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Livestock and pasture production from dryland lucerne and two lucerne/grass mixtures over four years in Canterbury

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Russell George Croy

Lincoln University

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DECLARATION

The candidate assisted in the collection of data for the spring, summer, and autumn of 2015/16. The remainder of data collection had already taken place prior to the commencement of degree. All analysis and their interpretation are the candidates work.

Livestock and pasture production from dryland lucerne and two lucerne/grass mixtures over four years in Canterbury

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ABSTRACT

The productivity of a lucerne monoculture, lucerne/brome and lucerne/cocksfoot binary mixtures grown on shallow soils at Ashley Dene, Canterbury, were compared under grazing over four years. Pastures were grazed with separate mobs of ewes & lambs during the spring, weaned lambs during the summer, and hoggets during autumn. The live weight gain of sheep was the ultimate measurement of pasture performance. In turn, this was related to seasonal pasture yield and pasture composition.

The live weight production of the lucerne monoculture averaged 28% more than the binary mixtures, which were not different from each other. During the first year annual live weight gain was 780 ($\pm$26.2) kg/ha for all treatments, because lucerne dominated their composition. Thereafter, lucerne made up >70% of pasture yield in the lucerne treatment and ~37% in the binary mixtures. Live weight gain was 550-800 kg/ha on the lucerne treatment and 400-550 kg/ha on the binary mixtures over the next three years.

Annual pasture yields were similar among treatments each year. These ranged from 6.3-10.8 ($\pm$0.28) t DM/ha with soil water availability during the growing season being a strong predictor of yield. The growth response to thermal time, while it appeared soil water was not limiting, averaged 6.1 ($\pm$0.21) kg DM/ha/°C day during the first two years and 4.3 kg DM/ha/°C day during the last two. The difference among years was related to higher pre-grazing pasture covers during the first two years which probably increased interception of photosynthetically active radiation. The onset of a soil water deficit, which limited pasture growth, was in mid-December during the first two years and in early/mid-November during the final two. This occurred at comparable times for each pasture treatment suggesting soil water accessibility was independent of this, on these shallow soils. This is consistent with 184 mm of soil water accessibility.

The higher live weight gain of the lucerne treatment eventuated through up to 30% higher metabolisable energy intake compared with the binary mixtures. The shoot structure of lucerne appeared to facilitate enhanced discrimination between more and less palatable portions during grazing relative to sown grass species. This may be complemented by the lower levels of neutral detergent fibre in lucerne which results in faster digestion and therefore increased pasture intake.

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ABBREVIATIONS

AMN	Anaerobically mineralisable nitrogen
CP	Crude protein- shoot nitrogen content as measured by NIRS*6.25
DM	Dry matter
DUL	Drained upper limit
GD	Grazing day
LAI	Leaf area index
LL	Lower limit
LWG	Live weight gain
ME	Metabolisable energy
N	Nitrogen
NDF	Neutral detergent fibre
NIRS	Near infra-red spectrometry
PAR	Photosynthetically active radiation
PAWC	Plant available water holding capacity
PET	Potential evapotranspiration
PSWD	Potential soil water deficit
S.E.M.	Standard error of the mean
TDR	Time domain reflectometer
TT	Thermal time
WUE	Water use efficiency

1   GENERAL INTRODUCTION

To ensure financial and social sustainability of dryland farming systems, species other than perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) are required (Avery *et al.*, 2008). Lucerne (*Medicago sativa* L.) is one option that was typically used as a hay or silage crop in New Zealand but began to lose favour with farmers towards the end of last century due to its susceptibility to pest, disease, and weed ingression (Crooks, 1975; Trought, 1977; Goulter, 1981). Development of cultivars exhibiting more pest and disease resistance and an improved understanding of stand management (Moot *et al.*, 2003) have led to high levels of livestock performance from grazed lucerne monocultures (Mills and Moot, 2010). This is consolidating a new appreciation of its fit in modern farming systems (Avery *et al.*, 2008; Anderson *et al.*, 2014). As a result, the popularity of lucerne has increased of late as indicated by annual seed sales (Monk *et al.*, 2016).

Best practice management of lucerne requires the delay of livestock introduction in the spring relative to grass species to enable this pasture to express its potential (Moot *et al.*, 2003). This limits feed supply at the onset of lactation compared with grass based pastures. The companion planting of a winter active grass species with lucerne is advocated as a means to extend the duration of feed availability compared with a lucerne monoculture. Additional advantages of binary mixtures may arise from increased utilisation of ecosystem resources (Cardinale *et al.*, 2011), and increased ground cover during regrowth periods to provide erosion control and protection from weed ingression (McLeod and Douglas, 1975; Murphy *et al.*, 2014). Experimental work on lucerne/grass binary mixtures has concentrated on the dry matter yield response relative to a lucerne monoculture (Cullen, 1960; O'Connor, 1967a; Vartha, 1967; Fraser, 1982). Experiments have reported that binary mixtures do generally provide earlier growth but results on annual pasture yield are inconclusive with variation among companion grass species, district, year, and season. None of these reports include animal production comparisons.

The ultimate performance of a pasture is the achievable livestock production it supports and the sustainability of this. Earlier pasture availability at the onset of lactation facilitates earlier lambing dates, which in turn enables lambs a longer growing period to achieve a killable live weight prior to limiting soil water deficits. However, pasture intake which drives animal productivity, is recognised to be higher on a legume dominated diet (Cosgrove and Edwards, 2007). When offered adjoining legume and grass swards, ruminants will consistently select 25-

30% of grass as their preferred diet (Rutter, 2006). The inclusion of grass appears to be an attempt to balance pasture intake with associated costs of a high legume diet thereby optimising pasture intake. To this end, the companion planting of a grass species with lucerne may indeed be beneficial to the diet of livestock.

Maintaining a desirable lucerne composition within binary mixtures (60-80%) is central to achieving live weight production greater than that achievable from a lucerne monoculture. Pastures are susceptible to species succession as one or more components exhibits a dominance at procuring ecosystem resources (Sanderson *et al.*, 2004). Grass species root and shoot structure enable them to dominate legume species in sourcing water and nutrients from the top soil, and at intercepting light during pasture establishment and early in a regrowth cycle. In addition, livestock preference for most legumes (Rutter, 2006) typically results in these mixtures becoming grass dominant over time. Lucerne has a tap root so has a greater potential rooting depth than companion grass species that enables access to deeper soil moisture. Furthermore, in association with *Sinorhizobium meliloti*, lucerne's ability to fix nitrogen (N) ensures a reliable supply of this nutrient. Given water and N are the primary limiting variables of dryland pasture production (Mills, 2007), this has the potential to provide an advantage to this species.

The primary aim of this research was to determine if there was a difference in the animal productivity of these lucerne/grass mixtures relative to a monoculture, and relate this to pasture production and composition. Further to this, pasture production was examined in relation to the environmental parameters of thermal time, soil water availability, and soil N status.

The null hypothesis is: that the live weight gain of pasture treatments will not be different over a four year period.

The structure of this dissertation is presented in the following flow diagram (Figure 1-1). Chapter 2 is a review of the literature and provides the relevance of this research to dryland farming systems and discusses the potential influence of pasture composition. Chapter 3 describes the setup and management of the experiment as well as explaining the measurements taken and the statistics calculated. Chapters 4 & 5 are the results section. Chapter 4 investigates the animal and pasture interface with a focus on what is driving the livestock productivity of these treatments. Chapter 5 quantifies the pasture response to the environmental parameters of

thermal time, soil water, and soil N. Finally in Chapter 6, a general discussion summarises the findings and relates implications of this research for dryland farming systems.

CHAPTER 1:	GENERAL INTRODUCTION

CHAPTER 2:	LITERATURE REVIEW

CHAPTER 3:	MATERIALS AND METHODS

RESULTS

CHAPTER 4: LIVE WEIGHT GAIN AND PASTURE YIELD

Objectives

Among pasture treatments

- Quantify live weight gain and calculate metabolisable energy requirement of livestock.
- Quantify pasture dry matter and metabolisable energy yield.
- Estimate pasture intake from livestock and pasture measurements, and assess the robustness of respective methods.

CHAPTER 5: PASTURE RESPONSE TO ENVIRONMENTAL PARAMETERS

Objectives

Among pasture treatments

- Quantify pasture growth against thermal time when soil water is non-limiting
- Quantify pasture effect on the duration of pasture growth by estimating the onset in the winter and time of cessation in the summer.
- Quantify pasture effect on soil nitrogen and organic matter status over time.

CHAPTER 6:	GENERAL DISCUSSION AND CONCLUSIONS

Figure 1-1: Flow diagram of dissertation structure.

2   LITERATURE REVIEW

2.1   Dryland pastures

Dryland pastures are those subject to a deficit in soil water availability late in the spring or during the summer each year. Prior to this, during the spring season, there is a window when both soil water availability and temperature are conducive to pasture growth. These dryland farms align lactation with the period of most abundant and reliable pasture growth. With the duration of feed supply limited by a soil water deficit, these systems are dependent on early lambing and rapid lamb growth to reduce the dependency on unreliable in season rainfall.

2.2   Lucerne

Lucerne is a perennial forage legume appropriate for dryland pastoral farming in New Zealand (Avery *et al.*, 2008).

2.2.1   Rooting depth

With an extensive tap root, lucerne is able to source soil water from deep within the soil profile. When soil depth allows, lucerne has access to soil water beyond the reach of other dryland pasture species. Potential evapotranspiration (PET) is a measure of the environmental demand of soil water when not limiting. When PET exceeds rainfall, dryland pastures are dependent on depleting plant available water holding capacity (PAWC) within the soil to maintain growth. Access to a larger reservoir of water enables the duration of lucerne growth to persist longer into the summer compared with grass based pastures. Moot *et al.* (2008) reported a lucerne monoculture extracted 328 mm of water to a depth of 2.3 m on a Wakanui silt loam, whereas perennial ryegrass only extracted 243 mm to a depth of 1.5 m, on the same soil.

2.2.2   Nitrogen fixation

In the absence of nitrogenous fertilisers, pasture ecosystems are reliant on N fixation of legumes to supplement mineralisation of soil N to maintain an N balance. Live lamb comprises 15-20% protein by weight (Maeno *et al.*, 2013) meaning N loss from the system is ~3% of live weight. There is the potential for additional N loss to the environment via volatilisation and leaching of mineral N in excreta.

Lucerne's association with the rhizobia *Sinorhizobium meliloti* ensures a reliable supply of N from fixation, which is typically limiting to the production of grass based pasture systems.

Legumes will typically fix between 2-2.5% of shoot dry matter (DM) production in N (Peoples *et al.*, 1998; Carlsson and Huss-Danell, 2003; Yang *et al.*, 2011; Taraken, 2014), however this is regulated by soil N status, as lucerne is a facultative fixer (Ledgard, 2001). Unkovich *et al.* (2010) reported this ranges from 0.5-3.0% of shoot weight for lucerne. This enables lucerne to maintain a high leaf crude protein (CP) content. Shoot CP levels of up to 30% can increase pasture growth rates (Belanger and Gastal, 2000) due to faster leaf extension rates and increased photosynthetic rates (Belanger, 1997; Peri *et al.*, 2002). For example, Mills (2007) compared the pasture yield of cocksfoot (*Dactylis glomerata* L.) fertilised with 800 kg N/ha to cocksfoot pasture receiving no N fertiliser. The CP content was ~27% and ~19%, respectively. The +N treatment grew 7.2 kg DM/ha/°C day compared with 3.2 kg DM/ha/°C day for the unfertilised pasture, when water was non-limiting to growth.

2.2.3 Pasture yield

On a Templeton silt loam soil (Udic Haplustept, USDA classification) in Canterbury, unirrigated lucerne was shown to be greater yielding than cocksfoot with clover species, and perennial ryegrass with white clover for six out of seven years (Mills *et al.*, 2015a). The lucerne monoculture produced 10.0-18.5 t DM/ha annually compared with the grass and clover mixtures which produced 6.0-13.0 t DM/ha. The variability experienced among years is mainly due to the amount of 'in season' rainfall which supported longer growing durations. On lighter land in Canterbury, yields of 12 t DM/ha have been recorded for lucerne (Moot *et al.*, 2016).

2.2.4 Nutritive value

Lucerne provides a nutritive feed for livestock. The metabolisable energy (ME) content of lucerne offered to livestock averages ~11 MJ ME/kg DM and the CP content ~25% (Mills and Moot, 2010). The concentration of these nutrients is higher in the leaf than in the stem. Black and Ryan-Salter (2016) measured 11.7 MJ ME/kg DM and 25.4% CP in the leaf and 9.2 MJ ME/kg DM and 13.5% CP in the stem of this plant. Brown and Moot (2004) separated the palatable and unpalatable portions of lucerne for different pre-grazing pasture yields. The nutritive value of these portions were analysed separately and showed a consistent ME content. The palatable lucerne had an energy content of 11.9 MJ ME/kg DM and the unpalatable 7.9 MJ ME/kg DM. Similarly, the CP content of palatable lucerne was ~30% and unpalatable lucerne had a consistent CP content of 11%. Reducing nutritive value of pre-grazing pasture yields arise from an increasing ratio of unpalatable to palatable pasture mass. Providing

livestock are not required to graze the hard stem, an ME content of 11-11.5 MJ ME/kg DM and a CP content in excess of 25% are frequently achieved by lucerne (Brown and Moot, 2004).

