Early weaning of twin-born lambs onto a herb-clover mix containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*)

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ABSTRACT

Early weaning of lambs may be a useful management tool when either herbage quality, or quantity, limits lamb growth. Herb-clover mixes containing chicory, plantain, red clover and white clover have been shown to improve the growth of suckling lambs and those weaned at a traditional age compared to ryegrass-clover based pastures. The objectives of this thesis were to examine; 1) the effect of lamb live weight at early weaning on their subsequent growth on a herb-clover mix; 2) the response of early weaning of lambs onto a herb-clover mix when ryegrass-clover based pasture herbage masses were restricted rather than *ad-libitum*; 3) the effect of weaning lambs at different minimum live weights (16 kg then 14 kg); 4) the impact of early exposure of lambs to a herb-clover mix prior to early weaning on their growth post weaning, and 5) to characterise the nutritional composition of the herb-clover mix during the late spring to autumn period. Lambs weaned early onto a herb-clover mix, at a minimum weight of 16 kg at approximately 50 days of age, had the potential to grow at a similar rate to unweaned lambs on a ryegrass-clover based pasture. This was more apparent when herb-clover mix had a high chicory (57%) and clover content (14%) or there was a low (< 5%) clover content in the ryegrass-clover based pasture. In first year of the study light lambs (< 18 kg) grew 50 g/day slower than heavy lambs (18-23 kg), however, in the second year they grew at a similar rate . Weaning lambs less than 16 kg onto a herb-clover mix, therefore, should be undertaken with caution. Further, the advantages of early weaning were enhanced when the supply ryegrass-clover based pasture resulted in restricted intake of ewes and lambs (< 1200 kg DM/ha). Lambs weaned at a minimum weight of 14 kg at approximately 40 days of age, were found to grow at a similar rate to unweaned lambs on a ryegrass-clover based pasture. Early exposure to a herb-clover mix prior to early weaning had no impact on subsequent growth of early-weaned lambs.

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INTRODUCTION

The New Zealand sheep industry relies on extensive low cost grazing pastoral systems in which pasture supplies 95% of the sheep diet (Morris 2013). Lambs are born in early spring and graze predominantly on ryegrass-clover based pastures. Lambs on ryegrass-clover based pasture are traditionally weaned between 10 to 14 weeks of age with an average weaning weight of 28-30 kg (Geenty 2010). Lamb growth rate is driven by ewe milk production during this period, therefore, *ad-libitum* supply of high-quality herbages is necessary to achieve maximum ewe milk production and lamb growth rates (Gibb & Treacher 1978; Gibb et al. 1981, Webby 1990). Unrestricted allowances of ryegrass-clover based pasture for twin and triplet bearing ewes require a minimum pasture height and mass of 4 cm and 1200 kg DM/ha, respectively (Morris & Kenyon 2004). When herbage supply is inadequate resulting in restricted allowance ewe milk production declines and lamb growth rates reduce as they compete for the same feed resources (Muir et al. 2000). Further, Hinch (1989) showed that by 3 weeks of age twin and triplet rearing ewes did not produce enough milk to meet their lamb's nutritional requirements, thus indicating the importance of high-quality herbage for lambs. These effects can be exacerbated by poor spring pasture conditions resulting in restricted pasture allowances for both the ewe and her lambs. It is, therefore, of interest to investigate the potential use of different herbages and management strategies under restricted ryegrass-clover based pasture conditions to achieve target lamb live weights at weaning.

Weaning lambs early can be a useful management tool when herbage production is inadequate or of poor quality (Kenyon & Webby 2007). To date in New Zealand, early weaning studies have primarily focused on using ryegrass-clover based pastures. Lambs weaned at 4-8 weeks of age onto a ryegrass-clover based pasture consistently displayed lower live weight gain and poorer survival compared to unweaned lambs on ryegrass-clover based pastures to approximately 14 weeks of age (Geenty 1979; Mulvaney et al. 2009; Mulvaney et al. 2011; Rattray et al. 1976). While lambs weaned at 4-6 weeks of age onto a Lucerne sward (Jagusch et al. 1977) and at 8 weeks of age onto a mix of plantain, red clover and white clover (Cranston et al. 2016) were found to grow at a slower rate compared to unweaned lambs on ryegrass-clover based pasture. In contrast to these studies, greater liveweght gains of lambs weaned at 6 weeks of age have been reported when offered lucerne or white clover compared those lambs offered ryegrass or prairie grass (Cruickshank et al. 1992). Interestingly, Corner-Thomas et al. (2018b) recently reported that lambs weaned early (approximately 8 weeks of age) onto a mix of chicory, plantain, red clover and white clover (termed a herb-clover mix) were heavier at the same age as unweaned lambs on ryegrass-clover based pasture. Combined these results suggest that there is potential for early weaning of lambs onto a legume-based herbage to achieve lamb live weight gains that are at least similar to lambs unweaned on a ryegrass-clover based pasture. Further investigations are necessary to evaluate the possibilities of using alternative high-quality herbages to support the early weaning of lambs.

Recent New Zealand studies have shown that a herb-clover mix can improve both ewe and lamb performance during lactation and in the traditional post weaning period. Herb-clover mixes have been shown to improve ewe live weight gain, body condition, milk production, lambing percentage and lamb produced per ewe, and lamb live weights and carcass weights compared to grazing a perennial grass-clover pasture (Corner-Thomas et al. 2014b; Fraser & Rowarth 1996; Golding et al. 2011; Hutton et al. 2011; Kemp et al. 2010; Kenyon et al. 2010; Lindsay et al. 2007; Somasiri 2014; Somasiri et al. 2015a,b,c;

2016). Herb-clover mixes have a greater nutritional quality including lower fibre, higher crude protein, higher organic matter digestibility and metabolisable energy than ryegrass-clover based pastures (Cranston et al. 2015a) In addition, herb-clover mixes have a higher rumen flow and, thus higher herbage intakes can be achieved compared to ryegrass-clover based pastures (Golding et al. 2008). This has likely helped improve animal performance on herb-clover mix. Further, lambs show a preference for plant components of the herb-clover mix compared to ryegrass-clover based pasture. Lambs grazed on a herb-clover mix displayed greater grazing preference for plantain and chicory ahead of red clover and white clover during early spring and for red clover from late spring to autumn (Cave et al. 2015). Lambs that were fed indoors with pure plantain, chicory, red clover and ryegrass showed a greater preference for red clover and chicory than white clover and plantain (Pain et al. 2010). Combined these results suggests that a herb-clover mix would be preferred by early-weaned lambs compared to ryegrass-clover based pasture and may assist in allowing them to achieve their target weights at a conventional weaning age.

This thesis primarily aims to identify the effects of early weaning of lambs onto a herb-clover mix on the post weaning performance of the lambs and their dams and to identify factors that affect the success of early weaning. Firstly, the thesis focuses on examining existing lamb live weight data to determine the effect of lamb live weight at early weaning on subsequent lamb growth (Chapter 2). Then based on those findings, chapter 3 examines the effect of early weaning at a minimum lamb live weight of 16 kg onto a herb-clover mix compared to lambs unweaned and offered unrestricted, or restricted, ryegrass-clover based pasture conditions. Chapter 4 investigates the impacts of early weaning of lambs at a lighter weight (a minimum live weight of 14 kg) onto the herb-clover mix. Chapter 5 focuses on investigating whether a longer period of prior exposure of lambs to the herb-clover mix prior to early weaning could result in improved post early-weaning performance. The performance of early-weaned lambs on herb-clover mix could differ due to variation in botanical and nutritional composition affecting animal selectivity and performance. Therefore, the final research chapter (Chapter 6) aims to characterise the nutritional composition of individual plant components of a herb-clover mix. Chapters 2, 3, and 6 have been published and chapter 4 is currently under review.

CHAPTER 1 Literature review

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1.1 Introduction

The New Zealand sheep industry relies on low cost extensive grazing systems in which pasture constitutes approximately 95% of the diet of sheep (Morris 2013). The industry contributes significantly to the economy of New Zealand with 9.4 % of total gross primary industry revenue (approximately 3.5 billion NZ$ annually, Ministry for Primary Industries 2019). The New Zealand lamb meat makes up approximately 36% of the global lamb meat trade (OECD/FAO 2019). For the year ended 30 September 2018, export plants and abattoirs processed 358,000 tonnes of sheep meat on a bone-in-basis. Of this sheep meat, 94% exported to destinations such as the European Union (45%), North Asia (28%), North America (15%), Middle East (5%), Pacific, Africa and South Asia (Beef + Lamb New Zealand Economic Service 2019). Total sheep numbers in New Zealand have decreased from approximately 44 million in 1999 to 27 million in 2018 (Beef + Lamb New Zealand Economic Service 2018). Regardless of this gradual decline in the sheep numbers, the annual lamb meat production has improved primarily due to improvements in plant breeding (e.g. breeding ryegrass endophytes for plant persistence and animal health; Woodfield & Easton 2004), the use of high quality pastures such as chicory, plantain, lucerne and clover for animal feed, improved lambing percentage and carcass weights, increased lamb production per ewe and improved labor productivity (Ferguson et al. 2014; Morris 2013; Morris & Kenyon 2014).

Growing lambs quickly from birth to weaning can provide greater returns for farmers (Beef + Lamb New Zealand 2014). Heavy lambs that are at, or close, to their target slaughter weights at weaning can be sold earlier resulting greater feed conversion efficiency and availability of feed for other classes of stock (Beef + Lamb New Zealand

2014). In addition, achieving heavy lamb weaning weights can increase the availability of ewe lambs for mating and their subsequent reproductive performance. Ewe and lamb nutrition are among the key drivers of rapid lamb growth during lactation. For the purpose of this thesis ewe and lamb nutrition in particular during lactation will be reviewed. Furthermore, strategies to improve the performance of ewes and lambs during lactation will be discussed. Lastly, the recent development in New Zealand of alternative herbages including the herb-clover mix containing chicory, plantain, red clover and white clover and their impacts on animal performance will be reviewed.

1.2 Ewe nutrition

The nutritional demand of the ewe varies according to live weight, age, grazing environment, topography, climate, feed quality, and physiological stage (Nicol & Brooks 2007). During pregnancy and lactation, poor nutritional management of the ewe can severely affect both her lactational performance and the growth, development and survival of offspring. Appropriate nutritional management in these periods is crucial to maximise the ewe and lamb productivity. The effects of ewe nutrition and body condition score during pregnancy on fetal growth, lamb birth weight, growth to weaning and survival have previously been reviewed (Kenyon et al. 2014; Piirsalu et al. 2013). The focus of this thesis, however, is the effect of ewe nutrition during lactation on ewe and lamb performance.

1.2.1 Ewe nutrition, milk production and lamb growth

Ewes utilise a significant amounts of nutrients to produce milk and recover body reserves depleted during pregnancy (Cannas 2004). If nutritional intake is inadequate during lactation, the ewe will mobilise her body fat reserves to compensate in an attempt to maintain milk production which results in a loss of live weight and body condition (Luther et al. 2007). Further, under-nutrition during lactation can negatively affect milk quality (Caja & Bocquier 2000), production (Peart 1970; Treacher & Caja 2002), length of lactation (Cannas 2004) and consequently lamb growth rates (Kenyon & Webby 2007; Kenyon et al. 2014; Muir et al. 2000).

1.2.2 Impact of rearing rank on ewe milk production and nutrition

In early lactation, lambs are solely dependent on their dam's milk for their nutritional requirements, therefore, multiple rearing ewes must produce more milk than single rearing ewes (Figure 1.1). Pollott & Gootwine (2004) reported that ewes rearing twin lambs produce approximately 20 L more milk per lactation than ewes rearing single lambs. Similarly, Peart (1982) reported that ewes rearing twin lambs produce 15-30 % more milk than ewes rearing a singleton lamb, while Peterson et al. (2006) reported that ewes rearing triplets do not produce significantly more milk compared to ewes rearing twin lambs. The feed requirements of multiple rearing ewes are greater than single rearing ewes (Cannas 2004; Nicol & Brooks 2007; Table 1.1) due to the higher nutrient requirements to support their greater milk production. To meet these greater energy demands, the voluntary dry matter intake of ewes rearing multiple lambs is greater than singleton rearing ewes during lactation (Geenty & Skyes 1983; Peart et al. 1975). Table 1.1 shows the additional metabolisable energy requirements of multiple rearing ewes and their lambs during lactation compared with ewes rearing singletons. Therefore, care should be taken to provide multiple rearing ewes with sufficient feed to meet their nutritional requirements in order to achieve optimal milk production and lamb growth rates during lactation.

Table 1.1 The metabolisable energy requirements of ewes and their lambs during lactation in addition to the ewe maintenance requirements (reproduced from Nicol & Brooks 2007)

Lamb weaning weights	Weeks after lambing				Total for lactation
	+2	+6	+10	+12	
	MJ ME/ewe plus lamb/day				MJ ME
20	8.5	10.5	12.5	13.0	855
25	10.5	13.0	16.0	17.0	1075
30	12.0	16.0	20.0	21.0	1335
35	14.5	19.5	24.5	26.0	1625

Twins of 25 kg at 10 weeks= 2*16=32 MJ ME/ewe/day

From 6 weeks onward add/subtract 10% per MJ ME/kg for diets below/above 11.0 MJ ME/kg DM

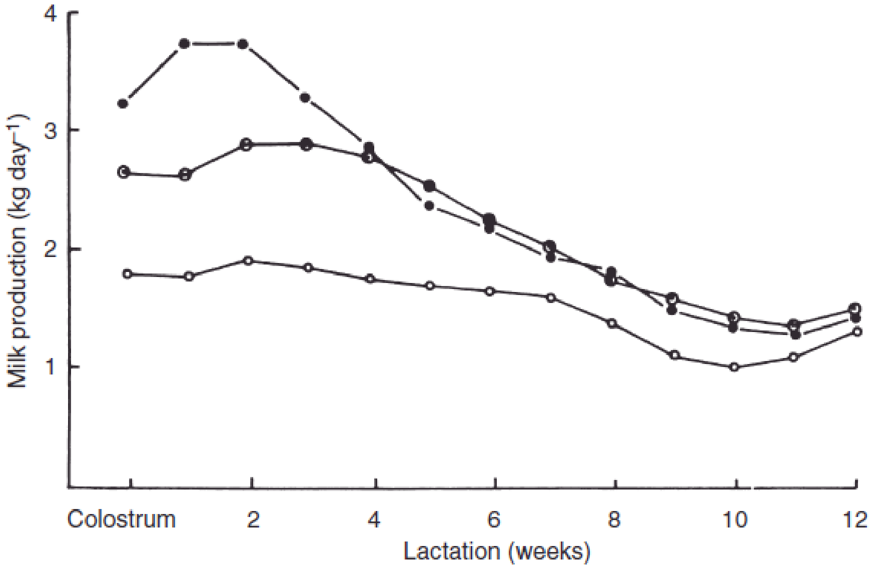

Figure 1.1 Mean lactation curves of ewes: ● triplet-suckled; ⊖ twin-suckled; ○ single suckled (reproduced from Peart et al. 1975)

1.2.3 Ewe body condition score and milk production

Body condition score (BCS) is an estimate of the body fat reserves and therefore nutritional status of a ewe and can be used to determine her future nutritional requirements (Kenyon et al. 2014). The influence of ewe BCS on breeding performance, fetal growth, lamb birth weight and milk production has previously been reviewed (Kenyon et al. 2014). Gibb & Treacher (1980); Hossamo et al. (1986) and Peart (1970) have reported positive relationships between milk production and ewe BCS in late pregnancy and during lactation. In contrast, a negative relationship between ewe BCS in mid-lactation and milk production was reported by Pulina et al. (2012). Gibb & Treacher (1982) reported no effect of ewe BCS in late pregnancy on milk production. This inconsistency between studies is likely due to differences in feeding levels, measurement times and the genetic potential between individuals and breeds.

1.2.4 Ewe body condition score and lamb growth

Ewe body condition score at late pregnancy, pre- lambing and mid-pregnancy shearing can positively affect the growth of lambs from birth to weaning (Gibb & Treacher 1980; Kenyon et al. 2004; Kenyon et al. 2011; Mathias-Davis et al. 2013; Molina et al. (1991). Further, Mathias-Davis et al. (2013) reported that lambs reared by ewes with high BCS pre lambing grew faster than lambs reared by ewes with lower BCS. The effect of ewe BCS on lamb growth, however, can vary due to differences in the timing of the BCS measurements, the absolute BCS being compared, number of lambs born and reared per ewe, feeding levels and quality of feed offered during the experimental period (Kenyon et al. 2014). Aliyari et al. (2012); Al-Sabbagh et al. (1995); Gibb & Treacher (1982); Litherland et al. (1999); Thompson et al. (2011) and Verbeek et al. (2012) reported that ewe BCS at mating, during late preganancy, at lambing, during lactation has no influence either on lamb growth from birth to weaning and weaning weight. Similarly, Corner-Thomas et al. (2014a) reported that there was no effect of ewe BCS at mating and late-pregnancy on lamb live weight at approximately 18 days of age or weaning at 97 days of age. Combined these findings, however, suggest that ewes with greater BCS at late pregnancy and lambing are likely to rear heavier lambs at weaning compared to ewes with BCS less than 2.0.

1.2.5 Impact of Feeding level and feed types on milk yield

The allowance and the type of feed offered during pregnancy and lactation can affect milk yield. Van der Linden et al. (2007) and Wallace (1948) reported that ewes offered a maintenance allowance during pregnancy had a lower milk yield than their counterparts fed *ad libitum*. Further, McCance & Alexander (1959) reported that feeding ewes below their requirements during pregnancy resulted in a delay in the onset of lactation, reduced milk production and reduced growth rate of lambs. Restricted feed allowances during the first 3 to 4 weeks of lactation can reduce total milk yield, however, ewes with high BCS are less likely to be impacted by this restriction (Coop et al. 1972; Jagusch et al. 1972; Peart 1970). Ewe nutritional management during pregnancy and lactation, therefore, should aim to provide unrestricted feed allowances in order to maintain optimal milk production thus maximal lamb growth (Maxwell et al. 1979; Rattray et al. 1982).

The type of herbage offered during lactation can affect milk production of ewes. Ewes grazing pure swards of chicory had improved milk production compared to ewes grazing a mixture of oat, clover and sulla (Antonino et al. 2012). Similarly, Hutton et al. (2011) reported that the milk production of multiple rearing ewes grazed on herb-clover mixtures, containing chicory, plantain, red clover and white clover, was increased by up to 25% without consistent changes in milk composition compared to ewes grazed on ryegrass-clover based pastures. Increased milk production was also observed in cows offered chicory, plantain, red clover and white clover compared to ryegrass-clover based pasture (Chapman et al. 2008; Waghorn & Clark 2004). These findings suggest that there is potential to use alternative herbages during lactation to improve ewe milk production and thus the lamb growth compared with ryegrass-clover based pasture.

In summary, ewe nutrition, particularly during pregnancy and early lactation, is more important than in late lactation in order to achieve maximal milk yield while maintaining the BCS of ewes. Multiple rearing ewes require greater nutrient intake to maintain their milk production than ewes rearing a single lamb. Therefore, in order to achieve rapid growth of lambs from birth to weaning, it is critical to maintain ewe nutrition at optimal levels. Alternative herbages can be used to improve ewe performance during lactation.

1.3 Nutrition of lambs during lactation

Appropriate nutritional management of lambs during lactation is vital to achieve high growth and survival rates (Rattray 1986). The nutritional requirements of lambs vary according to their live weight, liveweight gain, level of activity in eating and movements, body condition and age (Nicol & Brookes 2007).

1.3.1 Nutritional requirements of lambs for maintenance and growth during lactation

In most situations energy is the limiting nutrient for lamb growth (Freer et al. 2007). Metabolisable energy requirements are the sum of the metabolisable energy (ME: MJ ME/day) required for maintenance and liveweight change (Figure 1.2) and vary widely depending on the sex, live weight and age of lamb, quality of feed on offer, availability of pasture and environmental conditions (Nicol & Brookes 2007). Figure 1.2 illustrates the factors that influence the ME requirements of ewes and lambs. The influence of class of stock, live weights and liveweight gains on the ME requirements for maintenance of young sheep are shown in Table 1.2 and 1.3.

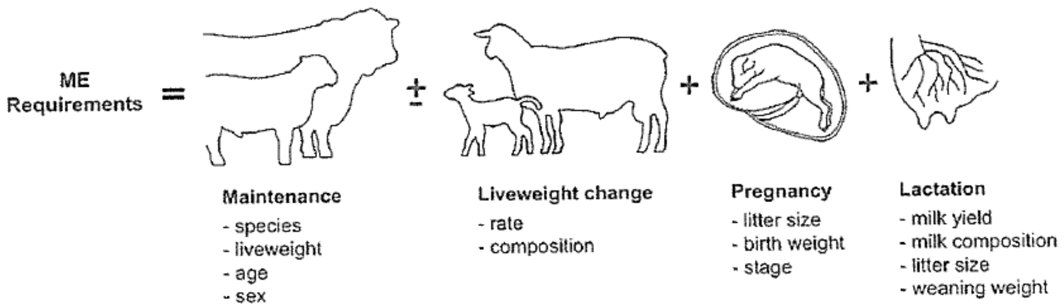

Figure 1.2 Diagrammatic illustration of the factorial approach for calculating metabolisable energy requirements (reproduced from Nicol & Brookes 2007)

Table 1.2 The metabolisable energy requirements for maintenance of young sheep of different classes and at varying live weights (adapted from Nicol & Brookes 2007)

Class of stock	Live weight (kg)				
	25	30	40	50	60
			(MJ ME/d)		
Ewes/wethers	4.5	5.5	7.0	8.5	10.0
Rams/cryptorchids	5.5	6.5	8.0	9.5	11.0

Note: Based on a flat land and diet of 11.0 MJ ME/kg DM

Table 1.3 Metabolisable energy requirement (MJ ME/d) of lambs in relation to body weights, growth rates and age (days of age are given in brackets; reproduced from Geenty & Skyes 1983)

Body weight (kg)	Growth rates (g/d)			
	180	230	280	320
4	7.1 (birth)	8.6 (birth)		
8	7.9 (22)	9.5 (17)	11.2 (14)	12.7 (12)
12	8.7 (44)	10.3 (35)	12.1 (29)	13.6 (25)
16	9.5 (67)	11.2 (52)	13.1 (43)	14.6 (38)
20	10.3 (89)	12.1 (70)	14.0 (57)	15.6 (50)
24	11.1 (111)	12.9 (87)	15.0 (71)	16.6 (63)

A lamb's metabolisable protein (MP: g MP/day) requirement is the sum of the protein required for maintenance and liveweight change. Metabolisable protein requirements for maintenance and liveweight gain, however, vary depending on the sex, live weights (Table 1.4), liveweight gains (Table 1.5) and age of lambs.

Table 1.4 Metabolisable protein (MP) requirements of lamb for maintenance in relation to live weights (reproduced from Nicol & Brookes 2007)

Lamb class	Live weights (kg)				
	20	30	40	50	60
			g MP/head/d		
Ewes/wethers	28	33	42	50	60
Rams/cryptorchids	29	34	44	52	62

Note: Based on ME of diets of 11 MJ ME/kg DM

Table 1.5 Metabolisable protein (MP) requirements of lamb for liveweight gain in relation to live weights (reproduced from Nicol & Brookes 2007)

Lamb class	Live weight (kg)			
	25	35	45	55
	g MP per 100 g/d liveweight gain			
Ewe lambs	30	28	26	25
Rams/cryptorchids	30	29	28	27

Note: Based on ME of diets of 11 MJ ME/kg DM

1.3.2 Milk and dry matter intake during lactation

Nutritional requirements of lambs during the first few weeks of lactation is primarily fulfilled from ewe milk and later in lactation from pasture (Treacher & Caja 2002). Lambs begin nibbling solid feed from as early as seven days after birth. Lambs then significantly increase their solid feed intake during the first four weeks at which time they begin to rely on pasture to fulfil their nutrient requirements (Corbett 1968; Janssens & Ternouth 1987). Twin lambs are driven to eat solid feed earlier than singleton lambs due to a lower availability of milk (Geenty & Dyson 1986). Geenty et al. (1985) and Geenty (2010) reported that at 6 weeks of age twin lambs fulfil approximately 50% of their ME requirement from pasture while 22% of ME requirement of singleton lambs is fulfilled from pasture (Figure 1.3). The percentage of the total ME requirement of a lamb's diet met by ewe milk (averaged across all breeds) for both single and twin lambs and theoretical residual energy requirement that needs to be met by grazing by difference is presented in Figure 1.4.

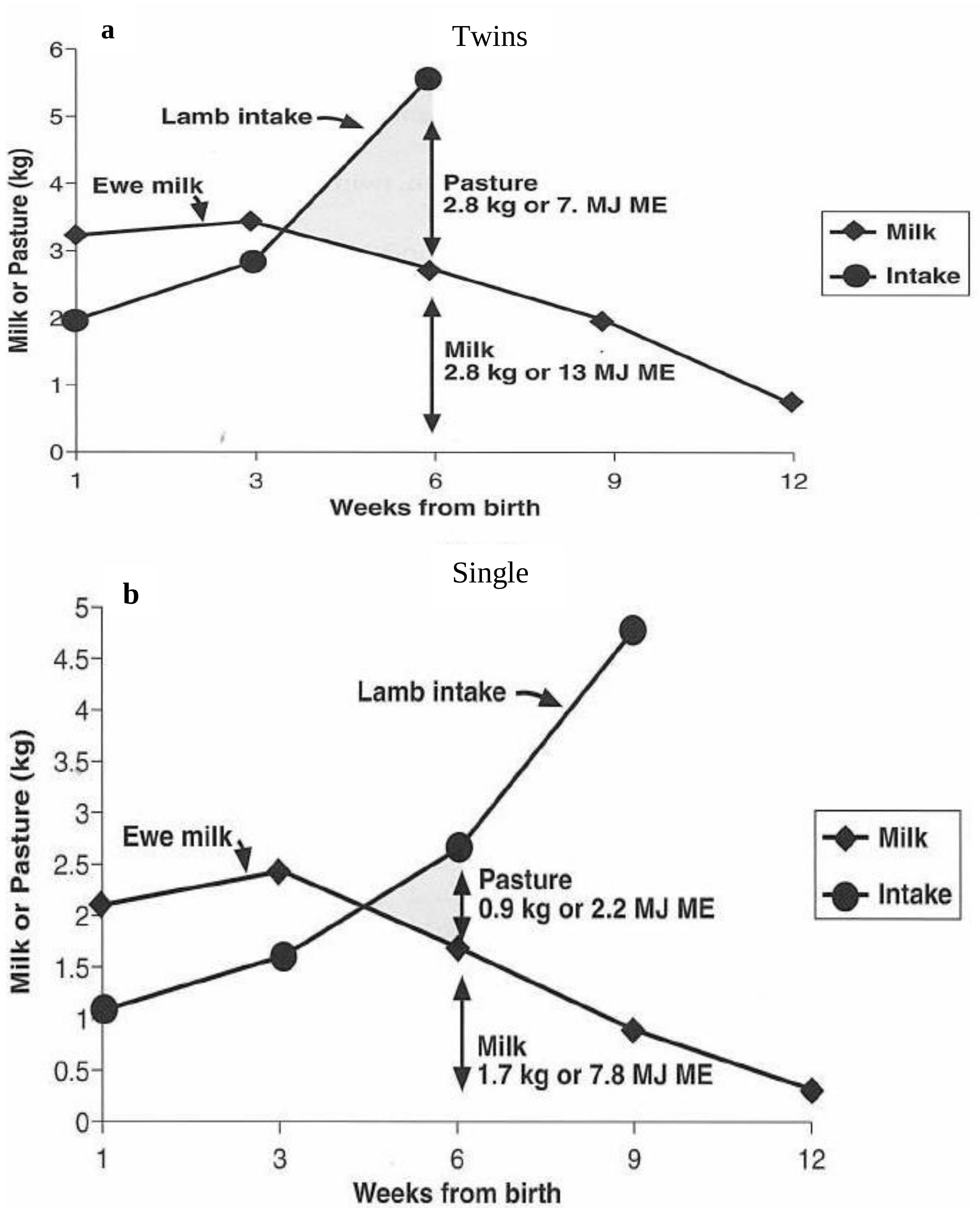

Figure 1.3 Pasture and milk intake by a) twin and b) singleton lambs during first 12 weeks of lactation (Reproduced from Geenty 2010)

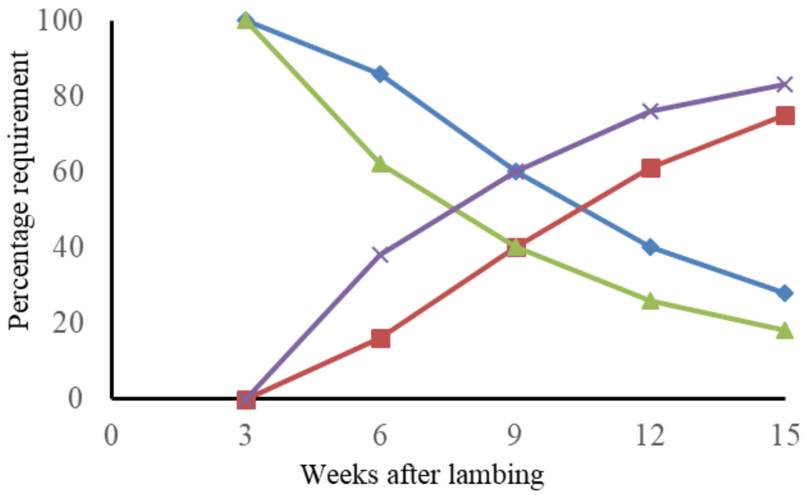

Figure 1.4 The percentage of total ME requirement of lambs met by ewe milk (averaged across all breeds) and by difference, the theoretical residual energy requirement to be met by grazing for both single and twin lambs: Milk (single); Grass (single); Milk (twin); Grass (twin) (adapted from Muir et al. 2000)

In summary, the performance of both ewes and lambs to weaning, is primarily driven by their nutritional demands. Lamb growth in early lactation is determined by the availability of milk and then by the quality and quantity of herbage available during the late lactation. Lamb growth can also vary depending on the sex, live weights and age of lambs. From 6 weeks of age twin and triplet lambs do not rely solely on ewe's milk, thus, should be provided with good quality herbage in order to achieve greater live weights at weaning.

1.4 Strategies to improve the performance of ewes and lambs during lactation

In New Zealand, lambs are conventionally weaned at between 10 and 14 weeks of age and have an average weaning weight of 28 to 30 kg (Geenty 2010). The timing of weaning and the weight of lambs at weaning can be variable due to the seasonal feed supply (Kenyon & Webby 2007). Greater ewe milk production and lamb growth rates can only be achieved if unrestricted allowances of good quality pasture are provided (Gibb &

Treacher 1978; Gibb et al. 1981). If herbage supply is inadequate to fulfil the requirements of both the ewe and lamb, ewe milk production will decline (Figure 1.5) and lamb growth will be reduced as they begin to compete for the same pasture feed resources (Muir et al. 2000). Figure 1.5 shows ewe milk production based on the pasture supply, and lamb feed demand. It is important, therefore, to identify management strategies that can improve the performance of ewes and lambs during lactation particularly when pasture supply is restricted.

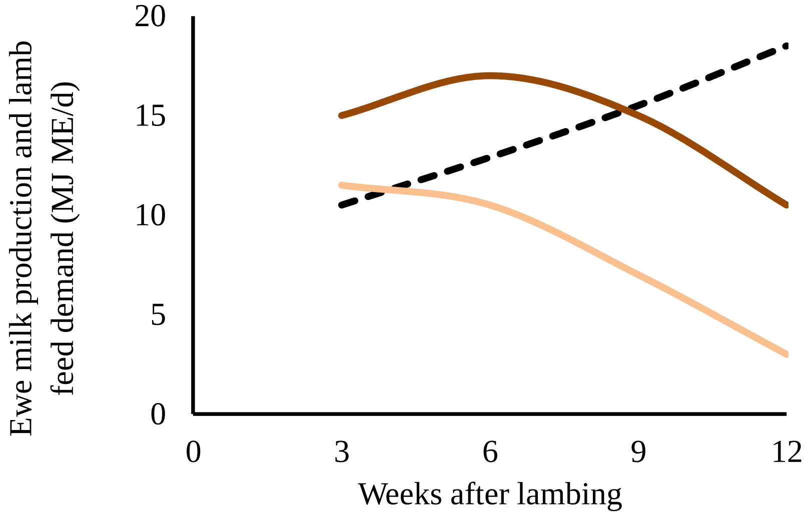

Figure 1.5 Ewe milk production based on the seasonal pasture supply, and lamb feed demand: ▬ lamb feed demand; ▬ ewe milk (pasture surplus); ▬ ewe milk (pasture shortage); source: Geenty 2010

1.4.1 Creep feeding and creep grazing

Creep feeding and grazing methods are two methods used to provide supplementary feed (e.g. hay, silage, grains, total mixed rations and high-quality pastures) to young animals prior to weaning while excluding their dams. Supplements are provided in a confined area that only young animals can access, allowing them unrestricted access to additional feed while still suckling their dams. Creep-fed lambs, therefore, can achieve greater weaning weights than lambs fed only on pasture due to their greater nutritional intake. This system works well when the quality or the quantity of grazing pasture is poor resulting an inability to fulfil both ewe and lamb nutritional requirements. Brand et al. (1999) reported that creep-fed lambs were an average 3.5 kg heavier than lambs fed only on pasture when pasture supply there was limited.

