11/13	3/12/13	28/12/13	<b>1</b>	25/1/14	13/3/14	25/3/14	2/5/14
<b>TF-2</b>		<b>2</b>		13/11/13		28/12/13		25/1/14		25/3/14	
<b>TF-4</b>				13/11/13				25/1/14			
<b>PR-1</b>	4/10/13	22/10/13	5/11/13	21/11/13	11/12/13	28/12/13	<b>1</b>	25/1/14	10/2/14	25/3/14	2/5/14
<b>PR-2</b>		22/10/13		21/11/13		11/12/13		25/1/14		10/2/14	
<b>PR-3</b>			5/11/13		28/12/13				12/2/14		
<b>TF-1</b>	27/5/14	17/7/14	15/8/14	28/8/14	26/9/14	15/10/14	23/10/14	7/11/14			
<b>TF-2</b>	27/5/14	17/7/14	15/8/14		26/9/14	15/10/14		7/11/14			
<b>TF-4</b>	27/5/14				26/9/14			7/11/14			
<b>PR-1</b>	27/5/14	17/7/14	15/8/14	28/8/14	26/9/14	15/10/14	23/10/14				
<b>PR-2</b>	27/5/14	17/7/14	15/8/14		15/10/14		23/10/14				
<b>PR-3</b>	27/5/14			28/8/14			23/10/14				

Yellow highlight = treatments missed defoliation.

## **3.4 Sampling and measurements**

### **3.4.1 Dry matter yield**

At each defoliation event, herbage was cut to the treatment height using a rotary mower (as shown in Figure 3-1). Herbage was collected from one mower width (0.46 m) by the length of the plot (5 m), weighed and the total wet weight recorded. A subsample from each plot was taken and dried in a forced-draught oven at 70°C for 48 hours and then weighed to obtain DM %, and this was multiplied by the total wet weight to give the total DM per plot.

Cumulative yield (kg DM/ha) and growth rate (kg DM/ha/day) of tall fescue and perennial ryegrass were divided into three identified periods as follows; (i) flowering period (1 October - 31 December 2013 and 1 October - 7 November 2014), (ii) summer/autumn period (1 January - 30 April 2014) and (iii) winter/early spring period (1 May - 30 September 2014), to investigate the seasonal distribution of DM yield.

The cumulative DM yield was calculated by summing the individual yields collected during the trial period (4 October 2013 - 7 November 2014). The growth rate was calculated by dividing each individual yield (expressed as kg DM/ha) by the number of days between each defoliation, to express as kg DM/ha/day.

### **3.4.2 Herbage quality**

A total of 38 sub-samples of approximately 10 g each were taken from four periods (4 August 2013, 15 November 2013, 27 May 2014 and 7 November 2014) for analysis of herbage quality. Samples from all plots were collected on 4 August 2013 (prior to the start of treatment) and bulked according to species. Samples from 15 November 2013 onwards were collected from each treatment of tall fescue 1-, 2- and 4-leaf and perennial ryegrass 1-, 2- and 3-leaf stages of both optimum and high cutting. These were ground to pass through a 1 mm diameter sieve. The samples were sent to Hill laboratories, Hamilton, for estimation of herbage nutritive value by using near infra-red spectrophotometry (NIRS). The samples were analysed for ME (MJ/kg DM), CP (% DM), ADF (% DM), NDF (% DM), digestibility of organic matter in dry matter (DOMD %) and WSC (% DM), using the following methods:

- CP - N multiplied by 6.25
- ADF - calibration using a modified National Forage Testing Association method (<http://foragetesting.org/>)

- NDF - calibration using the National Forage Testing Association method (<http://foragetesting.org/>)
- DOMD and ME - DOMD is calculated from organic matter digestibility using Australian Fodder Industry Association standard equation (see <http://www.hill-laboratories.com/file/fileid/45374>).  $ME = 0.16 * DOMD \%$ .
- WSC - WSC is calculated as  $WSC = 100 - (CP + ash + crude\ fat + NDF)$ .



Figure 3-1. Mowing of experimental plots using a rotary mower, for determination of pasture dry matter yields.

### ***3.4.3 Botanical composition***

Herbage samples were collected from all plots on 27 May 2014, from perennial ryegrass plots on 23 October 2014 and from tall fescue plots on 7 November 2014. Dates were chosen when the 1-, 2- and 4-leaf treatments of tall fescue and the 1-, 2- and 3-leaf treatments for perennial ryegrass coincided. Four hand-clipped herbage samples of approximately 20 x 10 cm<sup>2</sup> were taken from each plot (prior to defoliation of plots), cut to ground level, and bulked on a plot basis. The herbage samples were dissected into three groups; (i) tall fescue or perennial ryegrass, (ii) legumes and (iii) other species. The samples were dried in a forced-draught oven at 70°C for at least 48 hours before weighing to determine botanical composition on a DM basis (Whalley & Hardy, 2000).



### 3.4.4 Tiller density

The tiller density (number of tillers/m<sup>2</sup>) of each plot was determined on 23 January 2013 (9 weeks after emergence), and at the end of the trial (23 October (PR) and 7 November 2014 (TF)). At 23 January 2013, tiller density was calculated by multiplying plant density by the average number of tillers per plant (calculated from a subset). Plant density was measured by counting the number of plants in two separate row meters within each plot, and then averaging the two counts (Figure 3-2 Left). Both tiller density and plant density were measured on a total of eight row lengths (4 tall fescue plots and 4 perennial ryegrass plots). The tiller density of all plots was then estimated by multiplying their respective plant density by average number of tillers per plant.

The final tiller density count was more difficult due to invasion of other grasses into the sown plots. Tiller density was determined at the end of the study in late October - early November 2014. Five randomly selected divots (17.4 x 17.4 cm) were collected along an identifiable row within each plot (Figure 3-2 Right). The number of sown grass tillers per divot was recorded in each divot and then an average was obtained for each plot and converted to a tillers/ha basis.



Figure 3-2. Left - Tall fescue and perennial ryegrass plant and tiller density determined during the establishment phase (January 2013, 9 weeks after emergence). Right - Tiller density counts at the end of the trial (late October - early November 2014).

### 3.5 Statistical analysis

Dry matter yields, botanical composition, tiller density and herbage quality were analysed using the general linear model command in Minitab (Minitab 16). Tiller density was analysed separately for each measurement date. The models included the fixed effects of species, defoliation height, regrowth interval (leaves/tiller) and the two-way interaction between



species and cutting height, species and regrowth interval, regrowth interval and cutting height and the three-way interaction between species, cutting height, regrowth interval and the random effect of the 3 replicates. This model was used to investigate all parameters. When no significant interaction was present for botanical composition, the data were presented as sown species by leaf stage in order to show the treatment combinations.

## **4 Results**

### **4.1 Herbage dry matter yields**

There was no significant difference in DM yields between plots prior to treatments being imposed (from January 2013 - September 2013) - see Appendix A, Table 1.

Tall fescue out-yielded perennial ryegrass under all treatments for the duration of the experimental period (4 October 2013 - 7 November 2014), by an average of 56 %. All treatment interactions for cumulative DM yield, across the 4 identified time periods, are shown in Table 4-1.

Table 4-1. Cumulative dry matter (DM) yield (kg/ha) of tall fescue (TF) and perennial ryegrass (PR) under two defoliation heights (optimum (5cm, O) and high (8cm, H)) and subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3) and 4-leaf stage (TF-4)) for the periods 4 October - 31 December 2013, 1 January - 30 April 2014, 1 May - 30 September 2014 and 1 October - 7 November 2014. The total yield (kg DM/ha) throughout the trial period (4 October 2013 - 7 November 2014) is also shown.

	4 Oct-31 Dec 2013	1 Jan-30 Apr 2014	1 May-30 Sep 2014	1 Oct-7 Nov 2014	Total yield (kg DM/ha)
<i>Sown species</i>					
TF	5197 <sup>b</sup>	2699 <sup>b</sup>	2855 <sup>b</sup>	2927 <sup>b</sup>	13679 <sup>b</sup>
PR	3334 <sup>a</sup>	1437 <sup>a</sup>	2519 <sup>a</sup>	1451 <sup>a</sup>	8740 <sup>a</sup>
SEM	***	***	**	***	***
<i>Defoliation height</i>					
O	4429 <sup>b</sup>	2239 <sup>b</sup>	2634	2214	11516
H	4102 <sup>a</sup>	1897 <sup>a</sup>	2740	2163	10903
SEM	**	***	NS	NS	NS
<i>Sown species*Regrowth interval</i>					
TF-1	4853 <sup>c</sup>	1654 <sup>c</sup>	2367 <sup>a</sup>	2130 <sup>c</sup>	11004 <sup>c</sup>
TF-2	6751 <sup>d</sup>	1734 <sup>c</sup>	2450 <sup>ab</sup>	2619 <sup>d</sup>	13554 <sup>d</sup>
TF-4	3987 <sup>b</sup>	4711 <sup>d</sup>	3749 <sup>c</sup>	4032 <sup>e</sup>	16479 <sup>e</sup>
PR-1	2820 <sup>ab</sup>	1385 <sup>b</sup>	2580 <sup>b</sup>	603 <sup>a</sup>	7388 <sup>a</sup>
PR-2	2625 <sup>a</sup>	1842 <sup>c</sup>	2186 <sup>a</sup>	1735 <sup>b</sup>	8387 <sup>b</sup>
PR-3	4558 <sup>c</sup>	1083 <sup>a</sup>	2790 <sup>c</sup>	2015 <sup>bc</sup>	10446 <sup>c</sup>
SEM	***	***	***	***	**
<i>Sown species*Regrowth interval*Defoliation height</i>					
TF-1 O	4918	1762 <sup>bc</sup>	2432	2433	11545
TF-1 H	4788	1545 <sup>b</sup>	2303	1827	10463
TF-2 O	6662	1788 <sup>c</sup>	2216	2452	13119
TF-2 H	6840	1679 <sup>b</sup>	2684	2786	13989
TF-4 O	4210	5260 <sup>e</sup>	3493	3997	16960
TF-4 H	3765	4161 <sup>d</sup>	4004	4067	15997
PR-1 O	2999	1499 <sup>b</sup>	2595	608	7701
PR-1 H	2641	1272 <sup>ab</sup>	2565	596	7075
PR-2 O	2776	1984 <sup>c</sup>	2255	1748	8762
PR-2 H	2474	1699 <sup>b</sup>	2117	1722	8012
PR-3 O	5010	1138 <sup>a</sup>	2814	2051	11013
PR-3 H	4106	1028 <sup>a</sup>	2766	1979	9897
SEM	NS	**	NS	NS	NS