2.2.5 Livestock production

Lucerne has been shown to produce high live weight gain (LWG) of livestock. At 8-10 kg DM/ewe/day pasture allocation, Rattray *et al.* (1982) measured growth rates of lambs at foot of ~280 g/day on ryegrass/white clover and ~310 g/day on lucerne. Douglas *et al.* (1995) measured growth rates of 263 g/day on lucerne compared with 275 g/day on lotus (*Lotus corniculatus* L.). Daily growth rates of 180-270 g LWG/day have been reported for weaned lambs grazing lucerne (McLean *et al.*, 1967; Douglas *et al.*, 1995; Wang *et al.*, 2009). Cruickshank (1986) compared the growth rate of weaned lambs feeding on legumes and grasses, separately. The LWG of the lambs fed either white clover or lucerne was ~38% higher, at ~315 g/day, than those on perennial ryegrass or prairie grass (*Bromus willdenowii* Kunth.). This was associated with a larger dry matter intake on the legumes. Mills *et al.* (2015a) measured annual LWG of sheep grazing a lucerne monoculture of 750-1250 kg LWG/ha over an eight year period in Canterbury. A similar LWG range was measured on cocksfoot and subterranean clover (*Trifolium subterraneum* L.) pastures despite these pastures having lower DM yields. When related to pasture yield, sheep on the lucerne grew 72 g LWG/kg DM compared with 89 g LWG/kg DM on the cocksfoot/subterranean clover pasture. Annual live weight production of 1347 kg/ha has been realised from sheep grazing lucerne (Black and Ryan-Salter, 2016). These hoggets and weaned lambs maintained average growth rates of 250-260 g LWG/day over two years. With pasture yields ~10 t DM/ha, this resulted in 111 and 139 g LWG/kg DM yield in consecutive years.

2.2.6 Early spring feed availability

With the increased use of lucerne as a grazed crop there is a realisation that the pasture availability of this species does not fit the feed requirement of livestock that lamb early in the spring. It is recommended that livestock introduction should be delayed until the lucerne crop is 15 cm in height (Moot *et al.*, 2003). On the Canterbury Plains, this results in the introduction of ewes & lambs to lucerne monocultures typically ~20 days later in the spring than on grass based pastures (Mills and Moot, 2010). Without delaying lambing to better align pasture demand with pasture supply (which would reduce the duration of lactation prior to a limiting soil water deficit), increasing the pasture area in lucerne results in increased dependency on the reducing grass based pastures during early lactation. The companion planting of a winter active

grass species with lucerne is advocated as a solution to meeting early spring pasture requirements, maintaining lactation length, and providing transitional feed before grazing lucerne monocultures.

2.3   Lucerne/grass binary mixtures

It is considered advantageous to establish numerous species in a pasture. This ensures greater persistence and consistency of production as growing conditions vary. Greater diversity in an ecosystem is often reported to increase productivity (Cardinale *et al.*, 2011). However, the yield response could be positive due to greater utilisation of resources or beneficial interaction of species, or negative, whereby competition for resources reduces the use efficiency of these, or neutral, where one species simply replaces another (Sanderson *et al.*, 2004).

Pastoral farming in New Zealand has traditionally been based on legume/grass pastures. Legumes have traditionally been important for their ability to contribute N to the pasture but are also recognised to support higher levels of livestock production (Cruickshank, 1986; Waghorn *et al.*, 2007). The use of lucerne in combination with grass species has been investigated extensively both in New Zealand and overseas. Assessments of these swards have concentrated on the pasture yield advantage over a lucerne monoculture with the combined results being inconclusive.

2.3.1   Cool season growth

The companion planting of a cool season active grass species with lucerne has been shown to increase winter pasture production therefore increasing feed supply at the onset of lactation. Xu (1989) measured 45% and 31% higher winter dry matter production in lucerne/prairie grass and lucerne/phalaris (*Phalaris aquatic* L.) mixtures over a lucerne monoculture. During this period the pastures were grass dominant. In South Canterbury, lucerne sown with annual ryegrasses (*Lolium mutliflorum* L.) out yielded a lucerne monoculture in both the June and September cuts by 30-80%. In the final November cut, yield of the binary mixtures and monoculture were not different but the ryegrass was limiting lucerne production at this stage (McLeod and Douglas, 1975). These authors did not include the grass species grown as a monoculture in these experiments for comparison to the mixtures or lucerne monocultures.

A desirable companion grass species will provide cool season growth then succumb to the legume when spring temperatures allow the lucerne to thrive. When conditions are conducive

for lucerne growth, high lucerne composition in pasture will promote livestock productivity. O'Connor (1967a) expressed an interest in early flowering true annual ryegrasses as a companion species to confine additional dry matter production to when lucerne was less productive. However the use of annual species would forgo the advantage of increased ground cover during the summer and require successful re-establishment each autumn.

2.3.2 Nitrogen

2.3.2.1 Crude protein content

The sowing of a companion grass with lucerne potentially dilutes the CP content of pasture yield. In the absence of nitrogenous fertilisers grasses typically maintain lower shoot CP content than the ~25% of lucerne (Litherland and Lambert, 2007; Mills and Moot, 2010).

Reduced canopy CP content can decrease pasture growth rates (Mills *et al.*, 2006). This reduces a pastures ability to efficiently utilise the limited soil water. Moot *et al.* (2008) reported the spring water use efficiency (WUE) of a lucerne monoculture, a perennial ryegrass/white clover mixture, and a perennial ryegrass monoculture at 24 kg DM/ha/mm, 20 kg DM/ha/mm, and 13 kg DM/ha/mm, respectively. This equates to 2.4, 2.0 and 1.3 kg DM/t soil water. The WUE of a lucerne monoculture, lucerne/phalaris & lucerne/prairie grass binary mixtures were reported by McKenzie *et al.* (1990) as 25 kg DM/ha/mm, 22 kg DM/ha/mm, and 20 kg DM/ha/mm.

In addition, the suppressed CP content of decaying plant tissue and any reduction in rhizobia increases the carbon to N ratio of soil organic matter compared with a lucerne monoculture (McLaren and Cameron, 1996). This slows the rate of N mineralisation within the soil (Cameron, 1992). This is especially important on dryland, as summer drought is deleterious to soil organic matter and mineralisable N (Hill Laboratories, 2017).

The dilution of CP content of pasture allocation may promote livestock pasture intake and reduce the cost of metabolising this. CP is an essential component of the diet for ruminants but is required in lower concentrations than present in well managed pastures. The CP dietary requirement is reported to be up to 20% by weight of pasture intake for lactating livestock and 15-18% for finishing lambs (Hodgson and Brookes, 1999). The CP content of spring pastures is typically 21-25% (Litherland and Lambert, 2007) but when reduced grazing intensity allows, livestock select the most palatable portion of pasture therefore pasture intake could have a CP content of 25-30% (Brown and Moot, 2004; Black and Ryan-Salter, 2016). Excess CP

consumption results in inflated rumen ammonia levels. This is absorbed across the wall of the rumen and converted to urea in the liver to be eliminated in the urine. This inflicts an additional metabolic cost on the animal and has been shown to suppress pasture intake (Pacheco and Waghorn, 2008). It is hypothesised that ruminants select grass as a portion of their diet because this enables the dilution of CP in pasture intake (Chapman *et al.*, 2007). Increasing CP levels in the diet is also associated with inflated mineral N content in the urine. This increases the potential for this nutrient to be lost to the environment via volatilisation and leaching (Cameron *et al.*, 2013)

2.3.2.2 *Nitrogen transfer*

The growth of companion grass species of legume/grass mixtures is increased through the transfer of fixed N. The major means of this transfer under a grazing system is via the mineralisation of senesced shoots, roots, and rhizobia, and the N returned in livestock's excreta (Peoples *et al.*, 2012). Of the ingested N, 85-90% is returned to the paddock via excreta, most of this is in the mineral form (Cameron *et al.*, 2013). In a year, urine patches cover ~20% of the paddock area (Moir *et al.*, 2011) and provide mineral N in concentrations which exceed immediate plant requirement. This N transfer depletes this nutrient in the remainder of the paddock creating one zone of limited N supply and another of excess supply. In the zone of limited N, grasses are dependent on mineralisable N whereas legumes can supplement any deficit through fixation. The legume component of grass/legume mixtures can contribute fixed nitrogen in these pastures however, fixing capacity is limited by legume yield (Peoples *et al.*, 1998; Carlsson and Huss-Danell, 2003; Yang *et al.*, 2011; Taraken, 2014) which is typically suppressed through the companion planting of a grass species (Cullen, 1960; O'Connor, 1967a; Vartha, 1967; Fraser, 1982). However, grasses have been shown to benefit from growing in close proximity to legumes as this supports N transfer within this zone. O'Connor (1967b) reported 15% CP content of smooth brome grass (*Bromus inermis* Leyss.) when planted in an adjacent row to lucerne, this was 13% when planted three rows away. Furthermore, grasses' ability to scavenge available N reduces the supply for the legume requiring these to upscale the rate of fixation. Xie *et al.* (2015) measured the proportion of root and shoot N in lucerne that was derived from fixation when grown as a monoculture or with smooth bromegrass. When 150 kg/ha of N fertiliser was applied, 22% of lucerne N came from fixation in the monocultures compared with 69% in the binary mix. Within the urine patch, there is a reduced fixation requirement due to the high availability of mineral N. It has been demonstrated by Armstrong *et al.* (1999) that the proportion of lucerne shoot N from fixation exhibits exponential decay as

mineral soil N increases. This was ~50% when 20 kg/ha of nitrate was available in the top 1.2 m of soil and ~20% when this was 40 kg/ha. The mineral N availability under a sheep urine patch is much higher than these levels at 300-500 kg N/ha (Cameron *et al.*, 2013). Unkovich *et al.* (2010) reported that, on average, lucerne fixes 60% of shoot N content but this ranges from 17-90%. Lucerne's strategy of regulating N fixation dependent on soil mineral N status, reduces the opportunity for excessive accumulation of reactive N in these systems and allows a degree of compensation for reduced lucerne composition. Lucerne, like most legumes, is therefore known as a facultative fixer of N, whereby the rate is dependent on soil N status.

2.3.3 Soil water availability

When PET exceeds rainfall, continued pasture growth is dependent on stored soil water and the ability of plants to source this. The amount of stored water determines how long pasture growth of dryland pasture can persist in to late spring/summer. The storage capacity of a soil is influenced by the soil physical properties, including structure, pore space, organic matter content, and by the depth of soil (McLaren and Cameron, 1996). Moot *et al.* (2008) reported that dryland lucerne was able to extract 328 mm of soil water to a depth of 2.3 m when grown on a deep Wakanui silt loam soil and only 131 mm when grown on a stony Lismore soil. Water stored below the rooting depth of a pasture is unavailable to support pasture growth so rooting depth is also influential.

When planted in a binary mixture with a grass species, lucerne's tap root can provide deeper soil exploration than the companion species. This can provide lucerne with a competitive advantage. McKenzie *et al.* (1990) measured the botanical composition of a lucerne/prairie grass binary mixture grown on soils <500 mm or >800 mm to gravel and found the grass was 55% of the composition on the shallow soils compared with 26% on the deeper soils. The inability of prairie grass to dominate on the deeper soil was attributed to the availability of water beyond the rooting depth of the grass. These authors did not measure a yield increase compared with a lucerne monoculture on either the deep or shallow soils. There was no comparison to grass monocultures.

2.3.4 Canopy dynamics

Following grazing, lucerne presents a very open canopy which exposes this pasture to suppressed photosynthetically active radiation (PAR) interception, increased soil water evaporation and the increased opportunity for ingression of unsown species. Teixeira (2006)

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regularly measured the leaf area index (LAI) of lucerne at <0.5 immediately after grazing and noted initial canopy expansion was slow. It built in momentum later in the regrowth period providing the duration of this was sufficient. Sim (2014) investigated both PAR interception and soil evaporation of lucerne under both set stocked and rotationally grazed management. The set stocked treatments maintained a higher average canopy mass which intercepted 47% more PAR and lost 66% less soil water to evaporation than the rotationally grazed treatment. Total soil water use was independent of canopy mass as this was offset by rates of transpiration. Canopy mass becomes more influential over the life of a lucerne crop due to the natural self-thinning of plants as a result of inter and intra specific competition. Moot *et al.* (2012) found lucerne crops established with 200-600 plants/m^2, naturally thinned back to ~80 plants/m^2 over six years. Three, five, and seven years following the establishment of a lucerne crop, Coruh and Tan (2008) measured respective lucerne plant populations of 153, 72, and 37 plants/m^2. The weed composition of pasture yield was 6%, 26%, and 50% in respective years.

Companion planting of a grass species with lucerne increases ground cover following grazing. Grass species have a LAI of ~2 when grazed to ~50 mm (Pocock *et al.*, 2010), this promotes PAR interception and reduces soil evaporation compared to a lucerne monoculture. Grass species can reproduce through tillering which enables utilisation of bare ground when it becomes available. This has been shown to reduce weed ingression. McLeod and Douglas (1975) drilled annual ryegrass into established lucerne in South Canterbury during the autumn. Weed content through the following spring of the binary mixtures averaged <10% of pasture yield whereas the monoculture averaged 52% without an alternate method of weed control. In addition, this can provide wind erosion control. Murphy *et al.* (2014) identified a critical level of ground cover for this of 70% in New South Wales. Following establishment, a lucerne/cocksfoot mixture exceeded this level 74% of the time over the next three years whereas a lucerne monoculture exceeded this level only 26% of the time.