Creep-fed lambs consistently display greater growth rates compared to lambs fed only on pasture. Lambs offered a supplementary feed mix (12.3 MJ ME/kg and 11.7 % CP) while grazing Italian ryegrass (*Lolium multiflorum* cv Midmar) from 6 weeks of age to weaning approximately at 100 days of age displayed greater liveweight gains (297 g/day) than lambs fed a pasture only diet (196 g/day, Villiers et al. 2002). Similarly, Brand & Brundyn (2015) reported that lambs offered a supplementary feed mix (9.6 MJ/kg ME) were 25% heavier than lambs offered no creep feed while grazing on wheat stubble. Hayes et al. (2019) reported greater pre-weaning liveweight gains and weaning weights of meat goat kids supplemented with a creep feed (16% of CP and 2.51 Mcal/kg of digestible energy) compared to goat kids offered tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) pastures supplemented with orchardgrass hay (*Dactylis glomerata*). Hayes et al. (2019), however, reported no difference in financial return between creep-fed and non-creep-fed kids.

Creep grazing allows lambs to access grazing areas of additional high-quality pasture, which their dams cannot access, thus, reducing the competition between lamb and ewe for pasture (Moss et al. 2009). Lambs that were creep grazed from 6 weeks to 13 weeks of age, were 4 kg heavier at weaning (at 13 weeks of age) than lambs that did not have access to creep grazing (Moss et al. 2009). Creep grazing can also reduce weaning stress as temporary separation of lambs from their dams allows to habituate to separation from their dams (Brown 1964). Behavioral studies of lambs provided with creep grazing on ryegrass-clover based pasture showed that, during a 4-hour observation period in week 4 and 12 of lactation, lambs spent 16 and 30 min, respectively, in the restricted pasture area (Hyslop & Moffat 2001). In that study, however, creep grazing on ryegrass-clover based pasture did not increase lamb liveweight gain (Hyslop & Moffat 2001).

Early dry matter intake can facilitate rumen development and may increase subsequent performance of lambs. Providing supplementary feeds to young lambs can stimulate early rumen development, thus resulting in an increase in subsequent nutrient intake, and improved feed utilisation (Ward 2008). Early supplementation can support the growth of young ruminants due to improved cellular proliferation in the gastrointestinal tract, total nutrient usage and eventually, the availability of nutrients (Bhatt et al. 2009; Coverdale et al. 2004; Norouzian et al. 2011). Ward (2008) found that creep feeding facilitated the development of the alimentary tract such that the small intestine was longer in creep-fed (19.1 % CP, 81% TDN) lambs than lambs suckling their dams. They also found that creep-fed lambs had higher ruminoreticulum volume capacity, longer ruminal papillary, thus a greater surface area for nutrient absorption compared to lambs fed solely on milk. Wallace (1948) reported that the development of alimentary tract and its segments was proportionate to the order of importance for efficient digestion, absorption and utilisation of nutrients. These findings suggest, therefore, that creep feeding and creep grazing can accelerate the digestive system development which may result in greater growth rates.

The use of creep feeding in New Zealand farms is rare, although, some farmers do use creep grazing to improve lamb weaning weights (Beef + Lamb New Zealand 2011). Due to New Zealand's extensive farming systems and the relatively high cost of grain based concentrate, creep feeding using grains and concentrate feeds is not economically viable. Creep grazing has been successful in improving lamb weaning weights, however, can be difficult for most farmers to utilise. This suggests another management option is needed for farmers in New Zealand to increase the growth of lambs to weaning, particularly, when the pasture supply is restricted.

1.4.2 Early weaning of lambs

It has been suggested that weaning lambs earlier than the conventional weaning age (approximately 90 days of age) can be a useful management tool in circumstances where the herbage supply is inadequate (Brown 1964; Kenyon & Webby 2007). Early weaning of lambs during periods of inadequate pasture supply onto high quality herbage can reduce overall feed demand, allowing ewes to gain body condition and lambs to achieve target live weights. In mid- to late-lactation multiple reared lambs receive less milk than a singleton lamb which is further exacerbated when there is poor pasture supply (Figure 1.4). Figure 1.4 shows the ME requirement of lambs met by ewe milk (averaged across all breeds) for both single and twin lambs, and by difference, the theoretical residual energy requirement that is met by grazing. Hinch (1989) reported that multiple lambs had a greater suckling frequency and reduced duration of suckling than singleton lambs. It has been calculated that from 9 weeks of age onwards multiple lambs cannot fulfil their nutritional needs from milk alone thus resulting in nutritional stress and low liveweight gains (Joyce & Rattray 1970; Kenyon & Webby 2007; Muir et al. 2003). In response to this, multiple lambs attempt to compensate by increasing the grazing duration, resulting in ewes and lambs becoming competitors for the same feed resources. Increased duration of grazing by multiple lambs, however, can help them develop the ability to utilize herbage sooner than singleton lambs, which could allow lambs to utilize herbage more efficiently after weaning. Brown (1964) reported that a lamb's ability to utilize herbage prior to weaning affected their subsequent growth post weaning. Early weaning of lambs onto a high quality pasture, therefore, is a potential management tool to support lamb growth in circumstances where the herbage supply during lactation is inadequate.

Early weaning of lambs can create nutritional stress due to the removal of ewe milk from their diets. Careful nutritional management of weaned lambs should be able to minimise any nutritional stress and allow lambs to compensate for the removal of their dam's milk from their diets (Brown 1964; Chai et al. 2015; Moffat et al. 2002; Yang et al. 2015). Norouzian (2015) reported greater daily liveweight gain (154.5 g/day) and live weight at slaughter (17.2 kg) of Balouchi lambs when weaned at 6 weeks of age and offered hay (0.5 kg Lucerne) and concentrate (0.3 kg; 10.87 MJ ME/kg DM, 14.5% CP) compared to unweaned lambs offered pasture (liveweight gain of 149.6 g/day and live weight at slaughter 16.8 kg). Fernandes et al. (2012) reported that additional feed supplementation (12.8 MJ ME/kg DM) over 144 days while grazing on Tifton-85 (*Cynodon* spp.) pasture increased the live weight of lambs weaned at 6 weeks of age compared to weaned lambs offered only pasture. Further, Silva et al. (2014) reported that lambs weaned at 6 weeks of age and offered supplements (8.0 MJ ME/kg DM) while grazing Tifton-85 (*Cynodon* spp.) pasture grew faster (275 g/day) than weaned lambs fed on pasture only (57 g/day). This suggests that the addition of high-quality feed into the diets of early-weaned lambs grazing pasture can improve their growth. Combined these results suggest that early weaning is possible if lambs are provided with high quality feed such as supplementary diets post weaning. The use of grain based supplements for weaned lambs is not viable for New Zealand pastoral farms due high cost and the additional labour required to feed them. An alternative option is to use high-quality herbages to facilitate early weaning and to achieve target lamb live weights.

A small number of studies have examined early weaning of lambs in New Zealand. To date all previous studies have been based on grazing a ryegrass-clover based pasture. Mulvaney et al. (2009) reported that lambs born to ewe lambs that were weaned at 10-14 weeks of age (approximately 19 kg) grew at a similar rate as unweaned lambs, although their growth rates were low (180 g/day). This low growth was likely explained by the nutritional quality of ryegrass-clover based pasture offered (Mulvaney et al. 2009). Rattray et al. (1976) reported that lambs weaned at 4-6 weeks of age onto a ryegrass-clover based pasture were 2 kg lighter at 12 weeks compared to lambs weaned at 8 weeks of age. In addition, they reported that early-weaned lambs at 4-6 weeks of age had reduced survival and liveweight gain compared to lambs weaned at 12 weeks of age. This suggests that age at weaning can also affect the subsequent growth of lambs. Reduced growth of early-weaned lambs compared to unweaned lambs on ryegrass-clover based pasture was likely due to the lower energy content and digestibility of ryegrass-clover based pasture compared to ewe milk (11.0 and 26 MJ ME/kg, and 79.0 and 98.4 %, respectively; Burke et al. 2002; Jagusch & Mitchell 1971; Ulyatt & Macrae 1974). Positive impacts of early weaning onto ryegrass-clover based pasture on ewe performance, however, were observed. Mulvaney et al. (2009) reported that the live weight loss of ewes whose lambs were weaned early was lower (-0.26 kg/day) than that of unweaned ewes (-0.34 kg/day). Combined these results indicate that early weaning onto ryegrass-clover based pasture may be a useful tool to reduce ewe nutritional requirements when they are in poor condition. Early weaning onto ryegrass-clover based pasture, however, was not successful in terms of lamb liveweight gains.

1.5 Potential use of alternative herbage to facilitate early weaning

Sheep production systems in New Zealand are based on grazing pastures (Valentine & Kemp 2007). Use of these natural pastures to facilitate early weaning, therefore, may provide an economically viable alternative to high-cost supplementary feeds to grow weaned lambs. Optimum grazing conditions to maximise the growth rates of lambs weaned at a traditional age on ryegrass-clover based pastures are well established (Kenyon & Webby 2007; Figure 1.6). Ryegrass-clover based pasture have been consistently reported to be unsatisfactory for supporting the growth of early-weaned lambs due to a lower feeding value than other herbage species (Table 1.6), this therefore suggests that those alternative herbages could be used to support the growth of early-weaned lambs.

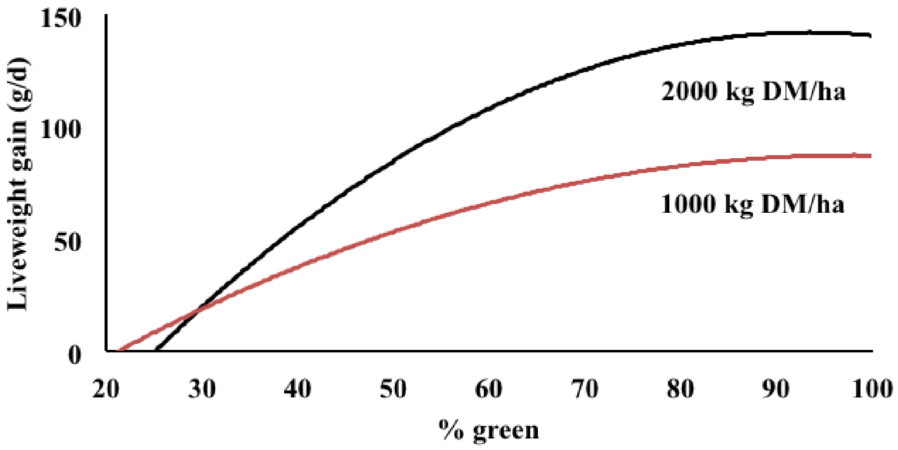

Figure 1.6 The relationship between the liveweight gain (g/day) of ewe lambs, the quantity (kg DM/ha) and quality (% green) of ryegrass-clover based pasture (reproduced from Webby 1990)

Table 1.6 Feeding value of temperate pasture species based on live weight gain when fed *ad- libitum* to growing lambs (Reproduced from Waghorn et al. 2007)

Species	Ranking
White clover (*Trifolium repens*)	100
Chicory (*Cichorium intybus*)	95
Birdsfoot trefoil (*Lotus corniculatus*)	87
Birdsfoot big trefoil (*Lotus pedunculatus*)	84
Tetraploid ryegrass (*Lolium multiflorum*)	83
Alfalfa (*Medicago sativa*)	82
Red clover (*Trifolium pratense*)	70
Timothy (*Phleum pratense*)	67
Perennial ryegrass (*Lolium perenne)*	52
Browntop (*Agrostis capillaris*)	46

Note: Ranking is relative to white clover (100)

Growth of lambs weaned at 10 weeks of age has been shown to increase when they are offered legume dominant swards (Figure 1.7) compared to ryegrass-clover based pastures (Fraser & Rowarth 1996; Jagusch et al. 1979). Further, a number of studies (Table 1.7) have shown that lambs weaned at the traditional age display faster growth rates when grazing a legume and herb mixed pasture due to greater nutritional quality (Table 1.8) than ryegrass-clover based pastures. Their use for early weaning, however, has not been examined.

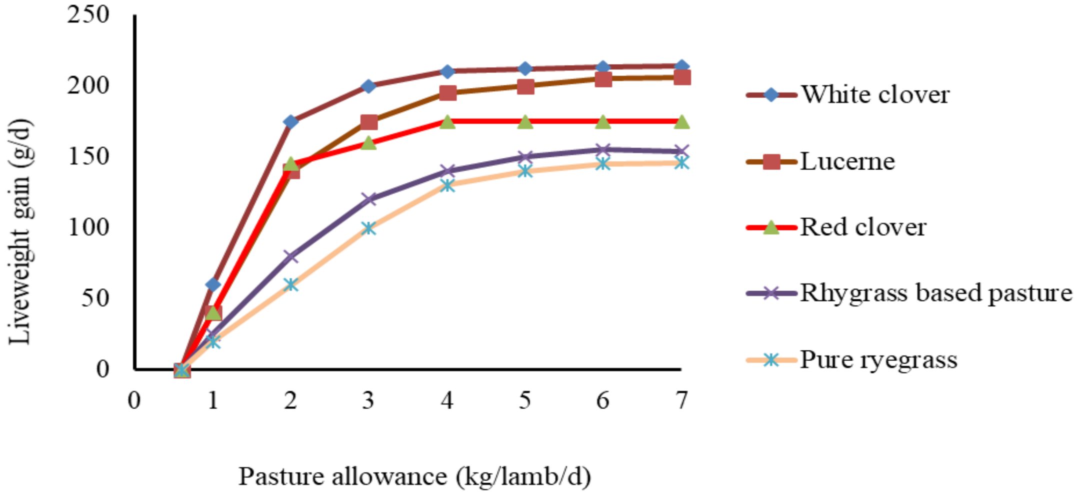

Figure 1.7 The effect of pasture allowance of different pasture types on lamb liveweight gain (Source: Jagusch et al. 1979)

Table 1.7 Summary of studies conducted in New Zealand of weaned lambs offered different forage types, showing study season, lambs weaning weight, treatment duration and average live weight gain

Forage type	Study season	Treatment duration (days)	weaning live weight (kg)	Average liveweight gain (g/day)		Reference
				herbage	Rye/WC	
Chicory	Summer	56	33.2	243	-	Hopkins et al. (1995)
	Summer to early autumn		22-23	181-214	98-136	Fraser & Rowarth (1996)
Plantain	Summer		26.0	222	135	Moorhead et al. (2002)
	Summer to early autumn			84-141	98-136	Fraser & Rowarth (1996)
White clover	Summer	28	-	269	226	Lindsay (2007)
	Summer to early autumn			219-233	98-136	Fraser & Rowarth (1996)
Red clover	Summer	38	33.0	305	184	Fraser et al. (2004)
Lotus	Summer to early autumn			175-239	98-136	Fraser & Rowarth (1996)
Leaf turnips	Summer	28	-	245	226	Lindsay (2007)
Lucerne	Summer	56	33.2	233	-	Hopkins et al. (1995)
	Summer	50	33.0	243	184	Fraser et al. (2004)
Plantain mix	Early spring		41.2	336	321	Somasiri et al. (2016)
	Early spring		34.8	397	320	Somasiri et al. (2016)
	Spring		41.2	336	322	Sinhadipathige et al. (2012)
	Late spring to early summer	27	32.5	304	190	Somasiri et al. (2015b)
	Late spring to early summer	36	32.6	315	243	Somasiri et al. (2015b)
	Summer	49	32.8	226	169	Somasiri et al. (2015a)
	Summer	25	35.8	231	120	Somasiri et al. (2015a)
	Autumn		34.2	294	159	Somasiri et al. (2015c)
	Autumn		34.2	252	169	Somasiri et al. (2015c)
	Late summer to early Autumn	50	36.7	107	119	Golding et al. (2011)
	Autumn	35	34.2	294	159	Somasiri (2014)
	Autumn	43	34.1	252	169	Somasiri (2014)
Chicory mix	Early spring		41.3	360	321	Somasiri et al. (2016)
	Early spring		34.9	366	320	Somasiri et al. (2016)
	Spring		41.3	360	322	Sinhadipathige et al. (2012)

	Late spring to early summer	27	32.5	262	190	Somasiri et al. (2015b)
	Late spring to early summer	36	32.6	328	243	Somasiri et al. (2015b)
	Summer	25	35.8	221	120	Somasiri et al. (2015a)
	Summer	49	32.8	214	169	Somasiri et al. (2015a)
	Autumn		34.3	254	159	Somasiri et al. (2015c)
	Autumn		34.1	207	169	Somasiri et al. (2015c)
	Autumn	35	34.2	254	159	Somasiri (2014)
	Autumn	43	34.1	207	169	Somasiri (2014)
Herb-clover mix	Summer		19.5	338	291	Corner-Thomas et al. (2018b)
	Summer		19.0	285	325	Corner-Thomas et al. (2018b)
	Late summer to early Autumn	29	35.3	247	119	Golding et al. (2011)
	Late summer to early Autumn	50	33.1	247	56	Golding et al. (2011)

Note: Plantain mix (Plantain, white clover and red clover); Chicory mix (Chicory, white clover and red clover); Herb-clover mix (Chicory, plantain, red clover and white clover) , Rye/WC (ryegrass-clover based pasture)

Table 1.8 The nutritional composition of forage used in studies summarised in Table 1.7

Herbage treatment	Protein (% DM)	ADF (% DM)	NDF (% DM)	ME (MJ/kg DM)	OMD (% DM)	Reference
Chicory	24.3	-	-	-	84.8	Fraser & Rowarth (1996)
Plantain	20.2	-	-	-	80.4	Fraser & Rowarth (1996)
White clover	28.0	-	-	-	83.0	Fraser & Rowarth (1996)
White clover	20.9-27.6	-	26.3-27.5	11.7-11.9	71.6-73.2	Lindsay (2007)
Lotus	25.7	-	-	-	79.8	Fraser & Rowarth (1996)
Leaf turnips	15.6-17.4	-	20.8-21.1	13.3	81.7-84.0	Lindsay (2007)
Plantain mix	19.1	15.1	26.3	-	-	Sinhadipathige et al. (2012)
	24.2-33.3	15.7-23.2	22.1-34.7	10.8-11.6	74.8-81.3	Somasiri (2014)
	24.2-33.3	15.7-23.2	22.1-34.7	10.8-11.6	74.8-81.3	Somasiri et al. (2015c)
	18.8-24.2	24.0-26.2	34.6-39.1	10.8	73.8-74.4	Somasiri et al. (2015a)
	18.6-25.2	20.8-24.7	32.9-37.6	10.7-10.9	74.5-75.0	Somasiri et al. (2015b)
	12.9	-	39.9	10.2	72.9	Golding et al. (2011)
Chicory mix	16.5	16.5	24.7	-	-	Sinhadipathige et al. (2012)
	23.0-23.7	17.0-20.7	19.5-29.3	11.1-11.6	77.6-82.0	Somasiri (2014)
	23.0-23.7	17.7-20.7	19.5-29.3	11.1-11.6	77.6-82.0	Somasiri et al. (2015c)
	17.2-20.1	20.6-23.1	29.2-32.3	10.8-11.1	74.8-77.1	Somasiri et al. (2015a)
	18.5-25.6	18.0-18.6	26.7-28.9	11.1-11.3	77.2-78.7	Somasiri et al. (2015b)
Herb-clover mix	15.8	-	28.1	11.4	82.9	Golding et al. (2011)
	11.7-12.7	22.8-24.5	35.0-41.8	9.7-10.0	66.7-69.1	Hutton et al. (2011)
	-	21.1-36.1	24.3-48.6	9.5-11.0	59.5-69.0	Corner-Thomas et al. (2018b)
Rye/WC	22.8	20.1	39.6	-	-	Sinhadipathige et al. (2012)
	19.8-29.3	19.3-23.9	39.5-48.5	9.9-10.8	67.7-74.9	Somasiri (2014)
	19.8-29.3	19.3-23.9	39.5-48.5	9.9-10.8	67.7-74.9	Somasiri et al. (2015c)
	11.5-18.7	23.6-28.6	46.3-53.7	9.5-10.1	64.5-69.4	Somasiri et al. (2015a)
	15.5-16.7	23.6-26.2	47.2-48.2	10.1-10.3	68.3-70.1	Somasiri et al. (2015b)
	19.6	-	53.7	9.0	64.1	Golding et al. (2011)
	8.0-10.3	26.1-26.9	49.9-50.4	9.4-9.5	63.8-64.9	Hutton et al. (2011)
	-	26.2-29.4	48.8-60.7	9.0-9.7	56.5-60.6	Corner-Thomas et al. (2018b)
Ryegrass	20.1	-	-	-	80.2	Fraser & Rowarth (1996)
	15.5-16.3	-	39.3-47.7	9.8-10.7	60.2-65.5	Lindsay (2007)

Note: Plantain mix (Plantain, white clover and red clover); Chicory mix (Chicory, white clover and red clover); Herb-clover mix (Chicory, plantain, red clover and white clover); Rye/WC (ryegrass-clover based pasture)

Early weaning requires that lambs are provided with greater nutrition post weaning than conventionally weaned lambs in order to achieve target live weight gains. Based on the studies summarised in Table 1.8, it is evident that unrestricted allowance to good-quality feed post weaning could support the growth of weaned lambs compared to ryegrass-clover based pastures. The greater growth of weaned lambs on legume and herb mixed pastures as shown Table 1.7, suggest that there is potential to use herb-clover mix to facilitate early weaning in New Zealand.

1.6 Herb-clover mix: a multi-species pasture

Growing several plant species together (multi-species pastures) can result in greater herbage production than growing one plant species in a monoculture. Sanderson et al. (2005) reported that multi-species pastures can have improved drought tolerance, uniform seasonal growth (yield stability) and better persistence than ryegrass-clover based pastures. As a result, a herb-clover mix containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*) has been developed in New Zealand. Recent studies of this herb-clover mix have shown potential advantages for improving sheep performance such as greater lamb liveweight gain, ewe body condition and milk production compared with perennial ryegrass-clover based pasture (Corner-Thomas et al. 2014b; Golding et al. 2008; Hutton et al. 2011; Kenyon et al. 2010; Somasiri et al. 2015a,b,c; 2016). Greater ewe and lamb performance when grazing the herb-clover mix during lactation can enable farmers to grow lambs faster than on ryegrass-clover based pasture.

1.6.1 Botanical composition

The botanical composition of the herb-clover mix can influence the potential herbage productivity, nutritional profile and the animal's selectivity for each species (Cave et al. 2015). The relative contribution of each sown species in the mix varies over time due to differences in seeding rates, growth patterns and grazing frequency (Cave et al. 2015). Somasiri et al. (2015b) reported that the proportion of plantain, chicory, white clover, red clover, weeds and dead matter in the herb-clover mix during late spring to early summer period in New Zealand was 38, 15, 15, 9, 21 and 2%, respectively in 2011. Whereas, in 2012, from the same experiment plots during the same growing period the proportions of each sown species differed (34, 26, 13, 9, 8 and 10%, respectively), suggesting that the botanical composition of the herb-clover mix can change across years. Golding et al. (2011) reported that the chicory, plantain, red clover, white clover and dead matter composition of the herb-clover mix during autumn in New Zealand were 40, 30, 5, 2 and 17%, respectively in 2007. In general, over the summer and autumn period in the Manawatu region of New Zealand, the herb-clover mix can comprise between 40–60% plantain, 20–40% chicory, 5–20% red clover and 0–10% white clover (Cranston et al. 2015a). These changes in botanical composition were reflected in the variation in nutritive value of the mix (Cranston et al. 2015a).

1.6.2 Nutritional composition of herb-clover mix

The nutritional quality of pure swards of chicory and plantain have been shown to be greater than that of ryegrass-clover based pastures in a number of studies (Barry 1998; Burke et al. 2000; Fraser & Rowarth 1996). Chicory contains greater CP, ME and water soluble carbohydrates (WSC), and lower NDF than ryegrass-clover based pastures (Barry

1998; Fraser & Rowarth 1996). In addition, plantain has greater ME and WSC compared to ryegrass-clover based pastures (Fraser & Rowarth 1996). Burke et al. (2000) reported that both chicory and plantain had a higher ratio of readily fermentable carbohydrates to structural carbohydrate indicating that they have greater digestibility compared to ryegrass-clover based pasture. Chicory and plantain also have greater herbage production (7-16 t DM/ha) compared to ryegrass-clover based pasture while maintaining high nutritive values during warm summer conditions (Lee et al. 2015; Minneé et al. 2013; Powell et al. 2007). This suggests that when ryegrass-clover based pasture production is low during dry summers in New Zealand, herb-clover mixes can be a valuable alternative forage. Lee et al. (2015) and Pain et al. (2015), however, reported that the crude protein content of a pure plantain sward could be low (< 15%) during summer, thus, potentially limiting its use for improving animal production. The addition of red clover and white clover, which both are high in CP, to the chicory and plantain (herb-clover mix) ameliorates these potential problems associated with the low crude protein content. The herb-clover mix, therefore, is a more suitable summer active perennial forage for sheep production than pure swards of chicory and plantain (Sinhadipathige et al. 2012). Goh & Bruce (2005) reported that mixtures of herbs and legumes were superior in herbage quality and had greater tolerance to dry summers than ryegrass-clover based pastures. The nutritive analysis of the herb-clover mix shows that it has a lower fibre content, greater CP, greater organic matter digestibility percentage and ME content during the summer compared to pure swards of either chicory, plantain, red clover, white clover or ryegrass-clover based pasture. A comparison of nutritional analysis of a herb-clover mix conducted at different seasons are presented in Table 1.9.

Table 1.9 Crude protein (CP), neutral detergent fibre (NDF), organic matter digestibility (OMD), and metabolisable energy content (ME) of the herb-clover mix containing chicory, plantain, red clover and white clover compared to ryegrass-clover based pasture (rye/wc) across different seasons; early spring (September/October), late spring (Nov/Dec), summer (Jan/Feb), early autumn (Mar/Apr), late autumn (Apr/May) in the Manawatu region, New Zealand (adapted from Cranston et al. 2015a)

Season and study	CP (%DM)		NDF (% DM)		OMD (% DM)		ME (MJ/kg DM)	
	Rye/wc	Herb-clover mix	Rye/wc	Herb-clover mix	Rye/wc	Herb-clover mix	Rye/wc	Herb-clover mix
Early spring								
Kenyon et al. (2010)	13	13	54	38			9.2	10.5
Hutton et al. (2011)	12	15	36	28	72	74	10.6	10.8
Somasiri (2014)	25	20	42	27	71	78	10.4	11.4
Late spring								
Somasiri et al. (2015b)	16	23	48	28	69	78	10.2	11.2
Summer								
Kenyon et al. (2010)	9	9	62	49			8.9	9.8
Hutton *et* al. (2011)	9	12	50	38	64	68	9.5	9.9
Cranston (2014)	21	25	40	24	74	81	10.6	11.6
Somasiri et al. (2015a)	15	18	50	30	67	76	9.8	10.9
Early autumn								
Golding et al. (2011)	20	16	48	28	64	83	9.0	11.4
Late autumn								
Somasiri (2014)	24	23	45	25	71	80	10.4	11.3

1.6.3 Seasonality of herbage production of herb-clover mix

The use of pure swards of chicory, plantain, red clover and white clover has been limited due to low yield stability associated with seasonality of production (Hodgson et al. 2005). Hodgson et al. (2005) reported that the productivity of white clover was restricted during the summer with its growth being predominantly during winter in New Zealand. In contrast, chicory and red clover, which are deep rooted plants, have been shown to be active during summer but not winter and have greater herbage production than ryegrass-clover based pastures in dryland conditions (Hunter et al. 1994). The growth of plantain is more apparent from early spring to autumn, while chicory and red clover are more productive than plantain and white clover during summer (Kemp et al. 2002; Kemp et al. 2010; Li & Kemp 2005). The uniform seasonal growth (yield stability) is evident during dry summers when chicory, plantain, red clover and white clover are grown in a mix (Nie et al. 2008). Cranston et al. (2015b) and Somasiri (2014) reported that a herb-clover mix had a greater herbage production during summer and autumn than during winter. The introduction of herb-clover mixes to pastoral systems in New Zealand has improved herbage availability and provides flexibility to lift the sustainability and sheep performance during dry summers. The greater availability of herbage mass from the herb-clover mix during summer than ryegrass-clover based pasture has the potential to provide farmers with an opportunity to finish early-weaned lambs, however, this has not yet been examined.

1.6.4 Animal selection on herb-clover mix

Sheep select certain plant species over the others, when different choices of plant species are available (Concha & Nicol 2000; Dumont & Gordon 2003; Foster et al. 2002; Parsons et al. 1994; Rutter 2006). There are number of reasons why sheep employ selective grazing behavior, for example avoiding grazing novel herbages (Parsons et al. 1994; Ramos & Tennessen 1992), taste aversion (Provenza 1995), maintaining effective rumen micro-flora (Rutter et al. 2000) or to meet their ideal protein intake (Kyriazakis & Oldham 1993; Kyriazakis et al. 1994). It is important to understand the diet selection of sheep grazing botanically diverse swards such as herb-clover mix in order to provide recommendations for herbage sward composition that will optimize animal performance (Rutter 2006).

To date, many of the studies based on the selective grazing of sheep have been conducted using perennial ryegrass-clover based pasture as a model herbage. Penning et al. (1991) reported that sheep eat clover more quickly than grass. Similarly, Newman et al. (1994) reported that both fasted and non-fasted sheep selected more clover than grass. Sheep show a strong preference for legumes in the morning and then prefer a grass in the diet over the course of the rest of the day (Harvey et al. 2000; Parsons et al. 1994; Rutter et al. 2005). Carrere et al. (2001); Harvey et al. (2000), and Rook et al. (2002) reported that the relative availability of clover in a herbage mix affected the proportion of clover in the diet of sheep. Few studies, however, have examined the selective grazing of sheep when offered herb and legume based mixes. Lambs grazed on a herb-clover mix displayed greater grazing preference for plantain and chicory ahead of red clover and white clover during early spring and for red clover from late spring to autumn (Cave et al. 2015). Lambs that were fed indoors with pure plantain, chicory, red clover and ryegrass showed a greater preference for red clover and chicory than white clover and plantain (Pain et al. 2010). Similar results were observed with lambs weaned and offered these plants (Corkran 2009). Cave et al. (2015) reported that sheep selectivity, and preference, changed among seasons and suggested this was due to changes in species availability and palatability.

1.6.5 Use of herb-clover mix for early weaning of lambs

It is evident that weaned lambs can compensate for the loss of nutrients from milk when offered high-quality supplementary diets or herbages such as a herb-clover mix. In addition, they have been observed to grow faster than unweaned lambs on ryegrass-clover based pastures. The use of a herb-clover mix to grow early-weaned lambs may be possible considering its greater nutritional quality than ryegrass-clover based pasture. Herb-clover mixes also have greater herbage mass production compared to ryegrass-clover based pastures during spring and also dry summers experienced in some areas of New Zealand. This suggests there is potential to use herb-clover mixes to facilitate early weaning. Little is known about forage selection and the contribution of each plant species in the herb-clover mix on animal performance, including early weaned lambs, on herb-clover mix. Studies based on sheep preference of different plant species, however, indicates that a herb-clover mix is likely to be preferred by early-weaned lambs compared to ryegrass-clover based pasture, and thus, can facilitate early weaning.

Purpose and scope of the investigation

Weaning lambs earlier than the conventional weaning age (approximately 90 days of age) may be a useful management tool in circumstances where the quality and quantity of herbages are inadequate for optimal lamb growth. Growth of lambs after early weaning can be greater when they are offered high-quality supplementary diets while grazing compared to those lambs offered only grass. Feeding early-weaned lambs with supplementary diets to achieve target weaning weights, however, may not be suitable for pastoral farms in New Zealand on which ryegrass-clover based pastures provide 95% of the lamb’s diet. Growth of early-weaned lambs offered ryegrass-clover based pastures has been poor compared to that of lambs weaned at the conventional age mainly due to the inadequate nutritional quality of ryegrass-clover based pastures. This suggests that early-weaned lambs may benefit from a forage that has greater nutritional value such as herb-clover mixes containing chicory, plantain, red clover and white clover. Herb-clover mixes have been shown to improve both ewe and lamb performance during lactation and post traditional weaning, however, to date they have not been used to facilitate early weaning. There is, however, a paucity of information on early weaning of lambs onto a herb-clover mix, which has highlighted the following areas of research and the focus of this thesis.

- The effect of lamb weight at early weaning on their growth when offered herb-clover mix post early weaning (Chapter 2)
- The growth of lambs weaned early, at a minimum live weight of 16 kg, onto a herb-clover mix when ryegrass-clover based pastures are restricted (Chapter 3)
- The growth of lambs when weaned early, at a minimum live weight of 14 kg, onto a herb-clover mix (Chapter 4)
- The effect of early exposure of lambs to a herb-clover mix prior to early weaning on their growth post weaning (Chapter 5)
- The nutritional composition of the individual plant components of the herb-clover mix during the late spring to autumn period (Chapter 6).

CHAPTER 2

The effect of live weight at weaning on liveweight gain of early-weaned lambs onto a herb-clover mix

Publications:

Ekanayake WEMLJ, Corner-Thomas RA, Cranston LM, Kenyon PR, Morris ST 2017. The effect of live weight at weaning on liveweight gain of early weaned lambs onto a herb-clover mixed sward. Proceedings of the New Zealand Society of Animal Production 77: 37- 42.