Means within columns having different letters are significantly different at  $P < 0.05$  (\*),  $P < 0.01$  (\*\*), or  $P < 0.001$  (\*\*\*). Not significant = NS.

Regrowth interval had a major impact on total DM yield, with longer regrowth periods resulting in significantly greater ( $P < 0.01$ ) DM yields. Defoliating tall fescue at the 4-leaf stage rather than the 1-leaf stage resulted in 50 % greater total DM yield, while defoliating perennial ryegrass at the 3-leaf stage rather than the 1-leaf stage resulted in 33 % greater total DM yield.

In contrast, there was a consistent but not always significant trend, in the full interaction of regrowth interval\*defoliation height, for greater cumulative DM yield under defoliation to 5 cm. The highest DM yields across both species and under all treatments were measured in spring of both years, and this is further explored in section 4.2.

## **4.2 Pasture growth rates**

Pasture growth rates (kg DM/ha/day) of both tall fescue and perennial ryegrass for all regrowth intervals across the 4 identified regrowth periods, are presented in Figure 4-1 (additional detail is provided in Appendix B).

The average time taken for the full regrowth of one leaf/tiller of both tall fescue and perennial ryegrass for each identified period is presented in Figure 4-2. Perennial ryegrass leaf emergence was 20 % faster than tall fescue leaf emergence in the first flowering period, 36 % faster in the following summer/autumn period, but then 33 % slower in the winter/early spring period. At the start of the second flowering period in 2014, leaf emergence of both species was identical at 11 days for full emergence of 1 leaf.

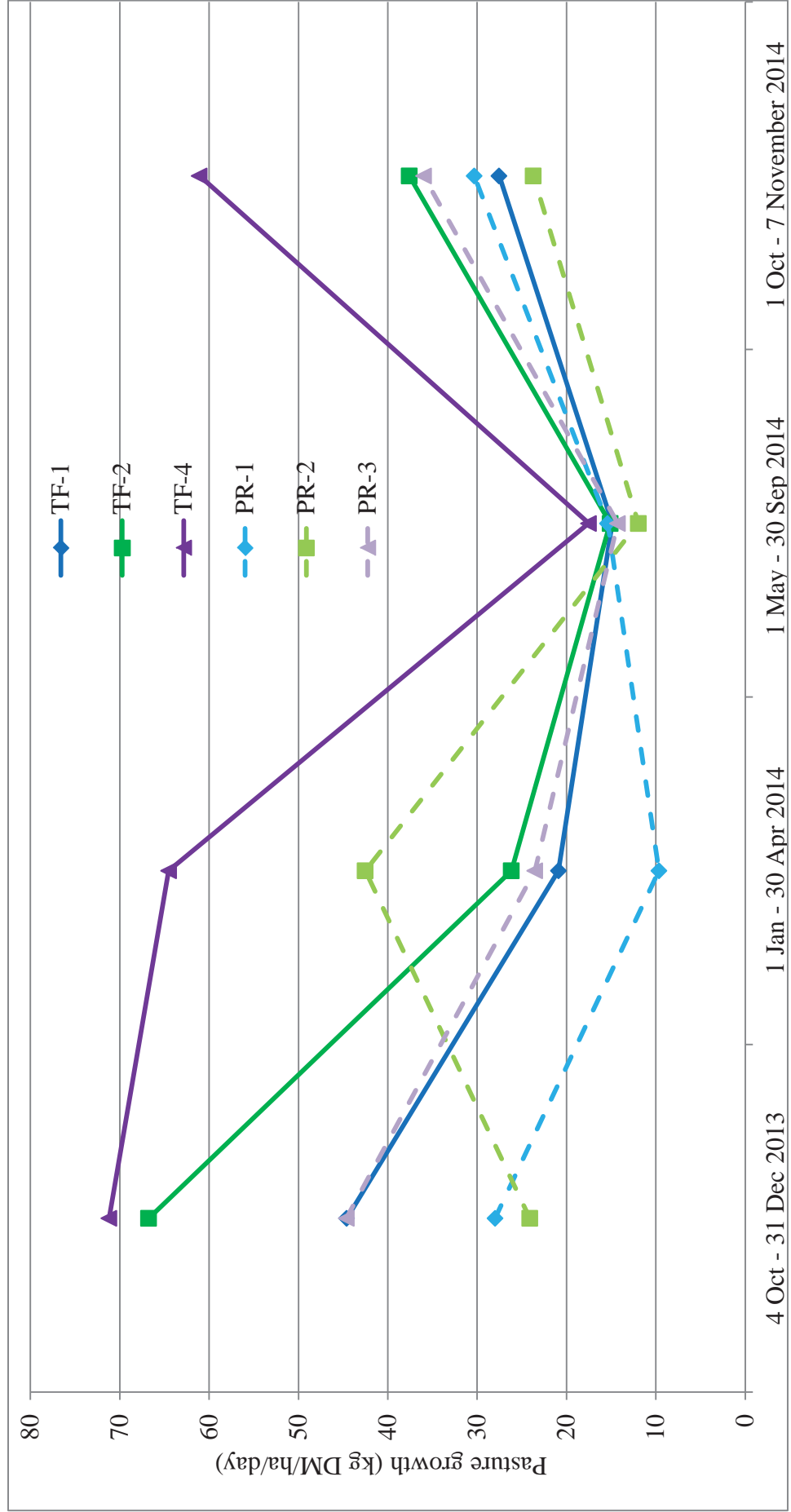


Figure 4-1. Average pasture growth rate (kg dry matter (DM)/ha/day) of tall fescue (TF) and perennial ryegrass (PR) subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3), and 4-leaf stage (TF-4)) for the periods 4 October - 31 December 2013, 1 January - 30 April 2014, 1 May - 30 September 2014 and 1 October - 7 November 2014.

