AN ABSTRACT OF THE THESIS OF

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ABSTRACT

Pasture legumes that persist under challenging agro-ecological conditions are crucial to ensure high lamb growth rates in dryland pastures. Pasture and lamb production from white clover (TF-Whc), birdsfoot trefoil (TF-Bft), balansa clover (TF-Bc) and subterranean clover (TF-Sc) planted with tall fescue either as binary mixtures or as a diverse combination of all (TF-Mix) were compared in a summer-dry hill site in Corvallis, Oregon over a two-year period. In 2018, all pasture combinations provided similar lamb liveweight gains (LWG, mean 177 g $d^{-1}$) in the first half of spring. Lambs in TF-Bc and TF-Mix pastures grew 31 to 41 g $d^{-1}$ faster than those grazing TF-Sc, TF-Whc and TF-Bft in the second half of spring ($P$<0.05). Overall, TF-Bc and TF-Mix had higher ($P$<0.05) legume content (32 and 37% respectively) compared to other pasture combinations. In spring 2019, lambs that grazed TF-Mix and TF-Whc pastures had higher LWG than those on other pastures ($P$<0.05). The superior lamb growth rates were associated with the higher legume content and pasture quality maintained into the late spring period. Overall, the legume content of all pastures decreased over the course of the two-year trial with the decline being substantial for balansa clover. The present study confirmed that high legume content of pastures leads to greater lamb growth rates. Total annual DM yield of the pastures that had greater legume content were superior to others ($P<0.05$). Combination of self-regenerating annual clovers with perennial legumes in pasture mixtures may ensure higher legume content and longer persistence in dryland hill pastures.

**Keywords**: lamb production, dryland, legumes, persistence, Pacific Northwest

Pasture Production and Lamb Growth from Dryland Hill Pastures in Western Oregon

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Yunus Gultekin, Author

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| | |
|---|---|
| ADF | Acid Detergent Fiber |
| ADG | Average Daily Gain |
| Bc | Balansa Clover |
| Bft | Birdsfoot Trefoil |
| CP | Crude Protein |
| CT | Condensed Tannins |
| DM | Dry Matter |
| EE | Ether Extract |
| LTM | Long Term Mean |
| LWG | Live Weight Gain |
| LWP | Live Weight Performance |
| NDF | Neutral Detergent Fiber |
| NRC | National Research Council |
| NV | Nutritive Value |
| PNW | Pacific Northwest |
| TF | Tall Fescue |
| Sc | Subterranean Clover |
| USDA | United States Department of Agriculture |
| Whc | White Clover |

# Chapter 1
# General Introduction

## 1.1 Background Information

Non-irrigated, summer dry pastures in Western Oregon are dominated by perennial cool-season grasses and weedy annuals and seldom have a significant percentage of actively growing legumes or other high-quality forbs. The feeding value of cool-season grasses decreases rapidly in late spring and into summer as plants mature and become more fibrous. This results in reduced animal performance. Numerous studies have shown that high legume content increases liveweight gain in grazing animals (Hyslop *et al*., 2000; Lee *et al*., 2004; Ates *et al*., 2015). Thus, introducing and maintaining a high percentage of legumes in pastures and the livestock diet is of vital importance. Pasture legumes have the potential to improve forage production and quality in summer because of their generally better warm season growth compared to cool-season grasses.

White clover (*Trifolium repens*) is the most commonly grown perennial legume in mixed grass-clover pasture systems due to its high productivity and persistence to intensive grazing. However, it has poor persistence in dryland conditions where the monthly rainfall is less than 40 mm (Brock, 2006). Alternative deep-rooted perennial or self-regenerating annual legumes that are more persistent and productive in dryland conditions are often included in pasture mixtures. For instance, when drilled into grass-dominated pastures, subterranean clover (*Trifolium subterraneum*) increased pasture yield as much as 40% in New Zealand (Ates *et al*., 2010). Balansa clover (*Trifolium michelianum*), not as widely tested as subterranean clover, has the potential to outperform subterranean clover in heavy clay soils of western Oregon due to its high tolerance of poor drainage. Birdsfoot trefoil (*Lotus corniculatus*), a condensed tannin-containing perennial legume, has been identified as having anthelmintic properties (capable of expelling or destroying parasitic worms of the intestine) (Ramírez-Restrepo *et al*., 2005). In addition, birdsfoot trefoil is tolerant of low pH and poorly drained soils, persists on low fertility soils, and can be grazed safely by ruminants (without fear of bloat) (Hunt *et al*., 2015).

Thus, this experiment was conducted to test the agronomic potential of annual and perennial legumes grown together with tall fescue (*Schedonorus arundinaceus* (*Schreb.*)) under several cutting regimes or sheep grazing. The experiment compared the pasture and lamb production from tall fescue-based pastures grown with annual and/or perennial legumes in the summer dry conditions of western Oregon.

## 1.2 Research aim and objectives

The overall objective is to identify productive and persistent pasture mixtures for improved sheep grazing systems in summer-dry areas of western Oregon. Specific objectives of the study are to:

1. Determine the seasonal and total annual dry matter yield and nutritive value of tall fescue-legume pastures.
2. Assess the lamb performance on various tall fescue-legume pastures.
3. Assess the persistence of self-regenerating annual legumes and perennial pasture species.

# Chapter 2
# Literature Review

## 2.1 Sheep farming in the USA and Pacific Northwest

There are approximately 101,000 sheep operations and 5.4 million sheep in the US (USDA, 2017). For the last 200 years, there has been a fluctuation in the number of sheep. In 1867, when the first inventory was taken, 45 million head were present in the US (USDA, 2019). It increased to 51 million in 1884, peaked in 1942 at 56 million head (Jones, 2004), and then steadily decreased.

However, since about 2015, the US sheep inventory has leveled off. There are several factors contributing to this situation such as increase in productivity, genetic improvements and increase in the number of hair sheep not requiring shearing and easy to care for (NRC, 2008). Nevertheless, predator pressure from coyotes (*Canis latrans*), feral dogs (*Canis lupus familiaris*), wolves *(Canis lupus)* and vultures (*Coragyps atratus*) is still a major constraint on sheep farming. According to USDA, predators caused 36.4 % of all lamb losses in 2014 (USDA, 2015). Currently, Oregon has 175,000 sheep and lambs (USDA, 2019), which makes Oregon in 9$^{th}$ place among the other states ("Top 10 States With The Most Sheep & Lamb", 2020). While sheep were raised mainly for wool in the past, sheep farming has reached a more complex structure so that the animals are now raised for meat, milk, wool and pelt.

There are basically two types of sheep operations in the US; range and farm flock. Range operations with large sheep flocks grazing on natural pastures are common in the west. Farm flock operations have flocks consisting of usually less than 50 animals. They are common in the midwest and the east. In farm flock operations, sheep graze on small-sized, improved pastures (NRC, 2008). Most lamb meat is produced and marketed via the traditional way in which lambs graze on pasture and range forage and then sent to feedlots where they are fed high energy rations containing grains. When they reach harvest weight, they are slaughtered. There are mainly two types of lamb marketing, commodity marketing and direct marketing. In commodity marketing, lambs are sold to a buyer, dealer or a slaughterhouse (Schoenian, 2019). In direct marketing, the customer buys lambs directly from the producer and customers mostly prefer lighter lambs (Schoenian, 2019). Lambs are usually slaughtered at the age of 8-14 months or when they weigh 54.5-72.5 kg (Redden *et al*., 2020). According to USDA, the average liveweight of market lambs in June 2018 was 62.5 kg. In non-traditional lamb production systems, in which lambs are directly sold to the consumer, slaughter weight can vary between 27.2 and 36.2 kg (Redden *et al*., 2020).

## 2.2 Seasonal Management of Sheep Production

In the US, 80% of lambs are born during the first five months of a year, while 20% of the US lambs are born in the second half of the year, mostly in fall (Redden *et al*., 2020). Predominantly, lambing occurs in mid-winter and early spring in Pacific Northwest. Overall, the lamb production cycle is driven by pasture production. Lambing season and weaning time are also dependent on several factors including labor availability and time-demands of the producer such as the Easter season and the Muslim Festival of the Sacrifice (Schoenian, 2019). In order to take advantage of economical feed during peak lactation, it is advised that lambing should start when the pasture production increases in spring (Kerr, 2000). However, some year-round lamb marketing strategies are profitable when alternative lambing times are used.

In Oregon, there are primarily two lambing seasons; winter lambing (December-January), late winter-early spring lambing (February-March). There is also a small percentage of fall lambing flocks. The availability of forages plays a critical role in determining the lambing season. Farmers who choose winter lambing generally have access to grass-seed fields. When ewes graze grass-seed areas during winter, tiller numbers and seed production of the plants increase (Brown, 1980). Since Oregon is the largest cool season forage seed producer in the world (Steiner *et al*., 2006), both sheep farmers and grass-seed producers benefit from this situation. Farmers who do not have access to the grass-seed areas prefers late winter lambing season because pasture provides high amounts of nutrients to both ewes and their lambs. When pasture production and energy are high, lambs grow faster. Therefore, maintaining high growth rates of high-quality pastures is pivotal in efficient pasture-based sheep production. This is mainly because the faster a lamb grows, the lower amount of overall feed it consumes. Therefore, feed conversion efficiency increases (See Table 2.1).

Table 2.1**.** Feed requirement and conversion efficiency of lambs at different growth rates.

| | **Lamb growth rate (g day$^{-1}$) from 24-34 kg** | | | |
|---|---|---|---|---|
| | **100** | **200** | **300** | **400** |
| Feed requirement (kg DM day$^{-1}$) | 1.2 | 1.5 | 1.9 | 2.4 |
| Days to target weight | 100 | 50 | 33 | 25 |
| Feed consumed (kg DM) | 120 | 75 | 63 | 60 |
| Conversion efficiency % (kg DM/liveweight gain × 100) | 8.3 | 13.3 | 15.8 | 16.6 |

(Adapted from Kerr, 2000)

Weaning age of lamb ranges between 30-90 days and depends on several factors including management system, amount of milk produced by the ewe, age of lambs and availability of feed. Specifically, pasture growth is the main determinant of the weaning decision. Overall, high lamb growth rates are targeted to achieve before the weaning at the onset of drought conditions. Although, weaning age may differ from one operation to another, lambs are usually weaned at 60 days of age in intensive operations in the eastern US due to intensive gain-based finishing (Barkley, 2014). In New Zealand, which is the largest lamb exporter in the world, accounting for 47% of world's trade in lamb, forage makes up 95% of sheep diet (Morris, 2013). With the help of the efficient grassland use and having a high proportion of the diet based on pasture, New Zealand producers managed to decrease feed costs and increase profitability over the years (Morris, 2013). Lambing season begins in late-winter, so lambs can utilize high quality pasture during spring and summer. They are marketed before the beginning of summer drought (Hodgson *et al*., 2005). Average carcass weight of lambs there is 18 kg (Morris, 2013).

## 2.3 Commonly grown pasture species for dryland pastures

### 2.3.1 Cool season perennial grasses

In the US, forage accounts for 91% of sheep diets, 61% of dairy cattle diets, 83% of beef cattle diets (Wilkins & Humphreys, 2003). Temperate grasses are the mainstay of the pasture systems in Oregon, and if properly managed can support livestock feed requirements. It is estimated that there are 10,000 grass species and 12,000 species of legumes in the world. Around 40 of them are used for pasture, hay and silage purposes. Tall fescue (*Schedonorus arundinaceus (Schreb.)*), perennial ryegrass (*Lolium perenne*) and orchardgrass (*Dactylis glomerata*) are common perennial grasses grown in western Oregon pastures. However, only tall fescue and orchardgrass will be covered in this review as the focus is mainly on the dryland pastures.

**Tall fescue (*Schedonorus arundinaceus (Schreb.)*)**

Tall fescue is the most widely grown grass species, covering over 15 million hectares in the United States (Ball *et al*., 2019). It is native to Europe and was introduced to the U.S. by European settlers in the 1800's (Hoveland, 2009). It can be easily adapted to different soil and climate conditions and tolerates soil pH between 4.5 and 9.0, with an ideal pH of 5.5-7.5 (Belesky and Fedders, 1995). It is also tolerant to waterlogging when air temperature is under 27 $^{o}$C (Hannaway *et al*., 2009). Tall fescue is more drought tolerant compared to other cool season grass species (Buckner *et al*., 1979). However, perennial ryegrass with softer leaves and higher palatability are favored in temperate pastures as compared to tall fescue with coarser leaves (Ball *et al*., 2019).

Forage yield of tall fescue primarily dictated by climate, fertility management, soil conditions, annual precipitation and irrigation. In a 2-year, non-irrigated experiment in Georgia, USA, Bouton *et al*. (2002) planted different cultivars of tall fescue at two different experimental sites, Athens and Blairsville. It was found that annual DM production ranged between 8.5-9.0 t $ha^{-1}$ in Athens and 11.7-14.0 t $ha^{-1}$ in Blairsville under 67 kg N $ha^{-1}$ and 56 kg N/ha application in the first and second year, respectively. In Saskatchewan, Canada, Foster *et al*. (2014) planted 9 grass species including tall fescue and orchardgrass with alfalfa and tested them in two different cutting systems under an average of 400 mm annual precipitation. As a result of the 4-year non-irrigated study, annual DM yields were 8-11 t $ha^{-1}$ in a two-cut regime and 6-8 t $ha^{-1}$ in a three-cut regime. The grass and legume percentage of the mixture was evaluated in the two-cut system. The percentage of grass decreased from a range of 69-91% in the first year to 22-60% in the last year. It was also noted that there was no tall fescue in the last year.

Tall fescue has advantages over other grasses in hay production as well. In Missouri, Angima *et al*. (2009) compared hay production of tall fescue, orchardgrass, timothy (*Phleum pratense*) and smooth bromegrass (*Bromus inermis*) in an area with 1,038 mm average annual rainfall. Forage production of the grasses was evaluated under 0, 56, 112 and 168 kg of N $ha^{-1}$ application. As a result, tall fescue out-yielded the other grasses with 5.4 t/ha under 168 kg of N ha- application rate.  In irrigated conditions, Jensen *et al*. (2001) and Waldron *et al*. (2002) reported, pasture production of tall fescue is higher than other cool season grasses. Its yield is positively correlated with the water level of soil (Wen, 2002). Even though tall fescue yields can be high, animal and forage performance increases when it is planted with legumes. (Stephenson and Prosler, 1988; Hoveland *et al*., 1981). Lauriault *et al*. (2003) reported higher DM yield of a tall fescue-alfalfa mixture compared to a tall fescue monoculture in New Mexico. In drier areas of the world, Mefti et al. (2012) compared DM yields of 5 tall fescue cultivars in semi-arid climate conditions with 396 mm annual precipitation in Algeria and obtained the highest annual yield from tall fescue stands with 1.27 t $ha^{-1}$ annual DM yield.