2.1 Abstract

The aim of the present study was to determine the effect of weaning lambs at a minimum 16 kg of live weight, at ~ 50 days of age, onto a herb-clover mix, and the live weight of lambs at early weaning on their liveweight gain post early weaning to a conventional weaning age. Twin lambs that weighed a minimum of 16 kg (n=134 in 2014 and n=124 in 2015) were randomly allocated to one of three treatments: (i) Early weaning (54 and 46 days after the midpoint of lambing in 2014 and 2015, respectively) onto a herb-clover mix (plantain, chicory, red clover and white clover) ($Herb_{EW}$); (ii) Lambs + dams unweaned on a herb-clover mix until conventional weaning at approximately 90 days of age ($Herb_{CW}$); and (iii) Lambs + dams unweaned on a ryegrass-clover based pasture until conventional weaning ($Grass_{CW}$). In 2014, overall lamb liveweight gains were 100 and 68 g/day greater ($P<0.05$) for $Herb_{CW}$ lambs and $Herb_{EW}$ than $Grass_{CW}$ lambs, respectively. In 2015, liveweight gains of $Herb_{CW}$ and $Grass_{CW}$ lambs did not differ ($P>0.05$) but were 45 g/day greater than gains of $Herb_{EW}$ lambs ($P<0.05$). In 2014, $Herb_{EW}$ lambs that were > 20 kg grew more quickly (50 g/day) than $Herb_{EW}$ lambs that were <18 kg ($P<0.05$). In 2015, $Herb_{EW}$ lambs had similar rate of liveweight gain irrespective of their live weight at treatment allocation ($P>0.05$). Lambs weaned early onto a herb-clover mix, at a minimum weight of 16 kg at approximately 50 days of age, had the potential to grow at a similar rate to unweaned lambs on a ryegrass-clover based pasture. Weaning lambs at less than 18 kg onto herb-clover mix, however, can result in lower lamb liveweight gain compared to heavier lambs.

2.2 Introduction

Herb-clover mixes containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*) increase lamb liveweight gain before and after weaning (Corner-Thomas et al. 2014b; Golding et al. 2008; Hutton et al. 2011; Somasiri et al. 2015b,c; 2016). These effects are due to the high nutritive value and digestibility of herb-clover mix compared to ryegrass (Cranston et al. 2015a; Somasiri et al. 2015b,c; 2016). Cranston et al. (2015a) reported that herb-clover mixes generally have a lower fibre content, similar crude protein content and higher organic matter digestibility and metabolisable energy content than ryegrass-clover based pasture.

In New Zealand, lambs are conventionally weaned between 10 and 14 weeks of age in a once-a-year-lamb production system with an average weaning live weight of 28-30 kg (Geenty 2010). Previous studies suggested that lambs can be weaned earlier onto ryegrass-clover based pastures, although growth rates (180 g/day) were low (Mulvaney et al. 2009). Further, Rattray et al. (1976) reported that lambs weaned at 4-6 weeks of age onto ryegrass-clover based pasture were lighter compared to lambs weaned at eight weeks of age. Early weaning can be a useful management tool if the availability of pasture is likely to result in the ewe and lamb being competitors (Kenyon & Webby 2007). Early weaning onto high-quality herbage can reduce overall feed demand, and thus, allow the ewe to gain body condition and allow for adequate liveweight gains of lambs (Muir et al.

2000). We hypothesised that lambs weaned at a minimum live weight of 16 kg onto herb-clover mix may achieve liveweight gains at least similar to lambs remaining with their dam on either a ryegrass-clover based pasture or a herb-clover mix.

The present study had two aims, firstly to determine the effect of early weaning onto herb-clover mix on lamb liveweight gain, and secondly, the effect of lamb live weight at early weaning on growth after weaning.

2.3 Materials and methods

2.3.1 Experimental design

The present study was conducted at Massey University’s Keeble farm, 5 km southeast of Palmerston North (40°24' S and 175°36' E), New Zealand over two years (2014 and 2015). All manipulations were approved by the Massey University Animal Ethics Committee. Romney ewes (n=120 in 2014 n=121 in 2015) which conceived during the first cycle, diagnosed as twin bearing 48 days after the end of breeding period, and those which successfully raised both lambs were used. Throughout the gestation period, within each year, ewes were managed as one mob under commercial farm conditions. Lambing began on 2 September and 9 September in 2014 and 2015, respectively. All lambs were weighed, ear tagged and identified to their dam within 24 h of birth. Lambs were orally drenched at docking and then every 28 days with Ancare 'Matrix' triple combination drench (Merial Ancare, Manukau City, New Zealand) at a rate of 1 mL per 5 kg live weight to eliminate internal parasites.

From the midpoint of lambing (L1) until the onset of the study (L54 in 2014 and L46 in 2015) lambs and ewes were managed as a single mob on ryegrass-clover based pasture. Twin lambs that weighed a minimum of 16 kg at L54 (19.0±0.2 kg; n=134) in 2014 and L46 (18.4±0.2; n= 124) in 2015 were randomly allocated to one of three treatments: (i) Early weaning at L54 (in 2014) and L46 (in 2015) onto a herb-clover mix (plantain [*Plantago lanceolata*], chicory [*Cichorium intybus*], red clover [*Trifolium pratense*] and white clover [*Trifolium repens*]) ($Herb_{EW}$); (ii) Lambs + dams unweaned on a herb-clover mix until conventional weaning ($Herb_{CW}$); and (iii)) Lambs + dams unweaned on a ryegrass-clover based pasture (perennial ryegrass [*Lolium perenne* L.] and white clover) until conventional weaning ($Grass_{CW}$). All groups (n= 44, 46, 44 in $Herb_{EW,}$ $Herb_{CW,}$ $Grass_{CW}$ in 2014 and n= 40, 44, 40 in $Herb_{EW,}$ $Herb_{CW,}$ $Grass_{CW}$ in 2015, respectively) remained on these treatments until conventional weaning at L93 in 2014 and L88 in 2015. Within 1-2 hr of birth, ewes develop an exclusive bond with their lambs and reject any alien lambs that attempt to suck for the remainder of the lactation (Nowak & Poindron 2006). Therefore, it is unlikely that weaned lambs were able to steal milk from unweaned ewes. Lambs and ewes assigned into $Herb_{EW}$ and $Herb_{CW}$ treatment groups were gradually introduced to the herb-clover mix over a four-day period of increasing duration each day (i.e. 4 h day 1, 8 h day 2, 12 h day 3, and 24 h day 4) prior to the onset of the study. Lambs and ewes were weighed within 1 h of being removed from pasture on L54, L83 and L93 in 2014 and, L46, L74 and L88 in 2015. At the end of the study, the percentage of lambs that had reached slaughter weight (> 35 kg) per each treatment was calculated. In both years of the study, all herbages were managed to provide in excess of 1200 kg DM/ha which provide for *ad-libitum* ewe and lamb intakes (Cranston et al. 2015b; Morris & Kenyon 2004). Sward surface heights after grazing were maintained at a minimum of 5 cm for ryegrass-clover based pasture and 7 cm for the herb-clover mix.

2.3.2 Herbage measurements

Herb-clover mix paddocks were sown during autumn in 2012 and 2013 with a seed mixture of chicory (6 kg/ha), plantain (6 kg/ha), white clover (4 kg/ha) and red clover (6 kg/ha). Herbage masses were measured on L54, L83 and L93 in 2014 and, L46, L74 and L88 in 2015. Four random quadrat cuts (0.1 m^2 each) were taken to ground level from each herbage type at each sampling date using an electric shearing hand-piece (Frame 1993). Samples were then oven dried to a constant weight to estimate herbage mass. In addition, four composite herbage samples each containing ten grab samples per herbage type, were also collected at each sampling date to determine the botanical and nutritional composition (Frame 1993). To determine the botanical composition of the herbage, a subsample from each composite sample (4 per herbage type) was sorted into each species (herb-clover mix: plantain, chicory, red clover, white clover; ryegrass-clover based pasture: ryegrass, clover; other grasses (combined), weeds, and dead matter) and then oven dried and weighed to determine the botanical composition. The remaining sample was then frozen, dried, ground, sieved (1 mm) and analysed using *in vitro* methods to determine the nutritional quality. These measures included percentage neutral detergent fibre (NDF, Robertson & Van Soest 1981), acid detergent fibre (ADF, Robertson & Van Soest 1981) and digestible organic matter digestibility (DOMD, Roughan & Holland 1977). Metabolisable energy (ME) content of herbages was calculated from the organic matter digestibility (DOMD×0.16 MJ/Kg DM, Roughan & Holland 1977).

2.3.3 Statistical analysis

Live weight and liveweight gain of lambs were subjected to analysis of variance using the MIXED procedure in SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US). The analysis was performed separately for each year due to the differences in the days in which measurements were collected. The effect of herbage treatments ($Herb_{EW}$, $Herb_{CW}$, and $Grass_{CW}$) on average liveweight gain of lambs was analysed using a model that included the fixed effects of herbage treatment and sex of lamb and age of lambs as a covariate. The effect of herbage treatments and weaning weight category of lambs (16-17, 18-19, 20-21, and 22-23 kg, individual lamb basis) on liveweight gain after weaning until conventional weaning was analysed using a model that included the fixed effects of herbage treatment, sex of lamb and live weight category, and age of lamb as a covariate. Herbage masses were analysed using a model that included herbage treatment and measurement dates as fixed effects. Botanical composition data were analysed using the MIXED procedure, with a model that included the fixed effects of plant species. Herbage quality data were analysed using the MIXED procedure, with a model that included the fixed effects of pasture type and measurement time. The percentage of lambs that reached the target slaughter weight was analysed using the GENMOD procedure in SAS that included herbage treatment as a fixed effect.

2.4 Results

2.4.1 Herbage mass, NDF, ADF and ME

In 2014, at the start of the study (L54) the herbage mass of herb-clover mix was ~ 1500 kg DM/ha greater ($P<0.05$) than that of ryegrass-clover based pasture (Table 2.1). At L93, however the reverse ($P<0.05$) was observed and no difference was observed at L83. The ME content of the herb-clover mixes was 1.2-1.6 MJ/kg DM greater ($P<0.05$) than that of ryegrass-clover based pasture treatments at all three measurement dates. In addition, NDF and ADF were higher in ryegrass-clover based pasture than in herb-clover mixes at all three time points ($P<0.05$).

Table 2.1 Herbage mass, acid detergent fibre (ADF) and metabolisable energy (ME) content of herbage treatments (ryegrass-clover based pasture and herb-clover mix) samples collected 54, 83, 93 days after the midpoint of lambing in 2014 (L54, L83, L93) and on L46, L74, L88 in 2015 (least-squares mean ±SEM)

Herbage treatment		Herbage mass (kg DM/ha)	NDF (% DM)	ADF (% DM)	ME (MJ/kg DM)
			2014		
Herb-clover mix	L54	3659±336^{c}	24.3±1.1^{a}	21.1±1.8^{a}	11.1±0.1^{d}
	L83	2130±336^{a}	31.1±1.1^{b}	22.9b±1.8^{a}	10.5±0.1^{c}
	L93	2688±336^{ab}	33.1±1.1^{b}	25.9±1.8^{bc}	10.5±0.1^{c}
Ryegrass-clover based pasture	L54	2335±336^{a}	52.6±1.1^{c}	28.2±1.8^{cd}	9.5±0.1^{b}
	L83	2827±336^{ab}	56.1±1.1^{c}	29.4±1.8^{cde}	9.3±0.1^{b}
	L93	4245±336^{c}	60.6±1.1^{d}	33.0±1.8^{e}	9.0±0.1^{a}
			2015		
Herb-clover mix	L46	4818±403^{c}	37.9±2.4^{a}	26.1±1.4^{a}	10.5±0.2^{b}
	L74	3527±403^{b}	44.9±2.4^{b}	36.1±1.4^{b}	9.5±0.2^{a}
	L88	2219±403^{a}	48.5±2.4^{b}	35.0±1.4^{b}	9.7±0.2^{a}
Ryegrass-clover based pasture	L46	2739±403^{ab}	48.7±2.4^{b}	26.2±1.4^{a}	9.7±0.2^{a}
	L74	2282±403^{a}	51.7±2.4^{b}	27.7±1.4^{a}	9.5±0.2^{a}
	L88	2649±403^{ab}	49.7±2.4^{b}	29.0±1.4^{a}	9.3±0.2^{a}

$^{a, b, c}$ Means with different superscripts are significantly different within each year ($P<0.05$)

In 2015, at L46 and L74 the herbage mass of herb-clover mixed sward was 1000 to 2000 kg DM/ha greater ($P<0.05$) than that of ryegrass-clover based pasture (Table 2.1). At L88 no difference of herbage mass was observed. At the start of the study, the NDF content of herb-clover mixes was ~ 10% lower ($P<0.05$) than that of ryegrass-clover based pasture, however, at L74 and L88 no difference ($P>0.05$) in NDF was observed among treatments. At the start of the study, no difference of ADF was observed among treatments; however, at L74 and L88 the ADF content of herb-clover mixes were ~ 8% greater ($P<0.05$) than that of ryegrass-clover based pasture. The ME content of herb-clover mixes was 0.8 MJ kg DM greater ($P<0.05$) than that of ryegrass-clover based pasture at L46 but did not differ to the ME content of ryegrass-clover based pasture at L74 and L88.

2.4.2 Botanical composition of herbage treatments

In both years of the study, ryegrass was the dominant species in the ryegrass-clover based pasture (Table 2.2). The clover content of ryegrass-clover based pasture, however, was higher in 2015 (10.5±1.6%) than in 2014 (0.9±0.2%). Chicory was the dominant species in herb-clover mix in both years, and the clover content in the herb-clover mix was 14.1±8.6% in 2014 and 11.8±3.0% in 2015.

Table 2.2 The botanical composition (% of various herbage species dry matter basis) within herbage treatments (ryegrass-clover based pasture and herb-clover mix) samples collected 54, 83, 93 days after the midpoint of lambing in 2014 (L54, L83, L93) and on L46, L74, L88 in 2015 (least-squares mean ±SEM)

Herbage species	Herbage type									
	Pasture					Herb-clover mix				
	2014									
	L54	L83	L93	Mean	SE	L54	L83	L93	Mean	SE
Grass	92.7	91.4	93	92.4	0.5	1.2	0	0	0.4	0.4
Clover	1	1.2	0.5	0.9	0.2	30	0.6	11.6	14.1	8.6
Chicory	-	-	-	-	-	54	48	69	57.0	6.2
Plantain	-	-	-	-	-	12	49	15.4	25.5	11.8
Weeds *	0.5	1	1	0.8	0.2	0	0	0	0.0	0.0
Dead	5.4	6.5	5	5.6	0.4	3	2	3.9	3.0	0.5
	2015									
	L46	L74	L88			L46	L74	L88		
Grass	88.2	77.4	74.9	80.2	4.1	21.9	10.3	8	13.4	4.3
Clover	7.3	12.7	11.6	10.5	1.6	14.7	5.9	14.9	11.8	3.0
Chicory	-	-	-	-	-	37.3	42.2	38.1	39.2	1.5
Plantain	-	-	-	-	-	22.6	30	25.7	26.1	2.1
Weeds *	1.4	6.9	9.7	6.0	2.4	1.2	1.4	0.5	1.0	0.3
Dead	3.2	3	3.7	3.3	0.2	2.4	10.2	12.8	8.5	3.1

*****All the other plant species except the main pasture and herb species in the treatments

2.4.3 Lamb live weight

The mean live weight of lambs at treatment allocation did not differ (19.0±0.2 kg in 2014 and 18.4±0.2 kg in 2015; P>0.05). At conventional weaning in 2014 (L93), the mean live weight of lambs in the $Herb_{EW}$ (33.6±0.4 kg) and $Herb_{CW}$ (34.4±0.4 kg) treatment groups did not differ (P>0.05), but were greater (P<0.05) than lambs in the $Grass_{CW}$ (30.4±0.4 kg) treatment group. At conventional weaning in 2015 (L88), the mean live weight of lambs in the $Herb_{CW}$ (31.8±0.4 kg) and $Grass_{CW}$ (32.6±0.4 kg) treatment groups did not differ (P>0.05) but were greater than the live weight of lambs in the $Herb_{EW}$ (30.6±0.4 kg) treatment group.

2.4.4 Lamb liveweight gain

In 2014, the overall lamb liveweight gain between L54 and L93 was greater in $Herb_{CW}$ (392±7 g/day) lambs compared to $Herb_{EW}$ (360±7 g/day) lambs which was greater than $Grass_{CW}$ (292±7 g/day) lambs (P<0.05).

In 2015, the liveweight gain between L46 and L88 of $Grass_{CW}$ (327±6 g/day) and $Herb_{CW}$ (318±6 g/day) lambs did not differ (P>0.05) but was greater than those of $Herb_{EW}$ (282±7 g/day).

2.4.5 Lamb liveweight gain based on live weight category

In 2014, in $Herb_{EW}$ treatment group, the mean liveweight gain of heavy lambs (20-21 and 22-23 kg) was 50 g/day greater ($P<0.05$; Table 2.3) than lighter lambs (16-17 kg). Liveweight gain of 18-19 kg lambs in the $Herb_{EW}$ treatment group did not differ ($P>0.05$) between lighter (16-17 kg) or heavier (20-21 and 22-23 kg) lambs. The liveweight gains of lambs in $Herb_{CW}$ and $Grass_{CW}$ treatment groups did not differ ($P>0.05$) between the live weight categories. Both the 16-17 kg and 18-19 kg $Herb_{EW}$ lambs grew more slowly ($P<0.05$) than lambs of the same weight in $Herb_{CW}$ treatment, however, this relationship was not observed among 20-21 and 22-23 kg live weight categories. $Herb_{CW}$ lambs in all weight categories grew faster than $Grass_{CW}$ lambs ($P<0.05$).

In 2015, within each herbage treatment lamb live weight categories had no effect ($P>0.05$; Table 2.3) on lamb liveweight gain between L46 and L88. Further, the liveweight gain of $Herb_{EW}$ lambs in all weight categories was less than that of $Herb_{CW}$ and $Grass_{CW}$ lambs.

2.4.6 Percentage of lambs that reached slaughter weight

In 2014, the percentage of lambs that reached the target slaughter weight of 35 kg was greater in $Herb_{EW}$ (47%) and $Herb_{CW}$ (42%) treatment groups than in $Grass_{CW}$ (11%) treatment group. In 2015, the percentage of lambs that reached the target slaughter weight of 35 kg did not differ ($P>0.05$) among treatment groups.

Table 2.3 Effect of herbage treatment; herb early weaning (Herb$_{EW}$), herb conventional weaning (Herb$_{CW}$) and grass conventional weaning (Grass$_{CW}$) on liveweight gain of lambs of different initial live weights (16-17, 18-19, 20-21, and 22-23 kg) between day 54 and 93 after the midpoint of lambing in 2014 (L54-L93), and between L46 and L88 in 2015 (least-squares mean ±SEM).

Herbage treatment	Live weight category (kg)									Overall liveweight gain (g/day)	Percentage of lambs that reached slaughter weight
	N	16-17	N	18-19	n	20-21	n	22-23	n		
	Liveweight gain (g/day) 2014 (L54- L93)										
Herb$_{EW}$	8	325±18^{bc}	14	352±12^{cd}	14	375±12de	8	375±17de	44	360±7^{b}	47 (33-61)^{b}
Herb$_{CW}$	12	381±14de	17	388±12^{e}	12	410±14^{e}	5	386±22de	46	392±7^{c}	42 (29-60)^{b}
Grass$_{CW}$	8	298±19^{ab}	24	282±10^{a}	4	310±23^{abc}	8	313±15^{abc}	44	292±7^{a}	11 (5-24)^{a}
	2015 (L46-L88)										
Herb$_{EW}$	16	272±11^{a}	14	287±11^{ab}	6	281±17^{ab}	4	295±20^{abc}	40	282±7^{a}	8 (2-21)
Herb$_{CW}$	11	305±12^{bc}	20	333±9^{cd}	9	305±14^{bc}	4	316±24^{bcd}	44	318±6^{b}	16 (8-30)
Grass$_{CW}$	9	307±14^{bcd}	13	326±11^{cd}	14	342±11^{d}	4	335±21^{cd}	40	327±6^{b}	23 (12-38)

[a,b,c,d,e] Means with different superscripts are significantly different within each year ($P<0.05$)

2.5 Discussion

The aim of the present study was to determine the effect of early weaning onto a herb-clover mix and the relationship of live weight of lambs at early weaning with their liveweight gain after weaning. In both years of the study, lambs weaned early onto the herb-clover mix achieved liveweight gains greater than 280 g/day, which was greater than previously reported liveweight gains (220 g/day) for commercially-reared and conventionally-weaned twin lambs in New Zealand (Litherland & Lambert 2000).

The first hypothesis was that early weaning lambs onto a herb-clover mix would not compromise their liveweight gain compared to those remaining unweaned on ryegrass-clover based pasture. This was found to be the case in 2014. Golding et al. (2011) and Somasiri et al. (2015b,c; 2016) reported that the liveweight gain of lambs after conventional weaning on herb-clover mixes were greater than the liveweight gain of lambs on ryegrass-clover based pasture. In 2015, however, the liveweight gain of lambs weaned early onto herb-clover mix was 35 g/day lower than unweaned lambs on ryegrass-clover based pasture. Cranston et al. (2016) reported that lambs weaned early onto a plantain-clover mixed sward grew more slowly than lambs that remained with their dam, either on ryegrass-clover based pasture or plantain-clover mixed swards. In both years of the study, all herbages were managed to provide *ad-libitum* intakes, excess of 1200 kg DM/ha (Cranston et al. 2015b; Morris & Kenyon 2004). Further, animals were managed using a rotational grazing system to allow for comparison of the effect of herbage treatments on lamb liveweight gains but not the effect of herbage mass differences on lamb liveweight gains over time. Variable liveweight gain responses of lambs may have been due to the ME content in herb-clover mixes being 1.2-1.6 MJ/kg DM greater than the ME content in ryegrass-clover based pasture in 2014 but similar to that of ryegrass-clover based pasture in 2015. This was likely due to the greater chicory content observed in 2014 compared to 2015 (57 vs 39%) which is preferred by lambs over plantain (Pain et al. 2010).

In 2014, the clover content was greater in the herb-clover mixes (14.1%) than in ryegrass-clover based pasture (0.9%) but in 2015, similar values were observed between ryegrass-clover based pasture (10.5%) and herb-clover mixes (11.8%). Moreover, the clover content of ryegrass-clover based pasture was greater in 2015 than 2014. Lambs are known to selectively graze white clover (Pain et al. 2010; Rutter 2006). White clover has high nutritional value, and lambs achieve greater liveweight gains when fed it is as a pure clover sward (Fraser & Rowarth 1996). Cave et al. (2015) reported that the growth of individual species in herb-clover mix varies according to the environmental conditions, thus resulting in a change in the botanical composition and nutritional composition between seasons. These results suggest that early weaning onto a herb-clover mix is likely to be more beneficial under conditions in which the clover content is low in grass, and chicory content is high in a herb-clover mix.

In 2014, the mean liveweight gain of early weaned heavy lambs (20-21 and 22-23 kg weight categories) on herb-clover mixes was 50 g/day greater than those of lighter lambs (16-17 kg weight category). Further, in both years, early-weaned lighter lambs (16-17 kg weight category) grew more slowly on the herb-clover mixes than their counterparts that were not weaned early. This suggests that lambs less than 18 kg may be better left with their dams. In 2014, early weaned lambs that were a minimum of 18 kg, however, gained greater live weights than those on ryegrass-clover based pasture, although this was not observed in 2015. These findings suggest that when ME and /or clover content of ryegrass-clover based pasture is above, or similar, to herb-clover mixes, lambs are best left with their dams to maintain their liveweight gains.

2.6 Conclusion

Overall, the results of this study suggest that lambs can be weaned early onto herb-clover mixes and achieve high liveweight gains after weaning. Weaning lambs less than 18 kg onto herb-clover mix can result in lower lamb liveweight gains compared to lambs weaned at a conventional age. Therefore, weaning of lambs less than 18 kg onto herb-clover mix should be undertaken with caution. Further, the benefits, in terms of lamb liveweight gain, when grazing a herb-clover mix compared to ryegrass-clover based pasture are most apparent when clover content in ryegrass-clover based pasture is low, regardless of whether lambs are weaned early or not.

CHAPTER 3

A comparison of liveweight gain of lambs weaned early onto a herb-clover mix and weaned conventionally onto a ryegrass-clover based pasture and herb-clover mix

Publications:

Ekanayake WEMLJ, Corner-Thomas RA, Cranston LM, Kenyon PR, Morris ST 2019. A comparison of liveweight gain of lambs weaned early onto a herb-clover mixed sward and weaned conventionally onto a ryegrass-clover pasture and herb-clover mixed sward. Asian-Australasian Journal of Animal Sciences 32: 201-208.

3.1 Abstract

The aim of the present study was to identify the impact of early weaning of lambs at approximately 58 days age onto a herb-clover mix on the liveweight gain of lambs and their dams. In 2015, twin-born lambs that weighed a minimum of 16 kg (n=134) were randomly allocated to one of three treatments:(i) Early-weaned (58 days after the midpoint of lambing) onto an unrestricted allowance (>1200 kg DM/ha) of herb-clover mix (HerbEW); (ii) Lambs + dams unweaned onto an unrestricted allowance of herb-clover mix until conventional weaning (95 days after the midpoint of lambing) (HerbCW); (iii) Lambs + dams unweaned onto an unrestricted allowance of ryegrass-clover based pasture until conventional weaning (GrassCW). In 2016, twin-born lambs that weighed a minimum of 16 kg (n=170) were randomly allocated to one of four treatments: i, ii, iii (similar to 2015) and (iv) Lambs + dams unweaned onto a restricted allowance (<1200 kg DM/ha) of ryegrass-clover based pasture until conventional weaning (93 days after the midpoint of lambing) (Restricted-GrassCW). In 2015, liveweight gain of lambs from L58 to L95 in the HerbCW and GrassCW treatments did not differ ($p>0.05$), but were 64 g/day greater ($p<0.05$) than HerbEW lambs. In 2016, HerbCW lambs had greater ($p<0.05$) liveweight gains from L51 to L93 than GrassCW followed by HerbEW and Restricted-GrassCW lambs. HerbEW lambs had 90 g/day greater liveweight gains than Restricted-GrassCW lambs In 2015, liveweight gain of ewes between L58 to L95 in the HerbEW treatment were greater than both GrassCW and HerbCW treatment, while in 2016, liveweight gain of ewes between L51 to L93 in the GrassCW and HerbCW treatments did not differ ($p>0.05$) but were greater ($p<0.05$) than those of the HerbEW and Restricted-GrassCW treatments. These results indicate that when ryegrass-clover based pasture supply can be maintained at unrestricted intake level,

there may be no benefit of weaning lambs early. However, at restricted pasture conditions lambs can achieve greater liveweight gains when weaned early onto a herb-clover mix.

3.2 Introduction

A herb-clover mix containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*) has been shown to produce greater herbage yields than a ryegrass-clover based pasture in New Zealand (Navarrete et al. 2013; Somasiri 2014). The herb-clover mix has higher nutritional quality and digestibility than ryegrass-clover based pasture (Cranston et al. 2015a; Somasiri 2014; Somasiri et al. 2015c; 2016). These traits of herb-clover mix can result in improved ewe performance (liveweight gain, body condition, milk production; Golding et al. 2008; Kenyon et al. 2010) and pre- and post-weaning lamb growth (Corner-Thomas et al. 2014b; Hutton et al. 2011; Somasiri 2014) compared to a ryegrass-clover based pasture.

In lamb production systems in New Zealand, lambs are conventionally weaned between 10 and 14 weeks of age onto ryegrass-clover based pastures (Geenty 2010). Under this system, and especially during seasons where there is a shortage of ryegrass-clover based pasture, the ewe and lamb can become competitors for the same feed resource (Kenyon & Webby 2007). As a result, the liveweight gain of lambs prior to conventional weaning can be disappointing. In New Zealand, the production of ryegrass-clover based pasture can be limited in late-spring and early-summer (Baars et al. 1990; Coop 1986). Therefore, offering *ad-libitum* feeding conditions (>1200 kg DM/ha; Cranston et al. 2015b; Morris & Kenyon 2004) can be a challenge for sheep farmers. Early weaning onto high quality herbages such a herb-clover mix during such conditions is a potential option to reduce overall feed demand, and allow both lambs and ewes to achieve higher liveweight gains (Kenyon & Webby 2007; Somasiri et al. 2016). Therefore, the aim of the present study was to identify the impact of early weaning of lambs at approximately seven weeks of age onto a herb-clover mix on lamb and ewe liveweight gains. Over a two-year period, unrestricted and restricted pasture conditions were utilized. It was hypothesised that a positive effect for both ewe and her lamb was more likely to occur from early weaning when pasture availability was low.

3.3 Materials and methods

3.3.1 Experimental design

This study was conducted at Massey University's Tuapaka farm 15 km east of Palmerston North, New Zealand (latitude 40°20'S, longitude 175°43'E). All manipulations were approved by the Massey University Animal Ethics Committee. Romney ewes (n=65 in 2015 and n=83 in 2016) which conceived during a 17-day breeding period and that were diagnosed bearing twin fetuses using transabdominal ultrasound were enrolled in the study. Throughout the gestation period, within each year, ewes were managed as one mob under commercial farming conditions. Lambing began on 02 September in 2015 and 31 August in 2016. All lambs were weighed, ear tagged and identified to their dam within 24 h of birth.

From the midpoint of lambing (L1) until the onset of the study (L58 and L51 in 2015 and 2016, respectively), lambs and ewes were managed as a single mob on a ryegrass-clover based pasture. Lambs were drenched with an oral anthelmintic (Ancare 'Matrix' triple combination drench, Merial Ancare, Manukau City, New Zealand) every 28 days, as per standard practice in New Zealand, beginning at L26 in 2015 and L25 in 2016 at a rate of 1 mL per 5 kg live weight to reduce the risk of worm burden. Ewes that successfully reared both lambs to minimum of 16 kg were subsequently enrolled in the study and allocated to one of three weaning treatments at L58 in 2015 and four weaning treatments at L51 in 2016 (Table 3.1). Two ryegrass-clover based pastures were used in 2016 to allow for comparison of the impact of early weaning onto herb-clover mix when pasture conditions were either restricted or unrestricted. In 2015, ewes in HerbEW treatment were managed with unweaned ewes and lambs on ryegrass-clover based pasture at unrestricted allowance (GrassCW) until conventional weaning. In 2016, ewes in HerbEW treatment were managed with unweaned ewes and lambs on ryegrass-clover based pasture at restricted allowance (Restricted-GrassCW) until conventional weaning. Early weaned lambs (HerbEW) on the herb-clover mix were managed with unweaned ewes and lambs (HerbCW) in both years. Within 1-2 hr of birth, ewes develop an exclusive bond with their lambs and reject any alien lambs that attempt to suck for the remainder of the lactation (Nowak & Poindron 2006). Therefore, it is unlikely that weaned lambs were able to steal milk from unweaned ewes.

Table 3.1 Summary of the experimental design including the number of lambs allocated to each weaning treatments

Year	Weaning treatment	Number of lambs	Treatment description
2015			
	HerbEW[A]	44	Early weaning 58 days after the mid-point if lambing (L58) with unrestricted allowance of herb-clover mix (plantain, red clover and white clover) until conventional weaning at L95
	HerbCW[B]	42	Lambs + dams offered an unrestricted allowance of herb-clover mix from L58 until conventional weaning at L95
	GrassCW[C]	44	Lambs + dams offered unrestricted allowance of ryegrass-clover based pasture (Ryegrass, red clover and white clover) from L58 until conventional weaning at L95
2016			
	HerbEW[D]	44	Early weaning at L51with unrestricted allowance of herb-clover mix until conventional weaning at L93
	HerbCW[E]	42	Lambs + dams offered an unrestricted allowance of herb-clover mix from L51 until conventional weaning at L93
	GrassCW[F]	38	Lambs + dams offered unrestricted allowance of ryegrass-clover based pasture from L51 until conventional weaning at L93
	Restricted-GrassCW[G]	40	Lambs + dams offered with restricted allowance of ryegrass-clover based pasture from L51 until conventional weaning at L93

Unrestricted allowance (>1200 kg DM/ha), Restricted allowance (<1200 kg DM/ha), CW (conventional weaning at 95 and 93 days after the midpoint of lambing in 2015 and 2016, respectively), EW (early weaning at 58 and 51 days after the midpoint of lambing in 2015 and 2016, respectively). A Early weaned ewes were managed with unweaned ewes and lambs in GrassCW in 2015 until conventional weaning. D Early weaned ewes were managed with unweaned ewes and lambs in Restricted-GrassCW in 2016 until conventional weaning. A+D Early weaned lambs were managed with unweaned ewes and lambs in HerbCW in both years.

Three paddocks of herb-clover mix (7.8 ha in total land area) and three paddocks of ryegrass-clover based pasture (5.2 ha in total land area) were used for the duration of the study. Lambs and ewes allocated to treatments at L58 in 2015 and L51 in 2016 were rotationally grazed. During the experimental period, pastures were managed to provide *ad-libitum* intakes (>1200 kg DM/ha) except in the Restricted-GrassCW treatment in 2016 which was managed to maintain masses below 1200 kg DM/ha to provide restricted supply of pasture. Ewes and lambs remained on their respective herbages until conventional weaning (at 95 and 93 days from midpoint of lambing in 2015 and 2016, respectively). Lambs and ewes assigned to the HerbEW and HerbCW treatments were gradually introduced to herb-clover mix over a four-day period from L55 in 2015 and from L48 in 2016) of increasing duration on each day (i.e. 4 h day 1, 8 h day 2, 12 h day 3, and 24 h day 4) prior to the onset of the main study. Lambs and ewes were weighed within 1 h of being removed from pasture on L58, L81 and L95 in 2015 and L51, L82 and L93 in 2016. Post-grazing sward surface heights were maintained by grazing down to a minimum of five cm in the ryegrass-clover based pasture and seven cm in the herb-clover mix to provide unrestricted access to herbage. In the Restricted-GrassCW treatment group pasture was maintained below five cm to restrict intakes. In 2015, n=1 and n=2 lambs either lost their identification tag or died in HerbCW and GrassCW treatments, respectively. In 2016, n=2, n=4, n=3, and n=1 lambs lost their tag or died in HerbEW, HerbCW, GrassCW and Restricted-GrassCW treatments, respectively. No ewes died in 2015. In 2016, one ewe either lost her tag or died in HerbEW treatment.