The maximum amount of palatable feed pastures can provide following a regrowth period is limited by a ceiling canopy mass. Lucerne has a critical LAI of 3.6 (Teixeira *et al.*, 2007) which is associated with a shoot mass of ~2500 kg DM/ha (Sim, 2014). Increasing pasture mass beyond this results in an increased stem to leaf ratio and the accumulation of dead material as shaded leaves senesce. Increasing proportions of stem and dead material are associated with decreased pasture utilisation by grazing livestock due to reducing palatability. Moot *et al.* (2016) speculated that the ceiling canopy mass for lucerne was ~2100 kg DM/ha on stony soils

at Ashley Dene. The inclusion of a grass species may enable the provision of a larger palatable canopy mass than lucerne grown on its own. Spehn *et al.* (2000) reported that temperate legumes have a critical LAI of 2 and temperate grasses 5 and in a binary mixture the critical LAI was 5.75.

2.4   Pasture intake

2.4.1   Partial preference and selective grazing

Livestock exhibit a partial preference for legumes over grass in their diet. In a review of 18 different experiments Rutter (2006) reported that legume made up ~75% of the diet of lactating stock and ~70% of the diet of dry stock when offered adjoining monocultures. When offered a pasture with a mixture of legume and grass species, the composition of pasture intake is restricted by the proportion each component represents in pasture yield (Parsons *et al.*, 1994). The legume has been shown to consistently represent a higher proportion of pasture intake relative to pasture allocation (Cosgrove and Edwards, 2007). The partial preference for legumes over grass potentially results in the detrimental overgrazing of the legume component leading to a diminishing composition within the pasture over time.

As the duration of grazing on a particular area increases, the ability to select reduces as pasture on offer is modified by earlier grazing selection. If the desired components diminish in the pasture there is either increased cost of foraging (Chapman *et al.*, 2007) or decreased pasture intake (Hodgson and Brookes, 1999). Champion *et al.* (2004) demonstrated this using lactating ewes on a perennial ryegrass/white clover binary mixture, perennial ryegrass monoculture, and white clover monoculture. The respective daily pasture intake and grazing duration was 2.8 kg DM/ewe grazing day (GD) in 664 minutes, 3.1 kg/ewe GD in 579 minutes, and 3.2 kg DM/ewe GD in 495 minutes. In addition, there may be a decrease in the nutritive value of the pasture consumed. Bhargava *et al.* (1988) demonstrated this with stalled sheep feeding on barley straw. At 80% utilisation the more palatable leaf blade made up 15% of intake, at 30% utilisation this made up 30% of intake.

Livestock have the ability and tendency to select palatable components of pasture yield. Green material is selected over dead material, leaf is selected over stem. This allows pasture intake to be of higher nutritive value than what is allocated to livestock. In addition, a higher digestibility level in the diet promotes pasture intake. The smaller the animals bite width, the greater the ability to select (Cosgrove and Edwards, 2007). Sheep have a greater ability than cattle, young

lambs have a greater ability than mature sheep. This ability may differ according to the shoot structure of the pasture species. For example, weaned lambs grazing lucerne have been reported to isolate firstly the stem apex and then the side leaves of the plant, leaving the stem (Jagusch *et al.*, 1971). The more uniform shoot structure of grass species may reduce the ability of livestock to select the most digestible plant parts. This may result in lower pasture intake and a diet with reduced nutritive value.

2.4.2 Reticulorumen capacity

Ruminants are reported to have a potential appetite of 3-4% of their live weight, this being limited by reticulorumen capacity (Court *et al.*, 2010). This can be further modified by retention time whereby a more digestible diet has a faster rate of disappearance (Waghorn *et al.*, 2007). This is probably diet dependent due to differing fibre levels. Legumes contain a lower proportion of cell wall relative to grass species, and therefore lower neutral detergent fibre (NDF) levels (Sleugh *et al.*, 2000). This was credited with a 1.8 kg DM/day pasture intake of weaned lambs on lucerne compared with 1.0 kg DM/day on grass. The reticulorumen fill was measured at 2.1 kg compared with 4.4 kg, respectively (McLean *et al.*, 1967). Relative reticulorumen capacity is smallest prior to parturition but increases rapidly following this (Stanley *et al.*, 1993). Park *et al.* (2001) found DM intake of cows following calving increased from ~2.5% to ~4.5% of cow live weight within the first 7 weeks of lactation. The energy requirement of a ewe with twins can triple following parturition (Nicol and Brookes, 2007). The rapid transition from the pregnancy to the lactation energy requirement is principal to livestock performance early in lactation. Reduced NDF levels in pasture intake can facilitate this transition.

At about eight weeks of age the lamb's rumen is fully functional and proportional in size to that of an adult sheep (Court *et al.*, 2010), reducing the importance of reticulorumen capacity of the lactating ewe.

2.4.3 Pasture intake rate and grazing duration

Daily DM intake is the product of bite mass, bite frequency during grazing and grazing duration over a day. Bite mass increases with pasture height (Cosgrove and Edwards, 2007). This larger bite mass takes longer for the animal to process leading to lower bite frequency during a grazing bout, however, rate of DM intake increases with pasture height to an asymptote. Bite mass is recognised to be larger on a legume diet than a grass diet when pastures are of similar height.

Dougherty *et al.* (1989) reported beef cows grazing lucerne had a bite mass of 1.5 g DM compared with 0.7 g DM for those grazing tall fescue (*Festuca arundinacea* Schreb.). Again, the larger bite mass was associated with lower bite frequency but DM intake rate was still 34% larger on the legume diet. Cruickshank (1986) measured a 36% higher pasture intake of weaned lambs grazing either lucerne or white clover compared with perennial ryegrass or prairie grass. Increasing grazing duration can compensate for low DM intake rate. Penning *et al.* (1991) found dry sheep spent 31% of the day grazing and ruminating on a white clover monoculture compared with 51% on a perennial ryegrass monoculture to achieve the same pasture intake. However, for productive livestock, time itself can become limiting as livestock show a reluctance to graze for longer than 10-12 hours in a day. This would inevitably result in suppressed pasture intake.

It is realised that a legume only diet would maximise pasture intake due to larger bite mass and lower NDF levels (Moseley and Jones, 1984). However, when possible, sheep and cattle always choose grass as a proportion of their diet. There is sufficient evidence to suggest that livestock are not trying to maximise intake but perhaps to optimise this (Cosgrove and Edwards, 2007).

A number of theories have been proposed to explain the reason why livestock include a proportion of grass in their diet. It has been shown this doesn't occur just by chance (Parsons *et al.*, 1994). The reason is likely to be a combination of some or all of the following; 1) livestock are maintaining an energy/protein balance (Hill *et al.*, 2009). An exclusively legume diet has higher CP content than one with a portion of grass. Within the rumen, an excess of protein relative to energy results in a reduction in microbial protein synthesis (Chapman *et al.*, 2007). This in turn leads to inflated rumen ammonia levels and the associated metabolic costs of eliminating this, 2) the sole consumption of legume could be having a toxic effect on the animal and the ingestion of grass may be able to neutralise this. For example, ingesting the higher fibre diet that grass provides increases saliva production, releasing bicarbonate and mucin, which reduces the risk of bloat, 3) because livestock show a preference for clover in the morning and grass in the afternoon it has been suggested that ingestion of grass is to slow digestion allowing gut fill to be maintained over night without continued grazing (Rutter, 2006), 4) by consuming a mixed diet a diverse population of rumen bacteria can be maintained ensuring quick adaption to a grass only diet if need be.

A legume only diet is not required to maximise livestock productivity and it is possible that the inclusion of grass in a legume diet can improve this. When consuming a diet of a ratio of perennial ryegrass: white clover of 75:25, 50:50, and 0:100, cow dry matter intake increased by 8%, 23%, and 30% respectively compared with a sole ryegrass diet (Harris et al., 1997). Milk production increased by 33% on a 50:50 diet compared with a ryegrass only diet but increased no more on the 100% clover only diet. It was suggested that any nutritional gain from increased dry matter intake derived from grazing the clover monoculture was counteracted by metabolic costs associated with a higher protein diet. The partial preference ratio of 25:75 was not examined but may be the level that can maximise milk production.

2.4.4 Pasture allocation and utilisation

Larger pasture allocation to livestock increases pasture intake, however this inevitably results in lower pasture utilisation. This lower grazing intensity allows the selection of an intake of higher palatability. Rattray et al. (1982) allocated either ryegrass/white clover or lucerne pastures to ewes & lambs during lactation at levels between 2 kg DM/ewe and 10 kg DM/ewe. These authors found pasture intake increased with pasture allocation up to at least 8 kg DM/ewe even when pre-grazing pasture mass was consistent. At 2 kg DM allocation, pasture intake was ~1.6 kg DM on both treatments, and at 8 kg DM allocation pasture intake was ~2.0 kg DM on the ryegrass/white clover and ~2.8 kg DM on the lucerne. Over the same range, pasture utilisation, being the difference in pre-grazing and post-grazing pasture mass divided by pre-grazing pasture mass, dropped from 80% to 25% on the ryegrass/white clover and from 80% to 35% on the lucerne.

Pasture utilisation can also be influenced by the proportion of unpalatable herbage in pasture allocation. Following the achievement of canopy closure increasing stem to leaf ratio and the accumulation of dead material reduces the palatability of pasture allocation resulting in lower pasture utilisation. Rattray et al. (1982) found lucerne utilisation decreased with increasing pasture cover, a trend also reported by Moot et al. (2016) as ewes & lambs rotationally grazed lucerne over the spring. On ryegrass/white clover, pasture utilisation was consistent over pre-grazing pasture mass of 2100-4140 kg DM/ha. Moot et al. (2016) found average utilisation of rotationally grazed lucerne was 75%, although this was as low as 33% for hoggets during the autumn. Black and Ryan-Salter (2016) measured pasture utilisation of lucerne at 58% and 64% when grazed by young sheep. Management of pasture allocation compromises high pasture intake against high pasture utilisation to maximise live weight productivity.

2.4.5 Estimating pasture intake

Actual feed intake is the primary driver of animal performance but the estimation of this intake presents difficulties. In stall fed experiments, feed allocation and refusal can be measured with a degree of accuracy, allowing the calculation of feed intake. Under a grazing situation however, it is not feasible to measure either the entire pasture allocation or pasture refusal. The measurement of specific long chain alkanes or other markers in livestock's faeces has been shown to provide a good estimate of feed intake when compared to the levels naturally present or added in pasture allowance (Lippke, 2002). However the use of this method is limited by the costs associated with it, particularly for grazing experiments run over several years. Typically, pasture intake of grazing experiments is calculated by the amount of pasture that has disappeared during the grazing period. Allowances can be made for pasture growth during grazing periods. As an alternative, pasture intake can be calculated from the levels of animal productivity achieved.

2.4.5.1 Pasture disappearance

The success of estimating pasture intake through the difference of pre and post-grazing pasture mass is dependent on the accuracy of measuring these. Destructive sampling of quadrat cuts taken from representative areas within a pasture provides an indication of pasture mass. The usefulness of this method is limited by the uniformity of the pasture. Variability of pasture mass is inevitable due to evolving botanical composition, grazing selection and nutrient transfer to name a few. This comes with an increasing requirement for more intensive sampling. Associated costs and time for sampling reduce the appropriateness of this method for large scale grazing experiments.

Numerous workers have identified a relationship between pasture height, or compressed height, and pasture mass which has allowed the non-destructive estimation of pasture allowance and post-grazing residual (Lile *et al.*, 2001; Robertson, 2014). Webby and Pengelly (1986) found a relationship (R^2=0.56-0.76) among pasture height and mass on grass based pastures, as did Mills *et al.* (2016) on rotationally grazed lucerne (R^2=0.31-0.88), when calibrating these with destructive pasture samples. This method has the benefit of being more rapid and less expensive than destructive sampling, allowing more samples to be collected. Regular calibration of height measurements with destructive samples improves the validity of this technique.

2.4.5.2 Livestock productivity

As an alternative to pasture measurements, livestock measurements, taken as matter of course, can be used to estimate pasture intake. The ability of a grazing experiment to provide useful livestock productivity data increases as the scale increases. However, this may reduce the ability to obtain robust pasture measurement data. As ME intake is usually the most limiting factor to ruminant performance (Waghorn *et al.*, 2007), the ME requirement of livestock to meet measured productive and maintenance levels can be calculated using data available in published manuals. This in turn can be divided by the ME content of pasture intake to give the mass of intake.

The limitation of calculating pasture intake through livestock ME requirement is the estimation of ME content of this intake. Due to selective grazing, this will probably be higher than the ME content of pasture allocation. The ME content of well managed New Zealand temperate pastures is generally 10-12 MJ ME/kg DM, being lowest in the summer when dead material levels are highest (Litherland and Lambert, 2007). This change in seasonal ME appears in proportion to the change in pasture composition, especially that of leaf, stem, and dead material. The palatable portion of pasture allocation maintains a more consistent ME content of 11.3-11.9 MJ ME/kg DM (Brown and Moot, 2004; Black and Ryan-Salter, 2016). When pasture allocation and grazing intensity allows livestock to select a highly palatable diet, it may be prudent to assume the ME content of pasture intake is 11-12 MJ ME/kg DM. Using 12 MJ ME/kg DM in calculations identifies the minimum pasture intake that would be required to meet livestock productivity levels as it is unlikely that the ME content of intake would exceed this.

At worst, estimating pasture intake by livestock productivity gives an indication of ME intake.

2.4.5.3 Checking robustness of method

The robustness of calculating pasture intake can be determined by identifying a potential range. The upper limit of this range will be limited by the capacity of the animal. Pasture intake much in excess of 4% of animal live weight is unlikely for sheep with older livestock in healthy condition being recognised to be lower than that of young and underweight livestock (Court *et al.*, 2010). The lower limit of the range is that necessary to meet the ME requirements to meet the level of productivity given an ME content of intake of 12 MJ ME/kg DM.

2.5 Pasture management

Compared with a monoculture, managing a mixed pasture presents difficulties in compromising the requirements of individual species in a way which promotes pasture yield, nutritive value, and botanical composition.