**Orchardgrass *(Dactylis glomerata)***

Orchardgrass (OG) is a cool-season perennial bunch grass, primarily used for grazing, hay and silage. It is naturally distributed in Europe, North Africa and some parts of Asia. It was first introduced to the US around 1750. In the US, 97% of total orchardgrass seed is produced in the Willamette Valley, Oregon. It can grow in regions with moderate to high rainfall such as the Pacific Northwest and eastern US.

Orchardgrass grows well at 20-22 $^{o}$C but its growth rates decrease when the temperature exceeds 28 $^{o}$C (Collins & Nelson, 2017) and the plant goes dormant. Volaire and Norton (2006) noted that summer dormancy occurs in perennial temperate grasses regardless of the availability of irrigation. Therefore, orchardgrass produces its highest quality forage in early spring (Collins & Nelson, 2017). Orchardgrass is known for its shade tolerance which increases the chance of survival under reduced light conditions.

Total annual DM yield of OG is similar to other grass species. In a study conducted in Iowa, forage yield of binary legume-grass mixtures and their monocultures was compared under dryland conditions (Sleugh *et al*., 2000). Annual DM production of the OG monoculture was 3.6 t DM $ha^{-1}$ in the first year and 2.2 t/ha in the second year. In the same study, its binary mixtures with BFT, alfalfa and kura clover were also evaluated. Their yields were 9.3, 11.2 and 8.5 t DM $ha^{-1}$ and 3.7, 5.7, 4.7 t DM $ha^{-1}$ in the first and second years, respectively.

In New Zealand dryland pasture conditions with 635 mm average annual precipitation, Mills *et al*. (2015) compared annual DM yields of pastures consisted of binary mixtures of orchardgrass with subterranean clover, balansa clover, white clover and Caucasian clover. A perennial ryegrass-white clover mixture and an alfalfa monoculture were also tested in this study. In the 9-year experiment, orchard grass-subterranean clover mixture had the highest yield among grass-based pastures with 8.7-13.0 t DM $ha^{-1}$.

### 2.3.2 Cool season perennial legumes

Legumes belong to the Fabaceae family, characterized by producing seed in pods (Duke, 2012). There are around 690 genera and around 180,000 species in the family. More than 1,500 species of legumes can be used as livestock feed, but 60 species have been developed and used extensively all around the world (Hanson, 2019).There are two main features attributed to legumes in pastures, nitrogen fixing ability and high quality animal feed value (Scott, 2003). Nitrogen fixation of legumes is dependant on *rhizobia* bacteria infecting the root of legumes and building nitrogen fixing nodules. Therefore, inoculation of an effective *rhizobia* species to legume seed before planting is a key factor for the pasture persistance.. The ability to fix N is also economically profitable. For example, it is estimated that *rhizobia* colonizing white clover annually fixes 1.57 million tonnes of N, which saves 1.49 million dollars in 13.5 million ha of New Zealand pastures (Caradus *et al.*, 1996). However, soil acidity remarkably decreases root growth, *rhizobia* nodulation, and nitrogen-fixing potential of the plants (Hayes *et al*., 2019). This makes legume growth challenging in western Oregon dryland conditions where the soil is typically acidic.  Therefore, factors such as climate and soil conditions should be considered when planting legumes in dryland pastures (Scott et al., 1995). Alfalfa, birdsfoot trefoil white clover, red clover are among the most commonly grown legumes in mixed pastures and hay systems in the Pacific Northwest.

Alfalfa is one of the most productive perennial legumes in terms of yield and nutritive value. Burke et al. (2000) reported that alfalfa has the highest crude protein (CP) among a number of legumes including white clover, birdsfoot trefoil and red clover. However, there are agroecological constraints in western Oregon for alfalfa such as soil acidity and poorly drained, heavy clay soils. Since alfalfa requires a minumum soil of pH 6.5 and does not tolerate waterlogging (Ball *et al*., 2007), it is not generally suitable for western Oregon. Therefore, other perennial legumes including white clover, birdsfoot trefoil and red clover are more commonly used in pasture mixtures.

**White clover (*Trifolium repens*)**

White clover is one of the most significant and extensively grown common forage legumes in the world. Approximately 5 million hectares of white clover is grown in US pastures, while it occupies around 15 million hectares in Australasia (Hoyos-Villegas *et al*., 2019). It is adapted to different climatic conditions and nutritionally is a highly valuable pasture species. Brock (2006) estimated that white clover requires 40 mm/month precipitation for persistence. The ideal air temperature for white clover to grow rapidly is 20-25 ºC. Therefore, it produces the highest yield in late spring and summer (Frame, 2005). White clover does not withstand excessive waterlogging conditions (Frame, 2005). It is more sensitive to water scarcity than drought resistant forage legumes such as birdsfoot trefoil or sainfoin. Leaf growth, size of the leaves and amount of stolon branching are often impeded by dry conditions (Belaygue *et al*., 1996).

White clover tolerates severe grazing (Burdon, 1983), although sheep selectively prefer white clover due to its high “palatability” (Nolan et al., 2001). While frequent defoliation is beneficial to the plant during spring, overgrazing is detrimental in summer, probably because of loss of stolon (Caradus *et al*., 1996). Persistence of white clover can be affected by the companion pasture species. Specifically, intensive grazing affects the ratio of white clover to companion plants. This is particularly the case when it is planted with a bunch-type grass such as tall fescue. Therefore, perennial ryegrass is usually planted with white clover in irrigated dairy pastures or in areas with more than 1,200 mm annual precipitation (Brock & Hay, 2001).

To ensure the compatibility, several white clover cultivars are often planted in grass clover mixtures. Williams *et al*. (2003) noted that mixing cultivars of clover results in more sustainable forage stands than planting as a monoculture. However, it is crucial to design compatible pasture mixtures for long-term persistence of white clover, especially in dryland pastures. The optimum ratio of white clover in a mixed pasture for both agronomic and animal performance standpoints is 20-40% (Barnes, 2007).

DM production of white clover is dependent on many factors such as soil type, mineral presence in the soil, annual precipitation, irrigation and fertilizer and lime application. Studies measuring DM yield of white clover in the US are limited. Brink and Fairbrother (1991) compared DM yields of grass pastures when over seeded with white clover and subterranean clover in Mississipi. Over 3 years of the experiment, forage yield increased by 58% after the legumes were introduced to the pastures. White clover contribution to the pastures averaged 1.9 t $ha^{-1}$ in the first year, 0.25 t $ha^{-1}$ in the second year and 1.5 t $ha^{-1}$ in the third year. The highest DM productions were observed in grazing trials in New Zealand as 12 t $ha^{-1}$ for hill sites, 16.2 t $ha^{-1}$ for non-irrigated dryland and 22.8 t/ha for fertile lowland fields (Frame, 2005). Berenji et al (2018) compared DM yield of 6 different legume species under non-irrigated conditions of New Zealand. White clover pastures yielded lower than 2 t DM $ha^{-1}$ in the first year, it increased to 4.5 t $ha^{-1}$ in the second year in pure swards.

**Birdsfoot trefoil (*Lotus corniculatus*)**

Birdsfoot trefoil is a cross-pollinated perennial legume with a lifespan of 2 to 4 years. It is used for grazing, hay or silage, and has a growing popularity in the US due to its agronomic and nutritional benefits. It is estimated that 1.38 million ha of land is occupied by Lotus species of which 90% is birdsfoot trefoil in North America (Díaz *et al*., 2005). It is naturally distributed in Europe, North Africa and some parts of Asia. Because it has the ability of wide adaptation, persistence and high forage yield, it has been planted in much of the fields previously sown with red clover and white clover in the north eastern USA. Oregon is one of the places in the US where birdsfoot trefoil has become naturalized particularly due to its tolerance to waterlogged soil conditions (Beuselnick and Grant, 1995).

Birdsfoot trefoil can grow on acid, infertile and saline soils (Beuselnick and Grant, 1995). It grows between spring and autumn, with peak growth in mid-summer (Frame, 2005). It tolerates poor soil drainage and is more tolerant to waterlogging than alfalfa (Frame, 2005). Although it grows better on fertile, well-drained soils with a pH of 6.2-6.5 or higher, it is not the best option for fertile soils because it can be out yielded by other common forage legumes (Beuselinck and Grant, 1995).

Birdsfoot trefoil has weak seedling development and its germination phase is slow (Frame, 2005). Therefore, it is essential to choose compatible grasses to plant with birdsfoot trefoil. Beuselinck and Grant (1995) and Frame (2005) stated that birdsfoot trefoil is compatible with tall fescue when they are sown together. However, proper pasture management practices should be applied when birdsfoot trefoil is planted with competitive and high producing grasses (Sheafter *et al*., 1984, Beuselinck *et al*., 1995). In Michigan, Leep *et al*. (2002) evaluated the herbage production of binary mixtures from 5 cool season grass species (smooth bromegrass, orchardgrass, timothy, perennial ryegrass, and tall fescue) with birdsfoot trefoil on two different experimental sites (Lake City and Chatham). Total herbage yield was 5.4 t $ha^{-1}$ to 10.0 t $ha^{-1}$ in Lake City and 2.9 t $ha^{-1}$ to 7.9 t $ha^{-1}$ in Chatham over two years. Birdsfoot trefoil and tall fescue mixtures produced the highest herbage yield compared to other binary mixtures.

Birdsfoot trefoil is generally compared with alfalfa in terms of its nutritive value and DM production. McGraw and Marten (1986) found that seasonal DM production of alfalfa is 25-100% greater than birdsfoot trefoil. MacAdam & Griggs (2013) reported that alfalfa and birdsfoot trefoil have similar digestibility, but alfalfa has a higher amount of CP. Although alfalfa has higher fiber content, its digestibility is higher than that of birdsfoot trefoil. Despite the superiority of alfalfa to birdsfoot trefoil, the agroecological conditions of western Oregon in particular acidic, poorly drained soils are not conducive to grow alfalfa. Since birdsfoot trefoil tolerates poor drainage and grows well in dry summer conditions it is considered a viable alternative for alfalfa.

Furthermore, alfalfa can cause bloat, while birdsfoot trefoil is a safe forage to graze due to the presence of condensed tannins (CT). The CT prevents bloat by precipitating soluble proteins in the rumen and prevent them producing foam. CT also improves protein metabolism and can help controlling internal parasites (Min *et al*., 2003; Waghorn, 2008; Piluzza *et al*., 2014). They increase protein utilization by turning highly digestible proteins to bypass proteins by binding them so that they are digested in the lower gut (Beuselnick and Grant, 1995, Waghorn *et al*., 1987). Therefore, CT may make protein metabolism more effective depending on how much CT is consumed (Hagerman and Butler, 1991). The most useful amount of CT in a plant is thought to be 20-40 mg/kg DM, but over 40 mg/kg DM of CT decreases the voluntary food intake and therefore negatively affects animal productivity (Barry & McNabb, 1999). Condensed tannin concentration in birdsfoot trefoil is typically 10-40 mg/kg DM (MacAdam and Villalba, 2015). Birdsfoot trefoil is also used for its anthelmintic effect due to the CT it contains. Marley *et al*. (2003) tested the anthelminthic effect of birdsfoot trefoil on lambs in a 35-day grazing experiment. As a result, lambs grazing on birdsfoot trefoil pastures had lower parasitic load compared to the lambs grazing on perennial ryegrass-white clover pastures.

### 2.3.3 Self-regenerating annual legumes

Self-regeneration, also known as self-reseeding, is the ability of annual plants to produce seeds for germination in subsequent years without soil tillage (McGourty *et al*., 2008).

Self-regenerating annual legumes provide high quality forage in winter and early spring periods. They are planted in fall, or remain from summer, germinate and grow in winter, and thrive in spring. Their growth is often more rapid than grasses and perennial legumes in late winter and early spring due to lower temperature requirements (Moot *et al*., 2000). In early summer, annual clovers become mature and produce seed. Regrowth starts in the following fall (Nori *et al*., 2019). Arrowleaf clover, balansa clover and subterranean clover are among the most commonly grown annual legumes that are successfully adapted to perennial pasture systems.

**Subterranean clover (*Trifolium subterraneum*)**

Subterranean clover, also known as sub clover, is a self-regenerating, annual legume grown extensively in summer dry, temperate agroecologies. *T. subterraneum* subsp. subterraneum L., T. *subterraneum* subsp brachycalycinum and *T. subterraneum* subsp yanninicum are the most well-known. *T. subterraneum* subsp. subterraneum is the most commonly grown across the world (Smetham, 2003).

The name of subterranean clover comes from its seed production pattern. When seeds develop in “burrs”, they are buried under soil. Therefore, the common name of the plant is subterranean clover (Friddle, 2018). It grows well in areas with hot dry summers, mild winters and annual precipitation of 350-1,000 mm (Frame, 2005). It does not have deep roots to survive under dry conditions, so it cannot do well on sandy soils (Hoveland and Evers, 1997). Although subterranean clover originated in Southern Europe, North Africa and West Asia (Frame, 2005), it is extensively grown in Australia where it was first introduced to more than 100 years ago. It covers much of the improved pastures (20 million ha) in Australia due to its excellent adaptation to dry areas through its drought escape strategy. Kemp *et al*. (2004) reported that it is also common in hill pastures or summer dry pastures on the east coasts of New Zealand. In New Zealand, subterranean clover is mostly sown with perennial ryegrass or orchardgrass (Smetham, 2003). The main subterranean clover areas in the US are west of the Cascade Mountain Range in Oregon and west of the Sierra Nevada Mountain Range in California (Hoveland and Evers, 1997).

Germination of subterranean clover begins in autumn and a slow growth lasts until spring (Frame, 2005). Subterranean clover produces larger seeds than other clover species and seeds are buried under soil before plant ultimately dies in summer. The burial of seeds in burrs enables the seeds to protect themselves from low humidity and high temperature conditions of the summer. Therefore, it helps the development of hardseededness (seed coat impermeability), meaning that its seed is unable to absorb water for years. This ability inhibits seed germination after summer rains (Smetham, 2003).