3.3.2 Herbage measurements

Herbage masses were measured on L58, L81 and L95 in 2015 and, L51, L69 and L82 in

2016. Four random quadrat cuts (0.1 m^2 each) were taken to ground level from each herbage type at each sampling date using an electric shearing hand-piece (Frame 1993). Samples were then oven dried to a constant weight to estimate herbage mass. In addition, four composite herbage samples each containing ten grab samples per herbage type, were also collected at each sampling date to determine the botanical and nutritional composition (Frame 1993). To determine the botanical composition of the herbage, a subsample from each composite sample (4 per herbage type) was sorted into each species (herb-clover mix: plantain, chicory, red clover, white clover; ryegrass-clover based pasture: ryegrass, clover; other grasses (combined), weeds, and dead matter) and then oven dried and weighed to determine the botanical composition. The remaining sample was then frozen, dried, ground, sieved (1 mm) and analysed using *in vitro* methods to determine the nutritional quality. These measures included dry matter digestibility (DMD, Roughan & Holland 1977), digestible organic matter digestibility (DOMD, Roughan & Holland 1977), percentage crude protein (CP; “Dumas” procedure, AOAC method 968.06 using a Leco total combustion method, LECO Corporation, St. Joseph, MI, USA). Percentage acid detergent fibre (ADF) was analysed by a Tecator Fibretec System (Robertson & Van Soest 1981). Metabolisable energy (ME) content of herbages was calculated from the organic matter digestibility (DOMD×0.16 MJ/Kg DM, Roughan & Holland 1977).

3.3.3 Statistical analysis

Lamb live weight and liveweight gain were subjected to analysis of variance using the MIXED procedure in SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US). The analysis was performed separately for each year due to the differences in the days on which measurements were collected. The effect of treatment on the liveweight gain of lambs and ewes were analysed using individual animals within year as the experimental unit allowing for repeated measures. The effect of weaning treatment on lamb live weight and liveweight gain were analysed using a model that included the fixed effects of weaning treatment and sex of lamb. The exact age of lambs at the start of the treatments was included in the model as a covariate but was found not to be significant ($p>0.05$), and therefore it was removed from the model. Ewe live weights were analysed in a model that included the fixed effects of measurement time, weaning treatment and the interaction between measurement time and weaning treatment. Ewe body condition score was analysed using the GENMOD procedure in SAS that included the fixed effect of weaning treatment.

Botanical composition data were analysed using the MIXED procedure, with a model including the fixed effects of plant species and measurement time. Herbage quality data were analysed using the MIXED procedure, with a model including the fixed effects of pasture type and measurement time. Means were separated using LSD procedure ($p<0.05$) in proc GLM. Herbage masses were analysed using a model that included weaning treatment and measurement times as fixed effects.

3.4 Results

3.4.1 Botanical composition, herbage mass and nutritional quality of herbage

The mean percentage of plantain in herb-clover mix was 63.3±5.6 % and 36.5±7.7 % in 2015 and 2016, respectively (Figure 3.1). Mean percentage of total clover in herb-clover mix was 16.4±3.3 % in 2015 and 9.2±4.3 % in 2016. The remaining portion of the herb-clover mix was made up of grasses and weeds. In both years, ryegrass was the dominant species (77-93% in 2015 and 64-87% in 2016) in the ryegrass-clover based pasture (Figure 3.1). The mean percentage of clover in ryegrass-clover based pasture was 6.1±1.2% in 2015 and 1.0±0.2% in 2016. The remaining portion of the ryegrass-clover based pasture was made up of weeds.

In 2015 the herbage mass of unrestricted herb-clover mix and ryegrass-clover based pasture was maintained at a minimum of 2647±349 and 1352±349 kg DM/ha, respectively. In 2016, the herbage mass was maintained at a minimum of 3501±275 for unrestricted herb-clover mix and 1353±390 kg DM/ha for ryegrass-clover based pasture. The minimum and maximum masses of restricted ryegrass-clover based pasture in 2016 were 799±390 and 935±318 kg DM/ha, respectively.

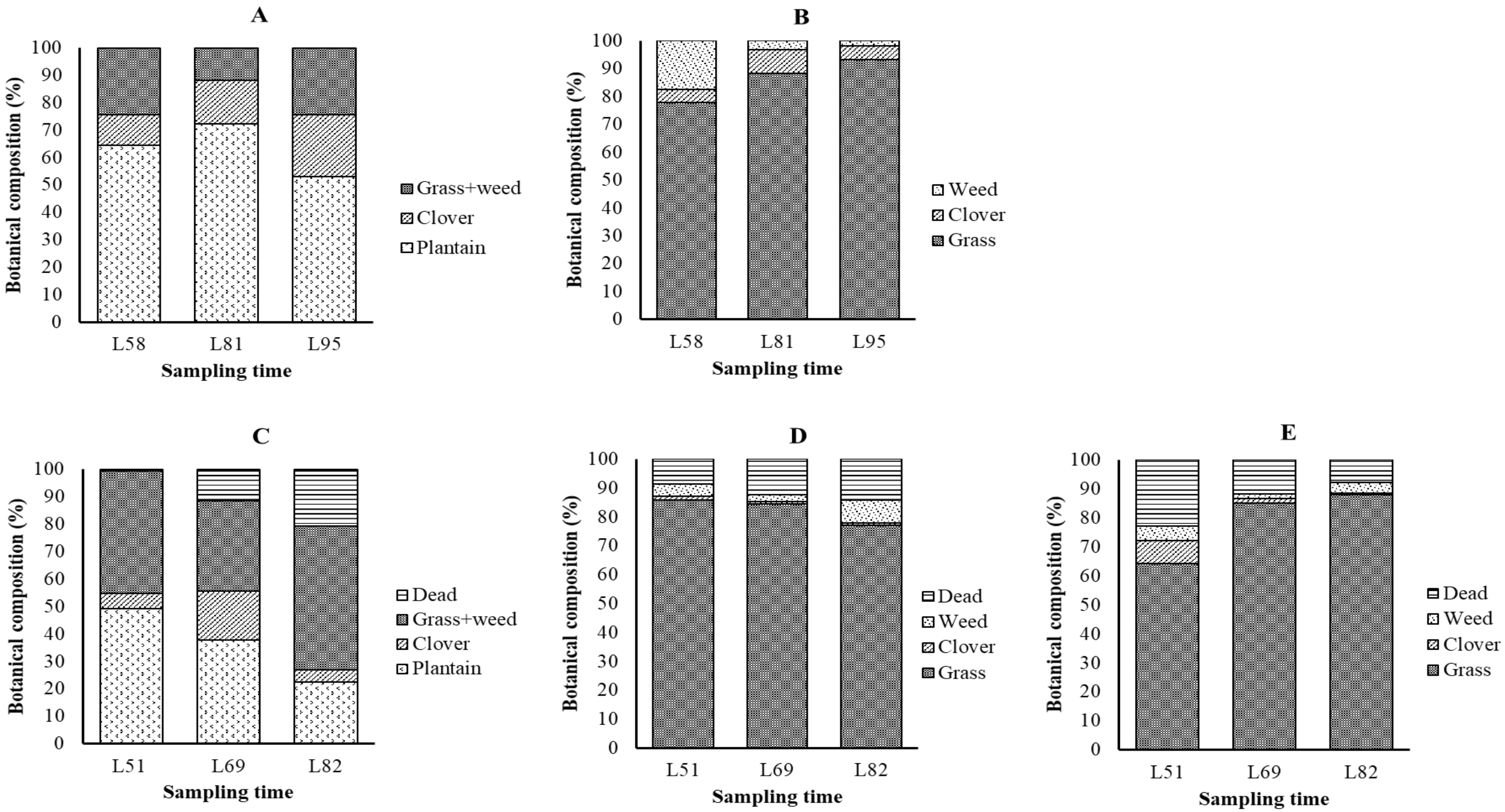

Figure 3.1 The botanical composition of herbages; herb-clover mix in 2015 (A), ryegrass-clover based pasture in 2015 (B), herb-clover mix in 2016 (C), ryegrass-clover based pasture in 2016 (D) and restricted-ryegrass-clover based pasture in 2016 (E). L, days after the midpoint of lambing; on herbage A and C there were HerbEW lambs, HerbCW lambs, and their ewes. On herbage B there were GrassCW lambs and their ewes and HerbEW ewes. On herbage D there were GrassCW lambs and their ewes. On herbage E there were Restricted-GrassCW lambs and their ewes and HerbEW ewes

In 2015, the CP content of ryegrass-clover based pasture at the start of the study was ~ 6% greater ($p<0.05$) than that of herb-clover mix (Table 3.2). At L95, however the reverse was observed and no difference ($p>0.05$) was observed at L81. The ADF content of ryegrass-clover based pasture and herb-clover mix at L58 and L81 did not differ ($p>0.05$), but at L95 ryegrass-clover based pasture had a ~11% greater ($p<0.05$) ADF content than the herb-clover mix. DMD of herb-clover mix was greater ($p<0.05$) than that of ryegrass-clover based pasture at all three measurement times. The ME content of ryegrass-clover based pasture was 0.3 MJ/kg greater ($p<0.05$) than herb-clover mix at L58 but reverse was observed at L81 and L95.

In 2016, at the start of the study the CP content of herb-clover mix and restricted-ryegrass-clover based pasture did not differ ($p>0.05$) but was ~ 4% less ($p<0.05$) than that of ryegrass-clover based pasture (Table 3.2). At L69 and L82, the CP content of restricted-ryegrass-clover based pasture, ryegrass-clover based pasture and herb-clover mix differed ($p<0.05$). At L51, the ADF content of ryegrass-clover based pasture and herb-clover mix did not differ ($p>0.05$) but was ~ 6% less ($p<0.05$) than that of restricted-ryegrass-clover based pasture. At L69, the ADF content of herb-clover mix did not differ ($p>0.05$) from the ADF content of ryegrass-clover based pasture but was ~ 5% greater ($p<0.05$) than that of restricted-ryegrass-clover based pasture. At L82, the ADF content of herb-clover did not differ ($p>0.05$) from the ADF content of restricted-ryegrass-clover based pasture but was ~ 10% greater ($p<0.05$) than ryegrass-clover based pasture. At L51, DMD of herb-clover mix was ~ 4 % greater ($p<0.05$) than that of ryegrass-clover based pasture which in turn was ~ 5% greater ($p<0.05$) than that of restricted-ryegrass-clover based pasture. At L69, DMD of herbage did not differ ($p>0.05$) between the three treatments. At L82, DMD of ryegrass-clover based pasture and restricted-ryegrass-clover based pasture did not differ ($p>0.05$) but was ~ 2% greater ($p<0.05$) than that of herb-clover mix. At the start of the study (L51), the ME content of all treatments differed ($p>0.05$). The ME content of herb-clover mix (10.2±0.3 MJ/Kg) was greater ($p<0.05$) than that of ryegrass-clover based pasture (9.1±0.3 MJ/Kg) followed by restricted-ryegrass-clover based pasture (7.5±0.3 MJ/Kg). At L69, the ME content of herb-clover mix (9.1±0.3 MJ/Kg). and restricted-ryegrass-clover based pasture (8.5±0.3 MJ/Kg). did not differ ($p>0.05$) but was greater ($p<0.05$) than ryegrass-clover based pasture (8.2±0.3 MJ/Kg).. At the end of the study the ME did not differ ($p>0.05$) between herbages.

Table 3.2 Dry matter (DM), crude protein (CP), acid detergent fibre (ADF), dry matter digestibility (DMD) and metabolisable energy content (ME) of herbages (Herb-clover mix, Grass-clover pasture and Restricted-grass-clover pasture) collected 58, 81, 95 days after the midpoint of lambing in 2015 (L58, L81, L95) and on L51, L69, L82 in 2016 (least-squares mean ±SEM)

Year	Herbage		CP (% DM)	ADF (% DM)	DMD (%)	ME (MJ/Kg)
2015						
	Herb-clover mix[A]	L58	$15.9^{b}\pm1.1$	$19.9^{a}\pm1.1$	$73.0^{e}\pm0.5$	$10.1^{c}\pm0.1$
		L81	$14.7^{b}\pm1.1$	$31.0^{c}\pm1.1$	$69.2^{c}\pm0.5$	$10.1^{c}\pm0.1$
		L95	$15.0^{b}\pm1.1$	$23.3^{b}\pm1.1$	$73.0^{e}\pm0.5$	$10.7^{e}\pm0.1$
	Ryegrass-clover based pasture[B]	L58	$22.6^{c}\pm1.1$	$21.4^{ab}\pm1.1$	$71.0^{d}\pm0.5$	$10.4^{d}\pm0.1$
		L81	$15.3^{b}\pm1.1$	$32.5^{c}\pm1.1$	$64.4^{b}\pm0.5$	$9.7^{b}\pm0.1$
		L95	$12.1^{a}\pm1.1$	$35.0^{d}\pm1.1$	$59.5^{a}\pm0.5$	$8.9^{a}\pm0.1$
2016						
	Herb-clover mix[C]	L51	$16.4^{b}\pm1.2$	$25.5^{a}\pm2.5$	$70.0^{e}\pm1.0$	$10.2^{e}\pm0.3$
		L69	$13.1^{a}\pm1.2$	$37.6^{d}\pm2.5$	$63.3^{abc}\pm1.0$	$9.1^{d}\pm0.3$
		L82	$12.8^{a}\pm1.2$	$38.2^{d}\pm2.5$	$62.0^{a}\pm1.0$	$8.5^{bcd}\pm0.3$
	Ryegrass-clover based pasture[D]	L51	$20.2^{cd}\pm1.2$	$28.3^{ab}\pm2.5$	$66.1^{d}\pm1.0$	$9.1^{d}\pm0.3$
		L69	$17.9^{bc}\pm1.2$	$35.6^{cd}\pm2.5$	$62.5^{ab}\pm1.0$	$8.2^{ab}\pm0.3$
		L82	$16.4^{b}\pm1.2$	$27.5^{ab}\pm2.5$	$64.2^{bcd}\pm1.0$	$9.0^{cd}\pm0.3$
	Restricted-ryegrass-clover based pasture[E]	L51	$16.4^{b}\pm1.2$	$34.7^{cd}\pm2.9$	$61.7^{a}\pm1.0$	$7.5^{a}\pm0.3$
		L69	$20.6^{d}\pm1.2$	$31.0^{bc}\pm2.5$	$63.2^{abc}\pm1.0$	$8.5^{bcd}\pm0.3$
		L82	$19.6^{cd}\pm1.2$	$38.3^{d}\pm2.5$	$64.6^{cd}\pm1.0$	$8.2^{abc}\pm0.3$

SEM, standard error of the mean; L, days after the midpoint of lambing; CP, crude protein; ADF, acid detergent fibre; DMD, dry matter digestibility; ME; metabolisable energy content

[a-e] Means with different superscripts are significantly different within each year ($p<0.05$). HerbEW lambs and HerbCW lambs and their ewes were managed on herbage A and C. GrassCW lambs and their ewes and HerbEW ewes were managed on herbage B. GrassCW lambs and their ewes were managed on herbage D. Restricted-GrassCW lambs and their ewes and HerbEW ewes were managed on herbage E

3.4.2 Lamb live weight and liveweight gain

In 2015, the live weight of lambs at L81 and L95 in HerbCW and GrassCW treatment groups did not differ ($p>0.05$) but were 2 to 3 kg greater ($p<0.05$) than lambs in HerbEW (Table 3.3). The liveweight gain of lambs between L58 and L95 in the HerbCW (325±7 g/day) and GrassCW (321±7 g/day) treatments did not differ ($p>0.05$) but were greater ($p<0.05$) than those of HerbEW lambs (251±7 g/day).

In 2016, the live weight of lambs in HerbCW treatment group was greater ($p<0.05$) at L82 (1 to 5 kg) and L93 (2 to 7 kg) than lambs in HerbEW, GrassCW and Restricted-GrassCW treatment groups (Table 3.3). Live weight at L82 and L93 of HerbEW and GrassCW lambs did not differ ($p>0.05$) but were 4 to 5 kg greater ($p<0.05$) than those of Restricted-GrassCW lambs. Lamb liveweight gains between L51 and L93 of HerbCW (307±8 g/day) lambs was greater ($p<0.05$) than those of GrassCW (263±7 g/day), HerbEW (240±7 g/day) and Restricted-GrassCW (153±7 g/day) lambs.

Table 3.3 Effect of weaning treatment; HerbEW, HerbCW, GrassCW in 2015 and HerbEW, HerbCW, GrassCW and Restricted-GrassCW in 2016 on live weight of lambs 58, 81, 95 days after the midpoint of lambing in 2015 (L58, L81, L95) and at L51, L82, L93 in 2016 (least-squares mean ±SEM)

Year	Weaning treatment	Live weight (kg)					
		n		n		n	
2015							
			L58		L81		L95
	HerbEW^{A}	44	22.5 ± 0.3^{a}	43	27.8 ± 0.3^{b}	44	31.8 ± 0.3^{d}
	HerbCW^{B}	42	22.5 ± 0.3^{a}	42	29.8 ± 0.3^{c}	41	34.5 ± 0.3^{e}
	GrassCW^{C}	44	22.7 ± 0.3^{a}	42	30.0 ± 0.3^{c}	42	34.2 ± 0.3^{e}
2016							
			L51		L82		L93
	HerbEW^{D}	44	19.9 ± 0.3^{a}	43	28.4 ± 0.3^{d}	42	30.0 ± 0.3^{e}
	HerbCW^{E}	42	20.0 ± 0.3^{a}	39	30.5 ± 0.3^{e}	38	33.0 ± 0.3^{f}
	GrassCW^{F}	38	19.7 ± 0.3^{a}	38	28.5 ± 0.3^{d}	35	30.8 ± 0.3^{e}
	Restricted-GrassCW^{G}	40	19.5 ± 0.3^{a}	39	24.8 ± 0.3^{b}	39	25.8 ± 0.3^{c}

SEM, standard error of the mean; L, days after the midpoint of lambing; HerbEW, Early weaning onto unrestricted allowance of herb-clover mix; HerbCW, Lambs + dams offered an unrestricted allowance of herb-clover mix until conventional weaning; GrassCW, Lambs + dams offered unrestricted allowance of ryegrass-clover based pasture until conventional weaning; Restricted-GrassCW, Lambs + dams offered with restricted allowance of ryegrass-clover based pasture until conventional weaning

$^{a\text{-}f}$ Means with different superscripts are significantly different within each year. Lambs in A and D grazed with lambs and their ewes in B and E in 2015 and 2016, respectively. Lambs in B and E grazed with their ewes in B (2015) and E (2016). In 2015, lambs in C grazed with C ewes and A ewes. In 2016, F lambs grazed with their ewes in F. Lambs in G grazed with G ewes and D ewes

3.4.3 Ewe live weight, liveweight gain and body condition score

In 2015, at L58 the live weight of ewes in each treatment group did not differ ($p>0.05$) (Table 3.4). At L81, live weight of ewes in HerbEW (77.8±1.8 kg) did not differ ($p>0.05$) from ewes in GrassCW (73.7±1.7 kg), but they were heavier ($p<0.05$) than HerbCW ewes (72.6±1.7 kg). At L95, HerbEW ewes were 4 kg heavier ($p<0.05$) than both HerbCW and GrassCW ewes. Liveweight gain between L58 and L95 of HerbEW ewes (211±18 g/day) were greater ($p<0.05$) than both GrassCW (142±18 g/day) and HerbCW ewes (130±19 g/day).

In 2016, live weight of ewes at L51 did not differ ($p>0.05$) (Table 3.4). Live weight of ewes in HerbCW and GrassCW treatment groups at L82 and L93 did not differ ($p>0.05$). HerbCW ewes were 6 and 8 kg heavier ($p<0.05$) than HerbEW and Restricted-GrassCW ewes, respectively. Liveweight gain between L51 and L93 of GrassCW (65±21 g/day) and HerbCW (61±20 g/day) ewes did not differ ($p>0.05$) but were greater ($p<0.05$) than those of HerbEW (-35±20 g/day) and Restricted-GrassCW (-102±20 g/day) ewes. In both years, body condition score of ewes in each treatment group did not differ ($p>0.05$) (Table 3.5).

Table 3.4 Effect of weaning treatment; HerbEW, HerbCW, GrassCW in 2015 and HerbEW, HerbCW, GrassCW and Restricted-GrassCW in 2016 on live weight of ewes 58, 81, 95 days after the midpoint of lambing in 2015 (L58, L81, L95) and at L51, L82, L93 in 2016 (least-squares mean ±SEM)

Year	Weaning treatment	Live weight (kg)					
		n		n		n	
2015							
			L58		L81		L95
	HerbEW^{A}	22	72.0±1.8^{a}	21	77.1±1.8^{de}	22	79.8±1.8^{e}
	HerbCW^{B}	21	70.8±1.7^{a}	20	72.6±1.7^{abc}	21	75.5±1.7^{bcd}
	GrassCW^{C}	22	70.6±1.7^{a}	22	73.7±1.7^{abcd}	22	75.9±1.7^{cd}
2016							
			L51		L82		L93
	HerbEW^{D}	22	70.8±1.6^{b}	22	68.8±1.6^{ab}	21	69.5±1.6^{ab}
	HerbCW^{E}	21	72.3±1.9^{bcd}	19	75.4±1.9^{d}	21	74.8±1.9^{cd}
	GrassCW^{F}	19	69.4±1.8^{ab}	19	72.2±1.9^{bcd}	19	72.2±1.9^{bcd}
	Restricted-GrassCW^{G}	20	71.3±2.0^{bc}	20	66.9±2.0^{a}	20	67.0±2.0^{a}

SEM, standard error of the mean; L, days after the midpoint of lambing; HerbEW, Early weaning onto unrestricted allowance of herb-clover mix; HerbCW, Lambs + dams offered an unrestricted allowance of herb-clover mix until conventional weaning; GrassCW, Lambs + dams offered unrestricted allowance of ryegrass-clover based pasture until conventional weaning; Restricted-GrassCW, Lambs + dams offered with restricted allowance of ryegrass-clover based pasture until conventional weaning

$^{a-d}$ Means with different superscripts are significantly different within each year. A ewes grazed with C lambs and their ewes in 2015. B and E ewes grazed with their lambs in B and E, respectively. C ewes grazed with C lambs and A ewes in 2015. In 2016, D ewes grazed with G ewes and their lambs. F ewes grazed with their lambs in F. G ewes grazed with their lambs in G and D ewes

Table 3.5. Effect of weaning treatment; HerbEW, HerbCW, GrassCW in 2015 and HerbEW, HerbCW, GrassCW and Restricted-GrassCW in 2016 on body condition score of ewes 58, 81, 95 days after the midpoint of lambing in 2015 (L58, L81, L95) and at L51, L82, L93 in 2016 (Results displayed as mean with 95% confidence interval)

Year	Weaning treatment	Body condition score					
		n		n		n	
2015							
			L58		L81		L95
	HerbEW[A]	22	2.5 (1.9-3.2)	21	2.9 (2.3-3.8)	22	2.9 (2.3-3.7)
	HerbCW[B]	21	2.5 (1.9-3.3)	20	2.8 (2.1-3.6)	21	2.7 (2.1-3.5)
	GrassCW[C]	22	2.6 (2.0-3.3)	22	2.8 (2.2-3.6)	22	2.7 (2.1-3.5)
2016							
			L51		L82		L93
	HerbEW[D]	22	3.0 (2.4-3.8)	22	2.9 (2.3-3.7)	21	3.0 (2.4-3.8)
	HerbCW[E]	21	2.9 (2.3-3.7)	19	2.9 (2.3-3.8)	21	3.1 (2.4-3.9)
	GrassCW[F]	19	2.8 (2.2-3.6)	19	3.1 (2.3-4.0)	19	2.9 (2.3-3.8)
	Restricted-GrassCW[G]	20	2.7 (2.0-3.5)	20	2.6 (1.9-3.4)	20	2.5 (1.9-3.3)

SEM, standard error of the mean; L, days after the midpoint of lambing; HerbEW, Early weaning onto unrestricted allowance of herb-clover mix; HerbCW, Lambs + dams offered an unrestricted allowance of herb-clover mix until conventional weaning; GrassCW, Lambs + dams offered unrestricted allowance of ryegrass-clover based pasture until conventional weaning; Restricted-GrassCW, Lambs + dams offered with restricted allowance of ryegrass-clover based pasture until conventional weaning

[a-c] Means with different superscripts are significantly different within each year. A ewes grazed with C lambs and their ewes in 2015. B and E ewes grazed with their lambs in B and E, respectively. C ewes grazed with C lambs and A ewes in 2015. In 2016, D ewes grazed with G ewes and their lambs. F ewes grazed with their lambs in F. G ewes grazed with their lambs in G and D ewes

3.5 Discussion

This study aimed to identify the impact of early weaning of lambs approximately 51-58 days after the midpoint of lambing using a herb-clover mix. Early weaned ewes were managed with unweaned ewes and lambs in grass-clover mix until conventional weaning age (in 2015 on unrestricted ryegrass-clover based pasture and in 2016 on restricted-ryegrass-clover based pasture). In the New Zealand system during late spring to early summer it is unlikely farmers would choose to graze weaned ewes on a high value herbage as a mechanism for them to gain body condition. This is because lambs are given the priority to achieve high liveweight gains to allow for an earlier slaughter date. Therefore, in this study early weaned lambs were managed with unweaned ewes and lambs on herb-clover mix in both years.

In 2015, when both herbages allowed for unrestricted intakes (>1200 kg DM/ha) early weaning onto herb-clover mix resulted in 60 g/day slower growth rates of lambs compared to those weaned at a conventional age on the herb-clover mix and ryegrass-clover based pasture. Pasture supply is often restricted during late spring and early summer in New Zealand (Baars et al. 1990; Coop 1986), therefore, in 2016 an additional weaning treatment; restricted allowance of ryegrass-clover based pasture (<1200 kg DM/ha) was added to simulate this scenario. In 2016, lambs weaned early onto the herb-clover mix had 90 g/day greater liveweight gains than lambs left with their dams on restricted ryegrass-clover based pasture. Restricted pasture availability during late lactation is known to have negative impacts on milk yield (Peart 1970), length of lactation (Cannas 2004) and lamb liveweight gain (Muir et al. 2000). Therefore, early weaning onto alternative forages such as a herb-clover mix can be a useful management tool if the availability of ryegrass-clover based pasture is likely to result in the ewe and lamb becoming competitors (Kenyon & Webby 2007). It is important to note that in both years of the study, growth of early weaned lambs on unrestricted allowance of pasture to conventional weaning was greater than 240 g/day. Therefore, even in years in which pasture availability was not limiting early weaning onto a herb-clover mix can be utilised to achieve acceptable lamb growth rates. The slower growth of early-weaned lambs onto herb-clover mix compared to lambs kept with their dams on herb-clover mix until conventional weaning is likely explained by the removal of milk from the lamb's diet which cannot be compensated for. This is further exuberated by the potential for increased milk production by HerbCW ewes as Hutton et al. (2011) reported that ewes grazing a herb-clover mix showed an increased milk production.

The current study design allowed for a comparison of the growth of lambs weaned conventionally on unrestricted herb-clover mix and ryegrass-clover based pasture. Previous studies have shown that lambs on a herb-clover mix have heavier weaning weights than lambs on grass-clover mix at conventional weaning (Hutton et al. 2011). In this study, there was no difference in weaning weights of lambs at conventional weaning in 2015 but in 2016 lambs on herb-clover mix were 3 kg heavier than those on ryegrass-clover based pasture. A potential explanation for these results could be the herbage quality and composition between years. In general, studies that have reported greater growth of lambs post weaning onto herb-clover mix, when the ME of herb-clover mix was clearly greater than that of the ryegrass-clover based pasture (Golding et al. 2011; Somasiri 2014). In this study, however, the ME of herb-clover mix and ryegrass-clover based pasture at times did not differ and when they did, the differences were small. The clover content of ryegrass-clover based pasture was higher in 2015 than in 2016. In 2016, the ryegrass-clover based pasture contained some dead plant matter that was not present in 2015 and only 1% clover. Lambs are known to selectively graze higher ME plant components (white clover) amongst a ryegrass-clover based pasture (Pain et al. 2010; Rutter 2006), and achieve greater liveweight gains when grazing as a pure clover sward (Fraser & Rowarth 1996). Given the lower clover content in ryegrass-clover based pasture in 2016 than in 2015, it would have been difficult for lambs to select white clover, which has higher digestibility and ME, and to support high liveweight gains in 2016. Combined these compositional changes could help explain why there was no difference of lamb growth in 2015 in herb-clover mix and ryegrass-clover based pasture but there was in 2016.

Early weaning of lambs was advantageous for the ewe in 2015 but this was not found to be the case in 2016. The difference of ewe live weight between years was likely due to the feed offered to ewes post early weaning in each year. In 2015, weaned ewes were offered unrestricted ryegrass-clover based pasture while in 2016 they were offered restricted ryegrass-clover based pasture post weaning. Nonetheless, no differences in ewe body condition score were observed in both years. Combined these results suggest that early weaning can be used as a tool to increase ewe liveweight gain if ewes are subsequently offered unrestricted pastures. The loss of live weight per day on the restricted conditions in 2016, however, was not as large as the live weight per day of unweaned ewes under same feeding conditions. This is likely due to the removal of lactational nutritional requirement from weaned ewes. This indicates that under conditions where the ryegrass-clover based pasture supply is restricted early weaning can still be advantageous for the ewe.

3.6 Conclusion

The effect of early weaning onto a herb-clover mix on lamb liveweight gain was more apparent when pasture conditions were restricted. This suggests that lambs can be weaned early onto herb-clover mix to gain 90 g/day greater live weight under conditions where ryegrass-clover based pasture supply is restricted than unrestricted. Early weaning of lambs onto herb-clover mix can also have positive effect on ewe liveweight gain particularly under unrestricted supply of ryegrass-clover based pasture conditions. Combined these results indicate that ewes and lambs are most likely to benefit from early weaning onto a herb-clover mix if ryegrass-clover based pastures are restricted.

CHAPTER 4

Early weaning of lambs at a minimum live weight of 14 kg, at approximately 50 days of age, onto a herb-clover mix

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4.1 Abstract

This experiment investigated the impact of weaning lambs early at a minimum live weight of 14 kg, at ~ 50 days of age, onto a herb-clover mix compared with lambs that remained unweaned on a ryegrass-clover based pasture or a herb-clover mix until conventional weaning (at ~ 99 days of age). Twin sets of lambs, both with a minimum live weight of 14 kg, were randomly allocated to one of three treatments: (1) Early weaning of lambs onto a herb-clover mix ($Herb_{EW}$); (2) Ewes and lambs grazing a herb-clover mix until conventional weaning ($Herb_{CW}$); and (3) Ewes and lambs grazing a ryegrass-clover based pasture until conventional weaning ($Grass_{CW}$). In 2016, $Herb_{EW}$ lambs had slower ($p<0.05$) growth rates to conventional weaning than $Grass_{CW}$ lambs and were 800 g lighter ($p<0.05$) by conventional weaning age. In 2017, however, both $Herb_{EW}$ and $Grass_{CW}$ had similar ($p>0.05$) growth rates and did not differ ($p>0.05$) in live weight at conventional weaning. $Herb_{CW}$ lambs had a greater ($p<0.05$) growth rates than both $Herb_{EW}$ and $Grass_{CW}$ lambs in both years. Lambs weaned early onto a herb-clover mix have the potential to achieve live weights similar to lambs unweaned on ryegrass-clover based pasture.

4.2 Introduction

In New Zealand, herb-clover mixes containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*) have been shown to increase the growth rate of both unweaned (Corner-Thomas et al. 2014b; 2018a; Hutton et al. 2011) and weaned lambs (Somasiri et al. 2015a,b,c; 2016), and are commonly being used by farmers (Kemp et al. 2010). Greater live weight gains of lambs between 4 and 8 months of age on the herb-clover mix are driven by greater nutritional quality (greater protein and metabolisable energy content and low fibre content) of the herb-clover mix compared with ryegrass-clover based pastures (Cranston et al. 2015a; Somasiri et al. 2015a,b,c; 2016). It is also known that white clover, chicory and red clover have greater feeding values than ryegrass (Waghorn et al. 2007). Studies indicate that chicory, red clover, and plantain are preferred by lambs compared to ryegrass (Pain et al. 2010). Lambs offered herb-clover mixes, therefore, achieve greater voluntary feed intakes compared with lambs offered ryegrass pastures (Kerr 2000).

Early weaning of lambs approximately at 50 days of age is a potential tool farmers can use to reduce the overall flock feed demand, by allowing ewes to cease lactating and return to a maintenance feeding levels. Lambs weaned early at a minimum live weight of 16 kg, at approximately 60 days of age, onto a herb-clover mix have been shown to achieve similar or improved liveweight gains to conventional weaning compared with lambs that remained with their dam on a ryegrass-clover based pasture (Chapter 3). It is, however, not known if lambs can be successfully weaned at a younger age (~ 50 days of age) and minimum live weight of 14 kg onto a herb-clover mix and still achieve similar growth rates as unweaned lambs grazing on a ryegrass-clover based pasture. The aim of the current study was to determine the impact of weaning lambs at approximately 50 days of age, at a minimum live weight of 14 kg, onto a herb-clover mix on the live weight of lambs and their dams. It was hypothesised that lambs weaned early onto a herb-clover mix could achieve similar growth rates to unweaned lambs on ryegrass-clover based pasture.