2.5.1 Establishment

The initial establishment of a lucerne/grass mixtures must prioritise the emerging legume. Lucerne is susceptible to shading from more vigorous grass species. This can be detrimental to the initial composition of these pastures. Considerable work has been done on alternate row sowing of lucerne and grass species compared with mixed rows or broadcasting (Cullen, 1960). The results have been inconclusive with regards to pasture yield and pasture composition, but it has been shown that N transfer from legume to grass is increased when these species are mixed within a row (O'Connor, 1967b). The use of low grass seeding rates restricts the grass composition during the establishment year and is a useful strategy to promote lucerne content. Thereafter the grass composition can expand through tillering. Over-sowing or drilling grass seed into existing lucerne crops ensures the legume is well established and is advocated as a solution to achieve a desirable lucerne composition (Vartha, 1967; McKenzie *et al.*, 1990). However these pastures are still susceptible to grass dominance over time.

2.5.2 Grazing

Lucerne based pastures should be rotationally grazed. The meristem of lucerne is positioned on the top end of each stem and exposed to grazing, once they are removed this stem dies. Regrowth occurs from new basal buds that form on the crown. Under a set stocking regime new buds would be unable to fulfil their potential before decapitation. Conversely, the meristem of grasses is contained within the crown of the plant close to ground level. This enables it to largely avoid grazing so it is tolerant of both rotational grazing and set stocking. Gyamtsho (1990) measured a 15% yield increase when grazing lucerne, lucerne/phalaris, and lucerne/prairie grass for 3-7 day bouts rather than 6-14 days. A shorter duration reduced the opportunity for damage to developing basal buds on the lucerne.

The desirable regrowth duration between grazings of lucerne is longer than that of temperate grass species. The number of live leaves a grass tiller can maintain is species dependent but generally as the fourth or fifth leaf emerges the first leaf dies. To maintain the nutritive value of temperate grass species, grazing should precede leaf death. However, due to the slow

recovery of a critical LAI, which takes about four weeks during the spring (Teixeira, 2006), lucerne is more suited to longer rotation lengths. Moot *et al.* (2016) reported that a grazing rotation of 29-36 days during the spring is preferred for a lucerne monoculture. This grazing frequency on a binary mixture would result in notable leaf senescence in the grass species so a compromise among pasture yield and nutritive value must be made. Vartha (1973) found grazing a binary mixture when the lucerne component was at the early flowering stage supported a 37% higher pasture yield than grazing prior to flowering. The longer grazing rotation maintained a 78% lucerne composition in the pasture compared with 52% when grazed at the pre-flowering stage. This study did not report on the nutritive value of the pasture which would have likely decreased with the longer grazing frequency.

2.6   Grass species

The grass species selected to accompany lucerne in this research needed to be tolerable of dryland conditions. At Ashley Dene, perennial ryegrass and tall fescue fail to persist due to the prolonged soil water deficit experienced most years. Cocksfoot thrives under this type of environment and typically dominates pastures over time when sown in mixtures. The Brome species are also recognised for their persistence on light soils but are less domineering in pasture mixtures.

2.6.1   Cocksfoot

Cocksfoot is a common grass species of New Zealand dryland that shows persistence and drought tolerance. It apportions more of its annual yield to the summer and autumn than perennial ryegrass under moderate fertility, with less in spring (Kemp *et al.*, 1999). Cocksfoot produces an extensive mat of fibrous roots within the top soil supporting efficient moisture and nutrient uptake from the soil profile (Evans, 1978). This also contributes to its competitiveness within a mixed sward. Low sowing rates (2-3 kg/ha) are utilised to allow companion species to establish high populations in the first year. When sown with white clover, cocksfoot tends to eliminate the legume population over time (Moloney, 1993; Mills *et al.*, 2015b). Cocksfoot is reported to have low digestibility relative to other temperate grass species (Barker *et al.*, 1993). As well as potentially limiting the ME content, this can suppress voluntary intake of livestock. Edwards *et al.* (1993) reported that sheep showed an aversion to cocksfoot relative to tall fescue, phalaris, and prairie grass but this was not apparent with the application of 300 kg N/ha which lifted the CP content from 23% to 32%. A companion legume species, could contribute fixed N to support higher CP content in the grass. Provided this can maintain a

substantial composition within cocksfoot it will, through N transfer, benefit the palatability of this grass. In well managed binary mixtures with subterranean and white clover the CP content of cocksfoot was found to be ~20% and the ME content was ~11.3 MJ ME/kg DM (Mills and Moot, 2010). Cocksfoot reportedly persists well with lucerne but often dominates these swards over time (Cullen, 1960; Vartha, 1973).

2.6.2 Brome

Two closely related species were included separately in the brome treatment in this research. Prairie grass and pasture brome (*Bromus valdivianus* Phil.). Both species prefer well drained soils (Kemp *et al.*, 1999). This makes them desired species for light land compared with perennial ryegrass (Sellars, 1988; Sutherland, 1994). High palatability has supported levels of livestock production similar to, or greater than perennial ryegrass. Pasture brome shows more persistence than prairie grass on soils with low fertility (Kemp *et al.*, 1999). Pasture brome has more, and smaller, tillers than prairie grass making it more suitable to continuous stocking. Prairie grass is recommended for over sowing into lucerne crops as it is more suited to lax rotational grazing (Vartha, 1967) and offers more winter growth. The combination of low tiller density and a high proportion of them going reproductive each year, decreases prairie grasses persistence through summer (Stewart, 1992). This reduced persistence may support a greater lucerne composition during this period. However, Stevens *et al.* (1992) found prairie grass was similarly yielding in the spring and higher yielding during the summer than five other temperate grass species, including cocksfoot, in Southland. Despite this, goat live weight gains were lowest on these pastures. These authors found the prairie grass pasture digestibility was similar to cocksfoot but CP was much lower. Low CP levels may have suppressed pasture intake as Edwards *et al.* (1993) reported for cocksfoot.

2.7 Summary

Lucerne is a forage species which is experiencing increasing popularity with dryland farmers. With improved breeding and a developing understanding of grazing management, lucerne has been successfully integrated into modern farming systems, compared with when it was predominantly used as a cut and carry crop. Its winter dormancy and best practice management, however, is not conducive to providing a comparable feed supply to alternative grass based pastures at the onset of lactation. As an alternative to delaying lambing date to match the

lucerne growth curve, companion planting of a grass species has been shown to increase early spring feed availability.

Previous research has found lucerne/grass binary mixtures typically provide similar pasture yields as lucerne monocultures but have not compared livestock productivity. Animal performance will likely be influenced by the proportion of legume and grass in pasture mixtures. Livestock productivity will be the primary measure of pasture treatment here, combining the effect of carrying capacity (related to pasture yield) and animal growth rate (related to ME intake). In addition, historically, research has rarely examined lucerne/grass mixtures under a grazing environment, disregarding the effect of preferential grazing and nutrient transfer. This research shall contribute to filling these gaps in the literature, and given the duration of this research (four years), the results can be related to evolving pastures under a range of seasonal environmental conditions.

3 MATERIALS AND METHODS

3.1 Experimental site

This experiment was performed over approximately 17.7 hectares of Ashley Dene, Lincoln University's dryland research farm located 14 km from the campus in North Canterbury, New Zealand (43°65' S, 172°32' E. 39 m a.s.l.). Three adjacent paddocks, C6E, C7W, and C7E, were selected on the Ashley Dene Cemetery block.

3.1.1 Soil type

Three different soil types are irregularly distributed over the experimental area, these are a Lismore stony silt loam, Lowcliff stony silt loam, and Ashley Dene deep fine sandy loam (Typic Dystrustept, USDA taxonomy). These are described as somewhat excessively drained, imperfectly drained, and moderately well drained soils, respectively (McLenaghen and Webb, 2012). The depth to gravel is less than 200 mm to over 900 mm with a water holding capacity of between 70-160 mm/m. The experimental area is dependent on spring/summer rainfall to provide any pasture growth over the summer. Typically there is an absence of growth due to severe soil water deficits for 3-4 months during the summer/autumn.

3.1.2 Paddock history

Prior to the beginning of the experiment, both paddocks C6E and C7E were in brassica crops. Paddock C7W had been in 'Kaituna' lucerne since the spring of 2006, this lucerne crop was retained for this experiment to examine the recommended technique of drilling grass into existing lucerne (McKenzie *et al.*, 1990).

Each of the three paddocks was subdivided with permanent netting fencing into six plots during the winter of 2011. Plots within each paddock were of equal size but because the original paddocks varied in size, plots in paddock C6E (1-6) were 0.97 ha, plots in C7W (7-12) were 1.30 ha, and plots in C7E (13-18) were 0.62 ha. A ring laneway was included within the original area to allow easy stock movement between plots and back and forth from the yards. Portable yards were erected adjacent to the ring laneway and were used for stock handling including weighing and drafting. Each plot had a plastic water trough so livestock always had access to water.

3.1.3 Soil fertility

In the winter of 2011 soil tests were taken for each of the three initial paddocks. These indicated below optimal pH so this was remediated with an application of 2 t/ha of lime in September of 2011, just prior to establishment of treatments. The same soil tests found C6E had an Olsen P of 23 whereas C7W and C7E had an Olsen P of 19. Application of Sulphur Super 15 (0, 9, 0, 15) at a rate of 250 kg/ha to paddock C6E and 350 kg/ha to C7W and C7E resulted in Olsen P levels of 20, 26, 29 for C6E, C7W, and C7E, respectively the following winter. In the same period the pH rose from 5.6-5.8 to 6.0-6.1. Soil tests were taken each winter through the duration of the experiment, the results of which are shown in Table 3-1. Annual fertiliser applications following establishment were identical for all plots. 180 kg/ha of 20% sulphur super (0, 8, 0, 20) was applied in August 2013 and 2014. 200 kg/ha of superphosphate (0, 9, 0, 10) was applied in July of 2015.

Table 3-1: Mean soil fertility levels measured in the winter prior to each year from 2012-2015 at Ashley Dene, Canterbury.

Treatment	Year	pH	P	K	SO$_4$S	Ca	Mg	Na
Combined	2012	6.0	25	15	17	10	14	4
	2013	6.1	26	16	9	10	14	4
Lucerne	2014	6.0	25	14	8	11	14	4
	2015	5.7	31	23	36	10	16	5
	2013	6.2	29	13	10	11	14	5
Lucerne/brome	2014	6.1	28	14	10	11	15	4
	2015	5.9	31	15	23	11	19	6
	2013	6.2	29	15	11	11	14	4
Lucerne/cocksfoot	2014	6.1	25	13	7	10	14	4
	2015	6.0	25	15	23	10	15	5

3.2 Herbicide application

The lucerne monocultures received a herbicide application to control weed ingression. These were sprayed with paraquat at 500 g a.i./ha and atrazine at 720 g a.i./ha. to reduce weed population. This was done in early July in 2012, between the 5th and 26th June in 2014, and on the 6th in July 2015. This was applied following the June/July 'clean up' graze to minimise any detrimental effect on the lucerne.

3.3 Animal health

Ewes were inoculated before mating with Toxovax® as two tooths to prevent Toxoplasma abortions, and each year with Campyvax4® for the prevention of Campylobacter abortion. Prior to lambing ewes receive Nilvax 5 in 1® to protect ewes and lambs from pulpy kidney, tetanus, black leg, black disease, and malignant oedema, and also to protect ewes from gastrointestinal parasites. Lambs were drenched with Evolve HiMin® combination drench for protection against gastrointestinal parasites at weaning and then if seen scouring. Livestock were monitored for foot rot/foot scald and treated with zinc sulphate as required. Salt blocks were available at all times as a source of sodium for livestock on the lucerne monoculture.
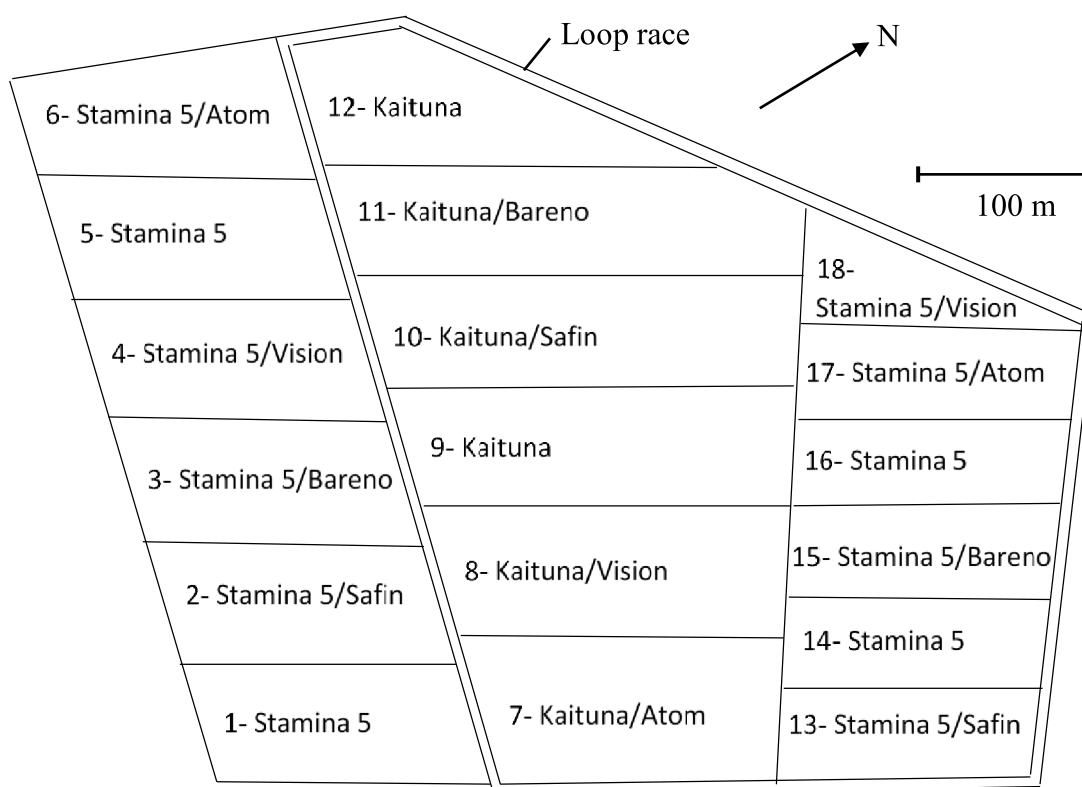
Plate 1: Map of the experimental area showing plot numbers and cultivars. Lucerne cultivars are 'Stamina 5' and 'Kaituna', brome cultivars are 'Atom' and 'Bareno', cocksfoot cultivars are 'Safin' and 'Vision'.