The growth of subterranean clover is positively correlated with P and S level in soil. That is, when there is high amount of P and S in soil, it is easy for subterranean clover to thrive (Frame, 2005). Additionally, it can tolerate low soil pH (<5.5), and the growth is not negatively affected by a soil pH of up to 7.3 (Hoveland and Evers, 1997).

Herbage production of subterranean clover is dependent on the cultivar, as well as climate and soil conditions. Late flowering cultivars produce more forage than early flowering varieties (Rossiter, 1959). For example, Evans (1996) reported that when flowering delayed for one day, forage yield increased 43 kg DM $ha^{-1}$. Similarly, in another study conducted in Australia, Widdup and Pennell (2000) compared DM production of early flowering and late flowering varieties. The yield was 2.5 t DM $ha^{-1}$ from early flowering varieties and 7.3 t DM $ha^{-1}$ from late flowering varieties.

Although subterranean clover is rarely used as a pure sward, there are studies showing that forage production is high for these monocultures. Smetham and Jack (1995) reported that annual DM production of pure subterranean clover was more than 5 t $ha^{-1}$ under intensive rotational sheep grazing in New Zealand. Subterranean clover has rapid spring growth due to its lower temperature requirement than most perennial legumes (Moot *et al*., 2000). This quick growth enables early-season forage production so that farmers are able to start lambing earlier in the season.

Grazing management of subterranean clover requires specific attention to balancing of animal and grass production, as well as legume persistence. Hard intensity grazing in spring in order to increase animal production decreases the amount of flowering and seed production for the next year because seeds and flowers are consumed by the animals (Ates *et al*., 2015). The amount of forage that subterranean clover produces is negatively affected by hard grazing (Smetham & Dear, 2003). On the other hand, relaxed grazing increases flowering and seed production of the plant. However, this results in decreased animal production (Ates *et al*., 2013 and 2015).

**Balansa clover (*Trifolium michelianum*)**

Balansa clover is another self-regenerating annual legume and is native to the eastern Mediterranean region, mainly Turkey (Frame, 2005). After being introduced in Australia, areas planted with balansa clover reached more than 1.5 million hectares due to its excellent drought and waterlogging tolerances (Craig and Ballard, 2000). It is adapted to the southeast region of the US (Frame, 2005)

Balansa clover can tolerate low soil pH values of 4.7-5.1 (Frame, 2005) and requires annual rainfall of 350-650 mm (Craig and Ballard, 2000). It can also do well in saline conditions (Frame, 2005), and grow well with legumes such as alfalfa and subterranean clover and grasses such as annual ryegrass (Frame, 2005). Rogers and West (1993) reported that root growth of balansa clover was greater than that of subterranean clover under waterlogging conditions. Therefore, it can be a complementary component of the pastures containing subterranean clover by colonising different soil type, drainage or pH range (Dear *et al*., 2003; Zhang *et al*., 2004).

Performance of of balansa clover is well-known in Australasia. In a study conducted at two sites in western Australia, researchers compared DM yields of 15 different legumes. DM production of of balansa clover ranked 4th with a yield of 5.1 t ha$^{-1}$ When grown for seed production, the seed yield of balansa clover was 670 kg to 1000 kg ha$^{-1}$ (Frame, 2005). The seed yield under proper grazing management was reported to be 200-300 kg ha$^{-1}$ (Frame, 2005). In New Zealand dryland pastures, when balansa clover was sown with orchardgrass, average annual DM production of the pasture was 9.3 t ha$^{-1}$ with the amount of balansa clover ranging from 2.2 t ha$^{-1}$ to 4.3 t ha$^{-1}$ in a 6-year study under rotational grazing (Monks *et al*., 2008).

Proper grazing management of balansa clover, in particular during the flowering stage is crucial for its persistence. When grazed during flowering stage, seed production can decrease more than 50% (Bolland, 1987). Therefore, animals should be taken out of the balansa pasture before flowering begins (Bolland, 1987). After seed production stage is done, Craig & Ballard

(2000) suggested a “clean-up” grazing in early summer to ensure re-establishment in the following autumn.

## 2.4 Production and persistence of dryland pastures

### 2.4.1 Forage biomass production

Estimating DM production is an important part of a grazing management to interpret animal response at a given stocking rate (Marten *et al*., 1989). However, herbage mass might not always reflect animal response. In different growing periods the ratio between DM production and nutritive value will be different. For example, during vegetative period, nutritive value of the forage will be greater than average sward production (Marten *et al*., 1989). Nevertheless, DM production is still an indirect indicator of animal performance.

Goh and Burce (2005) compared the DM yield of four different types of pasture mixture in dryland conditions of New Zealand. All annual DM yields varied from 6-7 t $ha^{-1}$. However, there was no significant difference among pasture mixtures. Dry matter production of alfalfa exceeded that of the other pastures. This was possibly due to the deep tap root of alfalfa that can reach the water in deeper levels of the soil. In a sheep grazing study, Ates *et al*. (2015) showed that DM production of a tall fescue-subterranean clover pasture was between 1.8 t $ha^{-1}$ $y^{-1}$ and 2.4 t $ha^{-1}$ $y^{-1}$ at a low stocking rate. In high stocking rate conditions, annual DM production varied from 1.4 t $ha^{-1}$ to 1.7 t $ha^{-1}$. In another study conducted in New Zealand by Ates *et al.* (2010) annual DM production of orchardgrass and perennial ryegrass dominated pastures with and without over drilled subterranean clover were compared. As a result of the study, it was demonstrated that perennial ryegrass and subterranean pastures yielded 12.7 t DM ha$^{-1}$ y$^{-1}$ while orchard grass and subterranean mixture produced 10.7 t DM ha$^{-1}$ y$^{-1}$. The orchardgrass pasture without any subterranean clover content produced only 6.6 t DM ha$^{-1}$ y$^{-1}$.

### 2.4.2 Seed production and persistence

Persistence of self-regenerating annual legumes in the pasture is mostly dependent on adequate amount of seed production, hardseededness, breakdown of seed dormancy and seedling survival and germination (Cocks, 1996). Since seed production will affect the next years' establishment, it is important to manage grazing of annual clovers during the flowering stage. Seed production can be optimized under appropriate grazing management. In Oregon, Steiner and Grabe (1986) noted that if subterranean clover is grazed between prior to the beginning of flowering and early burr fill, it produces its highest amount of seed. Subsequent pasture production of subterranean clover mainly depends on number of seedlings per unit of area. Taylor *et al*. (1991) reported that at least 1,000 seedlings/m$^2$ is required for a successful establishment. Seed production is advised to be at least 600 kg/ha for effective regeneration (Frame, 2005).

It is reported that seed production of balansa clover decreases by more than 50% when it is laxly grazed in the flowering period. The percentage is 8 for subterranean clover in the same conditions (Bolland, 1987). Seed production of balansa clover is between 340 million and 1.7 billion seed ha$^{-1}$ (Jansen and Ison, 1996; Craig, 1998). The amount of seed can vary among cultivars (see Table 2.2).

Table 2.2 Seed weight and annual seed production of 'Bolta', 'Paradana' and 'Frontier' balansa clover from a range of sources. (Adopted from Monks, 2009)

| **Variety** | **Seed weight (mg)** | **Seeds/m$^2$** | **Seed Production (t/ha)** | **Location** | **Reference** |
|---|---|---|---|---|---|
| Bolta | 1.17 | 85,500 | 1.0 | S. Australia | Craig (1998) |
| | | 111,000 | 1.3 | NSW, Australia | Jansen *et al*. (1996) |
| | | | 1.6 | Canterbury, NZ | Nori *et al*. (2019) |
| Paradana | 0.98 | | | S. Australia | Craig (1998) |
| | 0.72 | | | NSW, Australia | Jansen (1995) |
| | 0.72 | 69,000 | 0.5 | NSW | Jansen and Ison (1996) |
| Frontier | 1.2 | 42,000 | 0.5 | SE. Australia (Acidic soils) | Dear *et al* (2002) |
| | | 100,000 | 1.2 | S. Australia | Craig *et al* (2000) |

## 2.5 Grazing management of dryland pastures

Grazing systems are basically divided into two groups; continous grazing and rotational grazing (Hodgson, 1979). In continous grazing, animals have access to all parts of the pasture during the grazing season. This system requires less labor and equipment such as fencing and water trough placement compared to rotational grazing. However, plants are exposed to selective grazing, and as a result, desirable plants die early. Rotational grazing allows palatable plants to regrow. Therefore, legume persistence increases in rotational grazing (Ball, 2007). Consequently, a pasture produces higher amounts of forage in rotational grazing systems.

Utilization of dryland pastures is important to provide high quality pasture for livestock as well as wildlife habitat, ersoion control and weed prevention. The level of forage production is mainly determined by forage species, climate and grazing management (Wilson *et al*., 2006). When animals are offered a high amount of good quality feed, animal performance will increase (Holmes, 1987). However, it is to harmful to the pasture. The reverse condition, increasing the stocking rate will result in lower nutritive value, intake and animal performance.

In Corvallis, Oregon, Warner (1983) compared sheep grazing systems in dryland pastures in a 3-year study. Forage production in the rotationally grazed pastures was 32.8% to 52.7% higher than the pastures continously grazed. Additionally, higher liveweight gain of the lambs in rotational grazing systems is also reported by Warner (1983).

In another study comparing sheep performance on continous and rotational grazing in Oregon dryland pastures with subterranean clover being the only clover component, it was reported that at the end of the grazing period, lambs rotationally grazed were 10% heavier (35 kg head$^{-1}$) than those on continuous grazing (31 kg head$^{-1}$) during spring (May-July) (Sharrow and Krueger, 1979). This was due to the increase in subterranean clover content of the rotationally grazed pastures. Sharrow and Kruger (1979) suggested that rotational grazing can increase available forage for livestock and, therefore, animal performance during spring, when plants are actively growing.

## 2.6 Forage quality and lamb growth

Forage quality is a function of the chemical structure of forages voluntary feed intake and anti-quality factors Pasture quality is affected by maturity and species of plants, as well as environmental temperature and rainfall. Forages generally have 12-30% DM (Waghorn and Clark, 2004) in the vegetative phase and 60-90% DM in the reproductive phase. The percentage of non-structural carbohydrates such as soluble sugars, fructans, organic acids or starch is usually 10-20% of the DM (Frame, 2005; Chaves *et al* 2002). Pasture legumes have 15-20 % CP while cool season grasses contain around 7-12% CP on average (Collins and Newman, 2018). Grass and clover mixed pastures have lower NDF and ADF content and increased CP, mineral, and energy compared to grass monocultures at similar maturity stages. The higher the NDF a plant has, the lower dry matter intake the animals have. The ADF content of the plant includes cellulose and lignin, and this value reflects the digestibility of the forage. Overall, a level of 25-30% legume component in pastures is considered ideal for both forage and livestock production (Ball *et al*., 2019). In a study carried out in the northeast US, nutritive value of 14 different organic dairy pastures was determined. As a result, average CP was found to be 19.5%, average NDF was 51.0 % and ADF was 31.4% during the grazing season (Hafla *et al*., 2016).

Pastures are dominated by leafy sward in spring (vegetative growth), stem and seed head are produced in late spring (transition phase) and decrease in quality during summer (reproductive phase) since the growth rate is limited because of the change in water availability, photoperiod and fiber content of the mature plant. Level of CP and amount of leaves a plant has decreases as plants mature while percentages of NDF and ADF increases. Therefore, optimum grazing management is required for both animal and pasture performance.

Dietary requirements of adult sheep vary throughout the year. While sheep require feed only for maintenance for most of the year, their need for nutrients increases in the mating season and the later part of gestation. Rapid lamb growth is also desired to finish lambs early and increase the efficiency of feed conversion (Table 2.1). That is, when a lamb grows faster, it needs a lower proportion of food for maintenance and a higher proportion for growth. (Rattray et al., 1976). Average pasture requirements for sheep and weaned lambs are summarized in Table 2.3.

Legume content of pastures is important to increase pasture nutritive value. Hyslop *et al*. (2000) showed that average daily gain (ADG) of lambs is dependent on legume content of the pasture and that ADG increases remarkably from 0 to 20% legume content. While lambs fed tall fescue alone gained 100 $g^{-1}$ $d^{-1}$ $head^{-1}$, ADG was increased to 250 $g^{-1}$ $d^{-1}$ $head^{-1}$ when lambs fed pasture with 20% clover and 80% tall fescue. Although lambs fed concentrate based diets generally have higher ADG, studies show that similar gains can be achieved with high quality pastures (Ponnampalam *et al.*, 2017). Lambs growing on pasture containing mainly alfalfa had higher ADG and heavier carcass weights than the lambs finished on pasture containing annual ryegrass and grain supplements (Burnett *et al.*, 2012). In a study conducted in Australia, weaned lambs were offered alfalfa or perennial ryegrass-subterranean clover pastures for 6 weeks. Lambs grazed alfalfa gained 267 $g^{-1}$ $d^{-1}$ $head^{-1}$ while lambs that grazed perennial ryegrass-subterranean clover gained 286 $g^{-1}$ $d^{-1}$ $head^{-1}$ (Ponnampalam, 2017).

Table 2.3 Pasture requirements for sheep and weaned lambs.

| | Pasture DM (kg $ha^{-1}$) | Feed intake (kg $DM^{-1}d^{-1}$) | Production level (average daily gain) |
|---|---|---|---|
| **Ewes** | | | |
| Mid pregnancy | 400-500 | 1.0 | Maintenance |
| Last 6 weeks of gestation | 600-800 | 1.3 | 60-80 g $d^{-1}$ |
| Ewes and lambs | 1400-1600 | 1.8 | 180-200 g $d^{-1}$ (lambs) |
| Summer | 900-1000 | 1.0 | Maintenance |
| Mating | 1200-1400 | 1.4 | 120-150 g $d^{-1}$ |
| **Weaned lambs** | | | |
| Spring | 1200-1400 | 0.8 | 160-200 g $d^{-1}$ |
| Summer | 1400 | 1.0 | 130-150 g $d^{-1}$ |
| Fall | 1200 | 1.2 | 80-100 g $d^{-1}$ |
| Winter-spring | 1100 | 1.2 | 100-120 g $d^{-1}$ |

(Adopted from Kerr, 2000)

## 2.7 Conclusions

Grasses and legumes are important for pasture production and animal performance. However, their productivity is dependent on soil and climate conditions, precipitation and presence of mineral in the soil. It is proven that higher legume content in pastures results in higher liveweight gain in lambs. This is because legumes have higher feeding value than grasses and have the potential to fix atmospheric N in soil so that grasses can benefit. One of the main issues in dryland pastures is to sustain forage production in late spring and early summer. Balansa clover, birdsfoot trefoil and subterranean clover have the potential to thrive and provide high quality forage for animals in western Oregon dryland pastures. In conclusion, it is possible to increase and sustain pasture production and animal performance with ideal grazing management and use of ideal grass-legume mixtures in dryland pastures.