4.3 Materials and methods

4.3.1 Herbage treatments

Eight paddocks (13.85 ha in total land area) of herb-clover mix containing plantain, chicory, red clover and white clover and seven paddocks (15.85 ha in total land area) of ryegrass-clover based pasture (perennial ryegrass [*Lolium perenne* L.] and white clover) were used for the duration of the study in both years (2016 and 2017). During the experimental period (August to December), both herbage types were managed using rotational grazing to provide *ad-libitum* intakes such that post-grazing surface heights were maintained at a minimum of five cm in the ryegrass-clover based pasture and seven cm in the herb-clover mix (Cranston et al. 2015b; Morris & Kenyon 2014).

4.3.2 Experimental design

This study was conducted at Massey University's Keeble farm, 5 km southeast of Palmerston North, New Zealand (40°24' S and 175°36' E) and replicated over two consecutive springs. All manipulations were approved by the Massey University Animal Ethics Committee. Romney ewes that had conceived during a 17-day breeding period and diagnosed as twin bearing using transabdominal ultrasound were selected for the study. Throughout the gestation period, within each year, ewes were managed as a single flock (group) under commercial pastoral farming conditions as part of a larger flock on ryegrass-clover based pastures.

Lambing began on 26th of August in 2016 and 28th of August in 2017. All lambs were weighed, ear tagged and identified to their dam within 24 h of birth. In each year, lambs and ewes were managed as a single mob on a ryegrass-clover based pasture from the start of lambing (L0) until the start of the study (L53 in 2016 and L51 in 2017). At L26 in 2016 and L25 in 2017, lambs were drenched with an oral triple combination drench (Matrix, Merial Ancare, Manukau City, New Zealand) and thereafter at 28-day intervals throughout the study at a rate of 1 mL per 5 kg live weight to control internal parasites as per standard practice in New Zealand.

Twin rearing ewes (n = 75 in 2016 and n = 61 in 2017) with twin sets of lambs of which both had a minimum live weight of 14 kg at L50 in 2016 (range 14.2 to 22.5 kg; n = 150) and at L48 in 2017 (range 14.0 to 24.0 kg; n = 122) were allocated to one of three treatments: (1) Early weaning of lambs at ~ 50 days of age onto a herb-clover mix ($Herb_{EW}$, n = 54 in 2016 and n = 46 in 2017); (2) Ewes and lambs grazing a herb-clover mix until conventional weaning at ~ 99 days of age ($Herb_{CW,}$ n = 46 in 2016 and n = 42 lambs in 2017 and 2017); and (3) Ewes and lambs grazing a ryegrass-clover based pasture until conventional weaning ($Grass_{CW,}$ n = 50 in 2016 and n = 34 lambs in 2017). Twin sets of lambs were allocated to treatments using a stratified sampling procedure, based on their live weights, in order minimize the differences of average lamb live weights between groups.

Lambs and ewes allocated to treatments were managed as a single group on a ryegrass-clover based pasture from the start of lambing (L0) until the start of the study (L53 in 2016 and L51 in 2017). Beginning at L50 in 2016 and from L48 in 2017, $Herb_{EW}$ or $Herb_{CW}$ lambs were gradually introduced to herb-clover mix over a four-day period by increasing the duration on the herb-clover mix each day (i.e. 4 h day 1, 8 h day 2, 12 h day 3, and 24 h day 4), prior to the start of the main study. At L50 in 2016 and at L48 in 2017, average live weights of lambs were similar among treatments (17.1±0.8, 17.3±0.6, 16.9±0.4 kg in $Herb_{EW,}$ $Herb_{CW,}$ $Grass_{CW}$ in 2016, and 17.9±1.5, 18.4±1.3, 18.6±1.1 kg in $Herb_{EW,}$ $Herb_{CW,}$ $Grass_{CW}$ in 2017, respectively). The study began at L53 and L51 in 2016 and 2017, respectively. Once early weaning had been conducted the ewes in the $Herb_{EW}$ treatment were managed with $Grass_{CW}$ ewes and lambs on ryegrass-clover based pasture to L99 in both years. Lambs in the $Herb_{EW}$ treatment were managed with $Herb_{CW}$ ewes and lambs on herb-clover mix to L99 in both years. Ewes develop an exclusive bond with their lambs within 1 to 2 hr of birth, and avoid fostering alien lambs for the remainder of the lactation (Nowak & Poindron 2006). Therefore, it is unlikely that $Herb_{CW}$ ewes would have allowed $Herb_{EW}$ lambs to suck milk.

4.3.3 Animal measurements

Lambs and ewes were weighed within 1 h of removal from herbage at L53, L65 and L99 in 2016 and L51, L65 and L99 in 2017. Ewe body condition score (BCS), scale 1–5 including half units (Jefferies 1961), was assessed at each weighing by a single operator.

4.3.4 Herbage measurements

Herbage masses were measured at L47, L65 and L99 in both years of the study. Four random quadrat cuts (0.1 m^2 each) were taken to ground level from herb-clover mix and ryegrass-clover based pasture at each sampling date using an electric shearing hand-piece (Frame 1993). Samples were then oven dried to a constant weight to estimate herbage mass. In addition, four composite herbage samples each containing ten grab samples per herbage type, were also collected at each sampling date to determine the botanical and nutritional composition (Frame 1993). To determine the botanical composition of the herbage, a subsample from each composite sample (4 per herbage type) was sorted into each species (herb-clover mix: plantain, chicory, red clover, white clover; ryegrass-clover based pasture: ryegrass, clover; other grasses (combined), weeds, and dead matter) and then oven dried and weighed to determine the botanical composition. The remaining sample was then frozen, dried, ground, sieved (1 mm) and analysed using *in vitro* methods to determine the nutritional quality. These measures included dry matter digestibility (DMD, Roughan & Holland 1977), digestible organic matter digestibility (DOMD, Roughan & Holland 1977), percentage crude protein (CP; "Dumas" procedure, AOAC method 968.06 using a Leco total combustion method, LECO Corporation, St. Joseph, MI, USA). Percentage acid detergent fibre (ADF) was analysed by a Tecator Fibretec System (Robertson & Van Soest 1981). Metabolisable energy (ME) content of herbages was calculated from the organic matter digestibility (DOMD×0.16 MJ/Kg DM, Roughan & Holland 1977).

4.3.5 Statistical analysis

Analyses were performed separately for each year due to the differences in the days on which measurements were collected. The individual animal was considered to be the experimental unit for the analyses. Live weight of lambs and ewes were subjected to analysis of variance for repeated measures using the MIXED procedure in SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US). The model for lamb live weight included the fixed effects of weaning treatment ($Herb_{EW}$, $Herb_{CW}$, $Grass_{CW}$), sex of lamb (male, female), measurement date and the two-way interaction of treatment and measurement date. The live weight and age of lambs at the start of the treatment period was included in the model as covariates. The model for lamb liveweight gain included the fixed effects of weaning treatment and sex of lamb. The live weight of lambs at the start of the treatment period was included in the model as a covariate.

The model for ewe live weight included the fixed effects of weaning treatment and measurement date and two-way interaction of treatment and measurement date. The duration from lambing to the start of the treatments was included as a covariate. The model for ewe liveweight gain included the fixed effect of weaning treatment. The live weight of the ewe at the start of the treatment period was included in the model as a covariate. Ewe body condition score was analysed using a Poisson distribution and logit transformation using the GENMOD procedure in SAS. The model included the fixed effects of weaning treatment and measurement date.

Botanical composition of herbages were analysed using the MIXED procedure in SAS. The model included fixed effects of plant species and measurement date. Herbage masses were analysed using a model that included herbage type and measurement date as fixed effects. The nutritional quality data were analysed using the MIXED procedure in a model that included the fixed effects of herbage type and measurement date. In 2016, one lamb died in each of the $Herb_{EW}$ and $Herb_{CW}$ treatments and no lambs died in 2017. In the tables presented, the number of lambs and ewes reported vary between weighing dates due to data recording errors resulting in missing data.

4.4 Results

4.4.1 Botanical composition, herbage mass and nutritional quality of herbage

The combined percentage of chicory and plantain in the herb-clover mix was greater ($p<0.05$) in 2016 (73%) than in 2017 (53%) (Figure 4.1). Total clover (red clover and white clover) in the herb-clover mix did not differ ($p>0.05$) between years. Percentage of ryegrass in the ryegrass-clover based pasture was greater ($p<0.05$) in 2017 (34±5.3%) than in 2016 (19±8.7%). Percentage of total clover in the ryegrass-clover based pasture was 1.7±0.7% in 2017 and 2.2±0.8 in 2016. The combined percentage of other grass species was greater ($p<0.05$) in 2016 (64±2.5%) than in 2017 (51±1.8%).

In both years, the herbage mass of herb-clover mix was ~ 1400 kg DM/ha greater ($p<0.05$) than that of ryegrass-clover based pasture at the start of the study (L47, Table 4.1). Thereafter, herbage mass between herb-clover mix and ryegrass-clover based pasture did not differ ($p>0.05$).

In 2016, at L47, the CP content of herb-clover mix was 1.7% greater ($p<0.05$) than ryegrass-clover based pasture. At L65 and L99, however, CP content of herb-clover mix did not differ ($p>0.05$) from that of ryegrass-clover based pasture (Table 4.1). At L47, L65 and L99, the NDF content of herb-clover mix was 16 to 30% lower ($p<0.05$) than that of ryegrass-clover based pasture. At L47, L65 and L99 the DMD and ME of herb-clover mix were greater ($p<0.05$, ~ 8% and ~1.6 MJ/kg, respectively) than that of ryegrass-clover based pasture. The ADF content of herb-clover mix, however, did not differ ($p>0.05$) from that of ryegrass-clover based pasture at L47, L65 and L99.

In 2017, the CP content of herb-clover mix was 5.3% greater ($p<0.05$) than that of ryegrass-clover based pasture at L47, but did not differ ($p>0.05$) at L65 and L99. At L47, L65 and L99, the NDF content of herb-clover mix was 14 to 21% greater ($p<0.05$) and

DMD was 6 to 9% lower ($p<0.05$) than that of ryegrass-clover based pasture. The ADF content of herb-clover mix did not differ ($p>0.05$) from that of ryegrass-clover based pasture at L47 and L65, but was 7 % greater ($p<0.05$) at L99. The ME of ryegrass-clover based pasture was ~ 1.5 MJ/kg greater ($p<0.05$) than that of herb-clover mix at L47 and L99 but was similar ($p>0.05$) at L65.

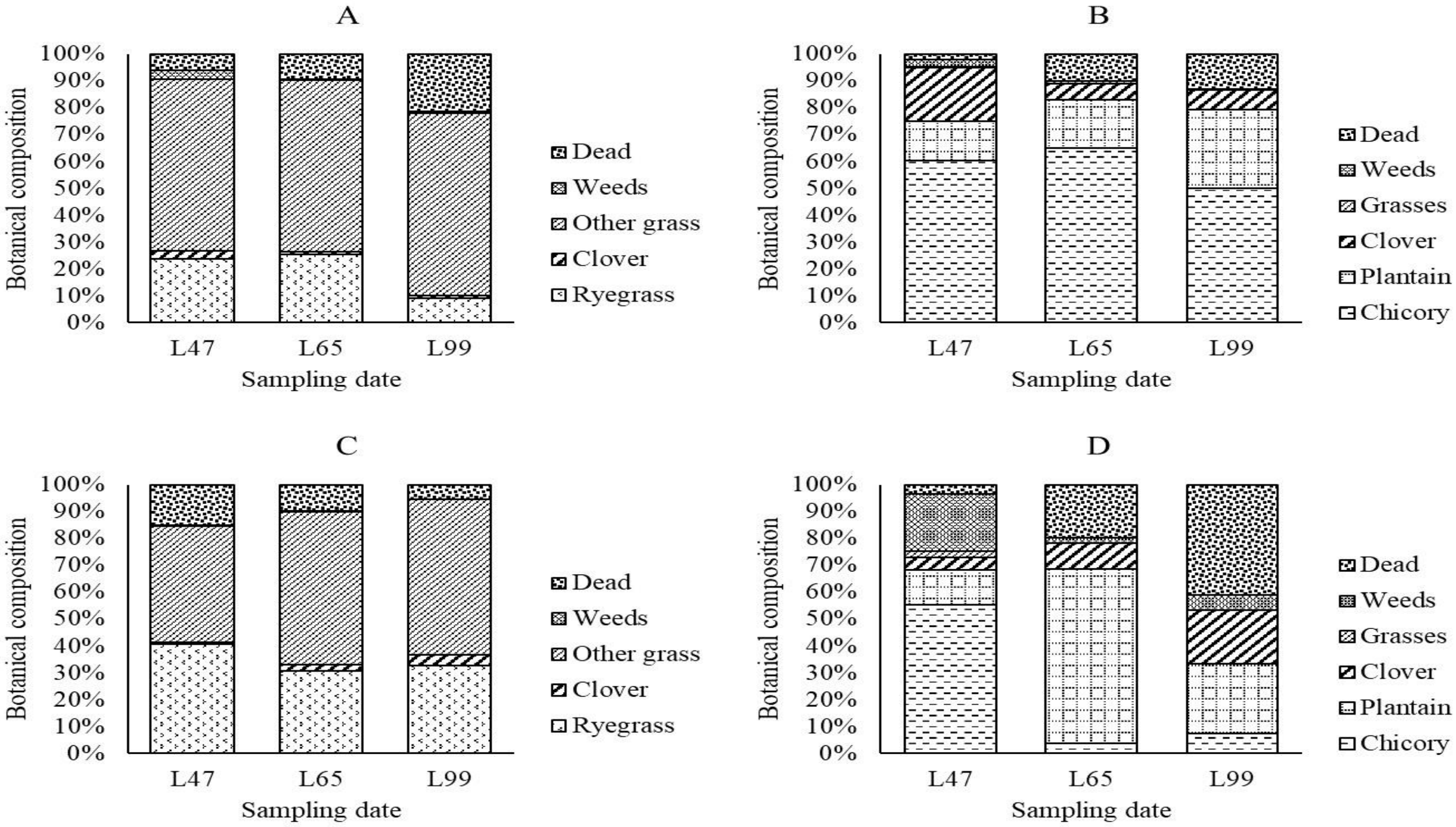

Figure 4.1 The botanical composition of the components of ryegrass-clover based pasture (A), herb-clover mix (B) in 2016 and ryegrass-clover based pasture (C) and herb-clover mix (D) in 2017 on 47, 65 and 99 days after the midpoint of lambing in 2016 and 2017 (L47, L65 and L99)

Table 4.1 Herbage mass (HM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), dry matter digestibility (DMD) and metabolisable energy content (ME) of herbage samples collected 47, 65, 99 days after the midpoint of lambing in 2016 and 2017 (L47, L65, L99) (least-squares mean ±SEM)

Year	Herbage type	Study day	HM (kg DM/ha)	CP (%)	NDF (%)	ADF (%)	DMD (%)	ME (MJ/Kg)
2016	Herb-clover mix	L47	3782^{b}±481	21.2^{c}±1.0	32.1^{a}±2.0	26.9^{a}±2.3	72.9^{e}±0.8	10.6^{d}±0.1
		L65	3362^{ab}±481	15.3^{a}±1.0	40.8^{b}±2.0	33.3^{ab}±2.3	70.3^{d}±0.8	10.2^{c}±0.1
		L99	3390^{ab}±481	13.4^{a}±1.0	45.6^{c}±2.0	36.2^{b}±2.3	68.5^{d}±0.8	9.8^{c}±0.1
	Ryegrass-clover based pasture	L47	2362^{a}±481	19.5^{b}±1.0	51.0^{d}±2.0	29.9^{a}±2.3	65.0^{c}±0.8	9.2^{b}±0.1
		L65	3308^{ab}±481	14.3^{a}±1.0	60.7^{e}±2.0	39.0^{b}±2.3	62.4^{b}±0.8	8.6^{a}±0.1
		L99	3270^{ab}±481	13.5^{a}±1.0	62.0^{e}±2.0	38.3^{b}±2.3	60.7^{a}±0.8	8.7^{a}±0.1
2017	Herb-clover mix	L47	3221^{b}±481	17.3^{c}±1.0	46.7^{c}±2.0	26.5^{a}±2.3	65.7^{b}±0.8	9.5^{ab}±0.1
		L65	2994^{ab}±481	9.8^{a}±1.0	48.4^{c}±2.0	25.5^{a}±2.3	65.4^{ab}±0.8	9.8^{bc}±0.1
		L99	3048^{b}±481	15.5^{bc}±1.0	53.7^{d}±2.0	30.5^{b}±2.3	63.4^{a}±0.8	9.1^{a}±0.1
	Ryegrass-clover based pasture	L47	1899^{a}±481	12.0^{a}±1.0	32.7^{a}±2.0	26.2^{a}±2.3	72.0^{d}±0.8	10.6^{d}±0.1
		L65	2659^{ab}±481	10.4^{a}±1.0	39.7^{b}±2.0	29.6^{a}±2.3	68.9^{c}±0.8	10.1^{c}±0.1
		L99	2680^{ab}±481	13.0^{b}±1.0	31.4^{a}±2.0	23.7^{a}±2.3	73.1^{d}±0.8	10.6^{d}±0.1

$^{a-e}$ Means with different superscripts within columns are significantly different across years and treatments ($p<0.05$)

4.4.2 Lamb live weight and liveweight gain

In 2016, the live weights of lambs in the $Herb_{EW}$, $Herb_{CW}$ and $Grass_{CW}$ treatments did not differ ($p>0.05$) at the start of the study (L53, Table 4.2). At L65, the live weight of lambs in $Herb_{CW}$ and $Grass_{CW}$ did not differ ($p>0.05$) but were ~ 2 kg heavier ($p<0.05$) than lambs in $Herb_{EW}$. At L99, the live weight of $Herb_{CW}$ lambs was ~ 2 kg greater ($p<0.05$) than $Grass_{CW}$ lambs, which in turn was 3 kg heavier ($p<0.05$) than $Herb_{EW}$ lambs. Lamb liveweight gains between L53 and L99 in $Herb_{CW}$ treatment (299±7 g/day) were greater ($p<0.05$) than $Grass_{CW}$ (263±6 g/day), which in turn were greater ($p<0.05$) than $Herb_{EW}$ (247±6 g/day).

In 2017, at the start of the study (L51), the live weight of lambs in $Herb_{EW}$, $Herb_{CW}$ and $Grass_{CW}$ did not differ ($p>0.05$). The live weight of lambs at L65 in $Herb_{CW}$ and $Grass_{CW}$ treatments did not differ ($p>0.05$) but were ~ 1.5 kg heavier ($p<0.05$) than $Herb_{EW}$ lambs. At L99, the live weight of $Herb_{CW}$ lambs (34.5±0.4 kg) was greater ($p<0.05$) than both the $Herb_{EW}$ (30.5±0.4 kg) and $Grass_{CW}$ lambs (30.2±0.4 kg), which did not differ ($p>0.05$). The liveweight gains of lambs between L51 and L99 in $Herb_{CW}$ treatment (317±8 g/day) were greater ($p<0.05$) than both $Herb_{EW}$ and $Grass_{CW}$ treatments, which did not differ ($p>0.05$) (239±7 g/day and 231±9 g/day, respectively). Data suggested that early weaning had no effect on lamb survival as in 2016 one lamb died in each of the $Herb_{EW}$ and $Herb_{CW}$ treatments and no lambs died in 2017.

Table 4.2 Live weight of lambs in Herb$_{EW}$, Herb$_{CW}$, Grass$_{CW}$ treatments at L53, L65 and L99 in 2016 and at L51, L65 and L99 in 2017 (least-squares mean ±SEM)

Herbage treatment	Lamb live weight (kg)					
	n		n		n	
	2016					
		L53		L65		L99
Herb$_{EW}$	54	19.3±0.1[a]	53	21.5±0.2[b]	53	30.7±0.3[d]
Herb$_{CW}$	45	19.5±0.1[a]	46	23.6±0.2[c]	45	33.2±0.4[f]
Grass$_{CW}$	48	19.4±0.1[a]	49	23.3±0.2[c]	50	31.5±0.3[e]
	2017					
		L51		L65		L99
Herb$_{EW}$	46	19.0±0.2[a]	45	21.5±0.2[b]	46	30.5±0.4[d]
Herb$_{CW}$	42	19.3±0.2[a]	41	23.0±0.2[c]	42	34.5±0.4[e]
Grass$_{CW}$	34	19.1±0.2[a]	33	22.7±0.2[c]	34	30.2±0.4[d]

L, days after the midpoint of lambing; Herb$_{EW}$, Early weaning onto unrestricted allowance of herb-clover mix; Herb$_{CW}$, Lambs and dams offered an unrestricted allowance of herb-clover mix until conventional weaning age; Grass$_{CW}$, Lambs and dams offered unrestricted allowance of ryegrass-clover based pasture until conventional weaning age

[a-f] Means with different superscripts are significantly different within each year and treatments

In each year, lambs in Herb$_{EW}$ grazed with lambs and their ewes in Herb$_{CW}$. Lambs in Grass$_{CW}$ grazed with both Grass$_{CW}$ and Herb$_{EW}$ ewes

4.4.3 Ewe live weight, liveweight gain and body condition score

In 2016, at the start of the study (L53), the live weights of ewes in each treatments did not differ ($p>0.05$) (Table 4.3). At both L65 and L99, the live weights of $Herb_{EW}$ and $Herb_{CW}$ ewes did not differ ($p>0.05$) but were 3 to 5 kg greater ($p<0.05$) than $Grass_{CW}$ ewes. The liveweight gain between L53 and L99 of $Herb_{EW}$ ewes (192±15 g/day) and $Herb_{CW}$ ewes (173±15 g/day) did not differ ($p>0.05$) but was greater ($p<0.05$) than $Grass_{CW}$ ewes (76±16 g/day).

In 2017, at the start of the study (L51), the live weights of ewes in each treatments did not differ ($p>0.05$) (Table 4.3). At L65, ewe live weights did not differ ($p>0.05$) between all three treatments. At L99, $Herb_{CW}$ ewes (76.4±1.5 kg) were heavier ($p<0.05$) than both $Herb_{EW}$ (73.3±1.4 kg) and $Grass_{CW}$ ewes (72.4±1.6 kg), which did not differ ($p>0.05$). The liveweight gains between L51 and L99 of $Herb_{EW}$ ewes (112±16 g/day) and $Herb_{CW}$ ewes (145±17 g/day) did not differ ($p>0.05$) but were greater ($p<0.05$) than $Grass_{CW}$ ewes (78±19 g/day).

In 2016, at L53, the BCS of ewes did not differ ($p>0.05$) between treatments (Table 4.4). At L65 and L99, the BCS of $Herb_{EW}$ ewes was greater ($p<0.05$) than that of $Herb_{CW}$ ewes, which in turn was greater ($p<0.05$) than $Grass_{CW}$ ewes. In 2017, at L51, BCS of ewes did not differ ($p>0.05$) between treatments. At L65, the BCS of $Herb_{CW}$ and $Grass_{CW}$ ewes did not differ ($p>0.05$) but was lower ($p<0.05$) than $Herb_{EW}$ ewes. At L99, the BCS of $Herb_{EW}$ and $Herb_{CW}$ did not differ ($p>0.05$) but was greater ($p<0.05$) than the $Grass_{CW}$ ewes.

Table 4.3 Live weight of ewes in Herb$_{EW}$, Herb$_{CW}$, Grass$_{CW}$ treatments at L53, L65 and L99 in 2016 and at L51, L65 and L99 in 2017 (least-squares mean ±SEM)

Herbage treatment	Ewe live weight (kg)					
	n		n		n	
	2016					
		L53		L65		L99
Herb$_{EW}$	27	71.3 ± 1.3^{a}	25	77.1 ± 1.3^{b}	25	80.3 ± 1.3^{c}
Herb$_{CW}$	23	72.2 ± 1.4^{ab}	23	76.5 ± 1.4^{b}	23	80.0 ± 1.4^{c}
Grass$_{CW}$	25	71.2 ± 1.3^{a}	24	73.6 ± 1.3^{a}	23	75.1 ± 1.4^{b}
	2017					
		L51		L65		L99
Herb$_{EW}$	23	67.9 ± 1.4^{a}	23	69.2 ± 1.4^{b}	22	73.3 ± 1.4^{b}
Herb$_{CW}$	21	69.4 ± 1.5^{ab}	20	70.5 ± 1.5^{b}	21	76.4 ± 1.5^{c}
Grass$_{CW}$	17	67.7 ± 1.6^{a}	16	69.2 ± 1.4^{ab}	17	72.4 ± 1.6^{b}

L, days after the midpoint of lambing; Herb$_{EW}$, Early weaning onto unrestricted allowance of herb-clover mix; Herb$_{CW}$, Lambs + dams offered an unrestricted allowance of herb-clover mix until conventional weaning age; Grass$_{CW}$, Lambs + dams offered unrestricted allowance of ryegrass-clover based pasture until conventional weaning age

$^{a-c}$ Means with different superscripts are significantly different within each year and treatments

In each year, Ewes in Herb$_{EW}$ grazed with lambs and their ewes in Grass$_{CW}$. Ewes in Herb$_{CW}$ grazed with their lambs and the weaned lambs in the Herb$_{EW}$ treatment

Table 4.4 Body condition score of ewes in the $Herb_{EW}$, $Herb_{CW}$, $Grass_{CW}$ treatments at L53, L65 and L99 in 2016 and at L51, L65 and L99 in 2017 (Results displayed as back transformed logit mean and 95% confidence interval)

Herbage treatment	Ewe body condition score					
	n		n		n	
	2016					
		L53		L65		L99
$Herb_{EW}$	26	2.3 (2.2-2.4)[a]	25	3.1 (2.9-3.3)[d]	25	3.4 (3.2-3.6)[e]
$Herb_{CW}$	23	2.1 (2.0-2.2)[a]	23	2.8 (2.6-2.9)[c]	23	3.0 (2.8-3.2)[d]
$Grass_{CW}$	25	2.1 (2.0-2.3)[a]	24	2.5 (2.4-2.6)[b]	23	2.5 (2.4-2.7)[b]
	2017					
		L51		L65		L99
$Herb_{EW}$	23	2.9 (2.8-3.1)[a]	23	3.3 (3.1-3.6)[b]	22	3.4 (3.2-3.5)[b]
$Herb_{CW}$	21	2.7 (2.5-2.9)[a]	20	2.8 (2.6-3.0)[a]	21	3.3 (3.1-3.4)[b]
$Grass_{CW}$	17	2.8 (2.6-3.0)[a]	16	2.6 (2.2-3.0)[a]	17	2.9 (2.7-3.1)[a]

L, days after the midpoint of lambing; $Herb_{EW}$, Early weaning onto unrestricted allowance of herb-clover mix; $Herb_{CW}$, Lambs and dams offered an unrestricted allowance of herb-clover mix until conventional weaning age; $Grass_{CW}$, Lambs and dams offered unrestricted allowance of ryegrass-clover based pasture until conventional weaning age

[a-d] Means with different superscripts are significantly different within each year and treatments

In each year, Ewes in $Herb_{EW}$ grazed with lambs and their ewes in $Grass_{CW}$. Ewes in $Herb_{CW}$ grazed with their lambs and the weaned lambs in the $Herb_{EW}$ treatment

4.5 Discussion

The aim of the present study was to determine the impact of weaning lambs early at a minimum live weight of 14 kg, at ~ 50 days of age, onto a herb-clover mix, on the liveweight of lambs and ewes compared to leaving lambs with their dams unweaned on a herb-clover mix or ryegrass-clover based pasture. Lambs weaned early onto a herb-clover mix at a minimum live weight of 14 kg had growth rates (239 to 247 g/day) that were similar to commercially-reared and conventionally-weaned twin lambs (220 g/day) in New Zealand (Litherland & Lambert 2000). These results suggest that lambs can be weaned at a minimum of 14 kg live weight, at ~ 50 days of age if provided with approximately 3000 kg DM/ha (pre-grazing) of herb-clover mix, without impacting their growth.

The liveweight gain of early-weaned lambs varied between years. In 2016, lambs weaned early onto a herb-clover mix were 800 g lighter at conventional weaning than lambs that remained with their dams on a ryegrass-clover based pasture. While in 2017, lambs weaned early had similar liveweight gains as lambs unweaned on ryegrass-clover based pasture resulting similar live weights at conventional weaning. This suggests that lambs weaned early onto a herb-clover mix have the potential to achieve similar live weights as lambs unweaned on ryegrass-clover based pasture at conventional weaning. The liveweight gain of early-weaned lambs in both years of the present study were similar to those previously reported for lambs weaned at a minimum live weight of 16 kg, at approximately 60 days of age, onto a herb-clover mix (Corner-Thomas et al. 2018b; Chapter 3).

The differences in growth rates between early-weaned lambs and unweaned lambs in 2016 and in 2017 is of interest as it might indicate when early weaning onto a herb-clover mix might be best utilized by farmers. In chapter 3, it was shown that when ryegrass-clover based pasture masses were lower than 1200 kg DM/ha, lamb growth rates were improved by early weaning onto a herb-clover mix. In the present study, pasture mass of ryegrass-clover based pasture was not limiting to lamb growth (Morris & Kenyon 2014), therefore, this does not explain the variation of growth rates observed between early-weaned lambs and unweaned lambs.

In the present study, the nutritional quality of herb-clover mix and ryegrass-clover based pastures differed between years. In 2016, when early-weaned lambs grew more slowly, ME of herb-clover mix was 1.1 to 1.6 MJ/kg DM higher than ryegrass-clover based pasture, while in 2017, when lambs growth did not differ, ME of herb-clover mix was 0.3 to 1.5 MJ/kg DM lower than ryegrass-clover based pasture. Combined these results suggest that the variation of ME is not the reason for the observed differences in lambs liveweight gains. In both years of the study, the CP of herb-clover mix was greater than ryegrass-clover based pasture at the start of the experiment, but did not differ throughout the remainder of the study period. Although, the CP of both herbages were at the lower end of that is required for lamb growth (15 to 18% CP) in both years (Hodgson & Brookes 2002), the variation in the CP content of the herb-clover mix and ryegrass-clover based pasture does not explain the variable liveweight gains.

The botanical composition of herbage changed between years within the herbage types, resulting in variation in the availability of the different plant species in both the herb-clover mix and ryegrass-clover based pasture. Lambs are known to preferentially select plant species when offered as cut-and-carried fresh forage (Pain et al. 2010) and under grazing conditions (Somasiri 2014). This variation in the botanical composition of herbage between years could affect the overall nutrient intake of lamb and thus their growth rates and their live weights at conventional weaning. The botanical composition of the herbages was determined using a quadrat-cut methods and therefore, may not reflect what the lambs were actually eating. In the future, to understand the potential causes of variation, studies should attempt to determine which plants the animals are choosing and undertake herbage quality analysis based on this. Although it is difficult to explain the variation of live weights based on the herbage information available, the live weight difference was 800 g in 2016 which is unlikely to have a significant impact on the overall production system.

In both years of the current study, unweaned lambs on herb-clover mix grew faster, and were heavier at conventional weaning, than lambs unweaned on ryegrass-clover based pasture. This has also been reported in previous studies (Corner-Thomas et al. 2018b; Chapter 3). In addition, Hutton et al. (2011) reported greater milk production of twin- and triplet-rearing ewes when grazing herb-clover mix compared with ryegrass-clover based pasture. Greater live weight gain of unweaned lambs on herb-clover mix than on ryegrass-clover based pasture could have been due to a greater milk production of ewes on herb-clover mix, resulting in greater lamb milk intake, increased herbage intake of lambs, the preferential selection of different plant species (Kerr 2000), or a combination of all these variables. Unfortunately, in the current study, neither milk nor herbage intake of lambs was measured.

In both years of the current study, unweaned lambs on herb-clover mix had 50 to 80 g/day greater liveweight gains than early-weaned lambs. This has also been found in previous studies (Corner-Thomas et al. 2018b; Chapter 3). Early-weaned lambs had access to only herbage post-weaning while unweaned lambs had access to both milk and herbage. This suggests that if there is enough herbage, lambs should be left with their dams on herb-clover mix to achieve the greatest growth rates. Early weaning onto a herb-clover mix, however, can allow farmers to graze lambs at much greater stocking density on herb-clover mix if only a small area is available, which is a common scenario in New Zealand, and thus can improve pasture utilisation efficiency.

Early weaned ewes had 30 to 100 g/day greater liveweight gains and BCS than unweaned ewes on ryegrass-clover based pasture in both years. Early-weaned ewes were managed along with unweaned ewes and lambs in ryegrass-clover based pasture until conventional weaning age, thus suggesting that their greater live weight and BCS were due to the cessation of lactation reducing their energy requirements (Kenyon & Webby 2007). Both weaned and unweaned ewes on herb-clover mix had similar liveweight gains to conventional weaning in both years of the study. Early weaning, therefore, can be used as a technique to improve ewe live weights and potentially their future performance as live weight at breeding has a positive impact on ewe reproductive performance which also in agreement with Corner-Thomas et al. (2015).

4.6 Conclusion

Lambs weaned early at a minimum live weight of 14 kg, at ~ 50 days of age, onto a herb-clover mix have the potential to achieve similar liveweight gains as lambs unweaned on ryegrass-clover based pasture. Early weaning can allow ewes to gain greater live weights and BCS compared to conventional weaning on ryegrass-clover based pasture. These results, therefore, indicate that early weaning of lambs is a management tool that farmers can use to potentially support twin-lamb growth and reduce the lactational requirements of ewes rather than weaning at the conventional age.