3.4 Treatments and experimental design

There were three primary treatments. These were lucerne monoculture, lucerne and brome binary mixture, and lucerne and cocksfoot binary mixture. Each of the three species is represented by two cultivars. The lucerne cultivars are 'Kaituna' in C7W and 'Stamina 5' in the other two paddocks (Plate 1). These are both mid dormancy cultivars, rated 4-5. The brome cultivars come from two different brome species. 'Atom' comes from the prairie grass species. 'Bareno' is a pasture brome and was selected as a more persistent species than prairie grass. The cocksfoot cultivars are 'Vision' and 'Safin'.

Two plots within each original paddock were allocated to each of the three primary treatments in a manner to avoid confounding influences. For the binary mixtures each of these was allocated to a separate grass cultivar. This meant that each grass cultivar was planted with 'Kaituna' in one replicate and with 'Stamina 5' in two replicates. There are two 'Kaituna' and four 'Stamina 5' monocultures. Each primary treatment had six replicates and covered almost 5.8 ha.

3.5 Sowing rates and dates

Following conventional cultivation the grass cultivars were sown in C6E and C7E with a triple disc drill in November 2011. The following day the 'Stamina 5' lucerne was sown into the same paddocks with a Duncan drill. Due to poor establishment of the grass species (perhaps due to a too deep sowing depth or delayed sowing) additional grass seed was broadcast on C6E and C7E in February 2012 with a Fiona drill. Grass cultivars were broadcast onto the established lucerne in C7W in February 2012 with a Fiona drill. Details of sowing rates and dates are shown in Table 3-2.

3.6 Livestock management

There was an effort to mimic a commercial farming operation for spring, summer, and autumn but this experiment was not self-contained with stock wintered off. Livestock from the Lincoln University Coopworth flock were used as required. Stocking rates were determined via a feed budget and as feed supply fell below demand, stock could be removed from the experiment and grazed on adjacent areas of the farm. As feed supply increased, additional animals were introduced. Stocking rates are depicted in Figure 3-1 to 3-4 for comparison among treatments

and across years. For statistical analysis 'grazing days' were used which was a combination of the stocking rate and the duration of a grazing period.

Mobs of productive livestock were rotationally grazed around the replicates within their respective treatment. The first replicate grazed at the onset of lactation was often stocked for about two weeks as ewes & lambs were progressively introduced as they became available. Thereafter, grazing periods were typically seven days on each replicate through each grazing rotation but were flexible to enable a desirable grazing residual which aimed to maximise consumption of palatable herbage without requiring productive livestock to graze unpalatable herbage. This residual was not constant and generally increased from spring to summer before non-productive stock (usually dry ewes) were used to reduce this again. Thus, emphasis was on animal production in spring and early summer and pasture maintenance in late summer/autumn. Regrowth periods were ~35 days during the spring and summer before successive grazings. Each autumn, six weeks of growth was allowed following effective rainfall before grazing. A summary of grazing is presented in Appendix 23, 24 & 25.

Each year was separated into three 'seasons' being 'spring', 'summer', and 'autumn' but were not necessarily associated with specific months of the year.

Spring was defined as beginning when ewes & lambs were introduced to each pasture within days of parturition. Introduction of stock was staggered based on both feed supply and stock availability. An attempt was made to use twins where possible, but singles and triplets were also used in combination to maintain a ratio of about two lambs per ewe. Once fully stocked, each treatment carried ~10 ewes/ha and ~18 lambs/ha (Figure 3-1). Initially the policy was to coordinate grazing rotations among treatments and stock were introduced on the 5th of September in 2012, and the 6th of September 2013. During the spring of the final two years stock were introduced according to treatment specific feed availability. This meant the lucerne/cocksfoot treatment was the first to be stocked in the final two springs on the 19th August and the 31st August. This was followed by the lucerne/brome on the 26th August and 1st September, followed by the lucerne monoculture on the 18th September and 17th September. Although management aimed to offer similar pasture allocation per head among treatments throughout the experiment, this delay in introduction in the spring period inadvertently increased pasture allocation to ewes & lambs on the lucerne treatment relative to the binary mixtures. Mobs completed between one and three spring rotations around the replicates prior

to weaning or destocking. This occurred around the 1st December during 2012 and 2013 but was much earlier on the 7th November in 2014 because of a dry spring (Figure 3-7), and was on the 20th November in 2015 which signified the end of this period.

Table 3-2: Sowing rates and dates of paddocks C6E, C7W, and C7E at Ashley Dene.

Paddock	Sowing date	Species	Cultivar	Sowing rate (kg/ha)
C6E & C7E	18/11/2011	Brome	'Atom'	10
			'Bareno'	10
		Cocksfoot	'Safin'	2
			'Vision'	2
	19/11/2011	Lucerne	'Stamina 5'	8
	20/2/2012	Cocksfoot	'Safin'	3
			'Vision'	3
	29/2/2012	Brome	'Atom'	9
			'Bareno'	10
C7W	13/10/2006	Lucerne	'Kaituna'	10
	20/2/2012	Brome	'Atom'	9
			'Bareno'	10
		Cocksfoot	'Safin'	3
			'Vision'	3

The summer period was stocked with 10-26 lambs/ha each year following weaning. This stocking rate was dependent on feed supply on each treatment which was sufficient to maintain high lamb growth rates by way of lax grazing. Lambs were ~26 kg live weight at weaning (Appendix 22). For the first two years this period began immediately after weaning, around the 1st of December. In the summer of 2014/15 and 2015/16 the treatments were destocked for about two and six week, respectively. This allowed pasture levels to recover and weaned lambs were then re-introduced. In 2015/16 ~75 mm of rain following destocking initiated this summer pasture growth and weaned lambs were reintroduced on the 7th January 2016. The end of the

summer periods were dictated by available pasture covers and occurred on the 11th January 2013, 3rd-7th February 2014, 5th-13th January 2015, and 3rd-14th March 2016.

Autumn management of these pastures aimed to prioritise the recharge of lucerne root reserves by destocking the experiment for at least six weeks of growth. In the autumn/winter this regrowth was grazed by hoggets. In 2012/13 the autumn grazing was completed by mobs of ewe hoggets with a live weight of ~35 kg. The following three years ram hoggets were used which weighed 39-46 kg (Appendix 22). Stock were introduced on the 24th March during 2013/14 and in May during the other three years. Treatments were stocked with 7-17 hoggets/ha with one full rotation around replicates being completed each autumn. This took ~45 days during the first three autumns. On the final year replicates three and four were dropped from the experiment prior to the autumn grazing as these pastures had run out. This final (shortened) rotation took 17 days. Following the summer grazing of weaned lambs the experimental area was usually grazed with non-productive sheep to reduce the grazing residual, but this did not occur in the last year. For the first three autumns, hoggets were offered regrowth which occurred following the clean-up graze. During the last autumn, hoggets were offered the pasture refusal of the weaned lambs in addition to regrowth. Despite this, these hoggets achieved lower residual pasture mass than the previous three years. During the first three years the hogget grazing was followed directly with another grazing rotation of non-productive livestock before destocking over the late winter. Following the last autumn grazing, a clean-up graze was not necessary.

Non-productive livestock were used as required to reduce the grazing residual of the plots to just above the crowns of pasture species. This was mainly non-lactating ewes. The diet of non-productive livestock was deemed to be maintenance only and not sufficient for live weight gain, which was not measured. The GD of these stock were recorded but are not presented here. Clean-up grazes were typically done with large mobs of livestock to allow grazing duration of a couple of days on each plot.

Plate 2: A) Ewe & lambs and B) weaned lamb from the Lincoln University Coopworth flock.

3.7 Measurements

3.7.1 Grazing days

A combination of stocking rate and grazing duration, measured in days, were tallied for each stock class for each season. These were defined as grazing days (GD) and reported on a per hectare basis. During the spring ewes and lambs at foot were measured separately and combined. Figures 3-1 to 3-4 depict the time of initial stocking and the stocking rate of the different stock classes over four years.

3.7.2 Live weight

Productive livestock were weighed 'off pasture' as they entered and left the experimental area with Tru Test XR 3000 scales in a Prattley weigh crate. If a productive period was sufficiently long e.g. 2-3 months, livestock may have been weighed again while remaining on the experimental area. The duration between two weighings was termed a 'live weight rotation'. Productive livestock were allowed to graze laxly over the 24 hours prior to weighing and considered 'full'. On the one occasion when livestock were held off pasture prior to entering the experiment, their weight was adjusted according to the findings of Burnham *et al.* (2009) to be comparable with the final weight when stock were 'full'. LWG/loss is calculated as weight upon leaving the experiment less weight upon entering the experiment. If additional livestock were introduced during a live weight rotation they were allocated the average daily LWG of the mob they were introduced to, for the days they were on the experimental area.