# Chapter 3
# Pasture production and lamb growth from dryland hill pastures in western Oregon

## 3.1 Introduction

Nitrogen is a pivotal element that drives plant growth and yet it is the most limiting nutrient for pasture production (Mills *et al*., 2009). In particular, soils of dryland pastures are often deprived of N. Therefore, increasing N availability in dryland pastures that are managed under low-input production systems is a primary focus to improve the productivity. Application of chemical fertilizers can be costly and challenging particularly in difficult terrains such as hill and high-country pastures. In such environments, biological N fixation by legumes through their symbiotic relationship with soil bacteria is an excellent tool to increase N availability for pasture plants (Ledgard and Steele, 1992). Nitrogen recycled through the grazed grass-legume pasture systems improves forage quality. Higher legume content of pastures leads to higher herbage DM intake and productivity of grazing livestock. However, the persistence of pasture legumes in dryland conditions where the evapotranspiration often exceeds the precipitation is challenging. Selective grazing of the legumes by livestock is an additional pressure that often hinders the persistence of legumes. Thus, incorporating legumes that are tolerant to both grazing and dry conditions is crucial to ensure high forage production and high animal performance in pastures.

White clover is the most commonly grown pasture legume in temperate agroecologies. It has the capacity to fix over 600 kg N $ha^{-1}yr^{-1}$ (range, 100–350 kg N $ha^{-1}$ $yr^{-1}$) (Whitehead, 1995) and can provide lamb growth rates exceeding 300 g $d^{-1}$ in summer (Cranston *et al*., 2015). Although it is highly tolerant to intensive grazing, it is hard to maintain white clover content due to its lack of persistence in dryland environment where the precipitation is less than 40 mm/month (Nicholas *et al*., 2004; Brock, 2006). White clover has a poor post-drought recovery due to its shallow root system and stoloniferous growth habit (Brock & Caradus, 1996; Knowles *et al*., 2003). Pasture legumes with deep tap roots, such as alfalfa, birdsfoot trefoil, and Caucasian clover, are extensively grown in arid environments. Although alfalfa is primarily used as a hay crop, successful grazing management practices have been developed in New Zealand (Moot *et al*., 2016) and grazing tolerant cultivars are available. Birdsfoot trefoil persists on poorly drained and low fertility soils and can be grazed safely by ruminants (Hunt *et al*., 2015). However, it's slow establishment and poor competitive ability is a major setback in mixed pastures.

A further legume option in dryland pastures can be self-regenerating annual legumes due to their drought escape strategy. They can be incorporated into perennial pasture systems given that the grazing management is optimized for both animal production and reproductive performance of annual legumes. When drilled into grass-dominated pastures where white clover failed to persist, subterranean clover increased pasture yields as much as 40% in New Zealand (Ates *et al*., 2010). Furthermore, pastures containing subterranean clover provide high lamb growth rates in spring enabling them to reach slaughter weight before the onset of drought (Muir *et al*., 2003; Ates *et al*., 2015). To a lesser extent, high lamb growth rates were also reported with balansa clover-grass pastures as well (Mills *et al*., 2008). Balansa clover, not as widely tested as subterranean clover, can outperform it in the PNW due to its high tolerance of poor drainage. As a top-flowering legume, while it presents higher value for pollinators than subterranean clover, it may be more susceptible to grazing in dryland conditions.

Persistent dryland pasture mixtures can be designed using the different functional and structural attributes of legumes. Norman *et al*. (2005) reported that using various annual clovers with different reproductive strategies in pasture mixtures may help sustain high clover content in pastures since different clovers are able to benefit from different climatic and grazing conditions. We hypothesized the legume content of pastures can be increased using either self-regenerating annual legumes or deep-rooted perennial legumes as compared to grass pastures containing white clover. It is also hypothesized that diverse legume mixtures sown with tall fescue may be provide higher legume content leading to higher forage and animal production than binary legume-grass mixtures.

## 3.2 Materials and methods

### 3.2.1 Site, establishment, and experimental design

This experiment was conducted at the Oregon State University Sheep Farm in Corvallis, Oregon (44° 34’ N, 123° 18’ W, elev. 187 m). The site was located on the south-west facing slope of the hill. The soils mainly consist of a Dixonville-Gellatly silty clay loam (Fine, mixed, superactive, mesic Pachic Ultic Argixerolls) with 12-30% slope (USDA, Web Soil Survey, 2019). Soil tests indicated the site had the following conditions: organic matter, 9.2%; available P (Bray), 11.1 ppm; Ca, 1.5 meq/100g; Mg, 0.8 meq/100g; K, 189 ppm; and soil pH, 6.0. The study was conducted from 16 October 2017 to 24 October 2019. A 1.5 ha paddock was divided into three, 0.5-ha blocks and sown with five pasture treatments. Each block contained five fenced 25 × 50 m plots (0.1 ha) opening onto an adjoining race. These 0.1 ha pasture plots were further divided into 3 subplots to apply rotational grazing within each plot. The plots were randomly assigned to the following mixtures: (1) tall fescue (*Schedonorus arundinaceus* (*Schreb.*)) and white clover (*Trifolium repens*), TF-Whc; (2) tall fescue and subterranean clover (*Trifolium subterraneum*), TF-Sc; (3) tall fescue and balansa clover (*Trifolium michelianum*), TF-Bc; (4) tall fescue and birdsfoot trefoil (*Lotus corniculatus*), TF-Bft; and (5) tall fescue, white clover, subterranean clover, balansa clover and birdsfoot trefoil, TF-Mix. The five pasture mixtures were sown at 15-cm row spacing in a randomized complete block design with 3 replications with each block as a replicate on 16 October 2017. The sowing rates of pasture treatments are presented in Table 3.1. All plots were fertilized with 50 N kg/ha as urea at seeding. A total of 80 kg 20-20-20 fertilizer /ha was applied to the paddock in both spring 2018 and 2019 before the grazing experiment started.

Table 3.1 Treatment details and sowing rates (kg ha$^{-1}$) of pasture species of the experiment.

| Pasture mixtures | Tall fescue cv. Brutus | White clover cv. Seminole | Birdsfoot trefoil cv. Bruce | Subterranean clover cv. Dalkeith | Balansa clover cv. Fixation |
|---|---|---|---|---|---|
| TF-Whc | 20 | 5 | | | |
| TF-Sc | 20 | | | 15 | |
| TF-Bc | 20 | | | | 6 |
| TF-Bft | 20 | | 8 | | |
| TF-Mix | 20 | 3 | 3 | 5 | 3 |

### 3.2.2 Meteorological conditions

Long-term mean (LTM) annual air temperature at this location is 11.4 °C (Figure 3.1). Mean daily air temperature between October 2017 and October 2019 followed a similar pattern with the LTM annual air temperature. However, it was below the average during January 2018 and above the average in the summer of 2018 and 2019. The LTM annual (Jan-Dec) rainfall is 1086 mm (1980–2010) but was 664 mm in 2018 and 703.6 mm in 2019. The LTM monthly rainfall is between 12 and 196 mm throughout the year (Figure 3.2).

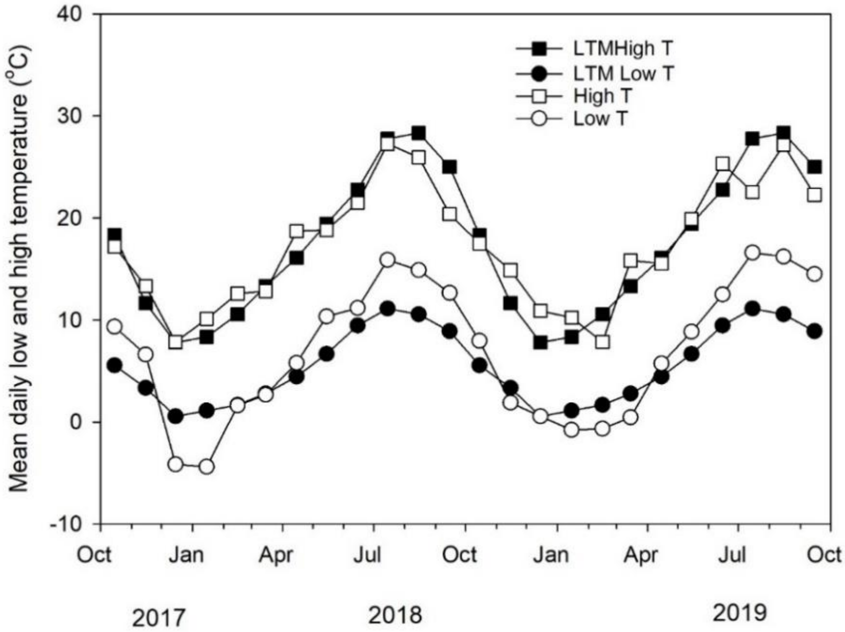


**Figure 3.1.** Monthly mean low (○) and high air temperature (□) from 1 October 2017 to 30 October 2019. Long-term means of low (●) and high (■) air temperature are for the period 1980-2010. The meteorological data was obtained from AgriMet Pacific Northwest Region, Bureau of Reclamation.

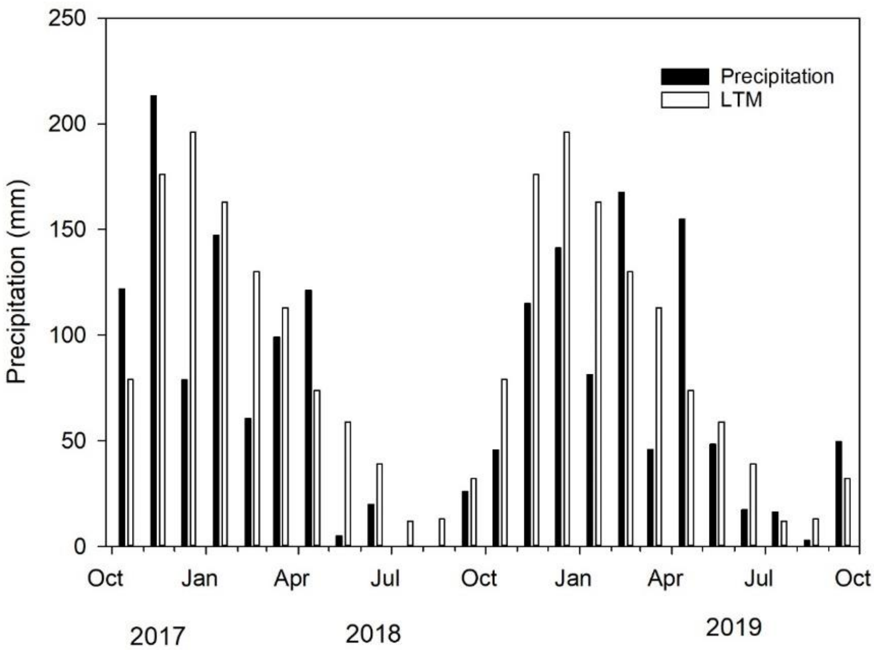


**Figure 3.2.** Mean monthly rainfall (■) at Corvallis from 1 October 2017 to 30 October 2019. Long-term averages (1980-2010) are shown (□). The meteorological data was obtained from AgriMet Pacific Northwest Region, Bureau of Reclamation

### 3.2.3 Grazing management

Weaned Polypay lambs (2.5 months old) were stratified by liveweight (mean LW = 22.0 ± 2.7 kg in 2018 and 23.2 ± 3.4 kg in 2019) and sex and allocated randomly to treatments in both years. Grazing management was designed to maximize lamb production from each treatment by applying optimal grazing management (i.e., stocking rate, duration of grazing, etc.). Number of lambs in each plot was adjusted at the end of each grazing period based on fluctuating pasture growth rates and available forage on offer in each plot. All treatments were rotationally grazed with a flock of lambs in each plot grazing one subplot while the other two subplots were rested. Each treatment had a core group of 6 weaned lambs (testers) with spare lambs (regulators) used in a put-and-take grazing system to match feed demand with fluctuating supply. In 2018, grazing lasted 42 days (20 April to 1 June). The rotation length was approximately 21 days with an average grazing duration of 6–8 days in each plot in early spring. The average grazing intensity was 80 and 60 weaned lambs ha$^{-1}$ in the first (20 April-10 May) and second rotations (11 May-1 June), respectively. In 2019, grazing commenced earlier (28 March) and ran through 7 June, lasting 70 days. The average grazing intensity was 65 lambs ha$^{-1}$ in early spring (28 March-18 April), 64 lambs ha$^{-1}$ (18 April-10 May) in mid-spring and 51 lambs ha$^{-1}$ in late spring (10 May-7 June). Average rotation length was 21 days in the first two periods, while it was 30 days in the final grazing period. Lambs had continuous access to fresh water and mineral supplement in each paddock.

### 3.2.4 Measurements

#### 3.2.4.1 Pasture dry matter production

Dry matter production and mean daily growth rates of the pasture plots were measured within 1-m$^2$ grazing exclosure cages (2 in each grazing plot) during active growth in spring, summer, and autumn. No samples were collected during the winter periods as pasture growth was minimal due to low temperatures. Pasture growth was measured from a 0.25-m$^2$ quadrat within each exclosure cage by cutting with electric shears to a stubble height of 30 mm. Cages were placed over a new area where the pasture was pre-trimmed to 30 mm of stubble height at the start of each new growth period. All herbage from the quadrat cuts was dried in an oven (65 °C) until constant weight. Samples were sorted into different botanical species before they were dried. Mean daily growth rates (kg DM $ha^{-1}$ $day^{-1}$) were calculated at each harvest by dividing total DM production (kg DM $ha^{-1}$) by the duration of regrowth since the previous harvest.

#### 3.2.4.2 Liveweight gains

Liveweight gain was determined by weighing individual tester animals prior to and following each grazing period. Lambs were held overnight without food and water and weighed “empty” the following morning. Liveweight gain per head of tester lambs was calculated from the change in weight between each liveweight measurement date. Liveweight gain (kg $ha^{-1}$ $d^{-1}$) was calculated by multiplying liveweight gain per head of tester lambs by the number of testers plus regulator lambs per hectare.