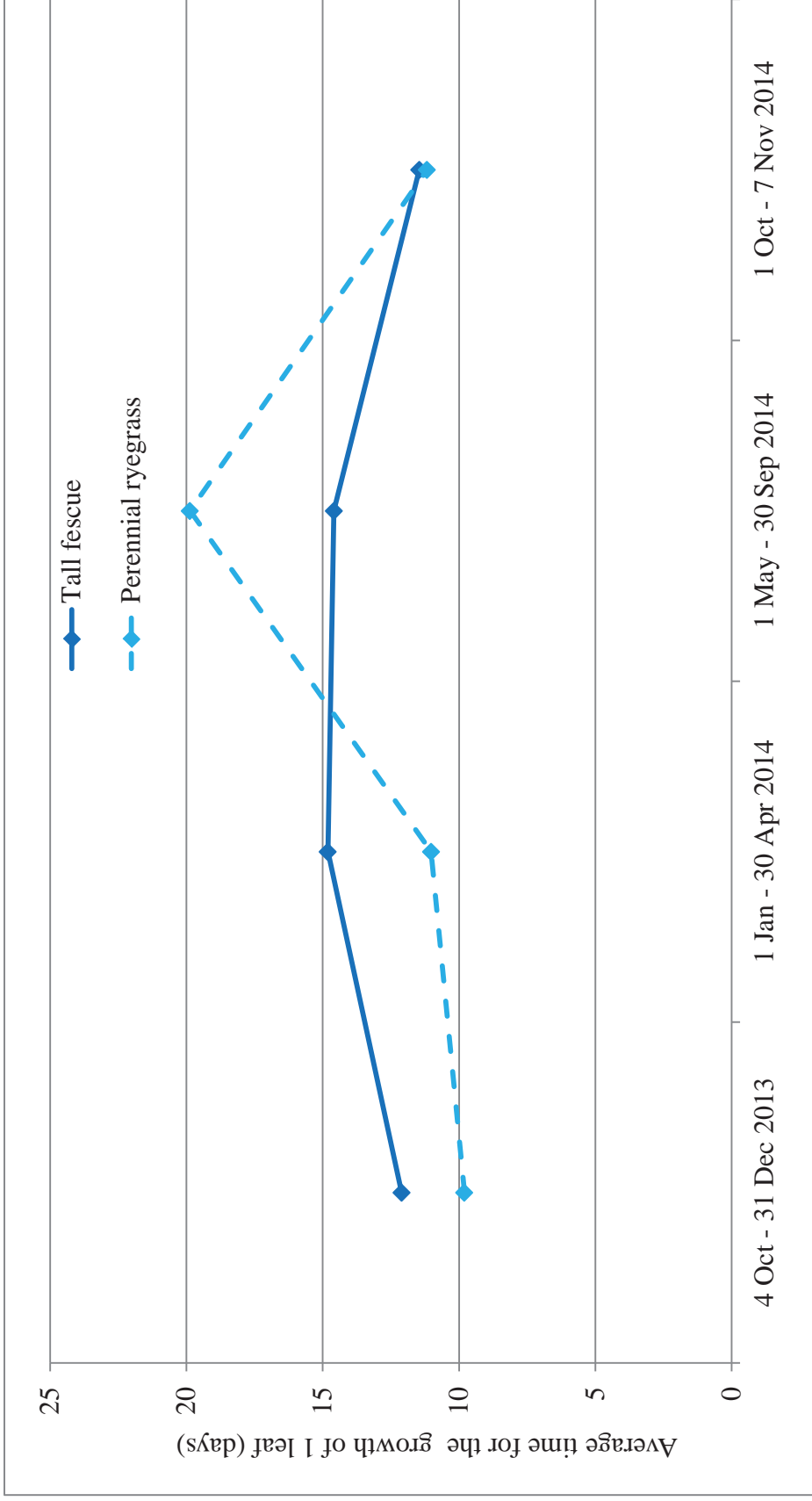


Figure 4-2. Average time taken for the full growth of 1 new leaf /tiller (days) in tall fescue and perennial ryegrass for the periods 4 October - 31 December 2013, 1 January - 30 April 2014, 1 May - 30 September 2014 and 1 October - 7 November 2014.

### 4.3 Botanical composition

In May 2014, 8 months after treatments started, there tended to be a significant interaction between species and leaf stage on the botanical composition (Figure 4-3). The average proportion of sown grass species in the perennial ryegrass plots had been maintained at nearly double that of the tall fescue plots (73 vs. 38 %, respectively). While the proportion of legumes in the tall fescue plots was double that of the perennial ryegrass plots, this was not significant as proportions of all legumes were less than 10 % on a DM basis.

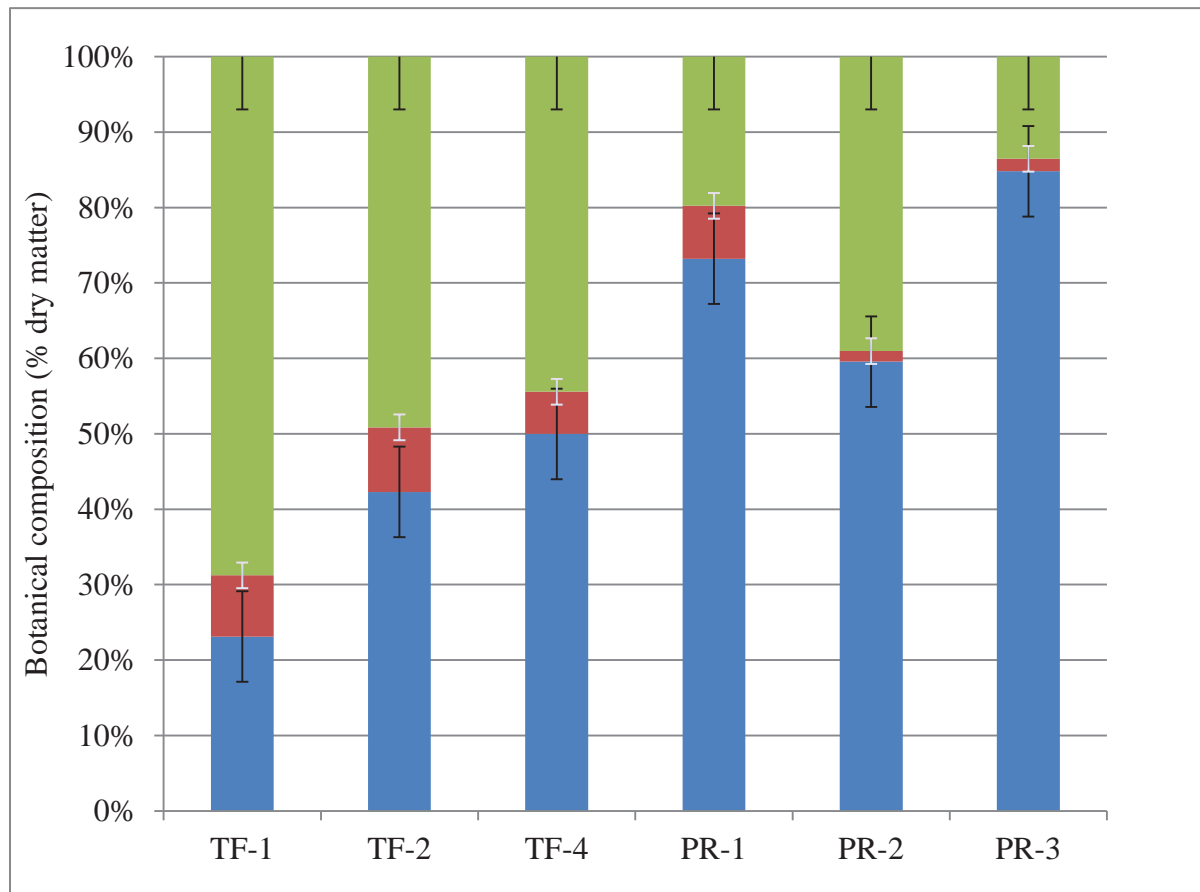


Figure 4-3. Botanical composition (on a percentage dry matter (DM) basis) of sown grass species (tall fescue (TF) and perennial ryegrass (PR) - blue columns), legumes (red columns) and other species (green columns), subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3) and 4-leaf stage (TF-4)), in May 2014. Vertical bars represent standard errors at  $P < 0.05$ .

When botanical compositions were measured after a further 6 months, there was a significant effect of regrowth interval ( $P < 0.001$ ) on the proportion of sown grasses (Figure 4-4). Frequent defoliation had a more detrimental effect on tall fescue than on perennial ryegrass,

with the proportion of tall fescue declining to less than 15 % on a DM basis under both the 1-leaf and 2-leaf stage optimum and high defoliations, while remaining at > 50 % under the 4-leaf stage for both optimum and high defoliations, which was similar to perennial ryegrass optimum and high defoliations under the 3-leaf stage.

Perennial ryegrass was also affected by frequent defoliation, with the proportion of perennial ryegrass declining to 17 % on a DM basis under the 1-leaf stage optimum defoliation; however close to 50 % ryegrass was maintained under the 2-leaf stage optimum and high defoliations, which were not significantly different from the 3-leaf stage optimum and high defoliations. There was a general trend for the higher defoliation heights to result in a greater proportion of sown grasses, but a lower proportion of legumes.