CHAPTER 5

Impact of prior exposure of lambs to a herb-clover mix prior to early weaning on their subsequent growth

5.1 Abstract

This experiment examined the impact of early exposure of lambs to a herb-clover mix from approximately 15 days of age, prior to early weaning at approximately ~ 45 days of age, on their subsequent growth. Twin sets of lambs, of which both had a minimum live weight of 14 kg, were randomly allocated to one of six treatments in 2017: (1) Lambs born and remained on ryegrass-clover based pasture until conventional weaning at 99 days of age (Grass-$Grass_{CW}$); (2) Lambs born on ryegrass-clover based pasture and early weaned onto herb-clover mix at 45 days of age (Grass-$Herb_{EW}$); (3) Lambs born on ryegrass-clover based pasture, transferred with their dam onto a herb-clover mix at 45 days of age and remained until conventional weaning (Grass-$Herb_{CW}$); (4) Lambs born on ryegrass-clover based pasture, transferred with their dam onto herb-clover mix at 15 days of age and early weaned onto herb-clover mix at 45 days of age (Grass-$Herb_{D15EW}$); (5) Lambs born on herb-clover mix and remained with their dam until conventional weaning at 99 days of age (Herb-$Herb_{CW}$); (6) Lambs born on herb-clover mix and weaned early onto herb-clover mix at 45 days of age (Herb-$Herb_{EW}$). In 2018, the Grass-$Grass_{CW}$ was omitted resulting in five treatment groups (Grass-$Herb_{EW,}$ Grass-$Herb_{CW,}$ Grass-$Herb_{D15EW}$, Herb-$Herb_{CW}$ and Herb-$Herb_{EW}$). In 2017, Herb-$Herb_{EW,}$ Grass-$Herb_{D15EW}$, Grass-$Herb_{EW}$ and Grass-$Grass_{CW}$ lambs had similar (p>0.05) growth rates. Similarly, in 2018, liveweight gain Herb-$Herb_{EW,}$ Grass-$Herb_{D15EW}$ and Grass-$Herb_{EW}$ did not differ (p>0.05). In both years, Herb-$Herb_{CW}$ lambs had 60 to 90 g/day greater (p<0.05) growth rates than Herb-$Herb_{EW,}$ Grass-$Herb_{D15EW}$ and Grass-$Herb_{EW}$ lambs. Ewe liveweight gain in 2017, showed that Grass-$Grass_{CW}$ ewes had slower (p<0.05) gains compared to ewes in all other treatment groups. In 2018, liveweight gain of ewes did not differ (p>0.05) between groups. Early exposure of lambs to herb-clover mix had no impact on the

subsequent growth of lambs. These results suggest that, early-weaned lambs on herb-clover mix have the potential to achieve similar liveweight gains as lambs unweaned on ryegrass-clover based pasture.

5.2 Introduction

Weaning lambs early onto a high-quality herbage is a management option that can reduce overall feed demand of ewes and allow them to gain body condition prior to the next breeding and support their lambs to achieve liveweight gain targets (Kenyon & Webby 2007; Muir et al. 2000). It has been shown that lambs weaned early, at a minimum of 14 kg live weight, onto a herb-clover mix containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pretanse*) and white clover (*Trifolium repens*) have the potential to achieve similar liveweight gains as unweaned lambs on a ryegrass-clover based pasture (Chapter 4). Live weights of ewes whose lambs were weaned early were generally greater than unweaned ewes on ryegrass-clover based pasture (Chapter 3, 4). The liveweight gain of early-weaned lambs on the herb-clover mix, however, has been inconsistent across studies compared to unweaned lambs on grass-clover based pastures (Corner-Thomas et al. 2018b; Chapter 3, 4). Early-weaned lambs have the potential to grow faster than unweaned lambs on a ryegrass-clover based pasture when herb-clover mix has a higher chicory and clover content and ryegrass-clover based pasture has less clover (Chapter 4). In addition, the variation in nutritional quality and the botanical composition of the herb-clover mix was found to be unlikely to affect the growth of early-weaned lambs. It is known that sheep select same plant species over others, when a mixed sward is available (Concha & Nicol 2000; Dumont & Gordon 2003; Foster et al. 2002; Parsons et al. 1994; Rutter 2006). The variation in the botanical composition of the herb-clover mix could affect the lamb selectivity and thus, their growth, however, this has not been investigated in previous studies. The cause of the inconsistent growth rates of early-weaned lambs on the herb-clover mix compared to unweaned lambs on grass-clover based pasture remains unclear.

Early development of the reticulo-rumen and its microbial population is important for efficient utilisation of herbage-based diets after weaning (Jiao et al. 2015; Yanez-Ruiz et al. 2015). Early exposure to herbage-based diets can help develop a strong host microbiota in the rumen (Distel et al. 1994; Kittelmann et al. 2014) and experience with a herbage type increases a lamb's preference for that herbage later in life (Provenza & Balph 1990). Sheep avoid grazing novel herbages (Parsons et al. 1994; Ramos & Tennessen 1992) for a number of reasons including taste aversion (Provenza 1995), a strategy to maintain effective rumen micro-flora (Rutter et al., 2000) and to meet their ideal protein intake (Kyriazakis & Oldham 1993; Kyriazakis et al. 1994). Early exposure to a herbage may facilitate early rumen development and may increase subsequent performance. It was hypothesised that exposure of lambs to a herb-clover mix for a prolonged period prior to early weaning would improve subsequent lamb growth after early-weaning. To test this hypothesis the current study examined the impact of early exposure of lambs to the herb-clover mix, at approximately 15 days of age with lambs born to the herb-clover mix, on their performance after early-weaning at approximately ~ 45 days of age.

5.3 Materials and Methods

5.3.1 Herbage treatments

Eight paddocks (12.85 ha in total land area) of herb-clover mix and seven paddocks (14.85 ha in total land area) of ryegrass-clover based pasture containing perennial ryegrass (*Lolium perenne* L.) and white clover were used in the study in two spring periods in 2017 and 2018. During the experimental period (August to December in 2017 and 2018), a rotational grazing system was used whereby the post-grazing sward surface heights were maintained at a minimum of 5 to 7 cm for both ryegrass-clover based pasture and herb-clover mix, respectively, in order to provide *ad-libitum* dry matter intakes for lambs and ewes (Cranston et al. 2015b; Morris & Kenyon 2004).

5.3.2 Experimental design

This study was conducted at Massey University's Keeble farm, 5 km southeast of Palmerston North, New Zealand (40°24' S and 175°36' E). All animal manipulations were approved by the Massey University Animal Ethics Committee. Romney ewes, naturally bred during a 17-day breeding period, and diagnosed as twin-bearing using transabdominal ultrasound at approximately 90 days of pregnancy, were included in the study. Throughout the gestation period, within each year, ewes were managed as a single flock (group) under commercial pastoral farming conditions on a ryegrass-clover based pasture.

Twin-bearing ewes were allocated to treatments three days prior to lambing using a stratified random sampling procedure, based on the live weights of ewes, in order to balance ewe live weights across groups. A summary of the experimental design can be found in Table 5.1. In brief in 2017, the study included six treatment groups (Grass-

$Grass_{CW,}$ Grass-$Herb_{EW,}$ Grass-$Herb_{CW,}$ Grass-$Herb_{D15EW}$, Herb-$Herb_{CW}$ and Herb-$Herb_{EW}$, Table 5.1), while in 2018, Grass-$Grass_{CW}$ was omitted resulting in five treatments were included (Grass-$Herb_{EW,}$ Grass-$Herb_{CW,}$ Grass-$Herb_{D15EW}$, Herb-$Herb_{CW}$ and Herb-$Herb_{EW}$). The Grass-$Grass_{CW}$ treatment had previously been examined over three years (Chapter 3, 4) and was determined to be unnecessary. Three days prior to lambing, ewes (n=117 in 2017 and n=161 in 2018) were allocated to Grass-$Grass_{CW}$ (only in 2017), Grass-$Herb_{EW,}$ Grass-$Herb_{CW,}$ and Grass-$Herb_{D15EW}$ treatments and grazed on a ryegrass-clover based pasture. Similarly, on the same date, ewes (n=80 in 2017 and n=82 in 2018) allocated to Herb-$Herb_{CW}$ and Herb-$Herb_{EW}$ treatments were move to the herb-clover mix.

Table 5.1 Summary of the experimental design with a description of treatments, number of lambs in each treatment, herbage type offered and age of weaning in 2017 and 2018

Treatment	Year	Number of lambs	Treatment description	Lamb age 0	15	47-51	87-99
Grass-Grass$_{CW}$	2017	36	Lambs born and remained on ryegrass-clover based pasture until conventional weaning	★	★	★	★●
Grass-Herb$_{EW}$	2017 2018	36 42	Lambs born on ryegrass-clover based pasture and early weaned onto herb-clover mix	★	★	□●	□
Grass-Herb$_{CW}$	2017 2018	36 44	Lambs born on ryegrass-clover based pasture, transferred with dam onto herb-clover mix at early weaning and remained until conventional weaning	★	★	□	□●
Grass-Herb$_{D15EW}$	2017 2018	30 42	Lambs born on ryegrass-clover based pasture, transferred with dam onto herb-clover mix at 15 days of age and early weaned	★	□	□●	□
Herb-Herb$_{CW}$	2017 2018	34 36	Lambs born and remained on herb-clover mix until conventional weaning	□	□	□	□●
Herb-Herb$_{EW}$	2017 2018	36 40	Lambs born on herb-clover mix and early weaned onto herb-clover mix	□	□	□●	□

★Lambs on ryegrass-clover based pasture; □Lambs on herb-clover mix; ●Weaning age

Note: Early weaned ewes were removed and grazed on ryegrass-clover based pastures; early weaning occurred at 51 and L44 days of in 2017 and 2018, respectively; conventional weaning occurred at 99 and L87 days of in 2017 and 2018, respectively

Lambing began on 28th and 27th of August in 2017 and 2018 (L0), respectively. All lambs were weighed, ear tagged and identified to their dam within 24 h of birth. In total, n=136 and n=138 lambs were born on herb-clover mix in 2017 and 2018, respectively. On ryegrass-clover based pasture n=224 and n=302 lambs were born in 2017 and 2018, respectively. On L27 in 2017 and L26 in 2018, lambs were drenched with an oral triple combination drench (Matrix, Merial Ancare, Manukau City, New Zealand) and thereafter at 28-day intervals throughout the study at a rate of 1 mL per 5 kg live weight to control internal parasites as per standard practice in New Zealand.

At L15 in both years, ewes and lambs allocated to the Grass-Herb$_{D15EW}$ treatment group were transferred from ryegrass-clover based pasture to a herb-clover mix where they remained until the onset of the main experiment (at L51 and L44 in 2017 and 2018, respectively). Ewes and lambs allocated to the other treatment groups remained on their respective herbage until the onset of the main experiment. At L51 in 2017 and at L44 in 2018 (early weaning), ewes rearing full twin sets of lambs (n = 104 and n = 102 in 2017 and 2018, respectively), of which, both had a minimum live weight of 14 kg (n = 208 and n = 204, in 2017 and 2018, respectively) were retained and any ewes and lambs that did not fulfil these criteria were excluded from the study.

After early-weaning, ewes in the Grass-Herb$_{EW}$, Grass-Herb$_{D15EW}$ and Herb-Herb$_{EW}$ treatments (weaned ewes) were managed with Grass-Grass$_{CW}$ treatment in 2017 or with a commercial flock under pastoral farming conditions on ryegrass-clover based pasture until L87 in 2018. Early-weaned lambs (Grass-Herb$_{EW}$, Grass-Herb$_{D15EW}$ and Herb-

Herb$_{EW}$) were managed with the Herb-Herb$_{CW}$ ewes and lambs until L99 and L87 in 2017 and 2018, respectively.

5.3.3 Animal measurements

Lambs and ewes were weighed within 1 h of removal from herbage at L15, L51, L65 and L99 in 2017 and L15, L44, L61 and L87 in 2018. Ewe body condition score (BCS, scale 1–5, including half units, Jefferies 1961) was assessed at each weighing by a single experienced operator.

5.3.4 Anatomical and histological examination of the digestive system

A subset of male lambs from the complete twin sets were selected for anatomical and histological examination of the digestive system either at L44 (n=12) or L87 (n=24) in 2018. Lambs were selected using stratified random sampling procedure, based on live weights, in order to obtain a representative sample of lambs from each treatment. At L44, lambs in the Grass-Herb$_{EW}$ (n=6, average live weight 19.0±1.5) and Herb-Herb$_{EW}$ (n=6, average live weight 21.0±1.5) groups were euthanized to determine the effect of feed type on offer prior to early weaning on the rumen development. At L87, 24 male lambs were selected from the Grass-Herb$_{EW}$ (n=6; average live weight 27.4±2.0), Grass-Herb$_{CW}$ (n=6; average live weight 31.0±2.0), Herb-Herb$_{CW}$ (n=6; average live weight 35.0±2.0) and Herb-Herb$_{EW}$ (n=6; average live weight 32.0±2.0) treatments to determine the impact of early weaning and the feed type offered after weaning on rumen development at conventional weaning (L87). Lambs selected for slaughter were weighed within 1 hr of removal from herbage. Lambs were euthanized using captive bolt stunning and exsanguination.

Immediately after euthanasia, lambs were skinned, eviscerated and the head was separated from the carcass. Hot carcass weight was then recorded. The digestive system was removed by severing the oesophagus which was tied at the cardia of the stomach. All the organs attached to the digestive system were removed and then weighed. The digestive system was then separated into its components (reticulo-rumen, small intestine and large intestine) which were then cleaned using tap water. Empty component weights were recorded to the nearest gram. The cleaned reticulo-rumen was dissected according to the procedure of McGavin & Morrill (1976) and the reticulo-rumen was opened and laid flat symmetrically. Two samples (1 cm^2 each) were collected from the right side of the caudal dorsal sac as Lesmeister et al. (2004) reported that samples from this region were representative of rumen development.

Rumen samples were immediately fixed in 10% formalin saline solution for 24 h. Samples were then processed using a Excelsior ES Tissue Processor (ThermoFisher®, USA). Dehydration was carried out by ascending graded series of ethyl alcohol 70, 95% and absolute Alcohol for 12 h, followed by clearing in Xylene at 60^{o}C. The samples were then embedded and impregnated in melted Paraffin wax at 55-58°C using a HistoStar Embedder (ThermoFisher®, USA). Embedded samples were cut using Rotary Microtome (MicroTec®, Germany) into sections (4 µm). Two sections were produced, 150 µm apart from each tissue sample resulting 4 sections per animal (replicates). The sections were floated in a Tissue Bath (ThermoFisher®, USA) at 43°C and were mounted onto HDS Adhesive pre-cleaned slides (90° ground edges, 76mm x 26mm). The sections were stained by Haemytoxelin and Eosin on a Autostainer XL (Leica®, Germany). The stained slides (2 slides per lamb) were covered using a Leica® CV5030 cover slips. Each slide contained two samples. All complete papillae in each section were examined microscopically to determine their length and width (Figure 5.1).

Figure 5.1 Histomorphometric measurements (papillae length and width) in the rumen of lambs measured using a computerised micrometre at 100× magnification

5.3.5 Herbage measurements

Herbage masses were measured at L15, L51 and L99 in 2017 and L15, L44 and L87 in 2018. Four random quadrat cuts (0.1 m^2 each) were taken to ground level from each herbage type at each sampling date using an electric shearing hand-piece (Frame 1993). Samples were then oven dried to a constant weight to estimate herbage mass. In addition, four composite herbage samples each containing ten grab samples per herbage type, were also collected at each sampling date to determine the botanical and nutritional composition (Frame 1993). To determine the botanical composition of the herbage, a subsample from each composite sample (4 per herbage type) was sorted into each species (herb-clover mix: plantain, chicory, red clover, white clover; ryegrass-clover based pasture: ryegrass, clover; other grasses (combined), weeds, and dead matter) and then oven dried and weighed to determine the botanical composition. The remaining sample was then frozen, dried, ground, sieved (1 mm) and analysed using *in vitro* methods to determine the nutritional quality. These measures included dry matter digestibility (DMD, Roughan & Holland 1977), digestible organic matter digestibility (DOMD, Roughan & Holland 1977), percentage crude protein (CP; "Dumas" procedure, AOAC method 968.06 using a Leco total combustion method, LECO Corporation, St. Joseph, MI, USA). Percentage acid detergent fibre (ADF) was analysed by a Tecator Fibretec System (Robertson & Van Soest 1981). Metabolisable energy (ME) content of herbages was calculated from the organic matter digestibility (DOMD×0.16 MJ/Kg DM, Roughan & Holland 1977).

5.3.6 Statistical analysis

The individual animal was considered the experimental unit for these analyses. Live weight of lambs and ewes were subjected to analysis of variance for repeated measures using the MIXED procedure in SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US). The analysis was performed separately for each year due to the differences in the days on which measurements were collected and the number of treatments in 2017 and 2018. The model for lamb live weight for L51 and L99 and L44 and L87 periods in 2017 and 2018, respectively, included the fixed effects of weaning treatment, sex of lamb (male, female), measurement date and the two-way interactions of treatment and measurement date. The live weight of lambs at the start of the treatment period was included in the model as a covariate. The model for lamb liveweight gain from early weaning to conventional weaning included the fixed effect of weaning treatment and sex of lamb.

The models for ewe live weight included the fixed effects of weaning treatment, measurement date and two-way interactions of treatment and measurement date. The model for ewe liveweight gain from early weaning to conventional weaning included the fixed effect of weaning treatment. The live weight of the ewe at the start of the treatment period was included in the model as a covariate. Ewe body condition score was analysed using a Poisson distribution and logit transformation using the GENMOD procedure in SAS. The model included the fixed effects of weaning treatment, measurement date and the two-way interaction of treatment and measurement date.

Papillae length and width were subjected to analysis of variance using the MIXED procedure in SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US). The models for papillae length and width included the fixed effect of weaning treatment and random effect of lamb, sample and replicate (sections) of each samples. The live weight of the lamb at slaughter was included in the model as a covariate. The models for the anatomical measurements of the rumen included the fixed effect of weaning treatment and lamb live weight at slaughter as a covariate.

The botanical composition of herbages was subjected to an analysis of variance for repeated measures using the MIXED procedure in SAS. The model included fixed effects of plant species and measurement date. Herbage masses were analysed using a model that included herbage type and measurement date as fixed effects. The nutritional quality data were analysed using the MIXED procedure in a model that included the fixed effects of herbage type and measurement date.

5.4 Results

5.4.1 Botanical composition, herbage mass and nutritional quality of herbage

The percentage of chicory and clover was 16% greater ($p<0.05$) and plantain was 23% lower ($p<0.05$) in the herb-clover mix in 2018 at L44 than in 2017 at L47 (Figure 5.2). The percentage of plantain was 20% greater ($p<0.05$) and dead matter content was 35% lower ($p<0.05$) in the herb-clover mix in 2018 at L87 than in 2017 at L99. Other plant components in the herb-clover mix did not differ ($p>0.05$) between years. At L15, percentage of ryegrass in the ryegrass-clover based pasture was 22% greater ($p<0.05$) in 2018 than 2017. Other plant components in the ryegrass-clover based pasture did not differ ($p>0.05$) between years.

In 2017, the herbage mass of the herb-clover mix was ~ 900 kg DM/ha greater ($p<0.05$) than that of ryegrass-clover based pasture at L51 but did not differ ($p>0.05$) at L15 or L99 (Table 5.2). In 2018, herbage mass of herb-clover mix was ~ 1500 to 2500 kg DM/ha greater ($p<0.05$) than that of ryegrass-clover based pasture throughout the study.

At L15, in 2017, the CP content of ryegrass-clover based pasture was ~ 4% greater ($p<0.05$) than herb-clover mix whereas the reverse was seen at L51. At L99, CP content did not differ ($p>0.05$) between herbages. At L15 and L99, the ADF content of herb-clover was greater (13% and 7%, respectively, $p<0.05$) than that of ryegrass-clover based pasture, however, at L51 ADF did not differ ($p>0.05$). The DMD, NDF and ME of herb-clover mix was greater (~ 6 to 10%, 14 to 22% and 1.1 to 1.8 MJ/Kg, respectively, $p<0.05$) than ryegrass-clover based pasture at all sampling times.

In 2018, at L15 and L87, the CP content of herb-clover mix was lower (~ 3 and 6% , respectively, $p<0.05$) than ryegrass-clover based pasture, whereas the CP content of herb-clover mix was ~ 3% greater ($p<0.05$) at L44 (Table 5.2). The ADF content of herb-clover mix did not differ ($p>0.05$) from that of ryegrass-clover based pasture at L15 and L87, but was ~ 5% lower ($p<0.05$) at L44. The NDF of herb-clover mix was 10 to 20 % lower ($p<0.05$) than that of ryegrass-clover based pasture at L15, L44 and L87. The DMD and ME of herb-clover mix was greater (~ 4 to 8% and 0.4 to 1.2 MJ/Kg, respectively, $p<0.05$) than that of ryegrass-clover based pasture at L15, L44 and L87.

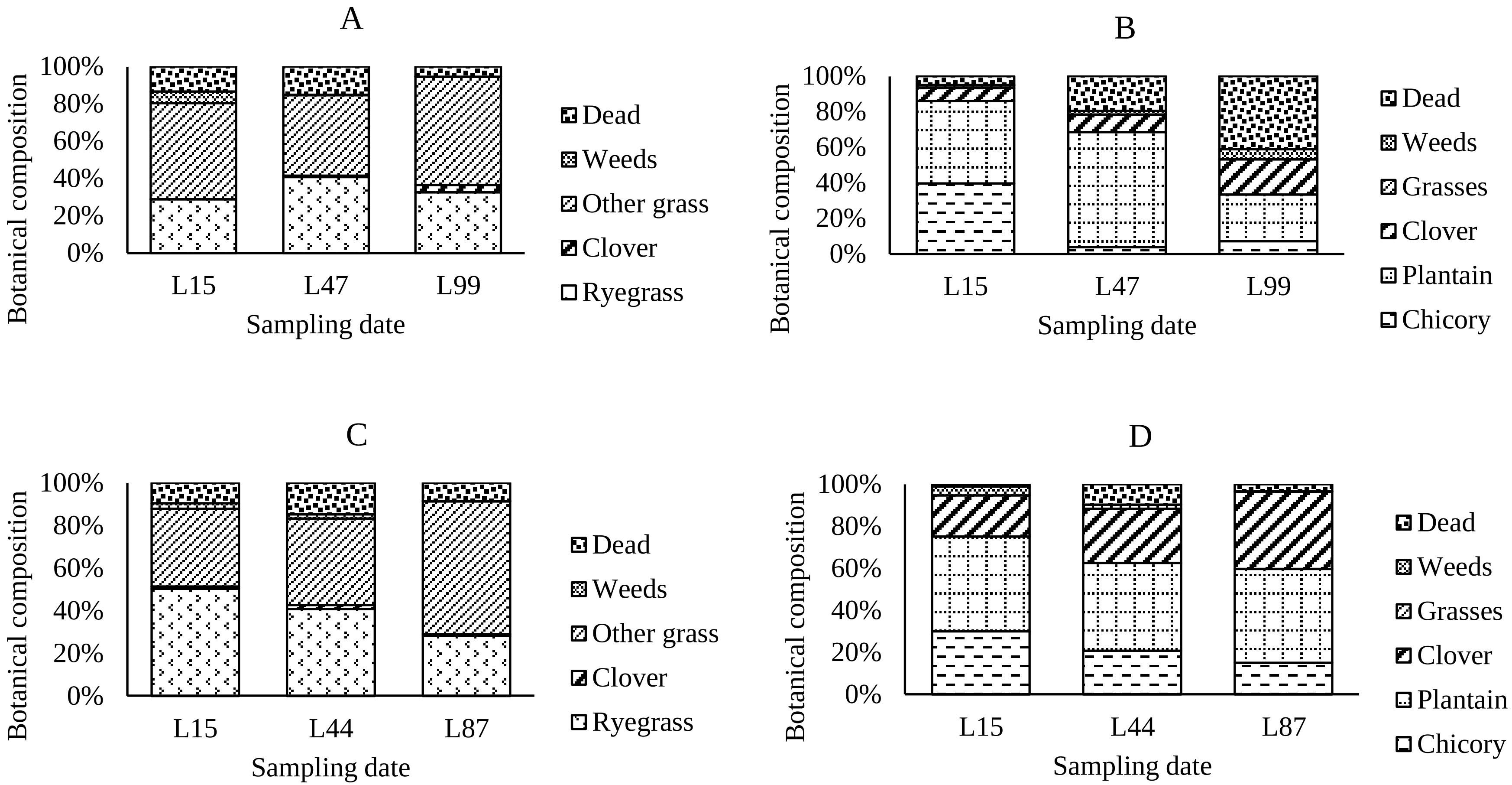

Figure 5.2 The botanical composition of the components of ryegrass-clover based pasture (A), herb-clover mix (B) in 2017 and ryegrass-clover based pasture (C) and herb-clover mix (D) in 2018 on 15, 51 and 99 days after the midpoint of lambing in 2017 and 2018 (L15, L44 and L87)

Table 5.2 Herbage mass (HM), crude protein (CP), neutral detergent fibre (NDF) acid detergent fibre (ADF), dry matter digestibility (DMD) and metabolisable energy content (ME) of herbages collected L15, L51, L99 in 2017 and 2018 (L15, L44, L87) (least-squares mean ±SEM)

Year	Herbage type	Study day	HM (kg DM/ha)	CP (%)	NDF (%)	ADF (%)	DMD (%)	ME (MJ/Kg)
2017	Herb-clover mix	L15	2742^{bc}±260	10.9^{a}±1.1	50.4^{cd}±1.4	35.6^{b}±1.3	65.7^{b}±0.7	9.2^{ab}±0.1
		L51	3221^{c}±260	17.3^{b}±1.1	46.7^{c}±1.4	26.6^{a}±1.3	65.8^{b}±0.7	9.5^{b}±0.1
		L99	3048^{bc}±260	15.6^{b}±1.1	53.7^{d}±1.4	30.5^{b}±1.3	63.5^{a}±0.7	9.1^{a}±0.1
	Ryegrass-clover based pasture	L15	2313^{ab}±260	16.5^{b}±1.1	28.7^{a}±1.4	22.9^{a}±1.3	75.5^{d}±0.7	11.0^{d}±0.1
		L51	1899^{a}±260	12.0^{a}±1.1	32.7^{b}±1.4	26.2^{a}±1.3	72.0^{c}±0.7	10.6^{c}±0.1
		L99	2680^{b}±260	13.0^{ab}±1.1	31.4^{ab}±1.4	23.7^{a}±1.3	73.1^{c}±0.7	10.6^{c}±0.1
2018	Herb-clover mix	L15	4298^{d}±260	14.4^{a}±1.1	34.0^{b}±1.4	24.2^{b}±1.3	71.4^{bc}±0.7	10.5^{cd}±0.1
		L44	3481^{c}±260	17.2^{b}±1.1	27.6^{a}±1.4	19.5^{a}±1.3	74.1^{d}±0.7	11.0^{e}±0.1
		L87	3857^{c}±260	12.1^{a}±1.1	31.7^{b}±1.4	22.4^{ab}±1.3	73.2^{cd}±0.7	10.8^{de}±0.1
	Ryegrass-clover based pasture	L15	1684^{a}±260	17.3^{b}±1.1	47.5^{d}±1.4	26.1^{b}±1.3	64.7^{a}±0.7	9.3^{a}±0.1
		L44	2057^{a}±260	12.9^{a}±1.1	48.0^{d}±1.4	24.6^{b}±1.3	65.9^{a}±0.7	9.8^{b}±0.1
		L87	2068^{a}±260	18.4^{b}±1.1	42.4^{c}±1.4	21.8^{ab}±1.3	69.5^{b}±0.7	10.4^{bc}±0.1

L, days after the midpoint of lambing

$^{a-e}$ Means with different superscripts within columns are significantly different across years and treatments ($p<0.05$)

5.4.2 Lamb live weight and liveweight gain

In 2017, at L51, the live weights of lambs did not differ ($p>0.05$) among treatment groups (Table 5.3). At L65, Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$ and Grass-Herb$_{EW}$ lambs did not differ ($p>0.05$) in live weight but were ~ 1 kg lighter ($p<0.05$) than Herb-Herb$_{CW}$, Grass-Herb$_{CW}$ and Grass-Grass$_{CW}$ lambs. At L65, Herb-Herb$_{CW}$ lambs were 0.8 kg heavier ($p<0.05$) than Grass-Grass$_{CW}$ lambs but neither differed ($p>0.05$) from Grass-Herb$_{CW}$ lambs. At L99, Herb-Herb$_{CW}$ and Grass-Herb$_{CW}$ lambs did not differ ($p>0.05$) in live weights but were 4 to 5 kg heavier ($p<0.05$) than lambs in all other treatments. Lamb liveweight gains between L51 and L99 in the Herb-Herb$_{CW}$ (317±7 g/day) and Grass-Herb$_{CW}$ (318±7 g/day) treatments were greater ($p<0.05$) than lambs in the Herb-Herb$_{EW}$ (244±7 g/day), Grass-Herb$_{D15EW}$ (231±8 g/day), Grass-Herb$_{EW}$ (239±7 g/day) and Grass-Grass$_{CW}$ (231±7 g/day) treatments.

In 2018, at L44, the live weights of lambs did not differ ($p>0.05$) among the treatment groups (Table 5.3). At L61 and L87, Herb-Herb$_{CW}$ and Grass-Herb$_{CW}$ lambs were 2 kg heavier ($p<0.05$) than Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$ and Grass-Herb$_{EW}$ lambs. Liveweight gain of Grass-Herb$_{CW}$ lambs (321±8 g/day) between L44 and L87 was greater ($p<0.05$) than Herb-Herb$_{CW}$ (289±8 g/day) lambs, which in turn was greater ($p<0.05$) than Herb-Herb$_{EW}$ (232±8 g/day), Grass-Herb$_{D15EW}$ (231±7 g/day) and Grass-Herb$_{EW}$ (237±7 g/day) lambs, which did not differ ($p>0.05$).

Table 5.3 Impact of weaning treatment; Herb-Herb$_{CW}$, Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$, Grass-Herb$_{CW}$, Grass-Herb$_{EW}$, Grass-Grass$_{CW}$ on live weight of lambs on L51, L65 and L99 in 2017 and L44, L61 and L87 in 2018; and liveweight gain (LWG) during L51-L99 in 2017 and during L44-L87 in 2018 (least-squares mean ±SEM)

Herbage treatment		Lamb live weight (kg)					LWG (g/day)
	n		n		n		
	2017						
		L51		L65		L99	L51-L99
Herb-Herb$_{CW}$	42	19.3±0.2^{a}	41	23.5±0.2^{d}	42	34.7±0.4^{f}	317±7^{b}
Herb-Herb$_{EW}$	44	19.4±0.2^{a}	43	21.9±0.2^{b}	43	31.1±0.4^{e}	244±7^{a}
Grass-Herb$_{D15EW}$	37	19.1±0.2^{a}	37	21.7±0.2^{b}	37	30.1±0.4^{e}	231±8^{a}
Grass-Herb$_{CW}$	42	19.3±0.2^{a}	41	23.1±0.2^{cd}	42	34.6±0.4^{f}	318±7^{b}
Grass-Herb$_{EW}$	46	19.0±0.2^{a}	45	21.6±0.2^{b}	46	30.6±0.4^{e}	239±7^{a}
Grass-Grass$_{CW}$	34	19.2±0.2^{a}	33	22.7±0.2^{c}	34	30.3±0.4^{e}	231±8^{a}
	2018						
		L44		L61		L87	L44-L87
Herb-Herb$_{CW}$	36	19.0±0.1^{a}	36	25.0±0.2^{c}	35	31.7±0.4^{e}	289±8^{b}
Herb-Herb$_{EW}$	36	18.9±0.1^{a}	34	23.0±0.2^{b}	33	28.9±0.4^{d}	232±8^{a}
Grass-Herb$_{D15EW}$	42	18.9±0.1^{a}	41	22.7±0.2^{b}	41	28.7±0.3^{d}	231±7^{a}
Grass-Herb$_{CW}$	34	18.8±0.1^{a}	34	24.8±0.2^{c}	34	32.1±0.3^{e}	321±8^{c}
Grass-Herb$_{EW}$	34	18.8±0.1^{a}	34	22.6±0.2^{b}	34	28.7±0.4^{d}	237±8^{a}

L, days after the midpoint of lambing; Herb-Herb$_{CW}$, lambs born on herb-clover and conventional weaning (~ at 99 days of age); Herb-Herb$_{EW}$, lambs born on herb-clover and early weaned onto herb-clover at ~ 45 days of age; Grass-Herb$_{D15EW}$, lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at 15 days of age and early weaned at ~ 45 days of age; Grass-Herb$_{CW,}$ lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at ~ 45 days of age and conventional weaning; Grass-Herb$_{EW}$, lambs born on ryegrass-clover based pasture and early weaned at ~ 45 days of age onto herb-clover; Grass-Grass$_{CW,}$ lambs born on ryegrass-clover based pasture and conventional weaning

$^{a-n}$ Means with different superscripts are significantly different across years and treatments

5.4.3 Ewe live weight and liveweight gain

In 2017 at L51, the live weights of ewes did not differ ($p>0.05$) between treatment groups (Table 5.4). At L65, the live weights of Herb-Herb$_{EW,}$ Herb-Herb$_{CW,}$ Grass-Herb$_{D15EW,}$ Grass-Herb$_{CW}$ ewes did not differ ($p>0.05$). At L99, Herb-Herb$_{CW,}$ Herb-Herb$_{EW,}$ Grass-Herb$_{D15EW,}$ Grass-Herb$_{CW}$ ewes did not differ ($p>0.05$) in live weights but were 2 to 5 kg heavier ($p<0.05$) than Grass-Herb$_{EW}$ and Grass-Grass$_{CW}$ ewes ($p>0.05$). Between L51 and L99, the liveweight gains of Herb-Herb$_{CW,}$ Herb-Herb$_{EW}$, Grass-Herb$_{D15EW,}$ Grass-Herb$_{CW}$ and Grass-Herb$_{EW}$ ewes did not differ ($p>0.05$) but were at least 30 g/day greater ($p<0.05$) than Grass-Grass$_{CW}$ ewes.