#### 3.2.4.3 Pasture mass on offer

Pre and post grazing pasture mass (kg DM $ha^{-1}$) was measured using a calibrated rising plate meter (JenQuip, Feilding, New Zealand). A total of 50 rising plate meter measurements were recorded across each pasture plot. Rising plate meter measurements were calibrated by regression against the herbage masses that were obtained from three 0.25-$m^2$ quadrats (Table 3.2). The calibrations of pre and post grazing pasture masses were performed in April in 2018 and March and May in 2018.

Table 3.2 Linear equations for pastures obtained by regression between plate meter readings (x) and herbage mass (y).

| Year | Period | Treatment | Pre-Grazing | $R^2$ | Post Grazing | $R^2$ |
|---|---|---|---|---|---|---|
| 2018 | April-June | TF-Whc | y = 91.539x + 1098.3 | 0.81 | y = 249.99x - 340.1 | 0.94 |
| | | TF-Sc | y = 133.28x + 191.5 | 0.94 | y = 250.13x - 454.4 | 0.79 |
| | | TF-Bft | y = 114.49x + 598.3 | 0.76 | y = 177.27x - 70.5 | 0.87 |
| | | TF-Bc | y = 200.54x - 992.1 | 0.86 | y = 164.35x - 61.1 | 0.84 |
| | | TF-Mix | y = 94.158x + 948.2 | 0.76 | y = 159.67x + 49.6 | 0.85 |
| 2019 | March-April | TF-Whc | y = 56.172x + 588.8 | 0.79 | y = 88.097x - 294.3 | 0.83 |
| | | TF-Sc | y = 26.068x + 1251.4 | 0.84 | y = 92.889x - 320.6 | 0.96 |
| | | TF-Bft | y = 45.995x + 803.8 | 0.68 | y = 109.94x - 287.7 | 0.92 |
| | | TF-Bc | y = 82.562x – 344.6 | 0.95 | y = 81.325x - 188.1 | 0.89 |
| | | TF-Mix | y = 60.366x + 569.2 | 0.80 | y = 92.547x - 203.0 | 0.75 |
| | May-June | TF-Whc | y = 100.5x - 91.7 | 0.94 | y = 140.34x - 619.5 | 0.97 |
| | | TF-Sc | y = 132.88x - 1170.2 | 0.93 | y = 115.67x - 397.9 | 0.79 |
| | | TF-Bft | y = 83.071x + 68.9 | 0.64 | y = 183.74x - 1309.1 | 0.92 |
| | | TF-Bc | y = 110.31x – 111.6 | 0.74 | y = 126.98x - 509.3 | 0.85 |
| | | TF-Mix | y = 92.231x - 52.4 | 0.81 | y = 120.53x - 621.6 | 0.98 |

#### 3.2.4.4 Nutritive value of forage on offer

A total of 50–75 snip samples, representative of herbage eaten by lambs, were collected by hand randomly across herbage in each plot prior to turning lambs onto plots. A subsample was sorted by botanical composition of the forages and dried in an oven at 65°C to a constant weight. Percentage botanical composition of samples on a dry weight basis was then calculated. A well-mixed bulk sample was ground in a Wiley mill with a 1-mm stainless steel sieve (Thomas/Wiley, Swedesboro, NJ) for chemical analyses. Samples were analyzed for DM (method 2001.12; AOAC, 2003), ash (method 942.05; AOAC, 2003), and ether extract (method 920.39; AOAC, 2003). The CP concentration of all samples was determined by the Kjeldahl method according to the Association of Official Analytical Chemists (1990; LECO FP828, MI, USA). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were assayed according to the methods described by Van Soest et al. (1991) using an Ankom$^{200}$ Fiber Analyzer (ANKOM Technology Corp., Macedon, NY).

#### 3.2.4.5 Flower, seed and seedling counts

Initial subterranean clover seed population in the top 50 mm of soil was determined by taking 45 random soil core samples (15 cores per block), each 80 mm in diameter across the paddock on 5 October 2017. Following the spring grazing in both years, a total of 15 random soil cores (total area of cores 0.075 $m^2$) were taken in each TF-Sc and TF-Mix plot on 18 July 2018 and 3 July 2019. On each occasion, soil cores collected from the same plots were bulked and washed to remove soil through mesh sieves with sizes of 500 µm and 250 µm. After the removal of the soil, individual subterranean clover seeds and seeds inside the burrs retained in each sieve were counted. Total number of inflorescences of balansa clover were also quantified on 7 June 2018 and 15 June in 2019 within three randomly placed 0.25 $m^2$ quadrats in each TF-Bc and TF-Mix plot. Five randomly selected balansa clover flowers within the quadrat were harvested to quantify the number and weight of seeds. As an indicator of effects of grazing management on persistence of annual clovers, balansa and subterranean clover seedling numbers were counted in three randomly placed 0.01 $m^2$ quadrats on 2 November 2018 and 6 October 2019.

### 3.2.5 Statistical analyses

Annual DM production, seed and seedling numbers were analysed by ANOVA based on a factorial model that accounted for the main effects of pasture mixtures and years in a complete randomized design. Seasonal DM production was analysed by one-way ANOVA with three replicates in both years. The liveweight gain of lambs per head (g $day^{-1}$) and per hectare (kg $ha^{-1}$), pasture nutritive value and herbage mass on offer were analysed by one-way ANOVA with repeated measures. Botanical composition of pasture on offer was by ANOVA based on a factorial model that accounted for the main effects of pasture mixtures and rotations.

Significance of differences among treatment means were compared by Fisher's method of protected least significant difference (LSD) at a P = 0.05. The computations were carried out using GENSTAT statistical software (Payne, 2009).

## 3.3 Results

### 3.3.1 Pasture dry matter (DM) production

Total annual DM yields of pastures were 7932 and 9812 kg $ha^{-1}$ $y^{-1}$ in 2018 and 2019, respectively (Figure 3.3) Averaged across the years, TF-Whc, TF-Mix and TF-Bc pastures provided greater ($P<0.05$) herbage yield than TF-Bft and TF-Sc pastures which did not differ from each other. No treatment × year interaction was detected for the total annual DM production of pastures ($P=0.54$). Contribution of legumes to total annual DM production varied across the pasture mixtures ($P<0.01$) but it was similar in both years ($P=0.36$). Overall, the legume in TF-Mix pastures provided the highest total annual DM with 2310 kg DM $ha^{-1}$ $y^{-1}$. This was substantially greater than the production of legumes in TF-Sc (1215 kg DM $ha^{-1}$ $y^{-1}$) and TF-Bft pastures (575 kg kg DM $ha^{-1}$ $y^{-1}$). The contribution of legumes in TF-Bc and TF-Whc were similar to the production from TF-Mix and TF-Sc but also higher than TF-Bft pastures. The proportion of weeds did not differ among the pasture mixtures ($P=0.46$) but it was greater in 2019 (816 kg DM $ha^{-1}$ $y^{-1}$) than 2018 (393 kg DM $ha^{-1}$ $y^{-1}$).

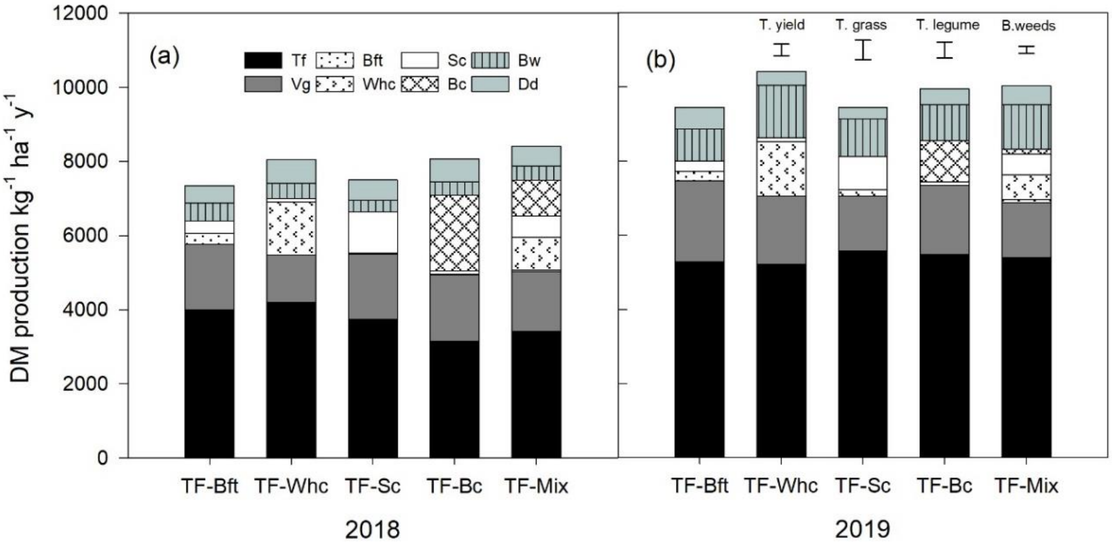


Figure 3.3. Annual DM production of tall fescue-birdsfoot trefoil (TF-Bft), tall fescue-white clover (TF-Whc), tall fescue-subterranean clover (TF-Sc), tall fescue-balansa clover (TF-Bc) and tall fescue-multi legume mixtures (TF-Mix) in 2018 and 2019. Panel (a): TF: Tall fescue Vg: Volunteer grass, Bw: Broadleaved weed, Dd: Dead materials, Panel (b): T. yield: Total yield, T grass: Total grass, T. legume: Total legume and B. weeds: Broadleaved weeds.

Average winter-spring production were comparable across the pasture mixtures in both years (Figure 3.4; $P>0.05$). The contribution of broadleaf weeds, dead material and total grasses also did not differ among pasture mixtures ($P>0.05$). While the proportion of legumes across pastures in winter-spring DM yields were comparable in 2018, balansa clover tended to have greater legume production than birdsfoot trefoil in 2019 ($P=0.054$).

In spring 2018, all pastures had similar total yield with the contribution of the components being comparable except the legumes. The TF-Bc and TF-Mix appeared to produce greater forage than TF-Bft ($P=0.06$). In 2019, neither the total spring production nor the yields of the pasture components differed from one another ($P>0.05$). No yield differences occurred in summer 2018 ($P>0.05$) but DM yield of TF-Bc and TF-Whc was greater than TF-Sc in summer 2019 ($P<0.05$). Fall DM yields and the components were comparable in both years except the legume yields in fall 2019 when TF-Mix had greater legume yield than TF-Bc and TF-Bft ($P<0.05$).

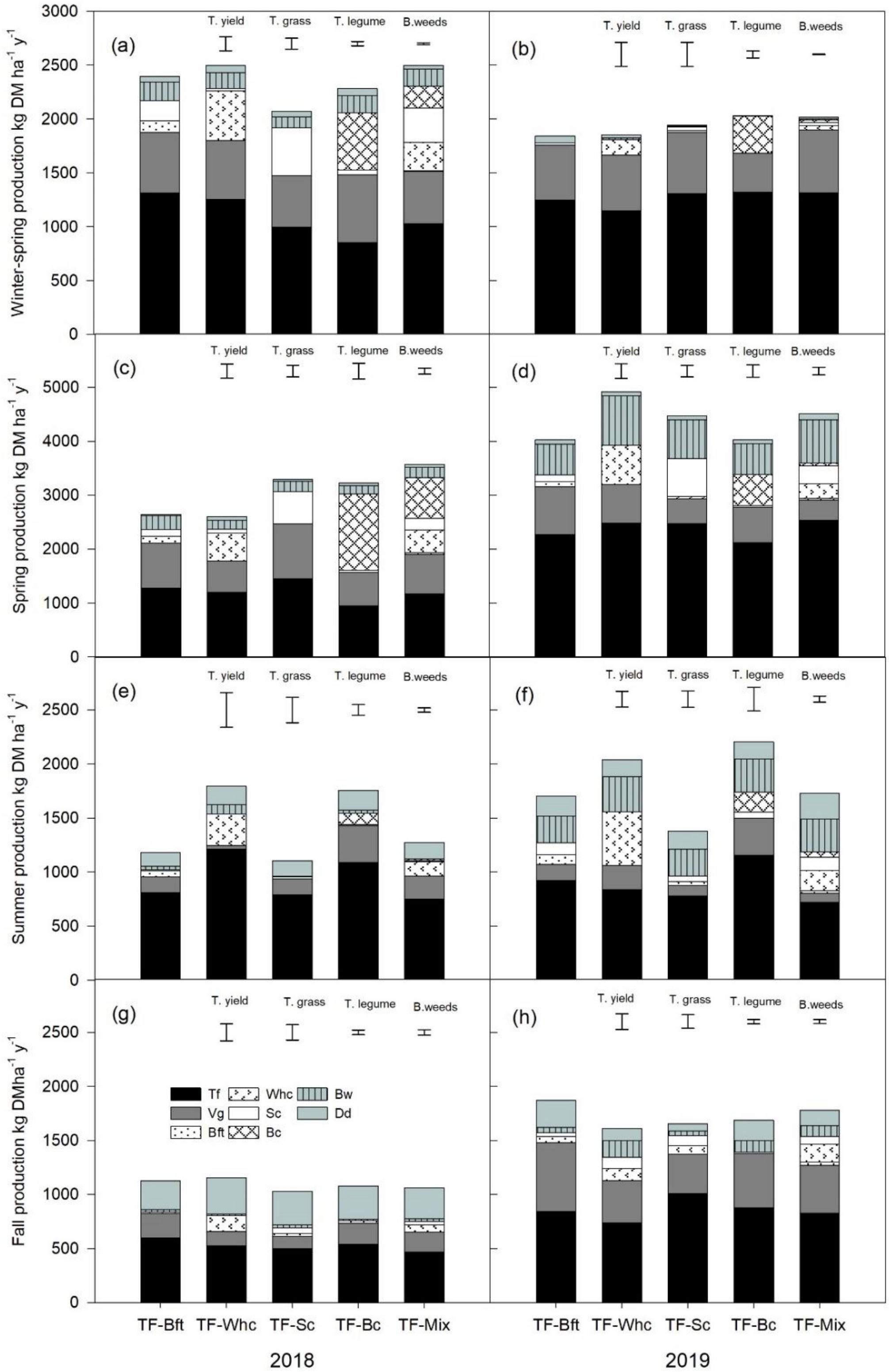


Figure 3.4. Seasonal dry matter (DM) production of tall fescue-birdsfoot trefoil (TF-Bft), tall fescue-white clover (TF-Whc), tall fescue-subterranean clover (TF-Sc), tall fescue-balansa clover (TF-Bc) and tall fescue-multi legume mixtures (TF-Mix) in 2018 and 2019. Bars represent SEM. T. yield: Total yield, T grass: Total grass, T. legume: Total legume and B. weeds: Broadleaved weeds. Panel (g): TF: Tall fescue Vg: Volunteer grass, Bw: Broadleaved weed, Dd: Dead materials.