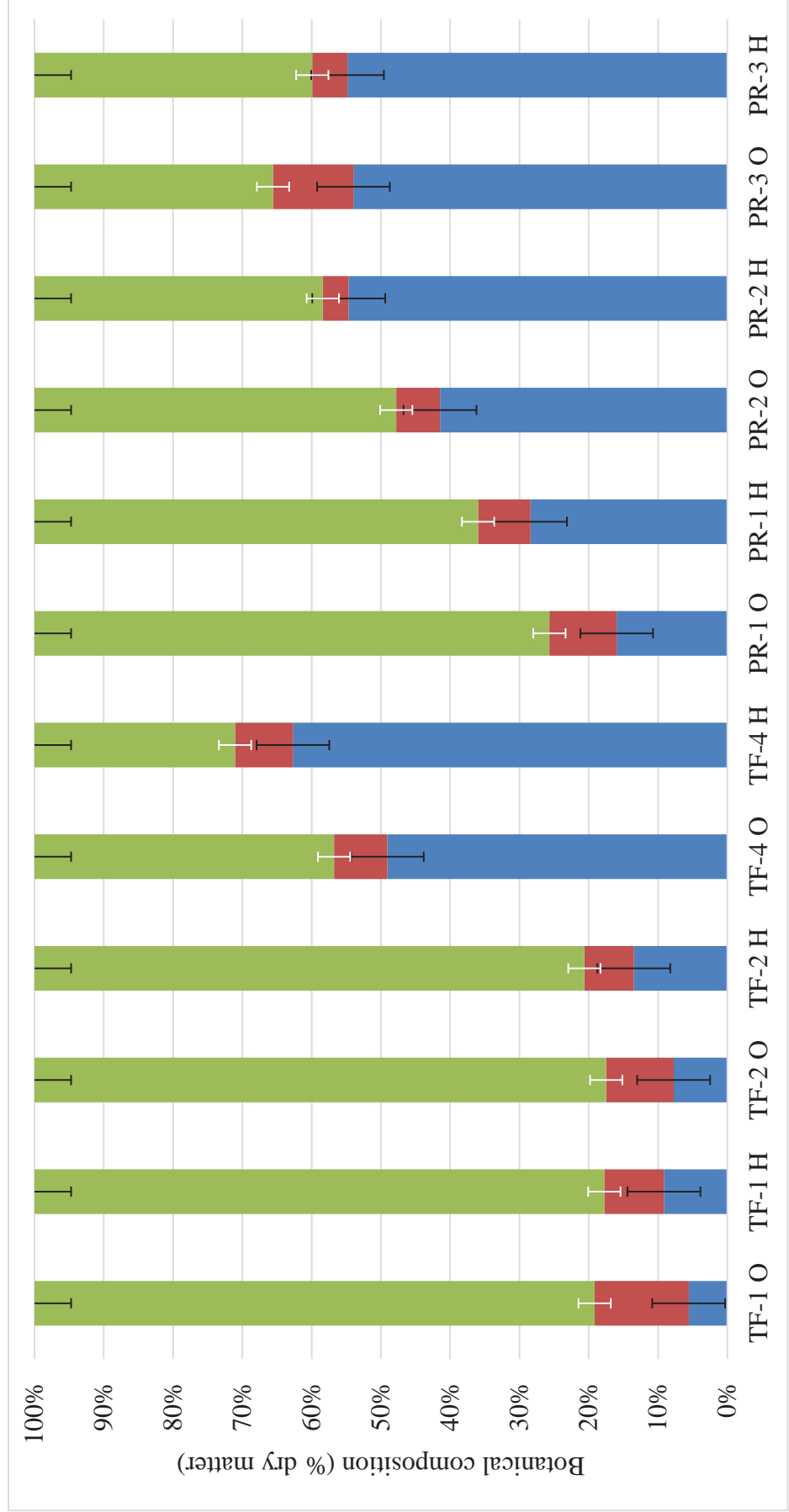


Figure 4-4. Botanical composition (on a percentage dry matter (DM) basis) of sown grass species (tall fescue (TF) and perennial ryegrass (PR) - blue columns), legumes (red columns) and other species (green columns), under two defoliation heights (optimum (5cm, O) and high (8cm, H)) and subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3) and 4-leaf stage (TF-4)), in October/November 2014. Vertical bars represent standard errors at  $P < 0.05$ .

#### 4.4 Tiller density of sown species

In January 2013, 9 weeks after sowing, the tiller density of perennial ryegrass plots was 2.6 times greater than that of tall fescue (3070 vs. 1190 tillers/m<sup>2</sup>, respectively;  $P < 0.001$ ) (Figure 4-5). By October/November 2014, tiller density had declined in both species, by 31 % in perennial ryegrass and by 44 % in tall fescue, so that perennial ryegrass plots remained just over twice as dense as tall fescue plots (1706 vs. 819 tillers/m<sup>2</sup>, respectively;  $P < 0.001$ ).

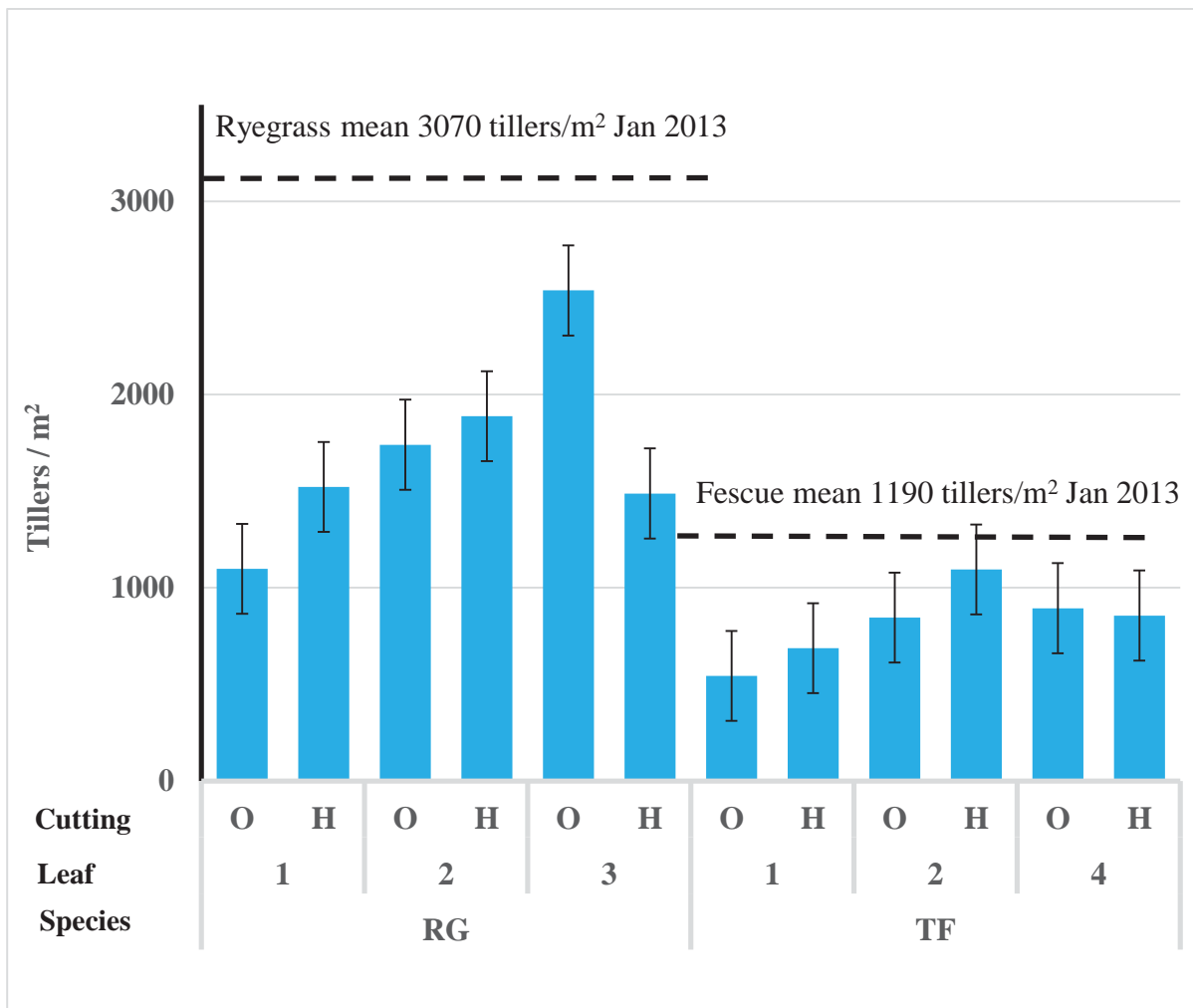


Figure 4-5. Tiller density (tillers/m<sup>2</sup>) of tall fescue (TF) and perennial ryegrass (PR) 9 weeks after sowing (January 2013 - dotted horizontal lines) and subjected to defoliation at two heights (optimum (5cm, O) and high (8cm, H)) and different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3) and 4-leaf stage (TF-4)) on October/November 2014 (blue vertical columns). Vertical lines at tops of columns represent standard errors at  $P < 0.05$ .

There was a trend for higher tiller density under a longer regrowth interval, and also with a higher defoliation height, apart from perennial ryegrass defoliated to 8 cm height at the 3-leaf stage, where tiller density declined, and tall fescue defoliated at the 4-leaf stage, where there was no difference in tiller density between plots defoliated at either 5 cm or 8 cm.

#### **4.5 Herbage nutritive value**

There was a decline in ME, DOMD and CP, and a concomitant increase in ADF and NDF, with regrowth interval in both tall fescue and perennial ryegrass over all periods (Table 4-2). The differences were generally more marked in spring (November 2013 and 2014) than in early winter (May 2014).

Table 4-2. Herbage nutritive value (metabolisable energy (ME, megajoules/kg dry matter (DM)), crude protein (CP, % of DM), acid detergent fibre (ADF, % of DM), neutral detergent fibre (NDF, % of DM), digestibility of organic DM (DOMD, %) and water soluble carbohydrate (WSC, % of DM)) of tall fescue (TF) and perennial ryegrass (PR) subjected to defoliation at different regrowth intervals (1-leaf stage (TF, PR-1), 2-leaf stage (TF, PR-2), 3-leaf stage (PR-3), and 4-leaf stage (TF-4)) during November 2013, May 2014, and November 2014.