On a few occasions, productive grazings have no associated live weight measurements. When this influenced treatments equally these grazings were classified as non-productive. On one occasion (the hogget grazing of 2014/15) the grazing rotation for the lucerne treatment was completed eight days earlier than the other two treatments at which point the final weighing (for all treatments) occurred. To adjust for the final eight days grazing of the binary mixes, the mob specific hogget growth rates prior to the final weighing were applied to the remaining grazing days on those two treatments. This enabled a balanced statistical analysis.
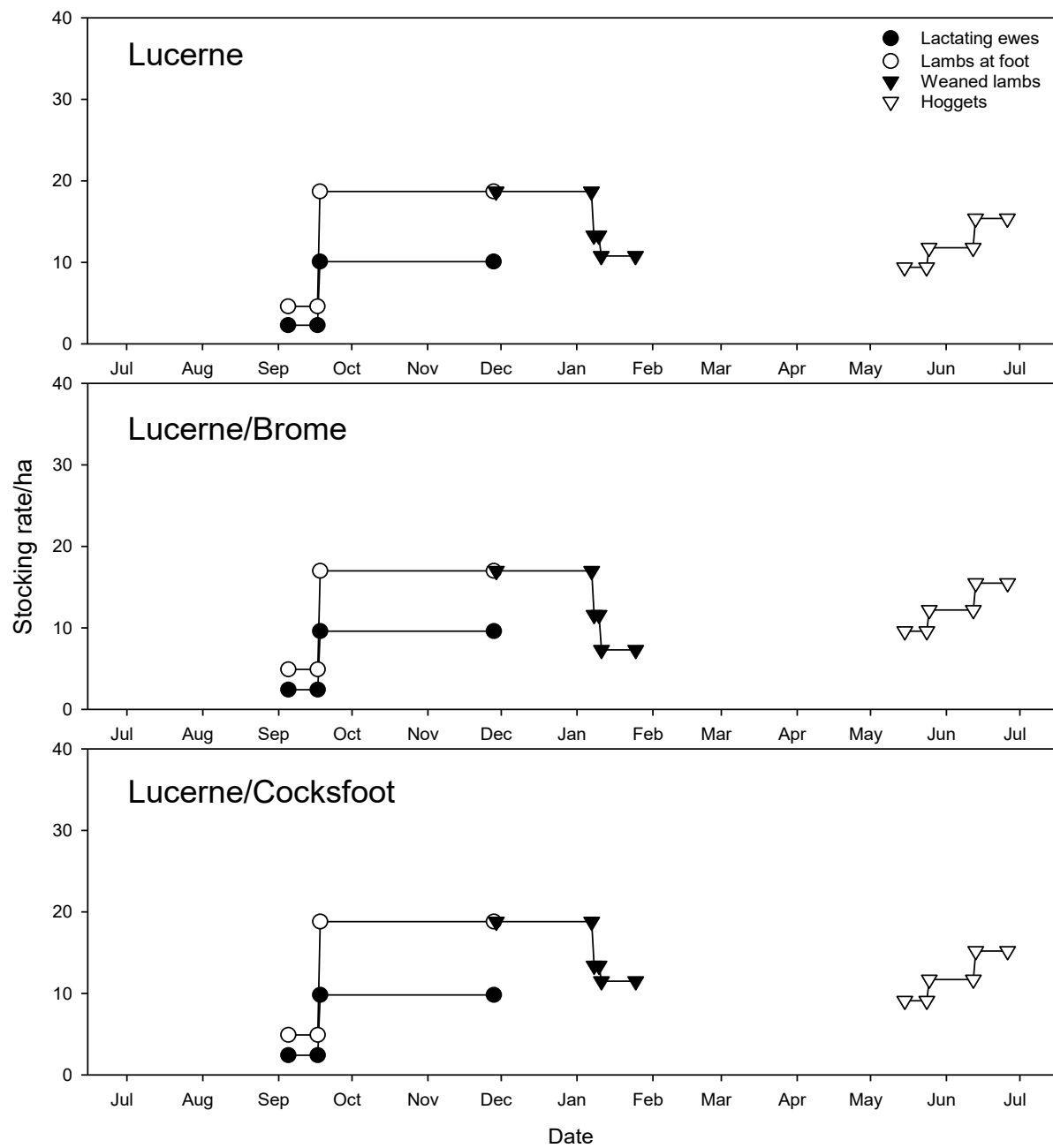
Figure 3-1: Stocking rate and duration of productive grazings of three dryland pastures during 2012/13.
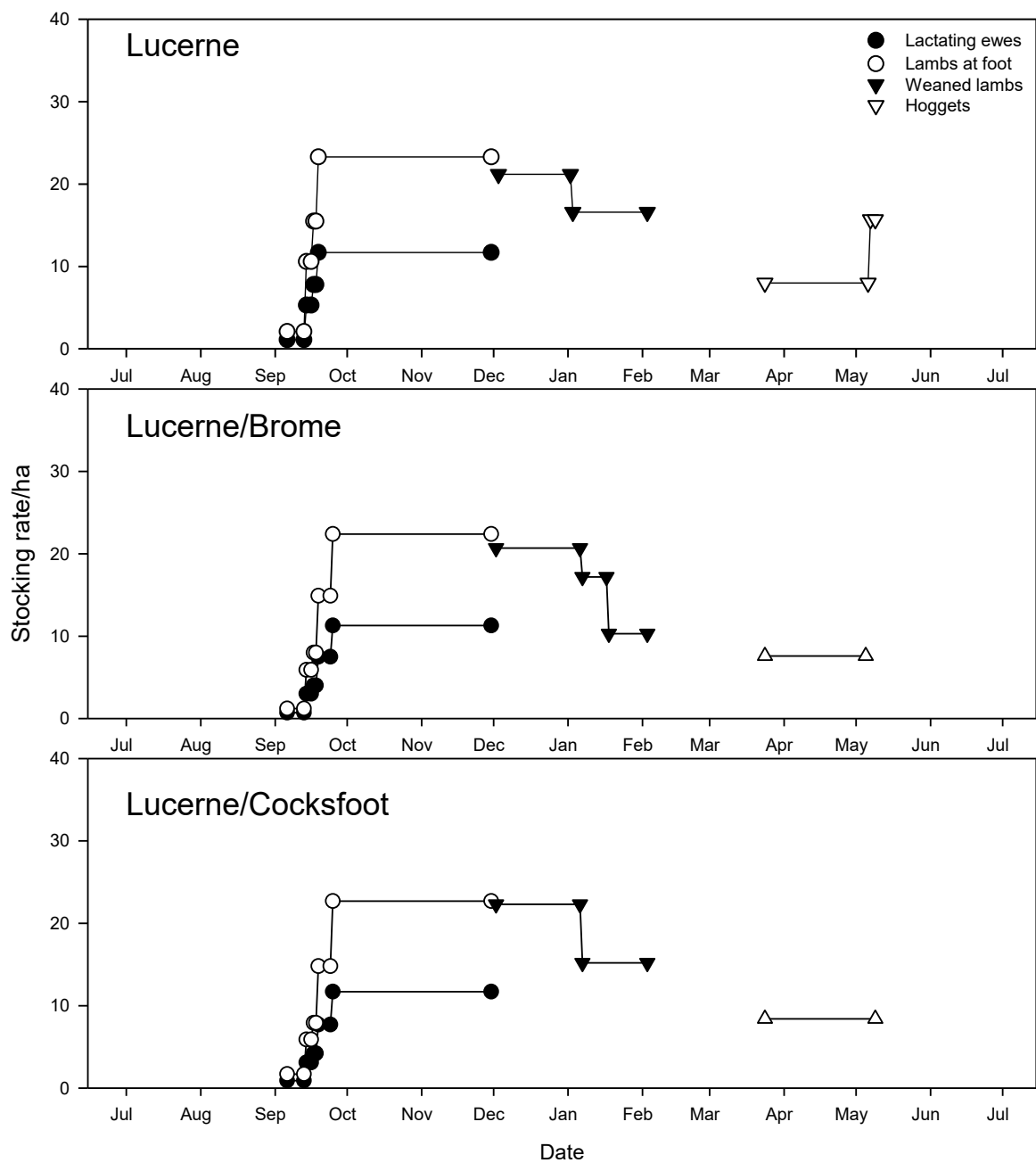
Figure 3-2: Stocking rate and duration of productive grazings of three dryland pastures during 2013/14.
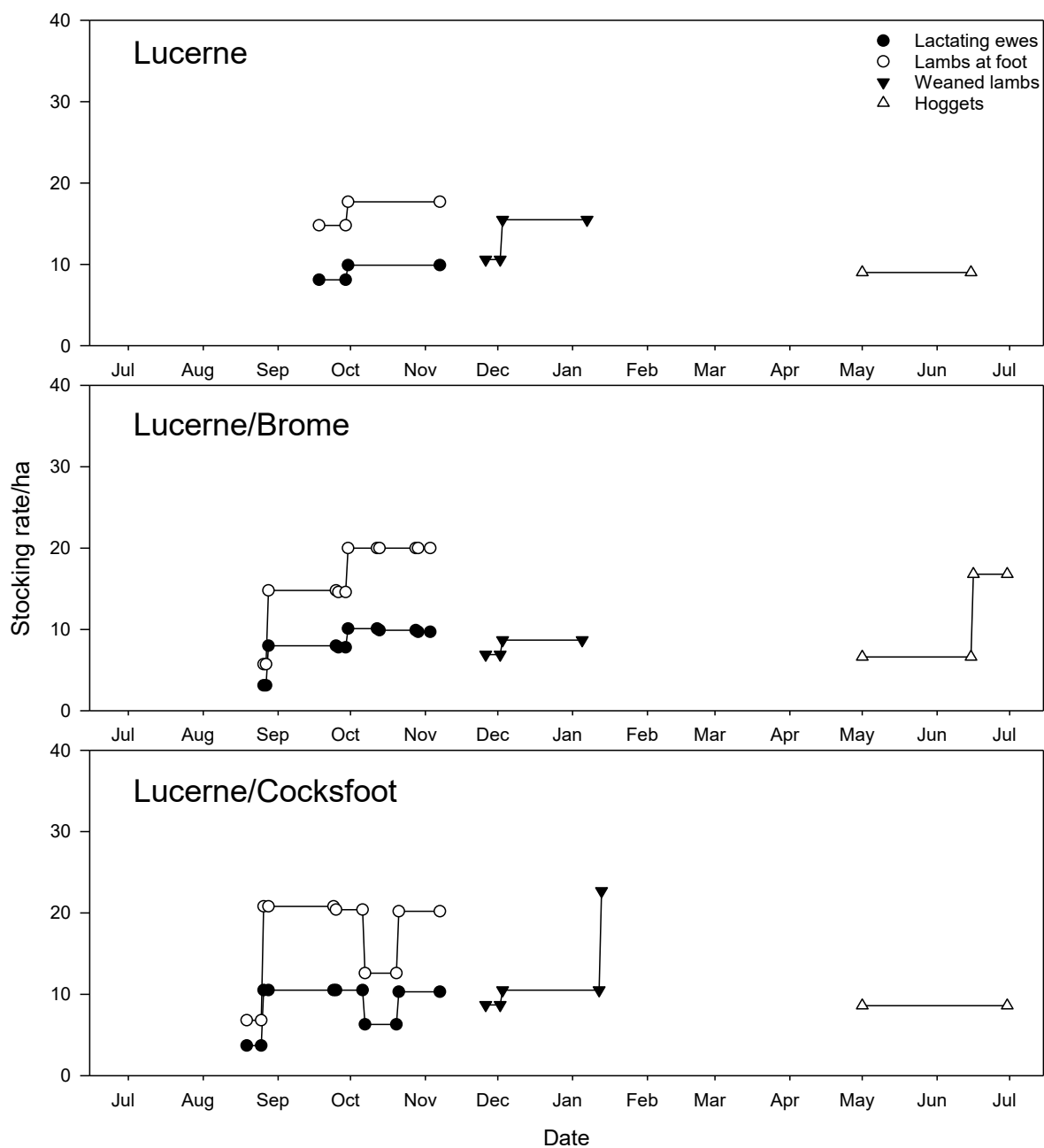
Figure 3-3: Stocking rate and duration of productive grazings of three dry land pastures during 2014/15.
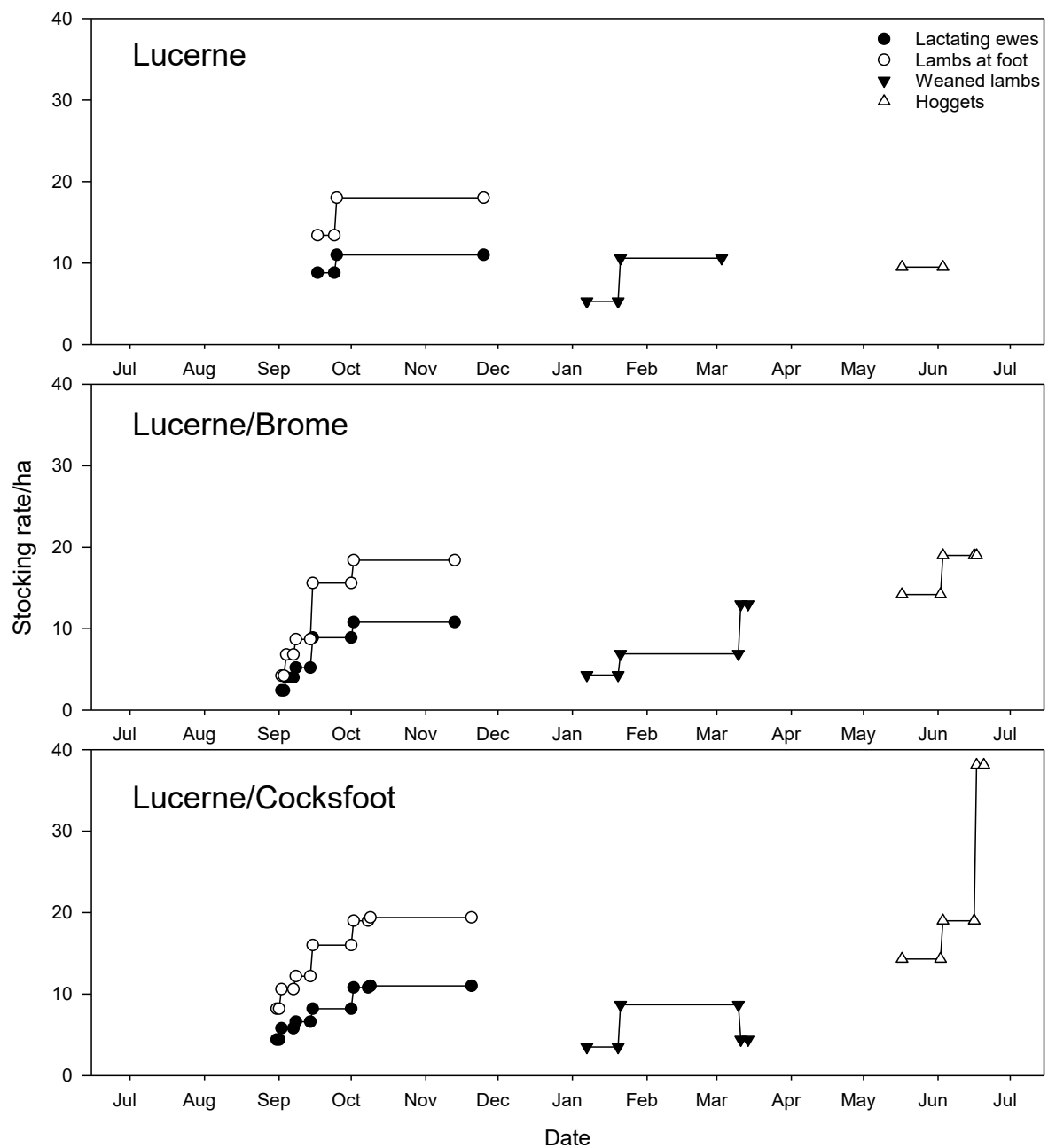
Figure 3-4: Stocking rate and duration of productive grazings of three dryland pastures during 2014/15.

3.7.3 Pasture measurements

Pasture measurements were made prior to and following each productive grazing. The process was as follows:

A quadrat site was selected from each of high, low and intermediate DM density areas in the plot (three in total). They were not randomly selected or intended to give a representative estimate of pasture mass however, there was a deliberate attempt to achieve a representative botanical composition. Prior to cutting, the height that relates to each individual quadrat was measured with a height stick. Only lucerne height was measured in the first year of the experiment in the binary mixes as this dominated these treatments but both lucerne and grass height were measured in the second, third and fourth year. The 0.2 m^2 quadrats were cut with a shearing hand piece close to ground level but leaving plant crowns. Concurrently the pasture height of the sown components within the plot were measured with the height stick (50 readings/sown component) to give the average pasture height. Quadrat cuts were sorted into lucerne, grass, weed, and dead material. Each component was dried in a forced air oven for 48 hours at 60° C and weighed on electronic scales. A portion of the dried lucerne and sown grass (and occasionally the weed) were ground in a Cyclotec sample mill and samples were analysed by Lincoln University with near infra-red spectrometry (NIRS) to determine ME and CP content. At each pre grazing cut the residual lucerne present at the preceding post grazing cut was disregarded from height, weight, and botanical measurements.

Following each grazing, normally within 48 hours of the stock departing, the process was repeated to get a post grazing pasture mass.