### 3.3.2 Lamb production

Mean daily liveweight gain of lambs is presented in Table 3.3. In 2018, lambs grew at 177.4 g $hd^{-1}d^{-1}$ in the first and 140.6 g $hd^{-1}d^{-1}$ in second periods of spring grazing. A pasture treatment × period interaction was detected for the lamb growth rates ($P$<0.01). Overall, the lambs that grazed TF-Bc, TF-Bft and TF-Mix had similar liveweight gains in both periods, while those grazed TF-Sc and TF-Whc had substantially lower daily LWGs in the second compared to the first period. The difference in lamb LWG was not significant in the first period, while TF-Bc and TF-Mix had greater LWG than TF-Bft and TF-Whc in the second grazing period.

Table 3.3 Mean liveweight gain of lambs from tall fescue-legume pastures over two grazing periods in 2018 and three grazing periods in 2019.

| Year | Period | TF-Sc | TF-Bc | TF-Bft | TF-Whc | TF-Mix |
|---|---|---|---|---|---|---|
| 2018 | 20 April-10 May | $192^{a}$ | $172^{a}$ | $159^{abc}$ | $187^{a}$ | $178^{a}$ |
| | 10 May-1 June | $129^{bc}$ | $164^{ab}$ | $124^{c}$ | $124^{c}$ | $163^{ab}$ |
| | Mean | 160 | 168 | 141 | 156 | 170 |
| $P_{\text{Pastures (Pas)}}$ | | | | 0.32 | | |
| $P_{\text{Periods (Per)}}$ | | | | 0.01 | | |
| $P_{\text{Pas x Per}}$ | | | | 0.01 | | |
| $SEM_{\text{Pas x Per}}$ | | | | 12.5 | | |
| 2019 | 28 March-18 April | 176 | 181 | 179 | 170 | 193 |
| | 18 April-10 May | 214 | 198 | 173 | 234 | 217 |
| | 10 May-7 June | 106 | 97 | 100 | 151 | 158 |
| | Mean | 165 | 159 | 150 | 185 | 190 |
| $P_{\text{Pastures (Pas)}}$ | | | | 0.09 | | |
| $P_{\text{Periods (Per)}}$ | | | | 0.01 | | |
| $P_{\text{Pas x Per}}$ | | | | 0.24 | | |
| $SEM_{\text{Pas x Per}}$ | | | | 15.4 | | |

TF-Sc: tall fescue-subterranean clover, TF-Bc: tall fescue-balansa clover, TF-Bft: tall fescue-birdsfoot trefoil, TF-Whc: tall fescue-white clover, TF-Mix: tall fescue-multiple legume mixtures. Means within a row with different superscripts differ (α = 0.05).

In 2019, average liveweight gain of lambs ranged from 150.4 g $hd^{-1}$ $d^{-1}$ (TF-Bft) to 189.5 g $hd^{-1}$ $d^{-1}$ (TF-Mix). Lambs that grazed TF-Mix (189.5 g $hd^{-1}$ $d^{-1}$) and TF-Whc (185 g $hd^{-1}$ $d^{-1}$) tended to have greater daily LWGs than those grazing TF-Bft (150 g $hd^{-1}$ $d^{-1}$) pastures (*P*=0.09). Overall, mean lamb growth rate increased from 179.8 g per head $d^{-1}$ in the first period (0-21 d) to 207.0 g per head $d^{-1}$ in the second period (21-42 d) before it decreased to 122.7 g $hd^{-1}$ $d^{-1}$ in the final period of grazing (42-72 d).

Table 3.4 Mean liveweight production of lambs (kg $ha^{-1}$ $d^{-1}$) from tall fescue-legume pastures over two grazing periods in 2018 and three grazing periods in 2019.

| Year | Period | TF-Sc | TF-Bc | TF-Bft | TF-Whc | TF-Mix |
|---|---|---|---|---|---|---|
| 2018 | 20 April-10 May | $15.4^{a}$ | $13.8^{ab}$ | $12.7^{b}$ | $14.9^{ab}$ | 14.2 |
| | 10 May-1 June | $7.7^{c}$ | $9.8^{c}$ | $7.4^{c}$ | $7.5^{c}$ | $9.8^{c}$ |
| | Mean | 11.5 | 11.8 | 10.1 | 11.2 | 12.0 |
| $P_{\text{Pastures (Pas)}}$ | | | | 0.41 | | |
| $P_{\text{Periods (Per)}}$ | | | | 0.01 | | |
| $P_{\text{Pas x Per}}$ | | | | 0.05 | | |
| $SEM_{\text{Pas x Per}}$ | | | | 0.92 | | |
| 2019 | 28 March-18 April | 11.7 | 11.5 | 11.3 | 10.8 | 12.4 |
| | 18 April-10 May | 13.6 | 11.6 | 10.8 | 13.7 | 13.6 |
| | 10 May-7 June | 4.9 | 4.4 | 5.0 | 6.9 | 7.9 |
| | Mean | 10.1 | 9.2 | 9.0 | 10.5 | 11.3 |
| $P_{\text{Pastures (Pas)}}$ | | | | 0.09 | | |
| $P_{\text{Periods (Per)}}$ | | | | 0.01 | | |
| $P_{\text{Pas x Per}}$ | | | | 0.44 | | |
| $SEM_{\text{Pas x Per}}$ | | | | 0.95 | | |

TF-Sc: tall fescue-subterranean clover, TF-Bc: tall fescue-balansa clover, TF-Bft: tall fescue-birdsfoot trefoil, TF-Whc: tall fescue-white clover, TF-Mix: tall fescue-multi legume mixtures. Means within a row with different superscripts differ (α = 0.05).

Mean liveweight production (LWP) of lambs (kg $ha^{-1}$ $d^{-1}$) are presented in Table 3.4. In 2018, there was an interaction between pasture treatments and grazing period for the LWP of lambs (*P*<0.05). Mean LWP from TF-Sc pastures was greater than that of TF-Bft in the first grazing period (0-21 d) while all pastures provided comparable lamb LWPs in the second grazing period (21-42). In 2019, LWP (kg $ha^{-1}$ $d^{-1}$) of pastures tended to be greater from TF-Mix pastures than TF-Bc and TF-Bft pastures (*P*=0.09). There was an increase in LWP from

11.5 kg ha$^{-1}$ d$^{-}$1 in the first period to 12.7 kg ha$^{-1}$ d$^{-1}$ in the second period before it sharply decreased to 5.8 kg ha$^{-1}$ d$^{-1}$ in the final grazing period ($P$<0.01).

### 3.3.3 Pre and post grazing pasture mass

Weekly pre and post grazing pasture mass in 2018 and 2019 are presented in Figure 3.5. In 2018, pre grazing pasture mass increased from 2180 kg DM ha$^{-1}$ at the beginning of the grazing period to 2667 kg DM ha$^{-1}$ until the end of first rotation (week 3). It then gradually decreased to 1779 kg DM ha$^{-1}$ in the last week of the spring grazing period ($P$<0.05). Averaged across the grazing season, TF-Bc (2253 kg DM ha$^{-1}$) and TF-Mix (2287 kg DM ha$^{-1}$) pastures had greater pre-grazing pasture mass than TF-Bft (2030 kg DM ha$^{-1}$) and TF-Sc (2017 kg DM ha$^{-1}$) pastures. All pasture mixtures had similar post grazing pasture masses ($P$=0.65). Overall post grazing pasture masses were maintained between 737 kg DM ha$^{-1}$ to 1226 kg DM ha$^{-1}$ over the course of spring grazing. On average, the post grazing pasture mass in the second rotation was 27% higher than in the first rotation ($P$<0.01).

In 2019, pre grazing pasture mass of pasture mixtures ranged from 1686 kg DM ha$^{-1}$ to 1870 kg DM ha$^{-1}$ but the difference was not significant ($P$=0.13). Pre grazing pasture mass over the 9-week grazing period in 2019 followed a similar trend to 2018. Pre grazing pasture mass increased from 1574 kg DM ha$^{-1}$ to 2246 kg DM ha$^{-1}$ toward the end of first rotation. Pre grazing pasture masses remained relatively stable during the second period but then reduced to 1360 kg DM ha$^{-1}$ in the final week of the grazing period ($P$<0.01). There was no interaction detected between weeks and pre grazing pasture mass in both years. In 2019, post grazing pasture mass ranged from 786 to 1023 kg DM ha$^{-1}$ across the entire grazing period but the difference was not significant ($P$=0.51). Similarly, all pasture mixtures had comparable post grazing pasture masses ($P$=0.20).

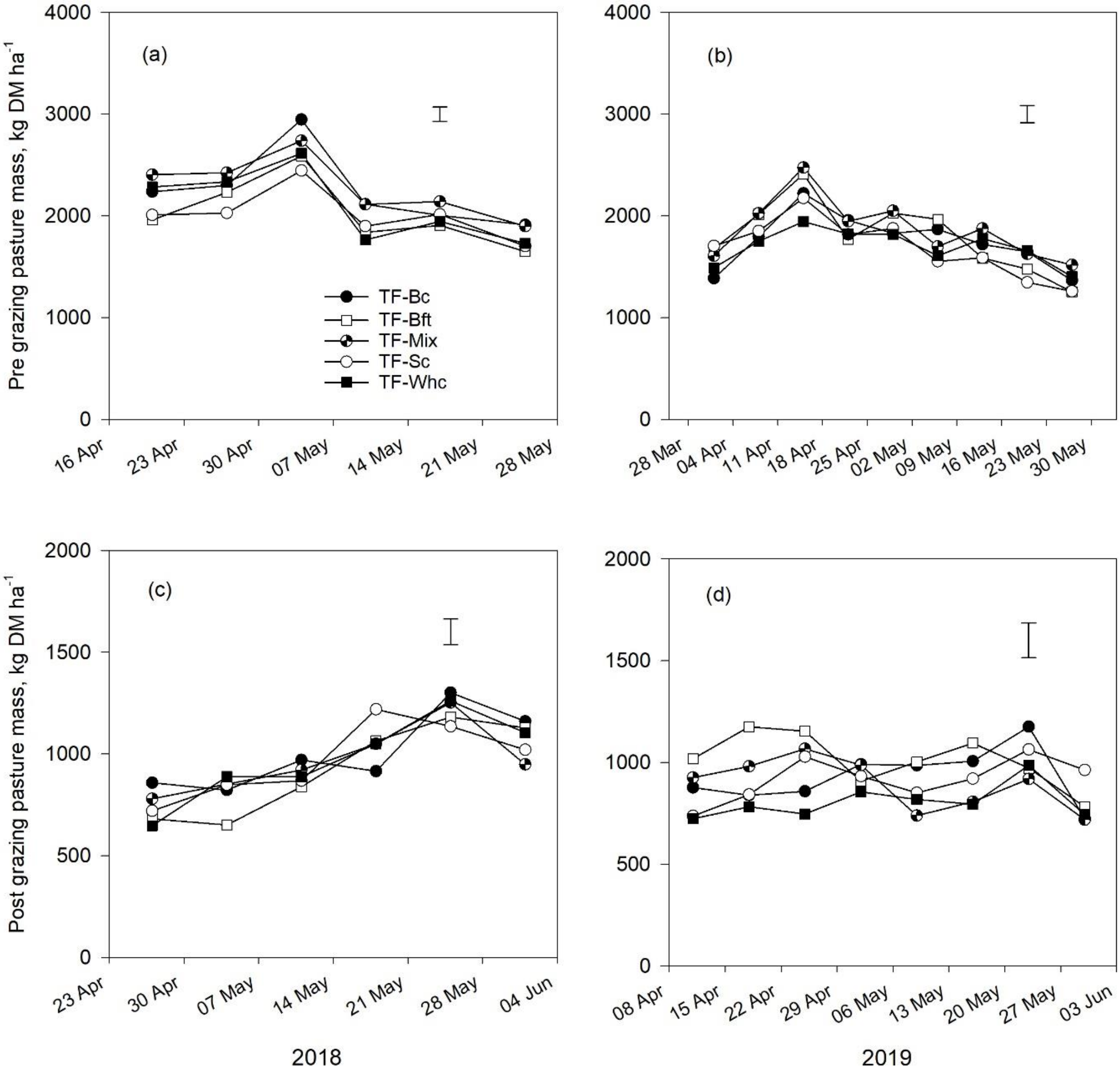


Figure 3.5. Weekly pre- and post-grazing pasture mass in tall fescue-legume pastures in spring 2018 and 2019 grazing seasons.

### 3.3.4 Botanical composition and nutritive value of pasture on offer

Botanical composition of the pastures on offer is presented in Figure 3.6 and 3.7. TF-Bc and TF-Mix pastures had higher ($P$<0.05) legume contents (32.4 and 36.9%, respectively) as compared to TF-Sc (18.3%), TF-Whc (20.3%) and TF-Bft (6.7%) in 2018. Legume content in both rotations were similar ($P$=0.38). Similarly, weed and dead material content of the pastures were comparable (all $P$>0.05). However, both TF and volunteer grass (predominantly, *Poa trivialis*) content of pastures were greater with TF-Bft than the TF-Bc, TF-Mix and TF-Whc ($P$<0.05).

In 2019, TF content of pastures gradually increased in each rotation ($P$<0.01). TF-Whc pastures had lower TF content than other pastures except TF-Mix pastures ($P$<0.01). Volunteer grass content did not differ among the pasture mixtures ($P$=0.12) but decreased from 17.8% in the first rotation to 2.7% in the third rotation ($P$<0.01). Total legume content of TF-Whc (22.9%) and TF-Mix were greater ($P$<0.01) than TF-Sc (15.7%) and TF-Bc (15.1%). TF-Bft had the lowest total legume content (8.2%). The legume content of pastures was approximately 20% in the first 2 rotations before it decreased to 11% in the final rotation ($P$<0.01).