15-Nov-13	ME	CP%	ADF%	NDF%	DOMD%	WSC
TF-1	10.6 <sup>bc</sup>	20.7 <sup>cd</sup>	26.8 <sup>bc</sup>	44 <sup>c</sup>	66.6 <sup>d</sup>	21.8 <sup>d</sup>
TF-2	9.7 <sup>b</sup>	12.9 <sup>ab</sup>	30.6 <sup>d</sup>	49.8 <sup>de</sup>	60.9 <sup>b</sup>	26.5 <sup>e</sup>
TF-4	9.6 <sup>a</sup>	13.3 <sup>b</sup>	31.2 <sup>d</sup>	50.5 <sup>de</sup>	59.9 <sup>ab</sup>	25.2 <sup>e</sup>
PR-1	11.1 <sup>cd</sup>	19.7 <sup>c</sup>	25.8 <sup>b</sup>	40.4 <sup>ab</sup>	69.6 <sup>e</sup>	26.5 <sup>e</sup>
PR-2	11.2 <sup>c</sup>	19.3 <sup>c</sup>	27.5 <sup>c</sup>	45.7 <sup>cd</sup>	70 <sup>e</sup>	21.7 <sup>d</sup>
PR-3	9.3 <sup>a</sup>	11.5 <sup>a</sup>	33.6 <sup>e</sup>	54.8 <sup>f</sup>	57.9 <sup>a</sup>	22 <sup>d</sup>
SEM	***	***	***	***	***	***
27-May-14						
TF-1	11.1 <sup>c</sup>	32.2 <sup>h</sup>	24.1 <sup>ab</sup>	40 <sup>ab</sup>	69.4 <sup>de</sup>	13.4 <sup>a</sup>
TF-2	10.3 <sup>bc</sup>	28.8 <sup>g</sup>	25.4 <sup>b</sup>	45.1 <sup>cd</sup>	64.7 <sup>cd</sup>	12.1 <sup>a</sup>
TF-4	9.5 <sup>a</sup>	24.5 <sup>ef</sup>	27.7 <sup>c</sup>	50.1 <sup>de</sup>	59.5 <sup>ab</sup>	12.1 <sup>a</sup>
PR-1	11.4 <sup>cd</sup>	27.6 <sup>fg</sup>	24.3 <sup>ab</sup>	40.9 <sup>b</sup>	71.4 <sup>ef</sup>	16.5 <sup>b</sup>
PR-2	10.3 <sup>b</sup>	23.6 <sup>e</sup>	25.5 <sup>b</sup>	45.4 <sup>cd</sup>	64.2 <sup>c</sup>	16.2 <sup>b</sup>
PR-3	10.2 <sup>b</sup>	22.9 <sup>de</sup>	25.9 <sup>b</sup>	46.4 <sup>cd</sup>	64.1 <sup>c</sup>	15.9 <sup>b</sup>
SEM	***	***	***	***	***	***
7-Nov-14						
TF-1	11.72 <sup>d</sup>	26.2 <sup>f</sup>	23.7 <sup>a</sup>	37.8 <sup>a</sup>	73.2 <sup>f</sup>	22 <sup>d</sup>
TF-2	11.42 <sup>cd</sup>	23.8 <sup>e</sup>	24.9 <sup>ab</sup>	39.7 <sup>ab</sup>	71.7 <sup>ef</sup>	22.5 <sup>d</sup>
TF-4	9.6 <sup>a</sup>	14.6 <sup>bc</sup>	30.9 <sup>d</sup>	51.2 <sup>e</sup>	59.9 <sup>ab</sup>	22.6 <sup>d</sup>
PR-1	11.6 <sup>cd</sup>	23.3 <sup>e</sup>	23.8 <sup>a</sup>	41.4 <sup>bc</sup>	72.8 <sup>f</sup>	22 <sup>d</sup>
PR-2	11.2 <sup>c</sup>	21.2 <sup>d</sup>	27.7 <sup>c</sup>	47.6 <sup>d</sup>	70.2 <sup>e</sup>	17.3 <sup>c</sup>
PR-3	11.6 <sup>cd</sup>	14.1 <sup>b</sup>	26.1 <sup>bc</sup>	44.8 <sup>cd</sup>	72.8 <sup>f</sup>	29.8 <sup>f</sup>
SEM	***	***	***	***	***	***

Means within columns having different letters and dates are significantly different at  $P < 0.05$  (\*),  $P < 0.01$  (\*\*), or  $P < 0.001$  (\*\*\*). Not significant = NS.

Crude protein concentration varied the most with regrowth: between the shortest (1-leaf stage) and the longest (3- or 4-leaf stage) regrowth intervals, CP declined by around 40 % in spring and by 20 % in winter. The CP concentration was higher in tall fescue plots than in perennial ryegrass plots, apart from the 2-leaf regrowth stage in November 2013. Changes in other herbage quality components were generally smaller and less consistent, although there was a trend for shorter defoliation intervals to result in higher CP, DOMD and ME, and lower ADF and NDF, than longer defoliation intervals.

## 5 Discussion

The present study provides evidence that both tall fescue and perennial ryegrass require a longer defoliation interval in order to achieve high DM yields and maintain adequate botanical composition (defoliated at the 3-leaf regrowth stage for perennial ryegrass and at the 4-leaf stage for tall fescue). Tall fescue out-yielded perennial ryegrass over the 13 month treatment period, due to higher growth rates from mid-spring (when tiller reproduction began) through the drier summer and autumn months, however this was only achieved under the longest defoliation interval (4-leaf stage). Dry matter yields, growth rates, botanical compositions and tiller densities of both species were all generally greater at the longest defoliation intervals (4-leaf stage for tall fescue, 3-leaf stage for perennial ryegrass), and while perennial ryegrass tolerated the moderately fast defoliation treatment (2-leaf stage), tall fescue DM yield and botanical composition were both significantly reduced. The fastest defoliation interval (1-leaf stage) was detrimental to both species. While the highest DM yields were recorded for tall fescue under a 4-leaf defoliation interval, this consistently resulted in the poorest quality herbage.

The finding that tall fescue out-yielded perennial ryegrass in the current study is in agreement with results from a number of previous studies throughout New Zealand (e.g. Allo & Southon 1967; Watkin, 1975; Thomson *et al.*, 1988; Judd *et al.*, 1990; McCallum *et al.*, 1992; Easton *et al.*, 1994; Rollo *et al.*, 1998; Clark *et al.*, 2010); the average DM yield of tall fescue from these studies was 114 % greater than perennial ryegrass. However, several of these studies (Thomson *et al.*, 1988; Judd *et al.*, 1990; McCallum *et al.*, 1992) compared newly-established tall fescue pastures with older, resident perennial ryegrass pastures, and this may have over-emphasised the yield of tall fescue, as DM yield tends to decline with pasture age (Easton *et al.*, 1994). In addition, several other New Zealand studies (Allen & Cullen, 1975; Hainsworth *et al.*, 1991; Parry *et al.*, 1992) reported an average DM yield advantage of 25 % for perennial ryegrass. Results from a study by Clark *et al.* (2010) show that tall fescue tended to have a greater summer DM yield compared to perennial ryegrass, although they found that this was inconsistent throughout the trial period. They also found that applying irrigation resulted in an additional 50 % DM yield for tall fescue compared to only an additional 13 % DM yield from perennial ryegrass. Similarly, Rollo *et al.* (1998) suggested that when soil moisture is not limiting, perennial ryegrass will produce more DM yield than will tall fescue. The current study supports the findings by Clark *et al.* (2010) and observed a greater DM yield from tall fescue during the dry summer/autumn period (January - April 2014 in Table 4-

1). Similarly, Allo and Southon (1967) reported that tall fescue out-yielded perennial ryegrass and this was due to tall fescue being more persistent, tolerating both wetter and drier conditions, and appearing resistant to crown rust, compared to perennial ryegrass. Conversely, other studies which found perennial ryegrass produced greater DM yield than tall fescue suggested this was due to poor establishment (Brock, 1983) or slow early growth of tall fescue seedlings (Brock, 1983; Kemp *et al.*, 2002).

There are several possible mechanisms for the greater recorded DM yield of tall fescue. Tall fescue plants are known to be more vigorous than perennial ryegrass during the warmer months as they maintain green herbage and higher growth rates for longer under conditions of soil moisture stress (Brock 1983; Charlton & Belgrave, 1992; Reed, 1996; Kemp *et al.*, 2002), and additionally, sustain growth and plant density under ambient temperatures reaching 30 - 35°C (Lowe & Bowdler, 1995; Greenwood *et al.*, 2006; Anon, 2008). The superior growth of tall fescue during warmer months and especially through drought periods is also due to its greater root length densities compared to perennial ryegrass, as tall fescue has the ability to extract moisture from a depth up to 200 cm in the soil profile compared to perennial ryegrass with a maximum of around 130 cm effective rooting depth (Evans, 1978; Garwood *et al.*, 1979; Boschma *et al.*, 2003; Nie *et al.*, 2008). Tall fescue also has a greater number of roots and weight of root material at 50 - 100 cm soil depth than perennial ryegrass (Garwood *et al.*, 1979; Wilman *et al.*, 1998; Boschma *et al.*, 2003; Raeside *et al.*, 2012). Finally, tall fescue has higher water use efficiency than perennial ryegrass, losing less water to evapotranspiration at higher temperatures (Minneé *et al.*, 2010).

Defoliation interval based on leaf regrowth is an accurate method of managing pastures as it readily reflects the extent of plant recovery from defoliation in terms of energy (WSC) levels (Fulkerson & Donaghy, 2001). Tall fescue produces longer and thicker leaves which have a slower elongation rate and a longer lifespan than those of perennial ryegrass, which may lead to differences in response to defoliation (Kemp *et al.*, 2001). The longer leaf lifespan of tall fescue means that more time is required to reach maximum photosynthetic capacity and to replenish WSC reserves than in grasses which have a shorter leaf lifespan such as perennial ryegrass. Under frequent defoliation, tall fescue leaves may be removed before they reach maximum photosynthetic capacity, resulting in less contribution of these leaves to the carbon economy of the plant (Tavakoli, 1993), and leading to a possible delay in build-up of WSC reserves in tall fescue compared with perennial ryegrass. A faster defoliation, by removing leaves before they have significantly contributed to replenishing WSC reserve levels, could

have a greater negative effect (lower growth, less persistence) on tall fescue than on perennial ryegrass pastures (Donaghy *et al.*, 2008).