3.7.4 Pasture composition

Botanical composition of pasture treatments over the course of the experiment was investigated to help explain differences in pasture yield and animal performance. Pasture composition also experienced seasonal change. Not all pasture measurements had associated botanical analysis however, most of spring measurements did. Each treatment had 10-16 (average 13) pre-grazing botanical measurements for each spring so was investigated to represent annual fluctuations through the duration of the experiment. Between 50-100% of pre-grazing botanicals each year also had associated post-grazing botanicals and these in conjunction with pre and post-grazing pasture mass were used to calculate the apparent composition of the diet selected by the sheep.

The components measured were sown grasses and lucerne, dead material, and weeds. The main weed ingression in the experiment was of perennial ryegrass but vulpia hair grass (*Vulpia bromoides* (L.) S.F. Gray), annual poa (*Poa annua* L.), white clover, subterranean clover, shepherds purse (*Capsella bursa-pastoris* (L.) Medik.), dandelion (*Taraxacum officinale* (L.)

Weber), dock (*Rumex obtusifolius* L.), and musky storksbill (*Erodium moschantum* (L.) L'Hér.) were also present.

Over the course of the experiment there were 22-23 pre and post-grazing pasture measurements with associated botanical compositions for each treatment during the summer and 15-16 during the autumn. Because there were fewer complete measurements, the results over four years were averaged for both the summer and autumn which did not allow the analysis of pasture succession over time.

3.7.5 Pasture height/mass regressions

Approximately 600 quadrat cuts of each treatment had pasture height and pasture mass measurements. Determining a relationship between these enabled an estimation of plot pasture mass. At the outset it was determined that pasture mass of the binary mixes was more closely related to the average of the grass and lucerne height than to either of them on their own. However in the incidents when lucerne was not present in a cut the grass height was used. Because there were no grass heights measured in the first year, as lucerne dominated these pastures, lucerne height was used and this data set was analysed separately. The following three years were analysed together.

Linear relationships where determined which were not forced through the origin. No non-linear relationships were examined. A subset regression identified a treatment and seasonal effect being the most influential during both the first year and the following three. As the year progressed from spring to autumn, pasture mass decreased relative to height for the lucerne treatment. For the binary mixtures, pasture mass relative to height increased during the spring to be greatest in November/December before reducing again towards the autumn (Figure 3-5). Over the course of the experiment it became apparent that the binary mixtures had greater mass per unit height and a larger proportion of the mass was in the base of the pasture, than the monoculture.

For the first year's data, separating relationships into bimonthly periods increased the coefficient of determination (R^2) from 0.82, 0.71, and 0.80 to 0.85, 0.76, and 0.81 for lucerne, lucerne/brome, and lucerne/cocksfoot, respectively. For the final three years the increase in R^2 was from 0.63, 0.68, and 0.66 to 0.69, 0.77, and 0.72. The equations used to estimate pasture mass are given in Table 3-3.

Regressions between pasture height and mass were not forced through the origin. The relationship below the lowest extent of the regression was assumed to be linear to the origin.
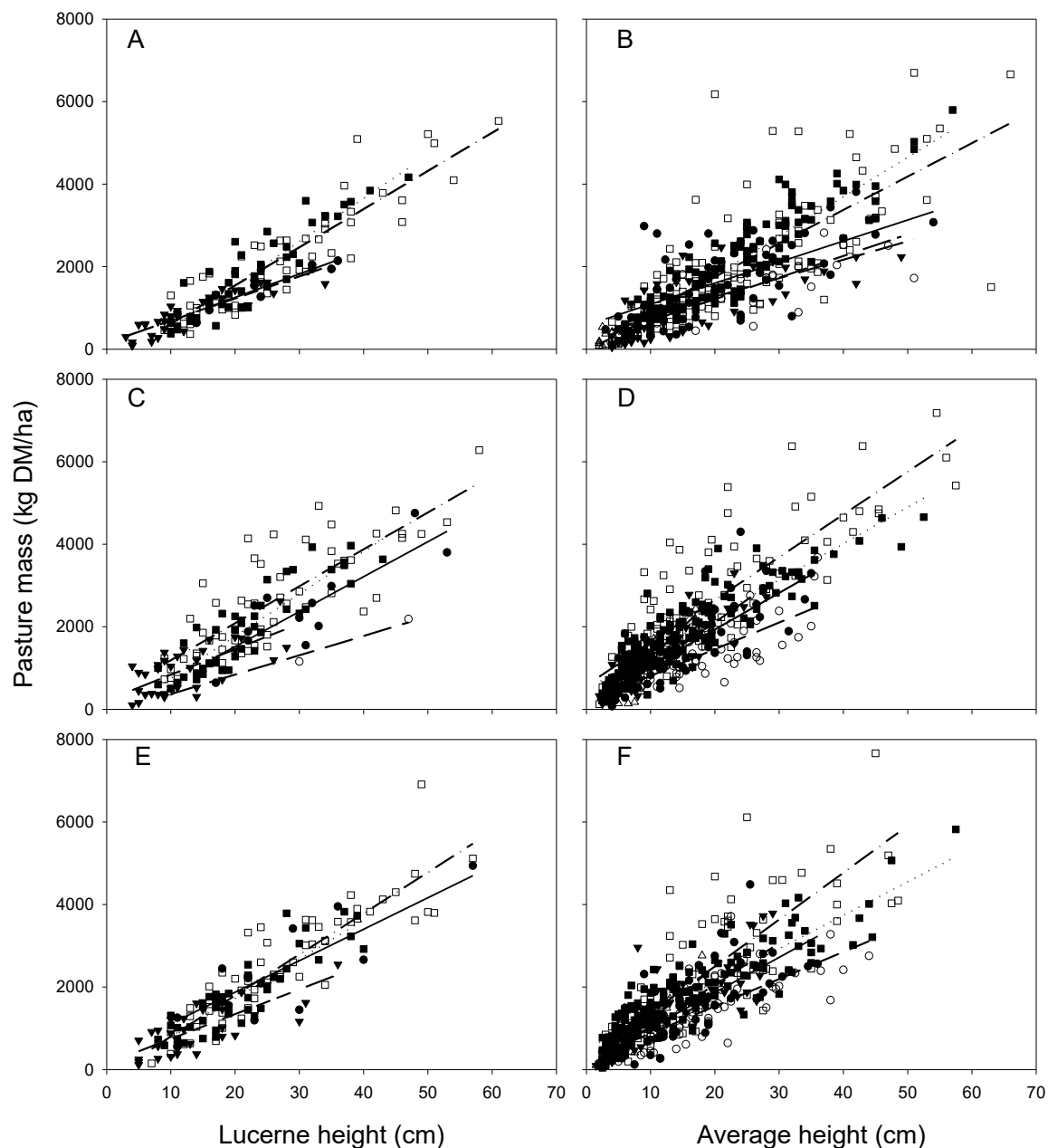
Figure 3-5: Regressions of pasture mass against height. A) Lucerne 2012/13, B) Lucerne years 2-4, C) Lucerne/brome 2012/13, D) Lucerne/brome years 2-4, E) Lucerne/cocksfoot 2012/13, F) Lucerne/cocksfoot years 2-4. Bimonthly periods are represented separately. Jan/Feb (● ——), Mar/Apr (○ — — —), May/Jun (▼—·—), Jul/Aug (△----), Sep/Oct (■·····), Nov/Dec (□—·—·—). Equations of regressions appear in Table 3-3.

3.7.6 Pasture calculations

3.7.6.1 Pasture yield

The pasture yield was calculated by accumulating the pre-grazing pasture mass of productive grazings less the residual of the grass (in binary mixtures) and weed components of the previous grazing. The residual lucerne component was already disregarded in pre-grazing pasture measurements. Dead material within the residual was assumed to have senesced prior to the following grazing. If the preceding grazing was non-productive and had no associated pasture measurements the residual was considered negligible. Non-productive livestock were utilised to clean up the residual that productive livestock refused which allowed them to avoid unpalatable herbage, as these grazings directly follow that of productive livestock it is assumed no growth, therefore no additional yield, occurred in the meantime. Pasture yields of individual grazings were accumulated for each replicate and averaged to give seasonal and annual yield.

3.7.6.2 Pasture allocation

The amount of pasture allocated to each productive GD was calculated by dividing pasture yield by GD. This ignores the pasture residual left by the previous productive livestock grazings so was often less than the pre-grazing pasture mass. During the spring, pasture allocation was calculated for each ewe GD and includes pasture offered to her lambs.

Table 3-3: Pasture height/mass regression equations for three dryland pastures for bimonthly periods for the 2012/13 year and the combined 2013/14-2015/16 years.

Treatment	Period	2012/13	2013/14-2015/16
Lucerne	Jan/Feb	$= 56.8 \pm 6.94\,x + 117 \pm 178\ R^2{=}0.87$	$= 51.0 \pm 8.39x + 582 \pm 199\ R^2{=}0.38$
	Mar/Apr		$= 44.9 \pm 8.73x + 370 \pm 249\ R^2{=}0.47$
	May/Jun	$= 53.7 \pm 5.12x + 152 \pm 75\ R^2{=}0.76$	$= 52.4 \pm 5.82x + 160 \pm 111\ R^2{=}0.55$
	Jul/Aug		$= 63.2 \pm 24.5x + 60 \pm 101\ R^2{=}0.25$
	Sep/Oct	$= 104.8 \pm 8.02x - 534 \pm 198\ R^2{=}0.81$	$= 95.5 \pm 3.78x - 126 \pm 95\ R^2{=}0.84$
	Nov/Dec	$= 92.6 \pm 5.8x - 310 \pm 170\ R^2{=}0.82$	$= 81.0 \pm 5.89x + 131 \pm 150\ R^2{=}0.59$
Lucerne/ brome	Jan/Feb	$= 84.7 \pm 17.40x - 176 \pm 567\ R^2{=}0.67$	$= 88.9 \pm 8.94x + 154 \pm 151\ R^2{=}0.62$
	Mar/Apr	$= 47.0 \pm 6.68x - 104 \pm 230\ R^2{=}0.96$	$= 64.6 \pm 8.95x + 161 \pm 185\ R^2{=}0.52$
	May/Jun	$= 62.0 \pm 11.0x + 215 \pm 155\ R^2{=}0.47$	$= 108.4 \pm 8.10x - 60 \pm 106\ R^2{=}0.73$
	Jul/Aug		$= 148.6 \pm 16.3x - 236 \pm 123\ R^2{=}0.76$
	Sep/Oct	$= 102.4 \pm 8.36x - 273 \pm 198\ R^2{=}0.78$	$= 88.2 \pm 3.38x + 489 \pm 57\ R^2{=}0.80$
	Nov/Dec	$= 89.5 \pm 8.43x + 293 \pm 240\ R^2{=}0.67$	$= 103.5 \pm 6.52x + 582 \pm 143\ R^2{=}0.71$
Lucerne/ cocksfoot	Jan/Feb	$= 76.3 \pm 17.1x + 349 \pm 507\ R^2{=}0.63$	$= 85.3 \pm 9.22x + 159 \pm 150\ R^2{=}0.55$
	Mar/Apr		$= 65.8 \pm 9.33x + 217 \pm 210\ R^2{=}0.51$
	May/Jun	$= 60.0 \pm 9.08x + 140 \pm 153\ R^2{=}0.57$	$= 100.4 \pm 8.26x + 48 \pm 118\ R^2{=}0.69$
	Jul/Aug		$= 132.2 \pm 7.74x - 134 \pm 68\ R^2{=}0.90$
	Sep/Oct	$= 95.1 \pm 8.02x - 180 \pm 180\ R^2{=}0.77$	$= 81.1 \pm 3.13x + 498 \pm 57\ R^2{=}0.80$
	Nov/Dec	$= 99.5 \pm 6.67x - 196 \pm 199\ R^2{=}0.80$	$= 113.6 \pm 7.91x + 226 \pm 163\ R^2{=}0.68$

3.7.6.3 Metabolisable energy requirement

Using the figures of Nicol and Brookes (2007) the treatment ME requirement for maintenance, lactation and LWG were calculated for each season of each year. This required the livestock measurements of live weight, prior to and following a live weight rotation, to determine LWG and average live weight during the rotation. In the spring, the stage (week) of lactation is required as this was influential for the energy requirement of lactation. Spring demand was adjusted for the average number of lambs each ewe was rearing. Per head ME requirement was multiplied by grazing days per hectare supported by each treatment during a live weight rotation.

An example of calculating ME requirement:

The pasture intake of weaned lamb was calculated as that required to supply the ME for maintenance (~0.2 MJ ME/kg live weight/day) and for LWG (~3.9 MJ ME/100 g LWG). A 30 kg lamb growing 200 g/day had a daily ME requirement of 30 kg * 0.2 MJ ME/kg/day = 6.0 MJ ME for maintenance, and 200 g * 3.9 MJ ME/100 g LWG = 7.8 MJ ME for LWG/day. Combined, the ME requirement is 13.8 MJ ME/day and was multiplied by the GD supported per hectare.

During lactation the energy requirement for every 1 kg of lamb weaning weight increased incrementally from 0.4-0.7 MJ ME/day over the 11 weeks of lactation. Ewe LWG had an energy requirement of 5.5 MJ ME/100 g and weight loss provided 3.0 MJ ME/100 g. Ewe maintenance requirement was ~0.15 MJ ME/kg live weight/day. Therefore, a 60 kg ewe rearing twin lambs that were weaned at 26 kg and was gaining 50 g LWG/day during the sixth week of lactation had an energy requirement of 60 kg * 0.15 MJ ME/kg/day = 9.0 MJ ME/day for maintenance, 50 g/day * 5.5 MJ ME/100 g LWG = 2.8 MJ ME/day for LWG, and (26 kg * 0.52 MJ ME/kg/day) * 2 lambs = 27.0 MJ ME/day for lactation. The total energy requirement from pasture is 38.8 MJ ME/day between ewe and lambs.