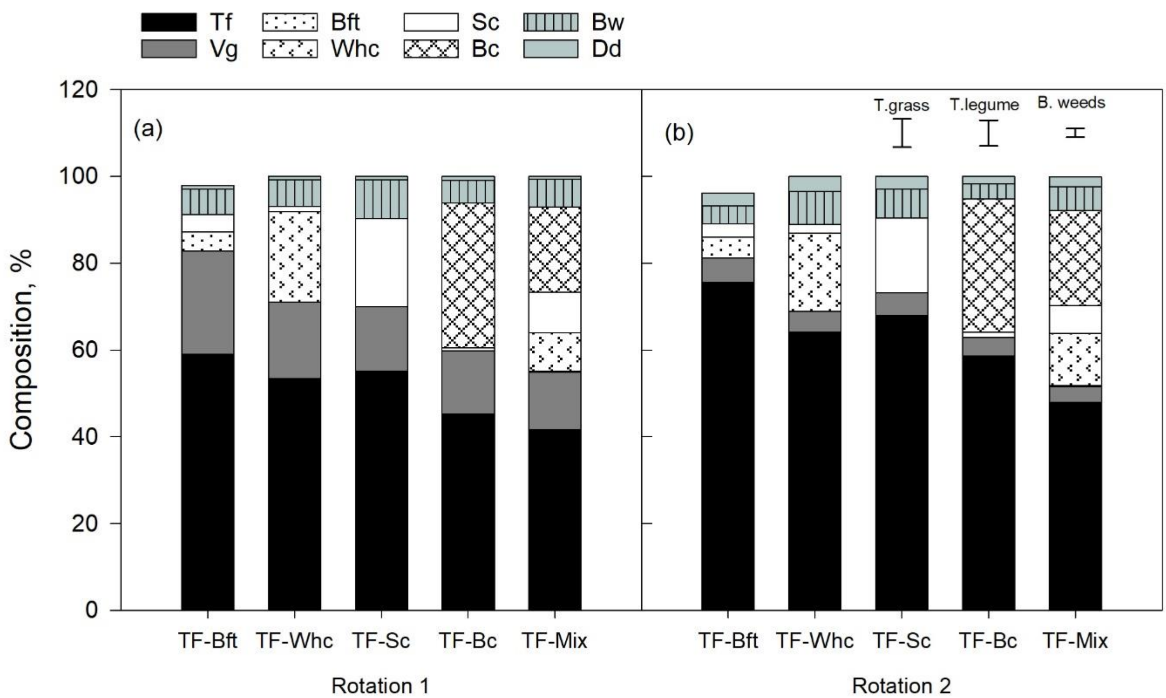


Figure 3.6. Botanical composition of pasture on offer in tall fescue-legume pastures over two grazing rotations in spring 2018. TF: Tall fescue Vg: Volunteer grass, Bw: Broadleaved weed, Dd: Dead materials, Panel (b): T grass: Total grass, T. legume: Total legume and B. weeds: Broadleaved weeds.

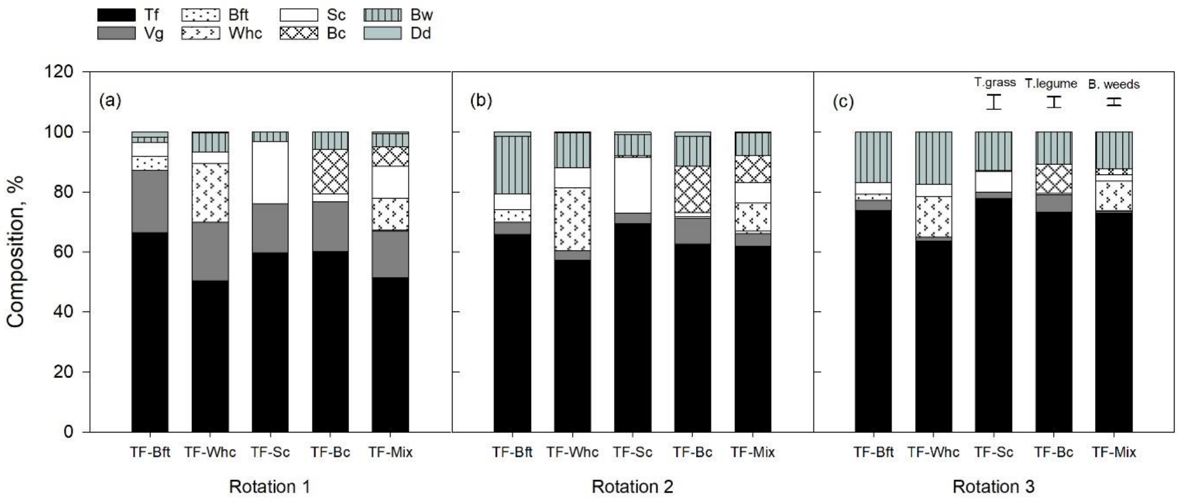


Figure 3.7. Botanical composition of pasture on offer in tall fescue-legume pastures over three grazing rotations in spring 2019

Nutritive value of the pastures for 2018 and 2019 is presented in Figure 3.8. In 2018, TF-Bc had the lowest mean NDF content (40.0%) and differed ($P$<0.05) from NDF values of TF-Bft (47.89%), TF-Sc (44.9%) and TF-Whc (44.6%). Weekly average NDF values of the pastures increased ($P$<0.01) from 37.9% (week 1) to 46.7% (week 6). TF-Bft had higher ($P$<0.01). ADF content (26.0%) than TF-Mix (23.1%) and TF-Bc (22.5%) but had comparable ADF content with TF-Whc (24.5%) and TF-Sc (24.5%). Pastures had the lowest average ADF content at the beginning of the grazing ($P$<0.01). ADF content then increased towards the end of each rotation. The CP content of TF-Bc (19.2%) was significantly higher ($P$<0.01) than that of TF-Mix (17.2%). Both pastures had higher average of CP than other pasture mixtures ($P$<0.05). The difference among weekly average CP levels of the pastures was highly significant ($P$<0.01). It consistently decreased starting from week 1 (19.2%) to week 6 (14.6%). There was no significant difference among treatments for EE content ($P$=0.72). However, average EE content of all pastures in week 1 was significantly higher than the rest of the grazing period ($P$<0.01).

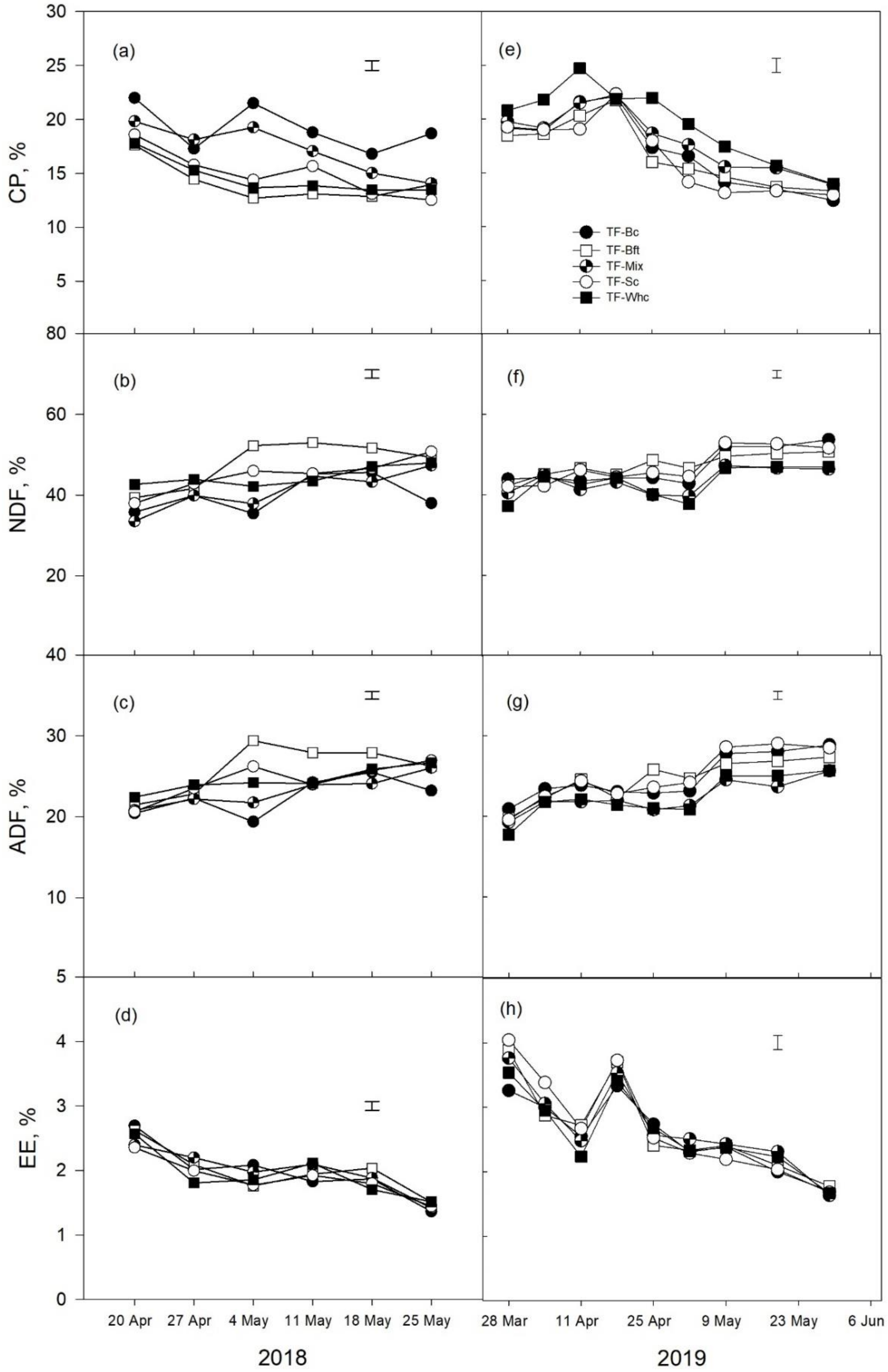


Figure 3.8. Mean weekly nutritive value of herbage on offer in tall fescue-legume pastures in spring 2018 and 2019. Bars represent SEM for interaction.

In 2019, TF-Bc (46.8%) and TF-Bft (47.2%) had a higher (*P*<0.01) NDF content than TF-Mix (43.4%) and TF-Whc (43.0%). Average NDF content of pastures fluctuated between 41.2% and 44.2% during the first 2 rotations before it increased to 49.8% in the final rotation of spring grazing. TF-Sc (24.8%), TF-Bft (24.4%) and TF-Bc (24.7%) pastures had a higher (*P*<0.05) ADF content than TF-Whc (22.3%) and TF-Mix (22.3%). Weekly pasture average ADF content followed a similar seasonal pattern with NDF content (*P*<0.05). TF-Whc (19.8%) appeared to have higher average CP content than TF-Bc (17.3%), TF-Bft (16.9%) and TF-Sc (16.8%) but comparable content with TF-Mix (18.2%) (*P*<0.06). Weekly average of CP content of pasture increased from 19.5% at the start of the grazing to 22.1% in week 4 before gradually decreasing to 13.3% in week 9 (*P*<0.01). There was no difference among EE content of the pastures (*P*=0.55). Weekly average EE contents decreased from 3.7% to 2.5% before it increased to 3.5% at the beginning of the second rotation (Week 4) then it gradually decreased to 1.7% in week 9 (*P*<0.01).

### 3.3.5 Persistence of annual legumes

Established seedling numbers of SC and BC in TF-Bc, TF-Sc and TF-Mix in fall 2017, 2018 and 2019 are presented in Figure 3.9. An interaction occurred between clover species and years for the established seedling numbers in binary TF-clover mixtures (*P*<0.01). Average seedling numbers were 340 pl/m$^2$ for BC and 282 pl/m$^2$ for SC in December 2017. While TF-Sc pastures had a similar number of established SC seedlings in November 2018, TF-Bc pastures had fewer established BC seedlings. In the following fall in 2019, there was a reduction in number of established subterranean clover seedlings in TF-Sc pastures. However, TF-Bc pasture had relatively similar number of established balansa clover seedlings in November 2019 compared to the previous fall. Similar to the seedling numbers in binary TF-legume mixtures, an interaction was detected for the established BC and SC seedling numbers in TF-Mix (P<0.01). Over the course of the three-year experiment, SC seedling numbers ranged from 122 to 187 pl/m$^2$, but the difference was not significant. However, there was a consistent and sharp decrease in established SC seedling numbers over time (186 pl/m$^2$ in December 2017 to 23 pl/m$^2$ in November 2019).

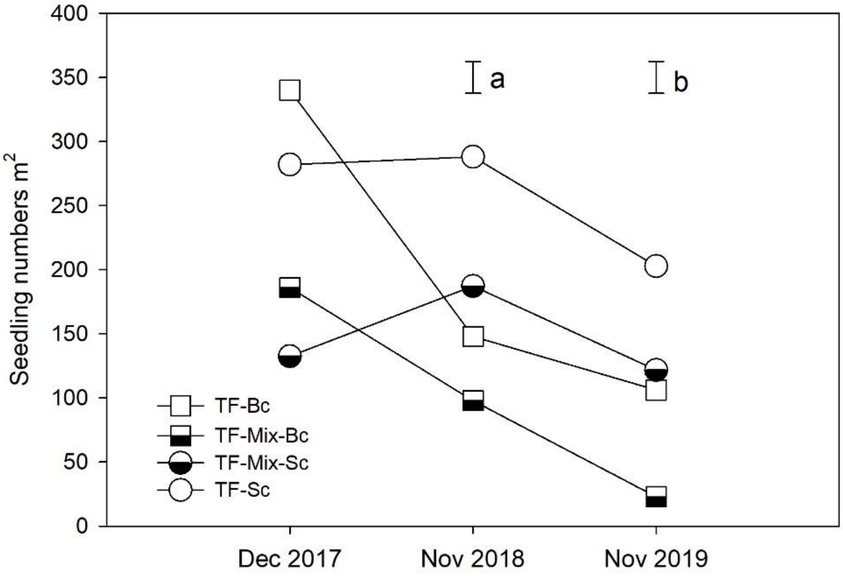


Figure 3.9**.** Balansa clover and subterranean clover seedling numbers in TF-Sc, TF-Bc and TF-Mix pastures in fall 2017, 2018 and 2019.Bars represent SEM for interaction a) in binary TF-legume and b) in TF-Mix pastures

Reproductive performance of BC in TF-Bc and TF-Mix pastures are presented in Table 3.5. Flower numbers in both TF-Bc and TF-Mix pastures reduced dramatically over the course of the experiment. The reduction was sharper in TF-Bc than TF-Mix, causing an interaction (*P*<0.01). Seed numbers produced per flower and floret number per flower were also lower in 2019 than in 2018. There was an interaction between treatments and year for the seed number per m$^2$ as BC in TF-mix produced comparable number of seed/m$^2$ in both years, while there were significantly fewer BC seeds produced in TF-Bc pastures in 2019 than 2018. Thousand seed weight of BC seed were similar in both TF-Bc and TF-Mix pastures, but the seeds were substantially smaller in 2019 than 2018 (*P*<0.01).