In 2018, at L44, L61 and L87, the live weights of ewes in each treatment groups did not differ ($p>0.05$) (Table 5.4). The liveweight gains between L44 and L87 of ewes in each treatment group did not differ ($p>0.05$).

Table 5.4 Impact of weaning treatment; Herb-Herb$_{CW}$, Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$, Grass-Herb$_{CW}$, Grass-Herb$_{EW}$, Grass-Grass$_{CW}$ on live weight of ewes on L51, L65 and L99 in 2017 and L44, L61 and L87 in 2018; and liveweight gain (LWG) during L51-L99 in 2017 and during L44-L87 in 2018 (least-squares mean ±SEM)

Weaning treatment	Ewe live weight (kg)						LWG (g/day)
	n		n		n		
	2017						
		L51		L65		L99	L51-L99
Herb-Herb$_{CW}$	21	68.8±0.9^{a}	21	71.0±0.9^{ab}	20	76.3±1.0^{b}	145±18^{b}
Herb-Herb$_{EW}$	22	70.0±0.8^{a}	22	73.0±0.8^{b}	21	76.7±0.9^{b}	129±17^{b}
Grass-Herb$_{D15EW}$	18	70.1±0.9^{a}	18	71.7±1.0^{ab}	18	76.3±1.0^{b}	119±19^{b}
Grass-Herb$_{CW}$	21	70.0±0.9^{a}	20	71.1±0.9^{ab}	21	77.1±0.9^{b}	136±17^{b}
Grass-Herb$_{EW}$	23	68.2±0.9^{a}	23	70.5±0.9^{a}	22	73.9±0.9^{a}	112±17^{b}
Grass-Grass$_{CW}$	17	68.1±0.9^{a}	16	70.4±1.0^{a}	17	72.0±1.0^{a}	78±19^{a}
	2018						
		L44		L61		L87	L44-L87
Herb-Herb$_{CW}$	18	69.5±1.0^{a}	18	72.2±1.0^{a}	18	74.0±1.0^{a}	113±19^{a}
Herb-Herb$_{EW}$	18	71.2±0.9^{a}	17	72.8±1.0^{a}	17	74.7±1.0^{a}	81±19^{a}
Grass-Herb$_{D15EW}$	21	71.0±0.9^{a}	21	72.8±0.9^{a}	21	74.5±0.9^{a}	76±18^{a}
Grass-Herb$_{CW}$	18	69.8±0.8^{a}	16	73.8±0.8^{a}	16	73.9±0.9^{a}	89±17^{a}
Grass-Herb$_{EW}$	17	70.1±0.9^{a}	17	74.3±0.9^{a}	14	74.6±1.0^{a}	103±19^{a}

L, days after the midpoint of lambing; Herb-Herb$_{CW}$, lambs born on herb-clover and conventional weaning (~ at 99 days of age); Herb-Herb$_{EW}$, lambs born on herb-clover and early weaned onto herb-clover at ~ 45 days of age; Grass-Herb$_{D15EW}$, lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at 15 days of age and early weaned at ~ 45 days of age; Grass-Herb$_{CW,}$ lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at ~ 45 days of age and conventional weaning; Grass-Herb$_{EW}$, lambs born on ryegrass-clover based pasture and early weaned at ~ 45 days of age onto herb-clover; Grass-Grass$_{CW,}$ lambs born on ryegrass-clover based pasture and conventional weaning

$^{a-n}$ Means with different superscripts are significantly different across years and treatments

5.4.4 Ewe body condition score

In 2017, at L51, the BCS of ewes did not differ ($p>0.05$) between treatments (Table 5.5). At L65, the BCS of Herb-Herb$_{CW}$, Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$ and Grass-Herb$_{EW}$ ewes did not differ ($p>0.05$). At L99, the BCS of Herb-Herb$_{CW}$, Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$ and Grass-Herb$_{EW}$ and Grass-Herb$_{CW}$ were greater ($p<0.05$) than Grass-Grass$_{CW}$ ewes.

In 2018, at L44, BCS of Herb-Herb$_{CW}$, Herb-Herb$_{EW}$ and Grass-Herb$_{D15EW}$ ewes were greater ($p<0.05$) than the Grass-Herb$_{CW}$ and Grass-Herb$_{EW}$ ewes. At L61, BCS of Herb-Herb$_{CW}$, Herb-Herb$_{EW}$ and Grass-Herb$_{D15EW}$ and Grass-Herb$_{EW}$ ewes did not differ ($p>0.05$). At L87, BCS of Grass-Herb$_{CW}$, Herb-Herb$_{CW}$ and Herb-Herb$_{EW}$ ewes did not differ ($p>0.05$), and that of Grass-Herb$_{D15EW}$ and Grass-Herb$_{EW}$ ewes also did not differ ($p>0.05$).

Table 5.5 Impact of weaning treatment; Herb-Herb$_{CW}$, Herb-Herb$_{EW}$, Grass-Herb$_{D15EW}$, Grass-Herb$_{CW}$, Grass-Herb$_{EW}$, Grass-Grass$_{CW}$ on the BCS of ewes at L51, L65 and L99 in 2017 and at L44, L61 and L87 in 2018 (results displayed as back transformed logit mean and 95% confidence interval)

Herbage treatment	Ewe body condition score					
	n		n		n	
	2017					
		L51		L65		L99
Herb-Herb$_{CW}$	21	2.9 (2.5-2.9)[a]	21	3.1 (3.1-3.6)[ab]	20	3.5 (3.1-3.4)[b]
Herb-Herb$_{EW}$	22	2.9 (2.8-3.1)[a]	22	3.3 (3.1-3.6)[b]	21	3.3 (3.1-3.6)[b]
Grass-Herb$_{D15EW}$	18	2.9 (2.7-3.1)[a]	18	3.4 (3.2-3.7)[b]	18	3.5 (3.3-3.7)[b]
Grass-Herb$_{CW}$	21	2.7 (2.5-2.9)[a]	20	2.8 (2.6-3.1)[a]	21	3.3 (3.1-3.4)[b]
Grass-Herb$_{EW}$	23	2.9 (2.8-3.1)[a]	23	3.4 (3.1-3.6)[b]	22	3.4 (3.2-3.5)[b]
Grass-Grass$_{CW}$	17	2.8 (2.6-3.0)[a]	16	2.9 (2.2-3.0)[a]	17	2.9 (2.7-3.1)[a]
	2018					
		L44		L61		L87
Herb-Herb$_{CW}$	18	2.5 (2.5-2.9)[b]	18	2.8 (2.6-3.0)[ab]	18	3.1 (2.8-3.4)[ab]
Herb-Herb$_{EW}$	18	2.9 (2.7-3.3)[b]	17	3.0 (2.8-3.3)[b]	17	3.1 (2.8-3.6)[ab]
Grass-Herb$_{D15EW}$	21	2.9 (2.6-3.2)[b]	21	3.0 (2.9-3.2)[b]	21	3.4 (3.2-3.7)[b]
Grass-Herb$_{CW}$	18	2.4 (2.2-2.6)[a]	16	2.6 (2.4-2.7)[a]	16	2.8 (2.6-3.1)[a]
Grass-Herb$_{EW}$	17	2.3 (2.1-2.5)[a]	17	2.9 (2.6-3.1)[ab]	14	3.3 (3.3-3.8)[b]

L, days after the midpoint of lambing; Herb-Herb$_{CW}$, lambs born on herb-clover and conventional weaning (~ at 99 days of age); Herb-Herb$_{EW}$, lambs born on herb-clover and early weaned onto herb-clover at ~ 45 days of age; Grass-Herb$_{D15EW}$, lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at 15 days of age and early weaned at ~ 45 days of age; Grass-Herb$_{CW,}$ lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at ~ 45 days of age and conventional weaning; Grass-Herb$_{EW}$, lambs born on ryegrass-clover based pasture and early weaned at ~ 45 days of age onto herb-clover; Grass-Grass$_{CW,}$ lambs born on ryegrass-clover based pasture and conventional weaning

[a-n] Means with different superscripts are significantly different across years and treatments

5.4.5 Lamb digestive tract components and rumen papillae dimensions

Weight of empty digestive tract components of lambs did not differ ($p>0.05$) between treatment groups at either L44 or L87. Papillae length and width of Grass-Herb$_{EW}$ and Herb-Herb$_{EW}$ lambs did not differ ($p>0.05$) at L44 (Table 5.6). At L87, Grass-Herb$_{EW}$ and Herb-Herb$_{EW}$ lambs had ~ 200 μm longer ($p<0.05$) papillae than Grass-Herb$_{CW}$ and Herb-Herb$_{CW}$ lambs, however, width of ruminal papillae did not differ ($p>0.05$) between treatments.

Table 5.6 Mean weight of hot carcass, digestive tract, reticulo-rumen, empty small intestine and empty large intestine and mean length and width of rumen papillae of Herb-Herb$_{EW}$ and Grass-Herb$_{EW}$ lambs at L44; and Grass-Herb$_{CW}$, Herb-Herb$_{CW}$, Herb-Herb$_{EW}$ and Grass-Herb$_{EW}$ lambs at L87 in 2018 (least-squares mean ±SEM)

Treatment	Sampling time	Hot carcass weight (kg)	Total digestive tract weight (kg)	Reticulo-rumen weight (g)	Empty small intestine weight (g)	Empty large intestine weight (g)	Papillae length (µm)	Papillae width (µm)
Herb-Herb$_{EW}$	L44	8.9±0.3	3.5±0.3	458±40	458±40	296±51	809±136	268±16
Grass-Herb$_{EW}$		9.6±0.3	3.3±0.3	410±40	410±40	234±51	732±148	260±17
Grass-Herb$_{CW}$	L87	14.7±0.3	10.1±0.3	951±50	1353±85	483±80	892±135[a]	221±16
Herb-Herb$_{CW}$		14.6±0.3	10.3±0.3	884±53	1275±90	425±85	1090±152[a]	211±18
Herb-Herb$_{EW}$		14.3±0.3	10.8±0.3	1013±51	1119±86	611±80	1225±137[b]	242±16
Grass-Herb$_{EW}$		14.0±0.3	10.9±0.3	970±55	1280±93	463±87	1333±122[b]	245±14

L, days after the midpoint of lambing; Herb-Herb$_{EW}$, lambs born on herb-clover and early weaned onto herb-clover at ~ 45 days of age; Grass-Herb$_{EW}$, lambs born on ryegrass-clover based pasture and early weaned at ~ 45 days of age onto herb-clover; Grass-Herb$_{CW}$, lambs born on ryegrass-clover based pasture and transferred with dam onto herb-clover at ~ 45 days of age and conventional weaning; Herb-Herb$_{CW}$, lambs born on herb-clover and conventional weaning (~ at 99 days of age)

[a-b] Means with different superscripts are significantly different across treatments

5.5 Discussion

In the current study, it was hypothesised that lambs exposed to a herb-clover mix for a prolonged period prior to early weaning would have improved growth after early weaning compared with lambs that had less exposure. The duration of the exposure of lambs to the herb-clover mix prior to early weaning (birth to early weaning, 15 days of age to early weaning and the four-day exposure prior to early weaning) had no effect on lamb growth rates after early weaning. In early life, lambs rely primarily on milk to fulfil their nutritional requirements thus herbage consumption is low (Kerr 2000). Lambs may have had *ad-libitum* access to milk prior to early weaning, resulting in no need to consume herbage to fulfil their nutritional requirements. This may have resulted in lambs growing at a similar rate post early weaning. Further, this suggests that gradually introducing lambs to herb-clover mix over a four-day period prior to early weaning, the weaning technique we adopted in previous studies, will not impact lamb growth post weaning, therefore, is effective to use in future early-weaning studies.

Lambs weaned early on to a herb-clover mix grew at a similar rate to unweaned lambs on a ryegrass-clover based pasture. The growth rates achieved in the current study were similar to those reported for commercially-reared-twin lambs in New Zealand (Litherland & Lambert 2000). This suggests that lambs weaned at ~ 45 days of age and a minimum live weight of 14 kg, can achieve live weight gains similar to unweaned lambs on ryegrass-clover based pasture. In both years of the current study, lambs weaned early on to a herb-clover mix had lower liveweight gains than unweaned lambs on herb-clover mix. This was likely due to unweaned lambs having greater nutrient intake from both milk and herbage compared to early-weaned lambs that had access only to herbage post-weaning.

The papillae length of early-weaned lambs were 200 μm greater than unweaned lambs on the herb-clover mix at conventional weaning age. The longer papillae of early-weaned lambs may have been due to the greater dry matter intake required to fulfil their nutritional requirements. Connor et al. (2013) reported that neonatal ruminants offered dry matter early in life had greater length and density of the rumen papillae compared to lambs that had *ad-libitum* access to milk alone, resulting greater growth rates. To achieve the greater live weight gains, lambs are best left unweaned on a herb-clover mix rather than remaining with their dams on ryegrass-clover based pasture or early weaning onto a herb-clover mix. Early weaning, however, allows farmers the opportunity to graze lambs at a higher stocking rate which can improve their pasture utilisation efficiency. In addition, this allows farmers to use herb-clover mix after weaning as a fattening feed for weaned lambs at higher stocking rates to achieve greater lamb growth. Further, early weaning can allow ewes to return to their maintenance nutrient requirement and gain body condition prior to the next breeding period.

Unweaned lambs on the herb-clover mix were 4 kg heavier at conventional weaning than unweaned lambs on ryegrass-clover based pastures. The greater growth rate lambs on herb-clover mix may be due to the greater milk production of their dams on herb-clover mix than on ryegrass-clover based pasture, allowing lambs to consume more milk (Hutton et al. 2011), although, the milk and herbage intake of lambs was not measured in this study. Lambs were provided with a minimum of 1200 kg DM/ha of either herb-clover mix or grass-clover pasture thus providing unrestricted grazing conditions for the lambs in the current study. The nutritional quality and herbage composition of herb-clover mix and ryegrass-clover based pastures differed both within and between years. This variation, however, appeared to have little impact on the growth of unweaned lambs. In both years of the study, ME and CP of both herbages were adequate to meet the requirements for lamb growth (Hodgson & Brookes 2002). Combined these results suggest that provided lambs have the access to *ad-libitum* intakes of herbage during spring in New Zealand, unweaned lambs grazing a herb-clover can be expected to have greater growth rates than those on ryegrass-clover based pastures.

The current study design also allowed a comparison of the effect of herbage offered from birth to early weaning on subsequent growth of early-weaned lambs. The liveweight gain of early-weaned lambs born on either ryegrass-clover based pasture or herb-clover mix were similar in both years of the study. Early-weaned lambs were offered *ad-libitum* intakes of the herb-clover mix both pre-and post-weaning. From birth to early weaning at approximately 45 days of age, lambs are dependent on their dam's milk, therefore, the herbage offered is likely to have less impact on their nutritional intake than later in lactation. The histological examination of rumen papillae at early weaning showed no difference in both their length and width of lambs born either on a ryegrass-clover based pasture or herb-clover mix. Lesmeister et al. (2004) reported that papillae length was the most important variable to measure rumen development of young ruminants, suggesting lambs born either on ryegrass-clover based pasture or herb-clover mix had similar rumen development thus growth rates. Furthermore, no differences in weight of reticulo-rumen, small intestine and large intestine of lambs offered either herb-clover mix or ryegrass-clover based pasture from birth to early weaning were observed, suggesting the type of forage offered from birth to early weaning had no effect on the development of rumen or other digestive tract components. These findings suggest that farmers can use ryegrass-clover based pastures during lambing in early spring and then move lambs to herb-clover mix as a fattening feed for early-weaned lambs in order to archive target liveweight gains.

Ewes whose lambs were weaned early and offered ryegrass-clover based pasture until conventional weaning had greater liveweight gains and BCS than unweaned ewes on ryegrass-clover based pasture. This was likely due to the cessation of lactation, allowing ewes to partition nutrients to gaining live weight. This result was consistent with previous studies (Chapter 3, 4). Weaning lambs early can be recommended to allow ewes to gain more weights prior to conventional weaning. In both years, unweaned ewes on herb-clover mix had similar liveweight gains compared to ewes whose lambs were weaned early and offered ryegrass-clover based pasture. This suggests that ewes either can be weaned early onto ryegrass-clover based pasture or left unweaned on herb-clover mix to achieve greater live weights compared to ewes on ryegrass-clover based pasture with their lambs. Greater live weights at weaning can lead to greater live weights at mating which has been reported to have a positive impact on ewe reproductive performance (Corner-Thomas et al. 2015). Early weaning, therefore, can be used as a technique to improve ewe live weights and their reproductive performance.

5.6 Conclusion

Early exposure of lambs to a herb-clover mix prior to early weaning had no impact on their subsequent growth. Early-weaned lambs on herb-clover mix had the potential to achieve similar liveweight gains as lambs unweaned on ryegrass-clover based pasture.

Ewes whose lambs were weaned early gained greater live weights and BCS compared to ewes remained with their lambs on grass-clover based pasture. Early weaning, therefore, can be used as a technique to improve ewe live weights at breeding which may improve their reproductive performance.

CHAPTER 6

Characterisation of the nutritional composition of plant components in a herb-clover mix during November to May in New Zealand

Publications:

Ekanayake WEMLJ, Corner-Thomas RA, Cranston LM, Kenyon PR, Morris ST 2019. Characterisation of the nutritional composition of plant components of a herb-clover mix during November to May in New Zealand. Proceedings of the New Zealand Society of Animal Production 79: 162-167.

6.1 Abstract

Animal performance on herb-clover mixes (containing plantain, chicory, red clover and white clover) can be inconsistent. Potentially this could be due to variation in botanical and nutritional composition of plant components affecting animal selectivity and, thus, performance. Herbage samples were collected monthly from November 2016 to May 2017, from 3 paddocks located at Massey University's Keeble farm, Palmerston North, New Zealand. Quadrat cut samples were used to determine the herbage mass and botanical composition. Hand-plucked samples of each plant component were analysed for the nutritional composition. The percentage of chicory stems increased (9.2 to 16.2%) and plantain stems decreased over time (14.7 to 1.0%, $P<0.001$). Overall, the crude protein and metabolisable energy of white clover, red clover, plantain and chicory leaves were higher ($P<0.05$) than those of plantain and chicory stems in each month except in November. These data indicate that a higher proportion of chicory and plantain stems in a herb-clover mix would reduce its overall metabolisable energy and crude protein. This information can be useful for farmers to manipulate both the botanical and nutritional composition of herb-clover mix to optimise animal performance.

6.2 Introduction

Recently, in New Zealand, the use of herb-clover mixes containing plantain (*Plantago lanceolata*), chicory (*Cichorium intybus*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*) has increased. This has been driven by improved sheep performance (ewe and lamb liveweight gains pre-weaning, ewe milk production, lamb growth after weaning) on herb-clover mix compared to that observed on perennial ryegrass (*Lolium perenne* L.) and clover based pasture during spring to autumn period

(Cranston et al. 2015a; Somasiri et al. 2015a,b,c). Liveweight gains of lambs and ewes after weaning on herb-clover mixes, however, have been reported to be inconsistent across years (Corner-Thomas et al. 2018b; chapter 3). These inconsistencies may be due to the variation in botanical composition, nutritional profile, palatability and animal selectivity of plant components in the herb-clover mix and ryegrass-clover based pasture.

The nutritional profile of chicory and plantain, grown as monocultures, has been reported previously (Lee et al. 2015; Martin et al. 2017) and shown to vary with nitrogen fertilizer application and rate of defoliation (Martin et al. 2017). Red clover and white clover improve the nitrogen concentration in the soil, thus, provide bioavailable nitrogen to companion plant species in pasture mixes (Ledgard 2001). The nutritional profile of chicory and plantain, therefore, may differ when grown with red clover and white clover in a mix sward compared to monoclultures. The nutritional composition of the herb-clover mix has previously only been analysed as a mixed sample (Cranston et al. 2015b; chapter 2, 3). The nutritional composition of the individual plant components within a herb-clover mix and their respective effects on overall nutritive value during November to May period is not known. Understanding the nutritional changes of each plant component of the herb-clover mix may help to explain at least some of the variations in animal performance observed in previous studies.

We hypothesised, therefore, that the nutritional and botanical composition of individual plant components of the herb-clover mix may change during November to May period. Thus, the nutritional composition and relative nutritional contribution of each plant component in the herb-clover mix was characterised during this period.

6.3 Material and methods

6.3.1 Experimental site

The experimental site was at Massey University's Keeble farm, 5 km southeast of Palmerston North (40°24' S and 175°36' E), New Zealand. The soil type at the experimental site was a recent alluvial soil. Five paddocks (a total area of 8.5 ha) of a herb-clover mix containing plantain (cultivar 'Ceres Tonic'), chicory (cultivar 'Puna 2'), red clover (cultivar 'Sensation') and white clover (cultivar 'Bounty') were used. These paddocks were sown during autumn in 2012 and 2013 with a seed mixture of chicory (6 kg/ha), plantain (6 kg/ha), white clover (4 kg/ha) and red clover (6 kg/ha). All paddocks were fertilised in April 2016 and May 2017 with 30% Potash Super (phosphorous 6.3%, potassium 15%, sulphur 7.7% and calcium 14%) basal fertiliser mixture (Ravensdown, New Zealand) at a rate of 400 kg/ha and with urea (Ravensdown, New Zealand) at a rate of 67 kg/ha (30 kg N/ha). Paddocks were treated with Preside herbicide (active ingredient; paraffinic oil 582 g/l and alkoxylated alcohol non-ionic surfactants 240 g/l, Corteva agriscience, New Zealand) in May 2016 and June 2017 to control the spread of broadleaf weeds and with Gallant Ultra (active ingredient; haloxyfop-P at 520 g/litre present as the haloxyfop-P-methyl in the form of an emulsifiable concentrate, Dow AgroSciences, New Zealand) to control the spread of grass. All paddocks were grazed by sheep in a rotational grazing system at 3-4 weekly intervals, to a post-grazing residual of ~ 7 cm. Herbage was then allowed to re-grow for 2 weeks and samples were collected. This procedure was followed for each month, therefore, the relative maturity of herbage at the time of sampling would have been consistent and had no effect on the differences of nutritional composition of plant species.

6.3.2 Herbage measurements

Herbage samples were collected monthly (11 November 2016, 13 December 2016, 13 January 2017, 16 February 2017, 16 March 2017, 17 April 2017 and 25 May 2017). At each sampling time, herbage samples were collected from three paddocks (of the five paddocks) that were ready to be grazed. Four random quadrat cuts (1.0 m^2 each) were taken to ground level in each of three paddocks using an electric shearing hand-piece (Frame 1993). Samples (1.0 m^2 each) were collected from different locations in a paddock at each sampling, therefore, it was unlikely that sample collection impacted the composition of herbage at next sampling. Herbage samples were then sorted into plantain leaf, plantain stem, chicory leaf, chicory stem, red clover, white clover, weeds and dead matter to estimate botanical composition. They were then oven dried at 60°C in a draught oven to a constant weight to estimate the herbage dry matter. For each paddock, the herbage mass was calculated as the average of four quadrat cuts.

At each sampling time, one hand-plucked sample of each of plantain leaf, plantain stem, chicory leaf, chicory stem, red clover and white clover were randomly collected from the same three paddocks for nutritional-quality analysis. Samples were collected between 9.00 AM and 12.00 PM at each sampling day. Whole leaves of chicory and plantain were collected from a minimum of 10 different plants to create one subsample from each paddock. Red clover and white clover leaves were collected with stems, but were not separated into leaves and stems. Weed and dead matter were not analysed for nutritional composition.

6.3.3 Nutritional composition

Samples were freeze dried, ground and then passed through a 1 mm sieve. Samples were analysed using *in vitro* methods to determine the nutritional quality including *in-vitro* organic matter digestibility (OMD), dry matter digestibility (DMD) and digestible organic matter digestibility (DOMD) (Roughan & Holland 1977). Percentage crude protein (CP) was determined by "Dumas" procedure (AOAC method 968.06) using a Leco total combustion method (LECO Corporation, St. Joseph, MI, USA). Percentage neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed by a Tecator Fibretec System (Robertson & Van Soest 1981). Metabolisable energy content (ME) of herbages was calculated using the organic matter digestibility (DOMD×0.16 MJ/kg; DM) (Roughan & Holland 1977).

6.3.4 Predicted metabolisable energy

Predicted ME of herb-clover mix (PME) was calculated in order to estimate the relative contribution of individual species to the total metabolisable energy concentration of the herb-clover mix, using the following equation:

PME (MJ/kg DM) = Sum of (ME of the plant component (MJ/kg DM) × proportion of the plant component in the herb-clover mix without weed and dead matter)

Sheep selectively graze high-energy plant species such as chicory, plantain and clover over other plant species in herb-clover mix (Cave et al. 2015; Pain et al. 2010). Therefore, in such a mix sheep are likely to fulfil their nutritional requirements from chicory, plantain and clover but not from weeds or dead matter. It was, therefore, assumed that weed and dead matter would only make a minor contribution to the overall consumed ME of the herb-clover mix that a sheep would choose, therefore, they were not included in the PME calculation. Predicted ME of herb-clover mix was calculated using ME of individual plant components and adjusted botanical composition, the composition of herb-clover mix adjusted to 100% without dead matter and weed. Further, Predicted ME of herb-clover mix was calculated both with the ME of plantain and chicory stems included ($PME_{with\text{-}stems}$) and without ($PME_{no\text{-}stems}$). $PME_{no\text{-}stems}$ was calculated as it is possible that animals would graze the herb-clover mix without choosing chicory and plantain stems.

6.3.5 Statistical analysis

All the data were tested for normality and outliers before analysis. Herbage mass, botanical composition and nutritional composition data were subjected to analysis of variance using the MIXED procedure in SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US), and analysed using a mixed model that allowed for repeated measures. Herbage masses were analysed using a model that included sampling month as a fixed effect and paddock as a random effect. The botanical composition was analysed separately with a generalised model using a poisson distribution and logit transformation. Botanical composition and herbage-quality data were analysed using the MIXED procedure, with a model including the fixed effects of sampling month and plant component and the random effect of paddock number.

6.4 Results

Comparisons within each nutritional component were undertaken both within (superscripts; l-p) and across (superscripts; a-f) months [November (late spring); December, January, February (summer); March, April, May (autumn)] resulting in a number of potential comparisons. Due to the large number of significant differences observed, the following sections outline only the main trends as individual comparisons can be seen in table 6.1 and 6.2.

6.4.1 Herbage mass (kg DM/ha) and botanical composition (%)

Herbage mass of the herb-clover mix ranged between 1154±113 to 4821±400 kg DM/ha during November to May period. The percentage of chicory leaves in the herb-clover mix increased significantly from 30% in November to 50% in March and then decreased to 33% in May (Figure 6.1). The percentage of chicory stems was higher ($P<0.05$) in December (9%), February (15%), April (11%) and May (8%) than in all other months (5-6.5%). The percentage of plantain leaves increased from 8% in November to 18% in May while plantain stems decreased from 13% in November to 0% in May.

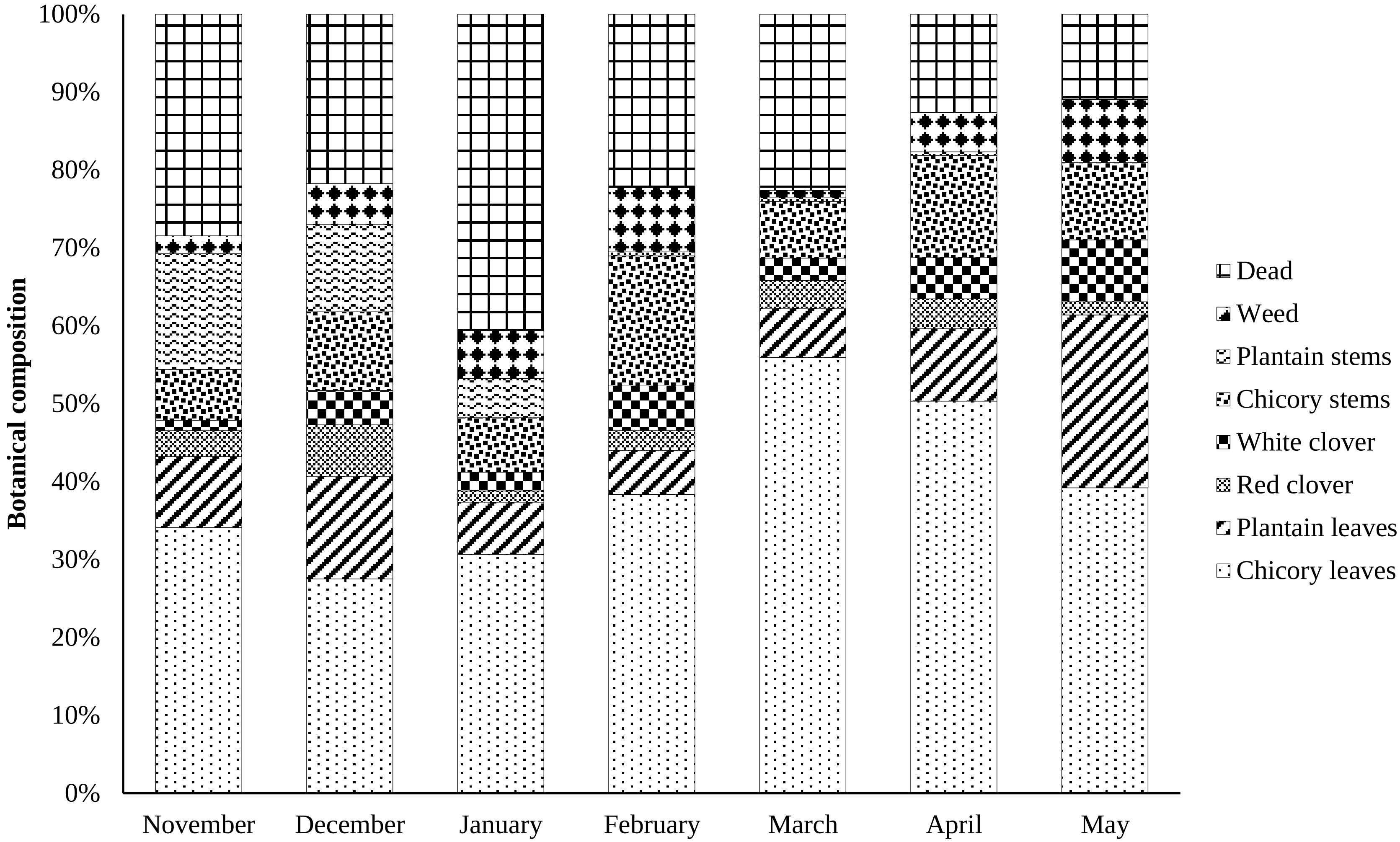

Figure 6.1 The botanical composition (% of herbage species) of herb-clover mix from November 2016 to May 2017

6.4.2 Crude protein (%) and ME (MJ/kg DM)

The CP of plant components differed within each month (Table 6.1). Crude protein of chicory leaves (15 to 23%) plantain leaves (16 to 23%), red clover (20 to 27%) and white clover (22 to 30%) was higher (P<0.05) than that of chicory stems (2 to 9%) and plantain stems (6 to 12%) in each month except November. The CP of each plant component across months showed that chicory leaves did not differ (P>0.05) during November to April (15 to 18%) but increased in May (23%). Crude protein of chicory stem decreased from 9% in November to 1.7% in May. Crude protein of plantain leaves did not differ (P>0.05) from November to March (16% to 20%) but increased in April and May (23%). Crude protein of plantain stems and white clover was higher (P<0.05) in November than in December and January and then increased to an intermediate level in late summer and autumn. Crude protein of red clover was higher (P<0.05) in November and December than in January and February and then was intermediate during March to April.

Metabolisable energy of chicory leaves (10.5 to 11.1 MJ/kg), plantain leaves (10.5 to 11.1 MJ/kg), red clover (10.3 to 11.4 MJ/kg) and white clover (10.9 to 11.5 MJ/kg) was higher (P<0.05) than that of chicory stems (7.2 to 10.6 MJ/kg) and plantain stems (8.9 to 10.0 MJ/kg) in each month except November. The ME of each plant component was compared across months and ME of chicory leaves did not differ (P>0.05) during November to April (11.0 to 11.4 MJ/kg) but decreased in May (10.5 MJ/kg). Similar trends were observed for plantain leaves and red clover. Metabolisable energy of chicory stem gradually decreased from 10.6 MJ/kg in November to 7.2 MJ/kg in May. Metabolisable energy of plantain stems in November and March was higher ($P<0.05$) than during rest of the time period. Metabolisable energy of white clover did not differ ($P>0.05$) over the course of time.