There is evidence from several studies showing that availability of WSC in tall fescue (Booyesen & Nelson, 1975; Volenec, 1986) and perennial ryegrass (Alberda, 1957; Davies, 1965; Gonzalez *et al.*, 1989; Fulkerson & Slack, 1994, 1995; Donaghy & Fulkerson, 1997, 1998) has a marked effect on their regrowth and persistence. These authors show that to grow and persist, grasses should have adequate available energy to cope with periods when either supply from current photosynthate is low (immediately after defoliation) or plants are subject to environmental stress (extremes of temperatures and drought). For example, Tavakoli (1993) reported that a sharp depletion of WSC occurred under close defoliation (a post-grazing residual of < 3 cm height) - a decline in WSC levels of 56 % and 44 % for tall fescue and perennial ryegrass, respectively. Although plant WSC reserve levels weren't measured in the current study, infrequent defoliation at the 4-leaf stage was previously shown to maximise WSC reserves and subsequently improve plant regrowth and survival (Donaghy *et al.*, 2008), in line with the current DM yield and botanical composition results.

Several studies also show that defoliation height affects tall fescue and perennial ryegrass growth and DM yield. For example, Zarrouh *et al.* (1983) suggested that raising cutting height from 5 cm to 10 cm resulted in increased DM yield per tiller and increased total herbage DM yield in tall fescue, while tiller density remained constant. In a field study comparing tall fescue and perennial ryegrass at different defoliation heights (10 cm vs. 6 cm vs. 4 cm), Tavakoli (1993) showed a reduction in tiller density, tiller weight and tiller numbers, leaf and root growth and DM yields of both tall fescue and perennial ryegrass under closer defoliation. However, in contrast to these results, a study undertaken by Hart *et al.* (1971) in Maryland USA, found that defoliating tall fescue to heights above 5 cm did not optimise pasture production; a defoliation height of 5 cm resulted in greater DM yields compared with longer defoliation heights (10 or 15 cm). Similar results were obtained for perennial ryegrass by Ollerenshaw and Hodgson (1977) - a higher DM yield occurred under a 5 cm defoliation height than an 8 cm defoliation height. However, as suggested by Zarrouh *et al.* (1983) defoliation heights greater than 5 cm can result in increased herbage DM yields in tall fescue, but reduced herbage quality. The current study found that defoliation interval had a greater effect on all aspects of plant performance measured than did defoliation height, possibly because the defoliation interval treatments implemented ranged from the maximum



number of live leaves/tillers (3 in perennial ryegrass and 4 in tall fescue) to the minimum number of 1-leaf/tiller, whereas defoliation height ranged from what is generally regarded as optimal (5 cm) to 8 cm, rather than a more extreme 10 or even 15 cm. Therefore in the current study the small difference in the defoliation height treatments (5 vs 8 cm) may not have been large enough to cause significant differences in the DM yields of tall fescue and perennial ryegrass.

Making comparisons between tall fescue and perennial ryegrass based on DM yields and growth rates alone are misleading, as evident from botanical composition (Figures 4-3 and 4-4). At the end of the study period (October/November 2014), tall fescue comprised less than 15 % of species present in 'tall fescue' plots under both 1-leaf and 2-leaf defoliation treatments. The 'other species' referred to in Figure 4-4 contained a mix of less productive species (predominantly broadleaved weeds and stoloniferous grasses) as well as equally productive grass species such as ryegrass and Yorkshire fog (*Holcus lanatus* L.) that had germinated from soil seed reserves. It was observed (though not measured) that a large proportion of the 'other species' that had colonised the 'tall fescue' plots was perennial ryegrass, and so a high proportion of the yield under the 1-leaf and 2-leaf tall fescue treatments was in fact ryegrass. Other authors (e.g. Allen & Cullen, 1975; Minneé, 2011) also report more weed ingressions in tall fescue than perennial ryegrass pastures, suggesting that perennial ryegrass has a superior competitive ability against broadleaf and grass weeds compared to tall fescue (Praat *et al.*, 1996).

A measure of persistence suggested by Nie *et al.* (2004) is for the pasture to maintain a botanical composition with over 70 % of sown species. By the end of the current study, a combination of sown grasses and companion legumes had remained, although not consistently at 70 %, at least close to or above 60 % in both the 4-leaf tall fescue and 3-leaf perennial ryegrass treatments, and an average of 55 % in the 2-leaf perennial ryegrass treatment. In contrast, the botanical composition of sown species was less than half the recommendation of Nie *et al.* (2004) in the tall fescue 1- and 2-leaf treatments, and the perennial ryegrass 1-leaf treatment. Because composition is a comparative measure between species present, it is possible that at later sampling dates, the sown species could again increase in proportion as other annual species died out for example; however, this would only likely occur to any significant extent in the perennial ryegrass 2- and 3-leaf and tall fescue 4-leaf treatments, as all other treatments had less than 25 % of sown species.

Tall fescue also showed lower tillering activity relative to perennial ryegrass, a result that is in line with studies undertaken by Tavakoli (1993). The tiller is considered to be the primary growth unit of a grassland community (Langer, 1990), and therefore management that can improve or maintain tiller density can increase the productivity as well as the persistence of pasture. Nie *et al.* (2004) proposed that a persistent, productive pasture could be characterised by a tiller density of greater than 3000 tillers/m<sup>2</sup> for ryegrass-based pastures and greater than 2300 tillers/m<sup>2</sup> for other grass species, including tall fescue. In the current study, only the perennial ryegrass plots measured 2 months after sowing had tiller densities close to these numbers; tall fescue tiller density at the same time was around 50 % lower than that proposed by Nie *et al.* (2004), and tiller densities across both species declined further when again measured 21 - 22 months later. This may indicate that neither species, under the conditions of the current study, would have been capable of maintaining production and persistence if the study had continued for a longer period. Alternatively, data from the current study, over only 2 time periods and using different methodology from that used by Nie *et al.* (2004), may not be robust enough to draw any conclusion regarding potential persistence.

What is interesting to note, is that despite starting at only 40 % and ending at only 50 % of the density of perennial ryegrass tillers, tall fescue plots managed to produce comparable or greater DM yields than perennial ryegrass plots. Some of this yield is undoubtedly due to the contribution by other species as discussed previously, however the 4-leaf tall fescue treatment, where a high composition of tall fescue was maintained, managed to significantly out-yield perennial ryegrass with around half the tiller density.

A contributing factor to the lower tiller densities in tall fescue is due to its slow establishment (Brock *et al.*, 1982; Hainsworth *et al.*, 1991; McCallum *et al.*, 1992; Praat *et al.*, 1996; Clark *et al.*, 2010), which in turn has been attributed to poor mobilisation of seed reserves, slower germination rate (Charlton *et al.*, 1986; Moot *et al.*, 2000) and slower seedling growth (Kemp *et al.*, 2001) than perennial ryegrass. On average, tall fescue tillers are about 1.6 times heavier than those of perennial ryegrass (Tavakoli 1993), however tiller appearance rate is slower than in perennial ryegrass (Kemp *et al.* 2001) as mentioned previously, indicating that tall fescue allocates greater resources towards individual tiller development, but less towards tiller initiation, than does perennial ryegrass. Lower tillering activity results in lower plant regeneration (Jewiss, 1972), and this could be a disadvantage for tall fescue under frequent defoliation, especially when grown with faster tillering species like perennial ryegrass, and may explain the easy colonisation of tall fescue plots by ryegrass under frequent defoliation.

The observed trend in the current study of a decline in tiller density with more frequent defoliation is in agreement with many previous studies undertaken on tall fescue (Tavakoli 1993, Thom *et al.*, 1998, Kemp *et al.*, 2001, Nie *et al.*, 2004 and Lowe *et al.* 2008) and perennial ryegrass (Kerrisk & Thompson, 1990; Tavakoli, 1993; Kemp *et al.*, 2001).

Tall fescue pastures are noted in some studies to have low nutritive value (Thomas & Wilson, 1979). The current study illustrates the impact of longer regrowth (PR-3 and TF-4) on the nutritive value of pastures, as pastures had the lowest quality on the longer intervals. Kolver (2000) suggest that herbage quality parameters of > 11.5 MJ/kg DM, > 70 % DOMD, 38 - 45 % NDF, and 18 - 24 % CP are considered good quality. The CP content of both tall fescue and perennial ryegrass pastures was consistently higher under the shorter regrowth (1-leaf) than the longer regrowth interval (i.e. 3- and 4-leaf stages), and this is in line with results from a number of grass species, where N levels and therefore CP content decrease with regrowth (Fulkerson *et al.*, 1998; Rawnsley *et al.*, 2002; Turner *et al.* 2006; Donaghy *et al.* 2008). The trend for slightly higher CP in tall fescue than perennial ryegrass pastures under all treatments (Table 4-2) may partly be a reflection of slightly greater legume content in tall fescue plots (Figures 4-3 and 4-4). In support of this, Milne *et al.* (1997) found that tall fescue pastures contained higher CP content than perennial ryegrass pastures, and this was both a function of higher CP content of tall fescue plants themselves along with greater legume content in tall fescue pastures, as legumes are usually higher in CP content than grasses (Harris *et al.*, 1997). A herbage CP content of at least 18 % is required to support the nutritive requirements of lactating cows (Kolver, 2000). In both spring periods in the current study, the CP content of tall fescue and perennial ryegrass fell below this threshold under longer rotations, but was at adequate levels under all treatments in the late autumn/early winter sampling period (27<sup>th</sup> May 2014).