Table 3.5 Reproductive performance of balansa clover in TF-Bc and TF-Mix pastures in 2018 and 2019.

| Year | Treatment | Flower number/ $m^2$ | Seed number /flower | Floret number /flower | Seed no/$m^2$ | Seed yield (kg/ha) | Thousand seed weight (g) |
|---|---|---|---|---|---|---|---|
| 2018 | TF-Bc | 301a | 55 | 40 | 17499a | 153a | 0.90 |
| | TF-Mix | 138b | 40 | 36 | 5601b | 47b | 0.83 |
| 2019 | TF-Bc | 105bc | 37 | 32 | 3807b | 18b | 0.49 |
| | TF-Mix | 69c | 36 | 26 | 2650b | 14b | 0.50 |
| SE | | 22.1 | 3.5 | 3.0 | 2644 | 15.6 | 0.037 |
| P Trt | | 0.01 | 0.05 | 0.12 | 0.01 | 0.01 | 0.42 |
| P Year | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| P Int. | | 0.01 | 0.06 | 0.73 | 0.01 | 0.01 | 0.22 |

Subterranean clover soil seed population following spring 2018 grazing was 1618 and 1031 seeds per $m^2$ for TF-Sc and TF-Mix, respectively (Table 3.6). The soil seed populations decreased by 19% and 12% TF-Sc and TF-Mix, respectively in 2019. No interaction between pasture mixtures and years for soil seed population was detected (*P*<0.36). Seed yield also followed a similar trend to seed populations.

Table 3.6 Soil seed populations of subterranean clover in TF-Sc and TF-Mix pastures in 2018 and 2019.

| Year | Treatment | Seed no/$m^2$ | Seed bank kg/ha* |
|---|---|---|---|
| 2018 | TF-Sc | 1618 | 115 |
| | TF-Mix | 1031 | 73 |
| 2019 | TF-Sc | 1311 | 93 |
| | TF-Mix | 904 | 64 |
| SE | | 97.5 | 6.9 |
| $P_{\text{Pasture (Pas)}}$ | | 0.01 | 0.01 |
| $P_{\text{Year (Y)}}$ | | 0.05 | 0.05 |
| $P_{\text{Pas} \times \text{Y}}$ | | 0.36 | 0.36 |

TF-Sc: tall fescue-subterranean clover, TF-Mix: tall fescue-multi legume mixtures.

*Seed yield was calculated based on average 1000 seed weight of subterranean clover reported by Dear *et al*. (2003)

## 3.4 Discussion

This study compared the productivity and persistence of white clover, birdsfoot trefoil, balansa clover and subterranean clover planted with tall fescue either as binary mixtures or as a diverse combination of all in a summer-dry hill site in Corvallis, Oregon over a two-year period. The effect of legume content of pastures on spring lamb production was also quantified in both years. Pasture DM yields and spring lamb growth rates in the current study confirmed the value of high legume content in pastures. The results of the study also indicated the challenge of maintaining a desirable legume content in dryland hill pastures where high evapotranspiration and erratic rainfall prevail. Combination of diverse legumes sown with tall fescue appeared to be a good strategy, both seasonally and annually, for extended availability of legumes in pastures.

**DM production and legume persistence**

Total annual DM yield of the pastures that had a greater legume content were superior to others. This was particularly highlighted in TF-Mix and TF-Bc pastures with a legume content exceeding 30% of DM in 2018 and TF-Mix and TF-Whc pastures with over 20% legume content in 2019. It is of note that TF-Mix was the only pasture combination where the legume production exceeded 2000 kg DM $ha^{-1}$ $y^{-1}$ in both years. The benefit of high legume content (30-40%) of pastures in increasing the harvested total DM yields was also pointed out by Sanderson *et al*. (2013) who reported greater forage yield of grass-legume mixtures than the legume or N-fertilized grass monocultures. Similarly, Brink and Fairbrother (1991) reported a 58% increase in forage yield when grass pastures were over seeded with white clover and subterranean clover in a three-year experiment in Mississippi, USA.

However, the average annual legume content of pastures reduced invariably for all pastures by 17% to 41% over the course of two-year experimental period. The reduction was more pronounced in TF-Bc pastures where the contribution of balansa clover to total production went down from 2160 kg DM $ha^{-1}$ $y^{-1}$ (25.9% of total DM yield) to 1311 kg DM $ha^{-1}$ $y^{-1}$ (13.3% of total DM yield). The decline in legume content was partly caused by the exceptionally dry late spring-early summer and fall seasons when the precipitation was lower than LTM by 75% and 45%, respectively. Despite the overall reduction in legume content, spring subterranean clover and white clover content in their respective binary pasture mixtures were relatively stable. A number of studies reported poor recovery of white clover after drought, leading to low proportions of white clover in dryland pastures particularly in pastures on shallow, stony soils (Brock, 2006; Knowles *et al*., 2003). However, in the current study, the white clover component of pastures remained similar in both TF-Mix and TF-Whc pastures. A feature of the results was that white clover content in TF-Whc pastures remained over 20% in early summer in 2019 when the legume components in other binary mixtures were less than 10%. It was of note that of all legumes in TF-Mix pastures, white clover was the highest contributor to DM yield in both years (9.4% in 2017/18 and 8.7% in 2018/19). This was possibly due to over 700 mm of annual precipitation and deep clay soils with higher water holding capacity than many shallow sandy soils typical in dryland hill pastures (McDaniel *et al*., 2005). These results indicate that in relatively favourable dryland conditions (>600 mm precipitation, clay soils, high soil fertility), white clover can still be a valuable component of pastures.

Regarding the deep tap-rooted perennial legume option in the current study, the legume content and total DM production of birdsfoot trefoil were relatively low and unsatisfactory. The establishment of birdsfoot trefoil was not ideal mainly due to the suppression from roughstalk bluegrass. While the roughstalk bluegrass provided high quality forage in early spring, it hindered the birdsfoot trefoil content of the pastures which was as low as 5%. Despite its highly desirable nutritional and agronomic characteristics, its slow establishment and poor competitiveness is a major disadvantage for birdsfoot trefoil in mixed pastures systems (Frame, 2005).

Subterranean clover is considered to be the primary alternative to white clover in dryland pastures from Oceania to Pacific Northwest and California due to its excellent grazing tolerance and drought escape strategy (Smetham, 2003). For example, Ates *et al*. (2010) who reported a 40% increase in pasture DM yield when subterranean clover was over-drilled into dryland pastures in New Zealand where white clover had failed to persist. It was of note that the subterranean clover content was as high as 50% of DM in pastures in the Ates *et al*. (2010) study. This compares favourably with only 16-18% of subterranean clover content in TF-Sc pastures in the spring of the current study. Similarly, in another dryland pasture study, subterranean clover was reported to be the superior dryland legume when compared to Caucasian clover, balansa clover and white clover sown with orchardgrass in New Zealand (Mills *et al*., 2015). It is probable that using mid-maturing or a combination of early and mid-maturing subterranean clover cultivars with white clover may be more productive in dry hill site at relatively higher but erratic rainfall conditions. Combinations of subterranean and white clover will possibly help extend the legume availability toward summer and fall seasons as was the case in TF-Mix pastures in the current study. Furthermore, in conditions where soil moisture is not too limiting in late spring early summer, for each day the flowering is delayed, forage production of subterranean clover increases 43 kg DM $ha^{-1}$ (Evans, 1993).

Maximizing early-spring plant growth is particularly crucial in dryland pastures to extend the grazing season and bring the lambs to slaughter weight before the onset of summer drought. Rapid growth rates of annual legumes in winter-early spring period helps to extend the grazing season and enable earlier lambing. For example, Moot et al. (2003) reported that the first trifoliate leaf emerged after 230 °Cd for a number of subterranean clover cultivars and 309 °Cd for white clover cultivars.  In the present study, DM yield of annual legumes in the winter-early spring period was not notably higher than the perennial legumes, except that balansa clover in early spring 2019 tended to have greater DM yield than other legumes or the legume mixture in TF-Mix pasture. However, this was not reflected in total winter-early spring DM yields of pastures. This can partly be attributed to the lower established seedling numbers than recommended for successful agronomic establishment of subterranean clover, although the recommended sowing rates (Smetham 2003) were applied. It was of note that subterranean clover seedling populations in the current study were lower than this recommended desirable seedling number of 500-1000 seedlings/m$^2$. Consequently, they did not promote adequate legume production in pastures in the following spring. Although, Prioul and Silsbury (1982) found no difference between 428 plants/m$^2$ and 4760 plants/m$^2$ for the DM production of subterranean clover, Ates *et al*. (2013) reported that seed numbers in autumn were positively correlated with the following spring production. This indicates that the number of seedlings under 500 plant/m$^2$ may have a strong effect on DM yields. In the current study, seedling populations of balansa clover and subterranean clover were proportional to annual legume production in TF-Sc and TF-Bc pastures. For instance, while legume production of TF-Bc pastures averaged 1451 kg DM ha$^{-1}$ (301 seedling/m$^2$ in previous fall) in spring 2018, it decreased to 627 kg DM ha$^{-1}$ (105 seedlings/m$^2$ in previous fall) in spring 2019.

One of the feature of the results is that both subterranean clover and balansa clover were able to produce copious amount of seeds in the establishment year.. Earlier closing pastures in June enabled the high seed production, offsetting the negative effects of early onset of drought. The benefit of early closing of pasture or reduced stocking rate on persistence of self-regenerating annual legumes were reported by Ates *et al*. (2013). However, the seed production and established seedling numbers of balansa clover were dramatically reduced over the course of the study. Furthermore, size of the seeds produced in summer 2019 was substantially smaller than the ones produced in the previous year indicating poorer seed viability and seedling vigor (Dear *et al*., 2006). Although, the current study aimed to adopt a low-input management practice, similar to traditional management of hill pastures, it is probable that at higher phosphorus application rates, seed sizes and viability may have been more desirable.

Similar to our findings, Monks *et al*. (2008) reported that balansa clover, when sown with orchardgrass, provided satisfactory production only in the first three years. In that study, balansa clover produced only 11% of initial seedset in the second fall after sowing, indicating the need for occasional overseeding. Similarly, soil seed population of subterranean clover decreased in both TF-Sc and TF-Mix pastures. Smetham (2003) calculated that 130 kg $ha^{-1}$ seed production is required for a successful establishment for early flowering subterranean clover varieties. Although, in the current study, initial seed populations were similar to Smetham's suggestion, there was a significant reduction in subterranean clover seed populations the following year. This indicates a vulnerability of self-regenerating annual legumes to dry conditions. Utilizing subterranean clovers with different maturity dates and matching that with the timing of grazing could help improve seed production. It was of note that the reduction in legume content in TF-Mix pastures was the lowest as compared to binary TF-legume mixtures. Both white clover and subterranean clover components in TF-Mix pastures were similar in both years, while the main reduction occurred in balansa clover component which declined from 7.4 to 3.1% of total composition. Overall, this indicates the value of diversification in pastures to reduce the risk of failures in legume populations and pasture yields. The basic premise behind the diversification of pastures compared to their binary mixtures is that legumes with different physiological and functional attributes may exploit the erratic rainfall and edaphic conditions of undulating topography that can cause variability in soil moisture (Norman et al., 2005).

**Lamb growth in relation to legume content and pasture quality in spring**

Increasing legume content of swards is essential for achieving high efficiency in low-input pasture systems where production of high-quality forages is constrained by low soil fertility and high evapotranspiration. In particular, providing grazing animals with high quantities of legumes leads to superior animal performance due to increased nutritive value. The higher feeding quality is a function of particle breakdown and a faster rate of digestion which promotes voluntary feed intake of animals (Waghorn, 2008; Lüscher *et al*., 2014). A number of studies reported increased voluntary intake and higher animal production both in high input dairies (Harris *et al*., 1997; Lee *et al*., 2004) and dryland sheep farming systems (Gibb and Treacher, 1984; Hyslop *et al*., 2000; Ates *et al*., 2015) due to increased legume content of swards. The positive effects of legumes in supporting high lamb liveweight gains was also highlighted in the current study as well. This effect on lamb growth was particularly apparent in mid-late spring when the overall quality of pastures was decreasing as the season progressed. The TF-Bc and TF-Mix pastures had 2.1 to 2.4 kg $ha^{-1}$ $d^{-1}$ greater lamb production than other pastures in the late spring period in 2018 because these pastures maintained the legume content over 30%. The effect of legumes in maintaining high lamb growth rates was consistent in the following year when TF-Mix pastures provided 1.0-3.5 kg $ha^{-1}$ $d^{-1}$ higher liveweight production in the final period of grazing. It was of note that increased legume content in TF-Bc and TF-Mix pastures in 2018 and in TF-Whc pastures in 2019 led to higher CP content. In contrast, ADF and NDF content were higher with TF-Bft pastures, which had the lowest legume content. Consequently, mean post-weaning lamb LWG were 29-40 g $head^{-1}$ $d^{-1}$ greater in TF-Mix than TF-Bft pastures. Similarly, Hyslop *et al*. (2000) reported 100 g $head^{-1}$ $d^{-1}$ greater lamb liveweight gains in pastures with 30% white clover content as compared to grass pastures.

**Conclusions**

The findings of this study confirmed that increasing the legume content of pastures leads to superior liveweight gain in lambs. The production and persistence of legumes differed substantially in both binary and diverse mixtures, although the legume content of tall fescue-diverse legumes mixtures remained higher than the binary mixtures. It was of note that the erratic rainfall highlights the potential benefit of diversification of pastures through including different legumes in mixtures. This indicates the value of designing pasture mixtures with diverse legumes with different reproductive strategies. Of all tested legume species, the contribution of white clover to pasture production was the most consistent on our test site. Introducing self-regenerating annual legumes to western Oregon dryland pastures can help increase both animal performance and pasture production. However, ensuring higher seed rates for subterranean clover at establishment may be needed to build the soil seedbank quickly. Overseeding pastures with balansa clover seeds every three years may be a good management practice to keep the balansa clover content of pastures high. The establishment and yield of birdsfoot trefoil was negatively affected by the severe competition with roughstalk bluegrass.

Therefore, the potential of birdsfoot trefoil in dryland sheep pastures in the current study was underestimated.

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