Table 6.1 Crude protein (CP), and metabolisable energy (ME) in dry matter of plant components in the herb-clover mix during November 2016 to May 2017 (Mean ± SEM)

Plant species/ component	November	December	January	February	March	April	May	SEM
				CP (%)				
Chicory leaf	15.7^{amn}	18.5^{an}	17.8^{amn}	15.4^{an}	19.7^{abno}	17.2^{an}	23.2^{bm}	1.8
Chicory stem	8.8^{bl}	4.2^{abl}	2.8^{al}	2.3^{al}	3.4^{al}	2.1^{al}	1.7^{al}	1.8
Plantain leaf	20.6^{abn}	16.9^{an}	16.7^{am}	16.3^{an}	18.1^{an}	22.3^{bno}	23.0^{bm}	1.8
Plantain stem	12.6^{clm}	7.2^{abm}	6.0^{al}	10.0^{abcm}	11.0^{bcm}	8.4^{abcm}	-	1.8
Red clover	27.5^{bo}	25.3^{bp}	20.4^{amn}	21.8^{ao}	23.3^{abo}	24.9^{abo}	27.7^{bm}	1.8
White clover	28.4^{bo}	22.7^{ao}	22.6^{an}	28.0^{bp}	28.4^{bp}	26.9^{abo}	30.4^{bn}	1.8
				ME (MJ/kg DM)				
Chicory leaf	11.1^{bn}	11.2^{bm}	11.4^{bn}	11.3^{bo}	11.5^{bo}	11.0^{bm}	10.5^{am}	0.1
Chicory stem	10.6^{fm}	9.4^{el}	8.8^{cdl}	8.6^{cdl}	8.5^{cl}	8.1^{bl}	7.2^{al}	0.1
Plantain leaf	11.0^{bmn}	11.0^{bm}	11.1^{bmn}	10.9^{bn}	11.1^{bn}	11.2^{bm}	10.5^{am}	0.1
Plantain stem	9.9^{cl}	9.3^{bl}	9.1^{abl}	9.3^{abm}	10.0^{cm}	8.9^{al}	-	0.1
Red clover	11.2^{bn}	11.4^{bm}	10.9^{bm}	10.8^{bn}	11.3^{bno}	11.1^{bm}	10.3^{am}	0.1
White clover	11.4^{an}	11.1^{am}	11.1^{amn}	11.1^{ano}	11.5^{ao}	11.3^{am}	10.9^{am}	0.1

SEM, standard error of the mean

$^{a-f}$ Means with different superscripts within rows are significantly different across months (P<0.05)

$^{l-p}$ Means with different superscripts within columns are significantly different across plant components (P<0.05)

6.4.3 Acid detergent fibre and NDF (%)

Acid detergent fibre of chicory and plantain stems was higher ($P<0.05$) than that of the other plant components in each month except November (Table 6.2). When compared across months, the ADF of chicory leaves was lower ($P<0.05$) in March than in May and November and it was intermediate in all other months. Acid detergent fibre of chicory stems gradually increased from 23% in November to 66% in May. Acid detergent fibre of plantain leaves was lower ($P<0.05$) in January, March and April than in May and then it was intermediate in all other months. Plantain stems had higher ($P<0.05$) ADF in December, January, February and April than in November and March. Red clover had higher ($P<0.05$) ADF in February and May than in December and it was intermediate during rest of the time period. Acid detergent fibre of white clover was lower ($P<0.05$) in March than in May and it did not differ ($P>0.05$) during the rest of the time period. Neutral detergent fibre of plant components showed a similar pattern of differences as ADF for each component.

Table 6.2 Acid detergent fibre (ADF), neutral detergent fibre (NDF) and lignin of plant components in the herb-clover mix during November 2016 to May 2017 (Mean ± SEM)

Plant species/ component	November	December	January	February	March	April	May	SEM
				ADF (%)				
Chicory leaf	18.3^{blmn}	15.6^{ablm}	17.1^{abl}	16.0^{abl}	13.1^{al}	16.9^{abl}	19.9^{bl}	1.7
Chicory stem	23.6^{an}	38.5^{bn}	45.6^{cn}	46.5^{cn}	46.8^{cn}	60.1^{dn}	66.3^{en}	1.7
Plantain leaf	20.4^{ablmn}	19.8^{ab}	18.4^{al}	19.8^{abl}	16.3^{al}	18.4^{al}	24.3^{bm}	1.7
Plantain stem	30.7^{ao}	40.9^{bn}	40.1^{bm}	38.7^{bm}	30.8^{am}	40.9^{bm}	-	1.7
Red clover	15.4^{abl}	14.4^{al}	19.5^{bcl}	20.9^{cl}	15.5^{abl}	17.5^{abcl}	21.3^{clm}	1.7
White clover	16.5^{ablm}	17.4^{ablm}	17.5^{abl}	17.4^{abl}	14.1^{al}	15.8^{abl}	19.0^{bl}	1.7
				NDF (%)				
Chicory leaf	22.9^{bl}	19.2^{abl}	18.0^{abl}	19.0^{abl}	16.6^{al}	21.0^{abl}	22.9^{abl}	1.9
Chicory stem	30.4^{al}	48.4^{bm}	55.8^{co}	56.9^{co}	57.6^{co}	66.8^{dn}	76.8^{em}	1.9
Plantain leaf	25.9^{abl}	25.7^{abl}	23.6^{abm}	24.7^{ablm}	20.8^{am}	22.1^{al}	28.4^{bl}	1.9
Plantain stem	46.1^{am}	53.3^{bm}	53.2^{bo}	49.0^{bn}	43.7^{an}	54.0^{bm}	-	1.9
Red clover	24.9^{abcl}	21.4^{al}	27.1^{bcdn}	30.3^{dm}	22.8^{abm}	24.7^{abcl}	29.1^{cdl}	1.9
White clover	22.0^{abl}	23.0^{abl}	22.5^{abm}	21.3^{abl}	19.5^{alm}	20.6^{al}	26.5^{bl}	1.9

Note: SEM, standard error of the mean. Red clover and white clover were not separated in to leaves and stems

$^{a-f}$ Means with different superscripts within rows are significantly different across months (P<0.05)

$^{l-p}$ Means with different superscripts within columns are significantly different across plant components (P<0.05)

6.4.4 Predicted ME (MJ/kg DM)

$PME_{no\text{-}stems}$ was higher ($p<0.05$) during November to March (10.8 to 11.2 MJ/kg DM) than during April to May (10.1 to 10.5 MJ/kg DM) (Figure 6.2). $PME_{no\text{-}stems}$ was higher than $PME_{with\text{-}stems}$ at each sampling month.

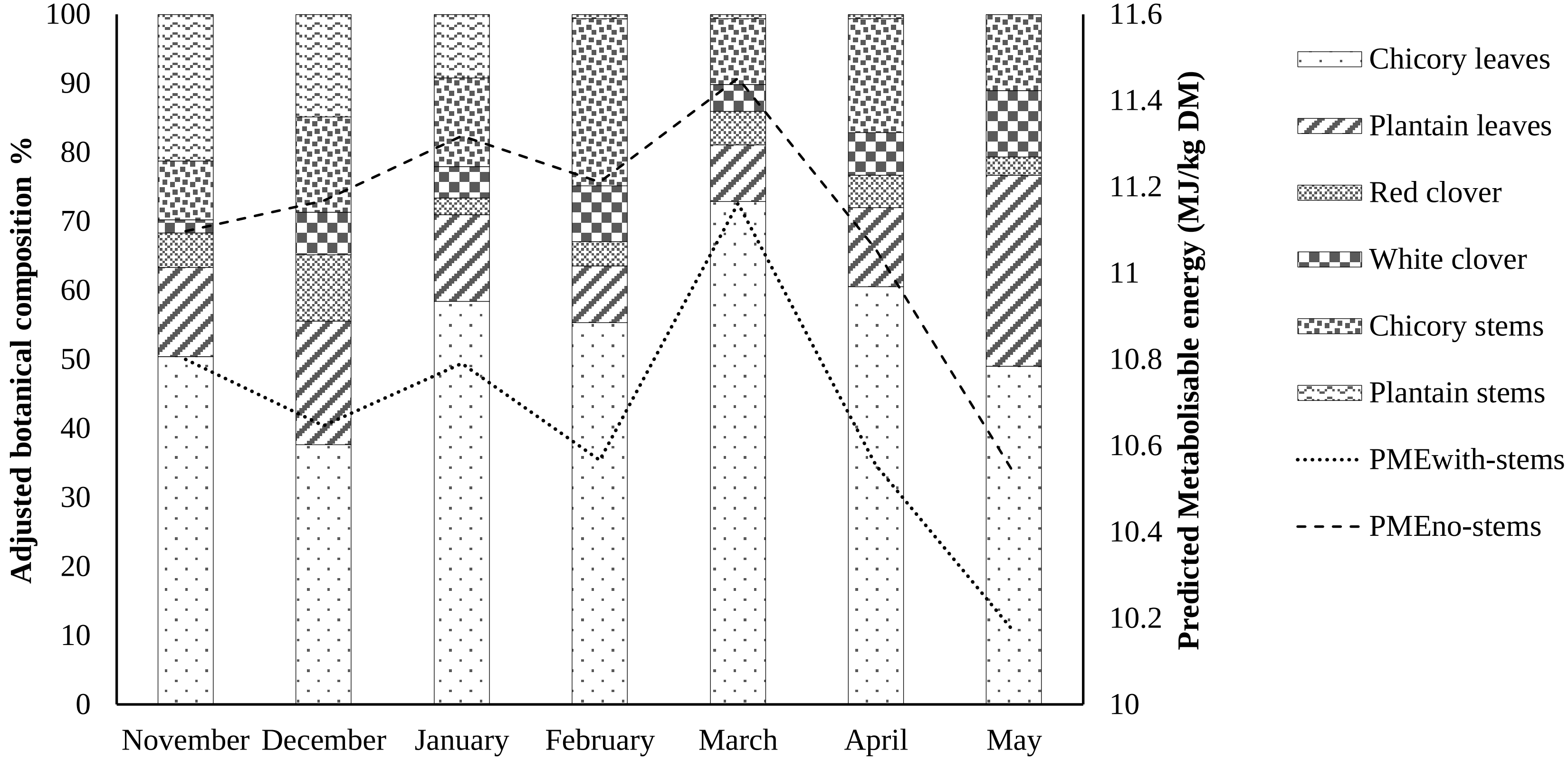

Figure 6.2 Adjusted botanical composition (% of herbage species without chicory and plantain stems) of herb-clover mix, predicted ME of herb-clover mix with the ME of plantain and chicory stems included ($PME_{with\text{-}stems}$) and without $PME_{no\text{-}stems}$ during November 2016 to May 2017

6.5 Discussion

The aim of this study was to characterise the nutritional composition of individual plant components of the herb-clover mix from November to May. In general, ME and CP of chicory and plantain leaves, red clover and white clover were higher than those of chicory and plantain stems during November to May period**,** while the NDF and ADF of plantain and chicory stems were higher than that of other plant components. Combined, this suggests that a farmer should manage the sward to allow for a higher proportion of chicory and plantain leaves, red clover and white clover during November to May to maximise the ME and CP of a herb-clover mix. The recommendations provided by Lee et al. (2015) to maximise leaf growth of plantain and chicory in pure swards could be applied to a herb-clover mix. Maximised leaf growth would also reduce the overall NDF and ADF of a herb-clover mix. Previous studies have shown that lambs demonstrate preferences for plantain and chicory leaves and clover (Cave et al. 2015; Pain et al. 2010) and show an aversion to reproductive stems in the herb-clover mix **(**Fraser & Rowarth 1996). By having a higher proportion of leaves and clover in the herb-clover mix, therefore, improved animal performance should be achieved. Stems of both chicory and plantain can accumulate in the herb-clover mix more rapidly during summer than in late spring (Fraser & Rowarth 1996; Rumball 1986) resulting in higher ADF and NDF which reduce feed intake and rumen outflow (Hodgson & Brookes (2002) and thus, animal performance. Further, Hodgson and Brookes (2002) reported that the higher concentrations of ADF and NDF in herbages can negatively affect CP and ME concentrations, further reducing animal performance. Somasiri (2014) and Cave et al. (2015) reported that a herb-clover mix contained lower ME and CP and higher ADF and NDF during summer than in early spring This was likely due to the higher proportion of plantain and chicory stems, which are high in ADF and NDF in summer than in early spring. The percentage of chicory and plantain stems in the herb-clover mix in this study was higher in early spring and summer than in autumn. The predicted ME of herb-clover mix, without ME of chicory and plantain stems, was also higher in late spring and summer than in autumn. Therefore, these results further suggest that the proportions of chicory and plantain stems greatly influence the overall ME of the herb-clover mix.

In previous studies, ME and CP of the herb-clover mix ranged from 9.8 to 11.6 MJ/kg DM and 9 to 25% DM, respectively, based on whole herb-clover samples (Cranston 2014; Kenyon et al. 2010). It is known, however, that animals prefer different plant components in the mix (Cave et al. 2015; Fraser & Rowarth 1996; Pain et al. 2010). This suggests that measuring ME and CP of a whole mixed herb-clover samples may not represent what an animal actually consumes. Therefore, using mixed herbage samples limits the ability to explain any variation in animal performance using these values. The results of the present study suggest that future nutritional analyses of the herb-clover mix should consider which plant components animals have eaten and their relative proportions in the mix, in order to be able to better explain animal performances.

6.6 Conclusion

Nutritional and botanical composition of individual plant components of the herb-clover mix changed during November to May period. Metabolisable energy and CP of chicory leaves, plantain leaves, red clover and white clover were higher than that of chicory and plantain stems during November to May period**.** NDF and ADF of plantain and chicory stems were higher than other plant components. Overall, the nutritional value of the herb-clover mix was likely driven by the proportion of chicory and plantain stems. It is important, therefore, to keep the growth of chicory and plantain stems under control for higher CP and ME of herb-clover mix during November to May.

GENERAL DISCUSSION

Introduction

Weaning lambs early can be a useful management tool to improve the efficiency of pasture utilisation particularly in circumstances where the quality and quantity of herbages are inadequate for lamb growth (Geenty 1979; Kenyon & Webby 2007). To date, in New Zealand, studies which have examined the impact of early weaning of lambs have primarily focused on using ryegrass-clover based pastures (Geenty 1979; Mulvaney et al. 2009; Mulvaney et al. 2011; Rattray et al. 1976). Growth of lambs after early weaning on ryegrass-clover based pastures has been poor compared to lambs weaned at the conventional age (approximately 90 days of age) and offered ryegrass-clover based pastures (Geenty 1979; Mulvaney et al. 2009; Mulvaney et al. 2011; Rattray et al. 1976). This suggests that early weaned lambs may benefit from a forage that has greater nutritional value such as herb-clover mix.

Herb-clover mixes containing chicory, plantain, red clover and white clover have been shown to improve both ewe and lamb performance during lactation and post weaning. For example the herb-clover mix can enhance ewe liveweight gain, body condition and milk production in lactation, and lamb growth pre and post conventional weaning age, carcass weights and survival compared to ryegrass-clover based pastures (Corner-Thomas et al. 2014b; Fraser & Rowarth 1996; Golding et al. 2008; Hutton et al. 2011; Kemp et al. 2010; Kenyon et al. 2010; Lindsay et al. 2007; Marley et al. 2005; Moorhead et al. 2002; Somasiri et al. 2015a,b,c; 2016). It was, therefore, hypothesised that growth of early-weaned lambs on herb-clover mix would be similar to unweaned lambs on a ryegrass-clover based pasture.

The main focus of this thesis was to;

1) Examine existing early weaning lamb live weight data to determine the effect of lamb live weight at early weaning on their subsequent growth
2) Compare the liveweight gain of lambs weaned at a minimum live weight of 16 kg, at approximately 50 days of age, onto a herb-clover mix with unweaned lambs grazed on a restricted ryegrass-clover based pasture
3) Investigate the impact of weaning lambs earlier at a minimum live weight of 14 kg, at approximately 40 days of age, onto a herb-clover mix compared with unweaned lambs grazed on a ryegrass-clover based pasture
4) Examine the impact of early exposure of lambs to the herb-clover mix prior to early weaning on their subsequent growth
5) Characterise the nutritional composition of the individual plant components of the herb-clover mix from November to May
6) Develop best-practice-farmer guidelines for early weaning of lambs onto a herb-clover mix in New Zealand

Summary of the experimental chapters

Chapter 2. The effect of live weight at weaning on liveweight gain of early-weaned lambs onto a herb-clover mix.

The aim of these studies was to determine if lambs weaned early at approximately 50 days of age onto a herb-clover mix could achieve growth rates similar to unweaned lambs on ryegrass-clover based pasture. It was found that early-weaned lambs achieved greater live weights than unweaned counterparts when the herb-clover mix had 1.2-1.6 MJ/kg DM greater ME content than the ryegrass-clover based pasture. The higher ME content compared to ryegrass-clover based pasture was due to high percentage of chicory (57%) and clover (14.1%) in herb-clover mix. Further, it appeared that when the ryegrass-clover based pasture had a low clover content (0.9 %), early-weaning of lambs onto a herb-clover mix improved lamb growth. Lighter lambs (<16-17 kg) at early weaning displayed a lower growth post early weaning compared to heavier lambs (> 18-19 kg). Lighter lambs, however, grew at a similar rate to unweaned counterparts on ryegrass-clover based pasture. Lambs heavier than 18 kg displayed a greater growth rate post early weaning than unweaned lambs on ryegrass-clover based pasture. These suggest that lighter lambs (<16-17 kg) have a potential to grow at a similar rate to unweaned counterparts on ryegrass-clover based pasture. Lighter lambs (<16-17 kg) weaned early onto a herb-clover mix also displayed a lower growth rate post early weaning than unweaned lambs on ryegrass-clover based pasture. Early weaning of lighter lambs, therefore, should be undertaken with caution and warranted further investigation.

Combined these results suggest when the clover content in a ryegrass-clover based pasture is low or the ME is lower than that of the herb-clover mix, farmers can improve lamb growth by weaning early at approximately 50 days of age on to a herb-clover mix. In this two-year study, lambs were provided *ad-libitum* allowance of both ryegrass-clover based pasture and herb-clover mix in their respective treatments. The impact of lower pasture availability on lamb growth rates was not investigated. Given the results of this study, it was hypothesised that early weaning of lambs on to a herb-clover mix would be an effective management tool particularly when ryegrass-clover based pasture supply was low.

Chapter 3. A comparison of liveweight gain of lambs weaned early onto a herb-clover mix and weaned conventionally onto a ryegrass-clover based pasture and herb-clover mix

In this chapter, it was hypothesised that the growth of early-weaned lambs on herb-clover mix would be greater when ryegrass-clover based pasture availability was low, a situation that can occur in New Zealand farms in the late spring or early summer. It was found that lambs weaned early onto the herb-clover mix displayed approximately 90 g/day greater liveweight gains than unweaned lambs on restricted ryegrass-clover based pasture (<1200 kg DM/ha). When ryegrass-clover based pasture allowance was unrestricted (<1200 kg DM/ha), however, unweaned lambs offered ryegrass-clover based pasture had greater growth rates than early-weaned lambs. These results suggest that when ryegrass-clover based pasture supply is low farmers should consider early weaning of lambs on to a herb-clover mix in order to achieve target weaning lamb weights.

Chapter 4. Early weaning of lambs at a minimum live weight of 14 kg, at approximately 50 days of age, onto a herb-clover mix

Early-weaned lambs in the previous studies were a minimum of 16 kg and their growth rates were within normal range of unweaned lambs on ryegrass-clover based pasture in New Zealand (Litherland & Lambert 2000). It was unknown if weaning at a lighter weight (and younger age) onto a herb-clover mix would subsequently impact on their growth after early-weaning. Hence, this study investigated the impact of early weaning of lambs at a minimum live weight of 14 kg onto a herb-clover mix. The liveweight gain of early-weaned lambs varied between years. Lambs weaned early onto a herb-clover mix were 800 g lighter at conventional weaning than lambs that remained with their dams on a ryegrass-clover based pasture in 2016, while in 2017 they had similar live weights. This suggests that lambs weaned early onto a herb-clover mix have the potential to achieve similar live weights as lambs unweaned on ryegrass-clover based pasture at conventional weaning. The variation of growth rates observed between early-weaned lambs and unweaned lambs on ryegrass-clover based pasture could not be explained using neither nutritional quality nor botanical composition of both herbages.

Chapter 5. Impact of prior exposure of lambs to a herb-clover mix prior to early weaning on their subsequent growth

Previous studies utilised a four-day adaptation period to the herb-clover mix prior to early weaning to allow lambs to become accustomed to the new feed type. It is possible that a longer exposure of lambs to a herb-clover mix in the period prior to early weaning should improve subsequent lamb growth after early-weaning. This study, therefore, examined the impact of early exposure of lambs to the herb-clover mix, from birth or, approximately 15 days of age, on their subsequent growth after early-weaning at approximately 40 days of age. Early-weaned lambs that had longer exposure to the herb-clover mix (Herb-Herb$_{EW}$ and Grass-Herb$_{D15EW}$) grew at a similar rate to lambs that had only four days of exposure. These results indicate that prolonged early exposure of lambs to herb-clover mix prior to early weaning is not required and that four-day-adaptation period prior to early weaning is adequate. This has potential benefits as the herb-clover mixes may be not ready to be grazed during lambing in late winter/early spring due to their delayed growth and potential plant damage in wet conditions.

Chapter 6. Characterisation of the nutritional composition of plant components in a herb-clover mix during November to May in New Zealand

The variation in botanical and nutritional composition of plant components of herb-clover mix can affect lamb selectivity and, thus their subsequent growth (Cave et al. 2015; Cranston et al. 2015a; Pain 2015). Understanding these variations and their effect on overall nutritive value of herb-clover may help to explain some of the variations in animal performance observed in previous early-weaning studies. It was hypothesised that the nutritional and botanical composition of individual plant components of the herb-clover mix including chicory leaves, chicory stems, plantain leaves, plantain stems, red clover and white clover of the herb-clover mix would change between November and May. This was found to be the case. Metabolisable energy and CP of chicory leaves, plantain leaves, red clover and white clover were greater than chicory and plantain stems throughout the measurement period. NDF and ADF of plantain and chicory stems were greater than other plant components. The proportions of chicory and plantain stems in the herb-clover mix greatly influenced the total ME content of the herb-clover mix. These results, therefore, indicate that it is important to keep the growth of chicory and plantain stems under control and ensure a large proportion of the mix is leaves to achieve higher CP and ME concentrations in the herb-clover mix. In previous studies**,** the proportion of chicory and plantain stems in the herb-clover mix was not considered but could have affected animal performance. The findings of this study, therefore, might also explain some of the variations observed in studies reported in the literature. In future, nutritional analysis of the herb-clover mix should account for the plant components animals have eaten and their relative proportions in the mix, in order to understand the nutrition-related drivers of lamb growth on herb-clover mixes.

Best-practice guidelines for early weaning of lambs

Based on the findings of this series of studies and literature relevant to early weaning of lambs onto a herb-clover mix, the following guidelines are suggested for farmers to achieve target-weaning lamb weights.

- If ryegrass-clover based pasture availability is low, potentially resulting restricted supply of herbage (less than 1200 kg DM/ha) to lambs and ewes, farmers should consider weaning lambs early on to a herb-clover mix.

- Unweaned lambs display a limited growth if the clover content of the ryegrass-clover based pastures is below 5%. When there is a low percentage of clover in ryegrass-clover based pastures, early weaning onto a herb-clover mix should be considered to achieve improved liveweight gains.
- An ideal herb-clover mix for improved lamb growth should contain greater proportions of chicory (~ 60%) and clover (~ 14%) and metabolisable energy of approximately 11.0 ME MJ/kg DM.
- An ideal herb-clover mix should contain higher proportions of chicory and plantain leaves and less chicory and plantain stems to achieve maximal nutritional quality and animal performance. The growth of plantain and chicory leaves in a herb-clover mix can be maximised by regular weed control, intensive grazing and topping .
- Lambs can be weaned at a minimum of 14 kg live weight onto a herb-clover mix and achieve similar growth rates to unweaned counterparts on a ryegrass-clover based pasture. Early-weaned lambs, however, can display ~ 16 g/day slower growth rate and be ~ 800 g lighter compared to their unweaned conterparts on ryegrass-clover based pasture in certain years.
- Lambs do not require prior exposure to herb-clover mix prior to early weaning, however, it is recommended that at least a four-day adaptation period to the herb-clover mix prior is utilised prior to early weaning.
- Herb-clover mix has the greatest quality and growth if it is not grazed below 7 cm in order to maintain unrestricted allowance of herbage for ewe and lambs.

Limitations of the study

Across studies, when greater liveweight gains of early-weaned lambs on the herb-clover mix were observed compared to unweaned lambs on ryegrass-clover based pasture, they were primarily due to a higher nutritional quality and herbage yield of herb-clover mix compared to ryegrass-clover based pasture. The nutritional quality of both herb-clover mix and ryegrass-clover based pasture can vary among different regions in New Zealand. The nutritional quality of the herb-clover mix has been reviewed (Cranston et al. 2015a), and found to vary between seasons, studies and months (Chapter 6). The nutritional quality of the ryegrass-clover based pasture was also found to vary between seasons in New Zealand sheep and beef farms (Litherland et al. 2002). To date, studies that have investigated the animal performance on herb-clover mix, including the current studies, have been primarily focused on the Manawatu region. This potentially could limit the application of these weaning practices to other regions of New Zealand. Based on the reported nutritional quality and herbage masses of chicory and plantain pure swards in dryland conditions in Canterbury (Brown et al. 2005; Hunter et al. 1994; Stewart 1996) and Waikato (Lee et al. 2015; Minnee et al. 2013), however, it is likely that the herb-clover mix would be a suitable herbage for early weaning in these other regions.

The current experiments included only twin lambs, therefore, care should be taken when applying early-weaning techniques to singleton or triplet lambs, as their growth is likely to be different. Triplet lambs can display slower growth rates during lactation due to lower individual milk intakes compared to twin and singleton lambs, resulting in lower weaning weights (Behrendt et al. 2019; Boujenane 2012; Corner-Thomas et al. 2008; Emsen &Yaprak 2006; Paganoni et al. 2014). Weaning singleton (heavy) and triplet (lighter) lambs onto a herb-clover mix could, therefore, result in different liveweight gains, compared to twin lambs.

Early-weaned lambs were managed together with unweaned lambs and their dams on the herb-clover mix, and potentially could have stolen milk from unweaned ewes, thus, increasing their growth rates. This is, however, unlikely as ewes develop an exclusive bond with their lambs (Nowak & Poindron 2006). Further, lambs begin nibbling solid feed from as early as seven days of age and increase their intake of solid feed during the first four weeks of life after which they start to rely on pasture to fulfil their nutrient requirements (Corbett 1968; Janssens & Ternouth 1987). Twin lambs are driven to eat more solid feed earlier than singleton lambs due to the reduced availability of milk (Geenty & Dyson 1986). These suggest, therefore, that lambs weaned early (at approximately 7 weeks of age) in this study would have primarily relied on herbage to meet their nutritional requirements rather than attempting to steal milk from ewes whose lambs were unweaned.

Due to the nature of treatment allocation, treatment numbers and area of paddocks, some treatment groups within each herbage type were grazed in different paddocks for at least a period of time. It was assumed that the variation in nutritional quality, botanical composition and thus animal selectivity within each paddock was negligible. Ideally, each treatment group should have been replicated across different paddocks to avoid this limitation. Replicates and large number of animals, however, were limited by ethical considerations. Within each herbage type, lambs and ewes were grazed rotationally thereby reducing the effect of individual paddocks. Further, treatment groups were replicated across both years and studies, providing confidence in results found.

Across the studies included in this thesis, early-weaned lambs grew at a rate of 237 to 360 g/day while their unweaned counterparts on ryegrass-clover based pasture were growing at 231 to 327 g/day. The growth rates of early-weaned lambs on the herb-clover mix were, however, inconsistent compared with unweaned lambs on ryegrass-clover based pasture between several seasons. It was found that early-weaned lambs grew faster than unweaned lambs when the nutritional quality, particularly ME, of herb-clover mix was greater than ryegrass-clover based pasture. This relationship was, however, not apperent across all the studies, suggesting that the growth of both early-weaned and unweaned lambs may have driven by unseen factors other than the nutritional quality of both herb-clover mix and ryegrass-clover based pasture. Selective grazing of some plant components of the herb-clover mix by lambs and the difference in botanical composition between studies could have been one of the reasons for this inconsitent results. Cave et al. (2015) reported that sheep selectivily grazed and had preference for some plant species in a mixed herbage changed across seasons. This change was likely due to variation in the species available and their palatability. Further, animal preference and selectivity studies (Pain et al. 2015) suggests that nutritive value and palatability of each component affects lamb preference. In this series of studies, it was found that the botanical composition of the herb-clover mix changed between years. Animal selectivity, therefore, could have also been changed thus accounting for variation in liveweight gains. Animal selectivity of different plant components of the herb-clover mix was not measured, therefore, it is not possible to determine exactly what was consumed. During each study in this thesis, herbage samples were collected only three times (at the time of early weaning, mid-way through the study and at conventional weaning). As a result, the variation in the nutritional quality during the study may not have been fully captured resulting in an inability to relate nutritional quality of herbage with animal performance. Estimations of animal selectivity and nutritional quality of selected plant species during the growing period, although not measured, could have helped in understanding the relationship between animal performance and nutritional quality. In Chapter 6, it was found that the nutritional quality of herb-clover mix changed between November and May and was driven by changes in the composition of individual plants. It is, therefore, possible that changes in the composition of individual plants in the herb-clover mix influenced its overall nutritional quality between years and may have been the reason for the inconsistent growth rates of early-weaned lambs observed. Further, nutritional estimations, particularly ME, did not account for what the lambs actually consumed. Therefore, the estimated ME content of the forages offered could have differed from that actual ME intake of lambs. As a result, the growth varaiation of early-weaned lambs between years could not be explained using the estimated ME of herb-clover mix.

The differences in dry matter intake of early-weaned lambs may have also accounted for the inconsistent growth compared with unweaned lambs on ryegrass-clover based pasture. Early-weaned lambs were offered unrestricted suppy of herb-clover mix (> 1200 kg DM/ha) across all the studies in this thesis. Regardless, changes in the botanical composition of the herb-clover mix occurred between years and may have affected the grazing behaviour and species selected by the lambs, thus, effecting the overall dry matter intakes. Pain et al. (2015) reported a seasonal variation of lamb's preference for different plant species in the herb-clover mix, and different dry matter intakes. This suggests that the dry matter intake of early-weaned lambs may have differed between years due the variation of the species avaiability in the herb-clover mix, thus, resulted in inconsistent growth rates compared to unweaned lambs on ryegrass-clover based pasture. The dry matter intake of early-weaned lambs, however, was not estimated, therefore, it's effect on their subsequent growth can not be estimated. In adddition, seasonal environmental factors such as climate and rainfall, and individual animals used in each study varied between years and may have impacted on the growth of both early-weaned lambs and unweaned lambs. These biological variations may result in an inconsistent growth of early-weaned lambs compared with unweaned lambs on ryegrass-clover based pasture between seasons.

Weeds such as broad leaved duck (Rumex obtusifolius L.) and giant buttercup (*Ranunculus acris*) were unaffected by the chemical and mechanical weed control treatments employed in these studies. These weeds were not separated from the other plant species in the herb-clover mix samples prior to analysis, and therefore, contributed to the nutritional quality assessments. Separation of weeds from the samples prior to the analysis could have avoided this. It is possible that lambs may have consumed these weeds as well as the sown plant species, and as such contributed to the nutritional intake of lambs. Further, weed growth within the mix could have also affected the growth of sown plant species, resulting variation in the animal selectively and nutritional quality. To avoid this, it is recommended that animal selectivity should be assessed to understand the relationship between nutritional quality and animal performance on herb-clover mix.

Future recommendations

Current early-weaning strategies have been developed using a series of studies conducted primarily in Manawatu region in New Zealand. These early-weaning strategies may not be appropriate to other regions of New Zealand due to the differences in growth and the nutritional quality of both herb-clover mix and ryegrass-clover based pasture in different regions. Further studies to estimate the feasibility of these early-weaning strategies to improve lamb growth post weaning in other regions of New Zealand would likely be of benefits.

Current early-weaning strategies have been successful for twin lambs above 14 kg of live weight. It is possible that weaning lambs lighter than 14 kg would be successful. Fraser & Saville (2000) reported that lighter lambs at weaning were light primarily due to a lower milk intake than their heavier counterparts that received more milk during lactation. They further reported that the growth rate of lighter lambs was less affected by weaning than that of their heavier counterparts. Early weaning of lighter lambs is likely to be a potential advantage when the herbage supply from a herb-clover mix is high and of good quality, therefore, warrants further investigation.

It is evident that lamb preference and selectivity for different plant species in the herb-clover mix can vary among seasons and is likely due to changes in species availability and palatability (Cave et al. 2015). Animal preference and selectivity studies on herb-clover mix are needed that focus on what plant, and plant components, actually contribute to the live weight gains of lambs post weaning on herb-clover mix. Further studies to identify sward conditions of the herb-clover mix that would result a maximised lamb and ewe performance are also recommended.

The nutritional quality of the herb-clover mix has been estimated in wide range of studies (Cranston et al. 2015a) including the current study. These estimations have been conducted using grab samples of herb-clover mix, therefore, these nutritional estimations have not accounted for what the lambs actually consumed. As a result, in certain studies, nutritional quality of the herb-clover mix has failed to explain its effect on animal growth post weaning. Estimations of animal selectivity and the nutritional quality of selected plant species during the growing period could have helped understand the relationship between animal performance and the nutritional quality, therefore, are recommended in future.

Overall conclusion

Early-weaned lambs at approximately 40 days of age and a minimum live weight of 14 kg on to a herb-clover mix have the potential to achieve growth rates at least similar to unweaned lambs on ryegrass-clover based pasture. Early-weaned lambs have the potential to grow faster than unweaned lambs on a ryegrass-clover based pasture when herb-clover mix has a greater chicory and clover content and/or there is a low clover content in ryegrass-clover based pasture. Further, the advantages of early weaning are enhanced, when ryegrass-clover based pasture supply was low (< 1200 kg DM/ha), resulting in restricted intake of ewes and lambs. Prolonged early exposure of lambs to herb-clover mix had no impact on the subsequent growth of lambs. Four-day adaptation period for lambs on herb-clover mix prior to early weaning is all that is required.

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