Levels of ADF and NDF were generally lower under shorter regrowth intervals, and higher under longer regrowth intervals, in both tall fescue and perennial ryegrass, and this resulted in the inverse pattern for DOMD and ME, as digestibility of herbage is largely driven by fibre content (Roche *et al.*, 2009). An increase in fibre and a decrease in digestibility and ME with leaf regrowth stage have been previously reported in a number of studies (Fulkerson & Donaghy, 2001; Rawnsley *et al.*, 2002; Turner *et al.*, 2006). The increase in fibre levels and subsequent decrease in digestibility with successive leaf development can be explained by an increasing proportion of sclerenchyma and vascular tissue that are present with increasing

leaf number (Ducrocq & Duru, 1997), and this in turn is related to an increase in the maximum length of the leaf with each successive emerging leaf (Wilson, 1976).

Overall, results from the current study indicated that only under a longer regrowth interval (at the 4-leaf stage) was tall fescue able to maintain adequate DM yield, pasture growth rates and plant survival (indicated by botanical composition). In fact, under this defoliation regime, tall fescue was able to out-compete perennial ryegrass, especially in the drier and warmer parts of the year. However, the decline in herbage quality under this longer rotation would have compromised animal production for some parts of the year. While repeated defoliation at the 2-leaf stage resulted in generally adequate herbage quality of tall fescue, it also resulted in inadequate pasture composition. This is in contrast to results from a glasshouse study undertaken by Donaghy *et al.* (2008) where defoliation at the 2-leaf stage maximised herbage quality, allowed WSC replenishment and resulted in a satisfactory rate of regrowth. The current study highlights that under field conditions, the 2-leaf stage may be too short, and the 4-leaf stage too long, for an adequate compromise between pasture growth and survival on the one hand, and herbage quality on the other. Therefore, additional research is required to explore defoliation options between the 2-leaf and 4-leaf regrowth stages of tall fescue.

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## Appendix A: Cumulative dry matter yields

Table 1. Sown species (tall fescue (TF) and perennial ryegrass (PR)) and defoliation height (optimum (5cm, O) and high (8cm, H)) main effects on cumulative dry matter (DM) yield (kg /ha) from sowing in January 2013 until imposition of treatments (September 2013).

<i>Sown species</i>	Mean
TF	5602
PR	5444
SEM	952
<i>P</i> -value	0.250
<i>Defoliation height</i>	
O	5446
H	5600
SEM	952
<i>P</i> -value	0.262

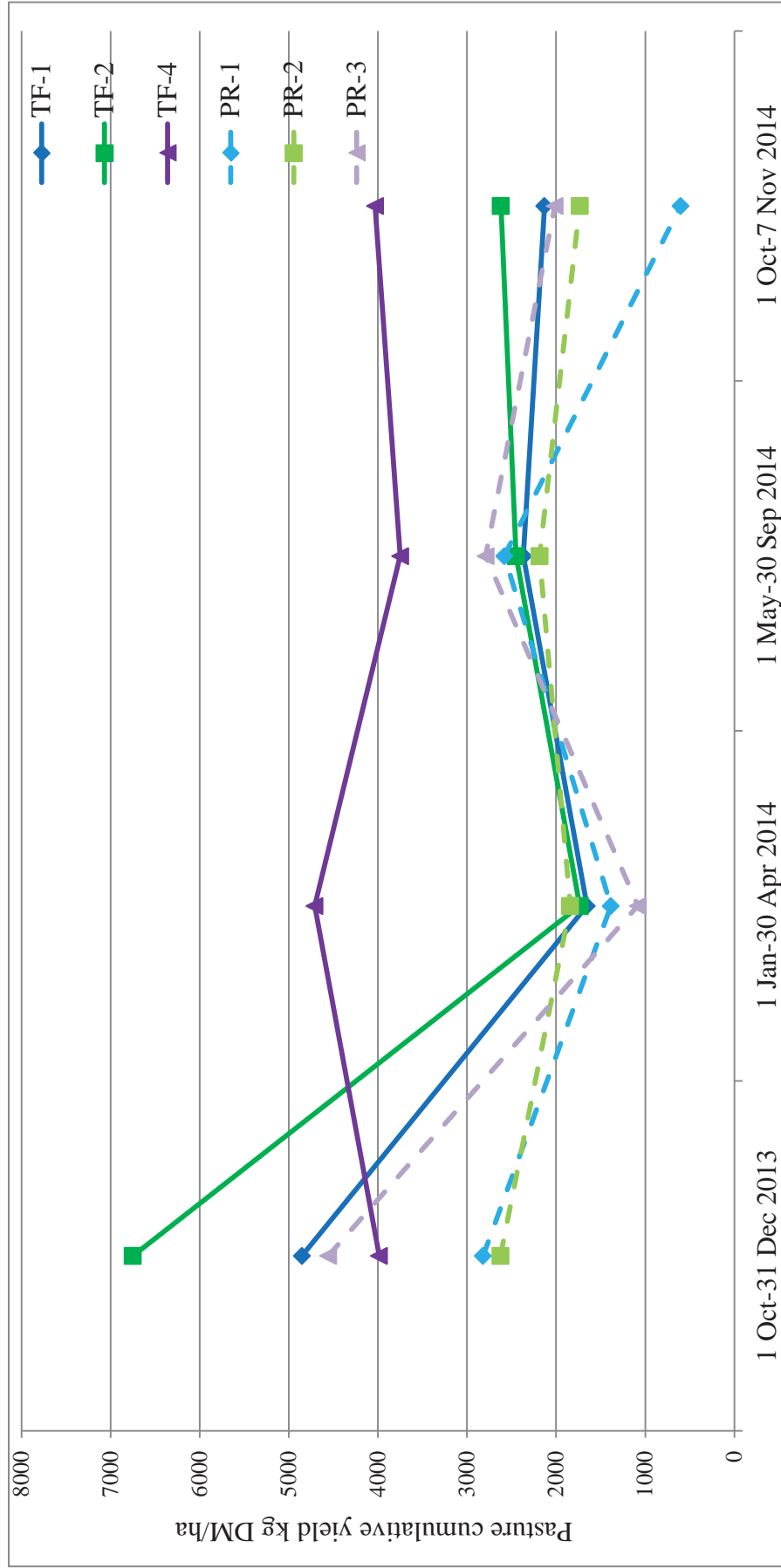


Figure 1. Pasture cumulative yield (kg dry matter (DM)/ha) of tall fescue (TF) and perennial ryegrass (PR) subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3), and 4-leaf stage (TF-4)), for the periods 1 October - 31 December 2013, 1 January - 30 April 2014, 1 May - 30 September 2014 and 1 October - 7 November 2014.



## Appendix B: Pasture growth rate

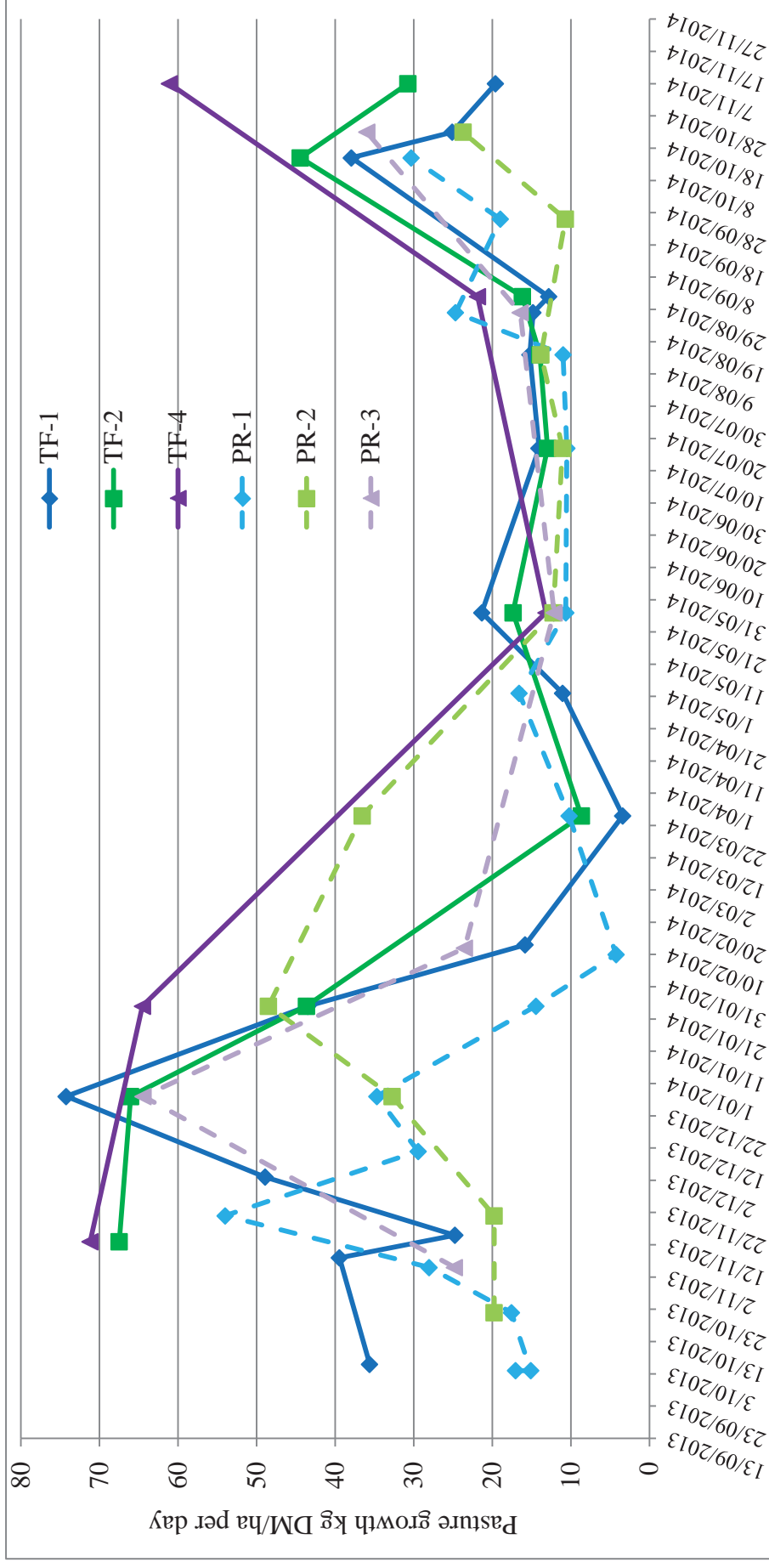


Figure 2. Pasture growth rate (kg dry matter (DM)/ha/day) of tall fescue (TF) and perennial ryegrass (PR) subjected to defoliation at different regrowth intervals (1-leaf stage (TF-1, PR-1), 2-leaf stage (TF-2, PR-2), 3-leaf stage (PR-3), and 4-leaf stage (TF-4)), throughout the trial period (4 October 2013 - 7 November 2014).

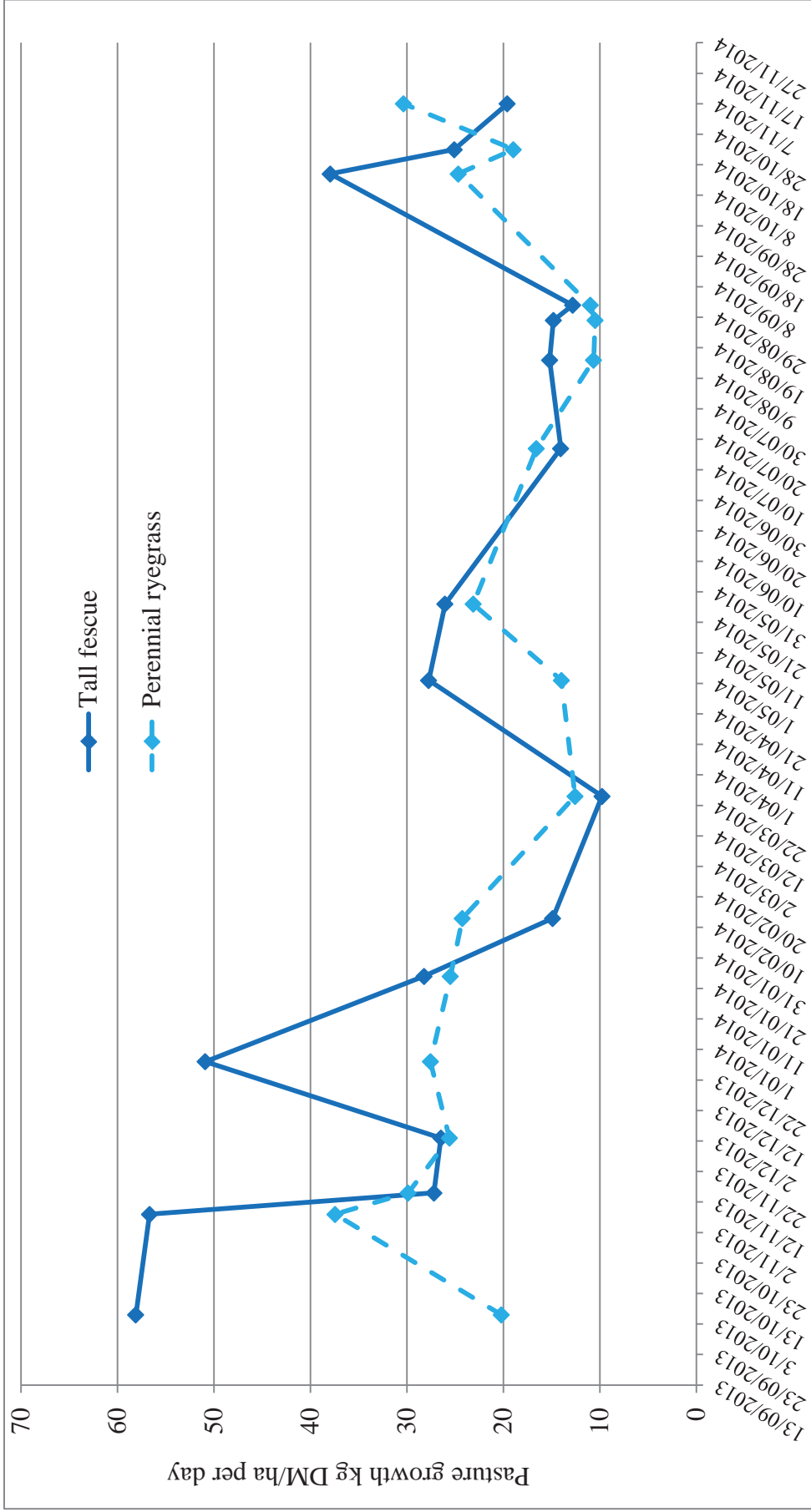


Figure 3. Pasture growth rate (kg dry matter (DM)/ha/day) of tall fescue (TF) and perennial ryegrass (PR), throughout the trial period (4 October 2013 - 7 November 2014).

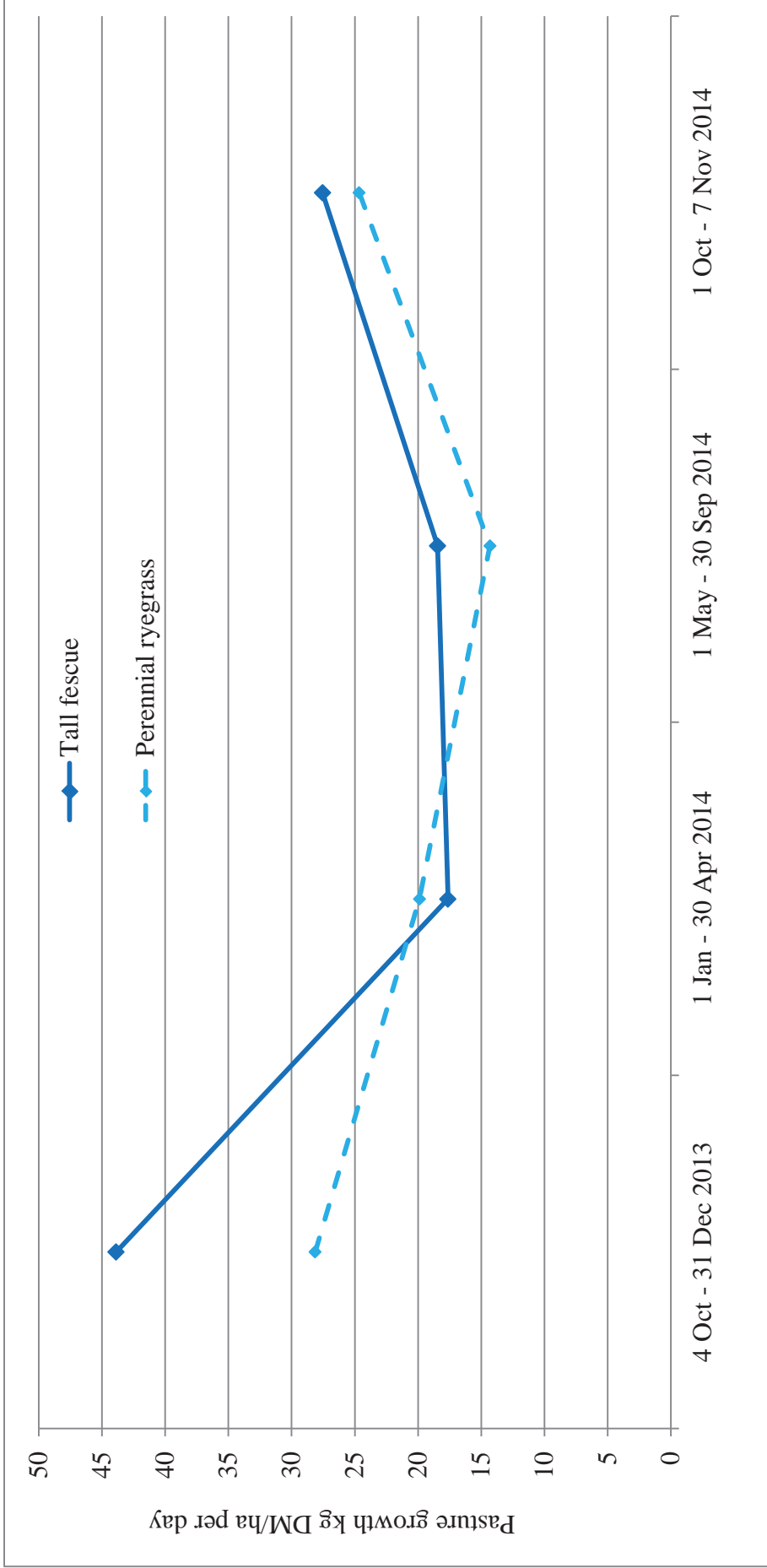


Figure 4. Pasture growth rate (kg dry matter (DM)/ha/day) of tall fescue (TF) and perennial ryegrass (PR), for the periods 4 October - 31 December 2013, 1 January - 30 April 2014, 1 May - 30 September 2014 and 1 October - 7 November 2014.