3.7.6.4 Crude protein requirement

Similarly to ME requirement, using the figures of Brookes and Nicol (2007) the metabolisable protein (MP) requirement for maintenance, lactation and live weight gain were determined for each season of each year. To convert this to CP requirement it was estimated that 55% of CP was absorbed as MP, being the midpoint of the 50-60% range given by those authors.

3.7.6.5 *Pasture intake*

Pasture intake was determined in two different ways. Firstly by pasture disappearance, where the difference in pre-grazing and post-grazing pasture mass was presumed to be consumed by livestock over the grazing duration. This assumed that no pasture growth occurred during the grazing period. An alternative method is to divide livestock ME requirement, to meet maintenance and LWG, by estimated ME content of intake. For the purpose of this experiment a content of 12 MJ ME/kg DM was chosen for all treatments for all seasons. This is at the upper end of the potential range (Litherland and Lambert, 2007), but reflects the low level of pasture utilisation typically shown which enabled a large degree of pasture selection. Using a high value would tend to underestimate pasture intake, especially if livestock were required to graze unpalatable herbage, therefore estimates the lowest possible pasture intake.

As an example, the ME requirement of the weaned lamb mentioned in Section 3.7.6.3 of 13.8 MJ ME can be divided by 12 MJ ME/kg DM to give pasture intake of 1.15 kg DM/GD. This was then multiplied by the GD per hectare during a grazing period.

The robustness of methods was investigated as part of this study. To do this, pasture intake as limited by animal size and by the potential to meet animal ME requirement, were compared.

The correlation between the two methods to calculate pasture intake of grazings was weak (Figure 3-6 A). LWG was distributed evenly over a live weight period and did not allow for variability in grazing intensity and weather conditions. Therefore, pasture intake of a particular grazing could easily be over or underestimated when determined this way. The relationship within live weight rotations was much stronger (Figure 3-6 B). The Pearson's correlation coefficient was higher for the lucerne treatment than the binary mixtures. This may suggest the ME of pasture intake on lucerne was more consistent over live weight periods relative to the binary mixtures.
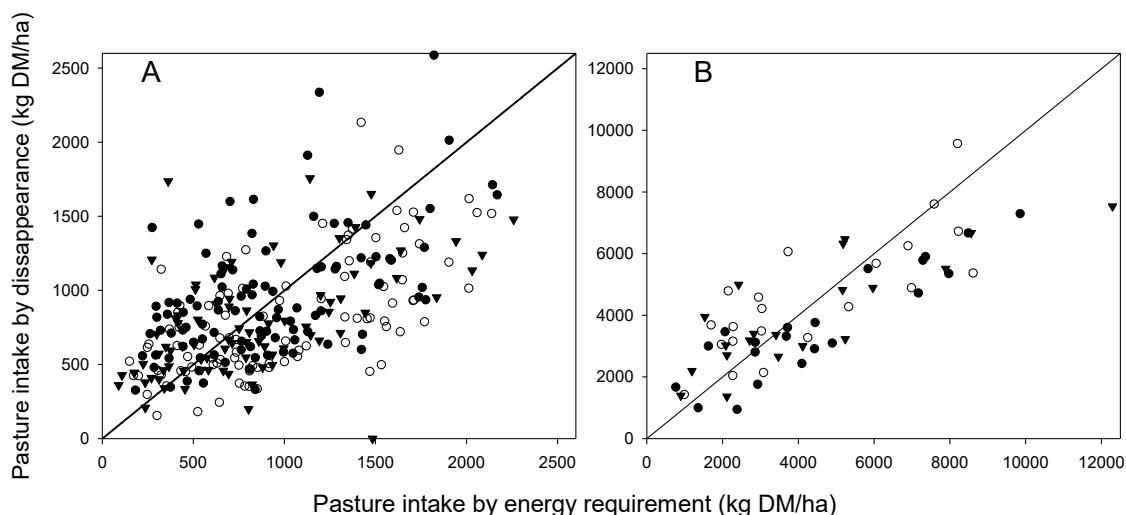
Figure 3-6: Correlation between pasture intake determined by energy requirement and pasture disappearance for productive grazings A), and live weight periods B) during 2012-2016 at Ashley Dene, Canterbury. Lucerne treatment (●), lucerne/brome (▼), and lucerne/cocksfoot (○). The Pearson's correlation coefficient for the grazings are 0.64 for the lucerne treatment and 0.54 for both of the binary mixtures. The Pearson's coefficient for live weight periods was 0.91, 0.81, and 0.79 for lucerne, lucerne/brome, and lucerne/cocksfoot treatments.

3.7.7 Meteorological data

Long term meteorological data have been collected at the Broadfield weather station located approximately 14 km north east from the experimental site (43°62'S,172°47'E). Meteorological data were collected on site for periods of the research but as this was incomplete, Broadfield data were used for consistency. Pollock (2012) reported that annual rainfall at Broadfield was usually within 15% of that measured at Ashley Dene although on a monthly basis there was more variation. At Broadfield the long term average (1981-2010) rainfall was 599 mm/annum distributed evenly throughout the year with average monthly rainfall over the same period ranging from 39-61 mm (Figure 3-7). This experiment ran from July 2012 to June 2016 and the annual rainfall was 670, 883, 376, and 507 mm for these consecutive seasons. Due to limited soil water holding capacity, spread of rainfall over the growing season is important for maintaining pasture growth. The long term mean monthly rainfall has a degree of consistency during the year, however this obscures the variability from one year to the next. An example of this is April rainfall which has a long term mean of ~50 mm but during the experiment ranged from 10 mm to 160 mm (Figure 3-7). Penman's potential evapotranspiration exceeded rainfall each year being 900-1020 mm, annually. Below average

summer rainfall during 2012/13 ensured a pronounced summer soil water deficit which was replenished only following significant rainfall in May. Much of the 210 mm rainfall which fell in June of the second year would have been lost as drainage through the soil profile due to the limited soil water holding capacity of these soils. Timely rainfall, especially in December and March, resulted in a short drought period during that summer. Below average rainfall during winter, spring, and summer in 2014/15 resulted in a long period of soil water deficit. Pasture growth was dependent on significant in season rainfall. With minimal rainfall during October and November of 2015, pasture growth ceased prior to the summer, but significant rainfall during late December and early January supported substantial summer growth.
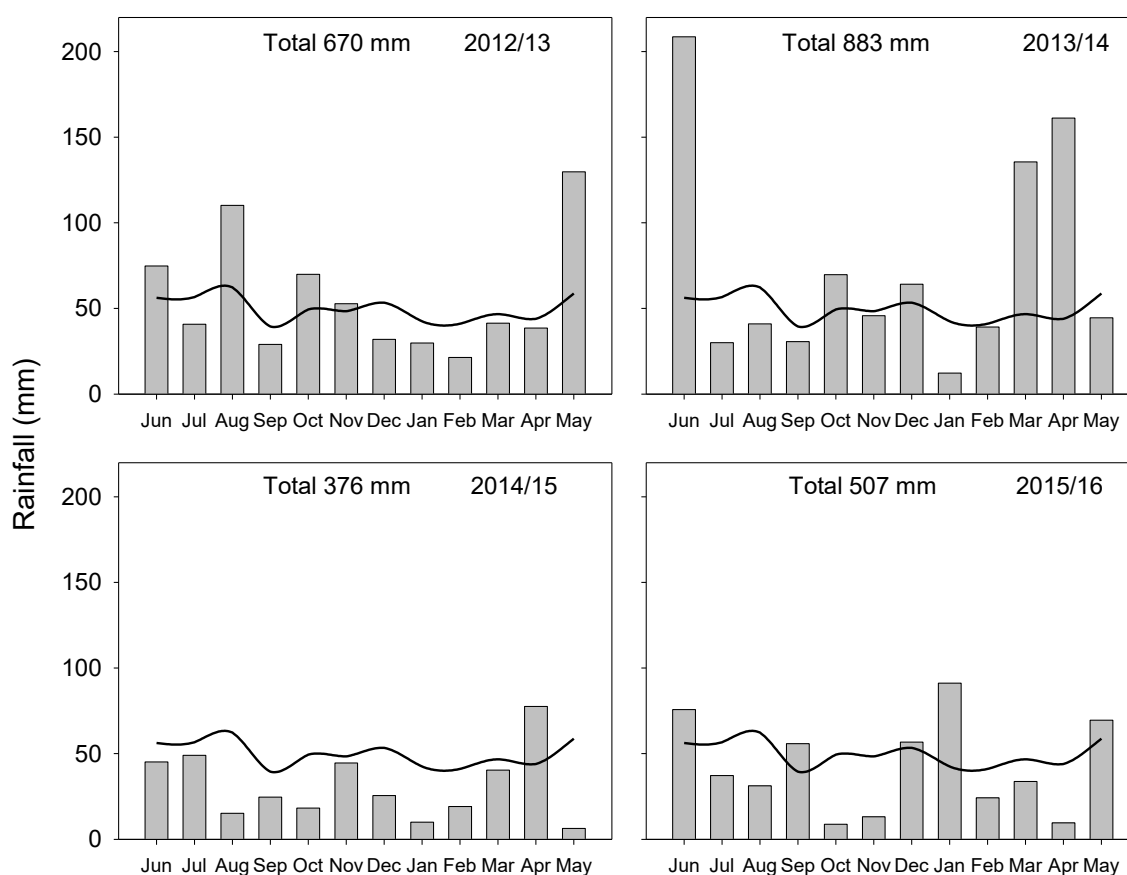
Figure 3-7: Monthly rainfall for four years of experiment measured at Broadfield weather station. A) 2012/13, B) 2013/14, C) 2014/15, D) 2015/16. The line on each graph represents the long term mean (1981-2010).

The long term average daily air temperature is 11.7° C. This is highest in January at 16.9° C and lowest in July at 6.1° C (Figure 3-8). Monthly mean temperatures appeared consistent from

year to year. However, as expected, during the spring and summer this was related to monthly rainfall being typically above average during months when rainfall was below average and vice versa.
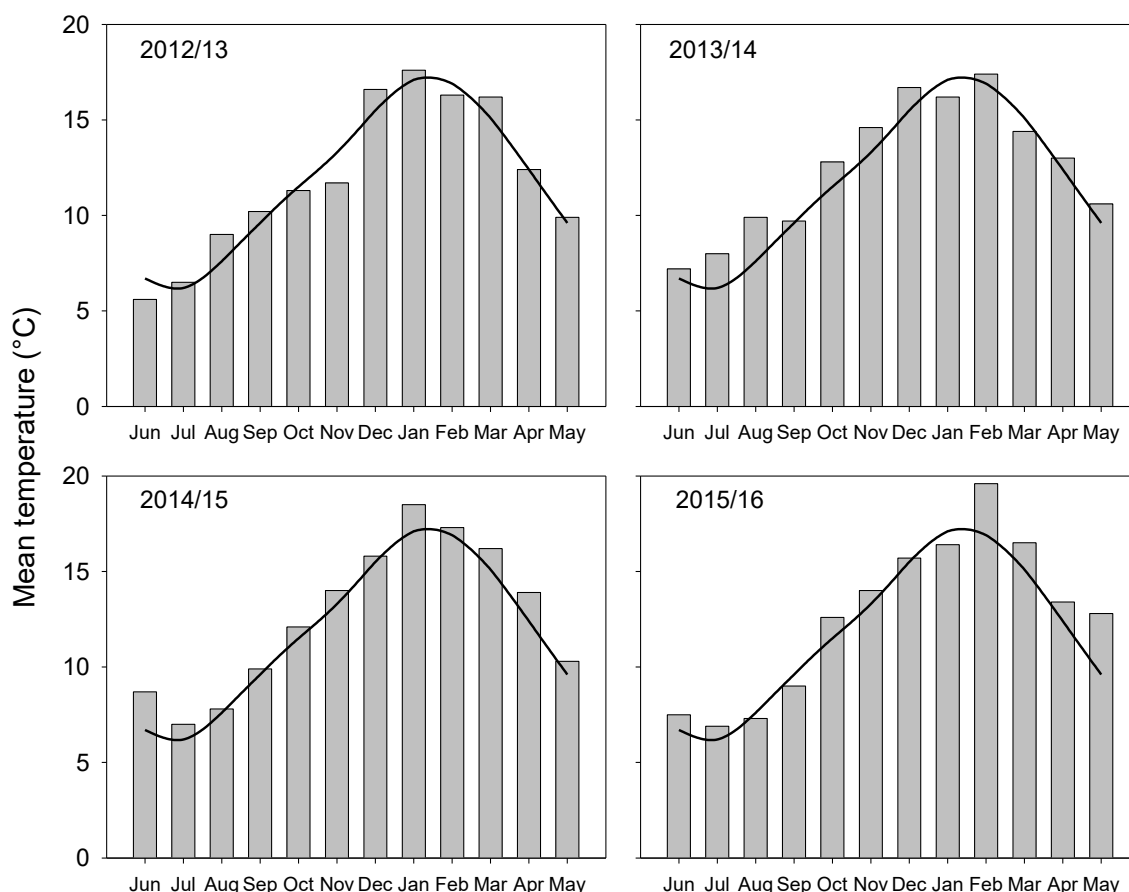
Figure 3-8: Monthly mean daily temperature for four years of the experiment measured at Broadfield weather station. The line on each graph represents the long term mean (1981-2010).

3.7.8 Soil moisture

Volumetric soil moisture content was measured throughout the experiment. A 2.3 m neutron probe tube was inserted in each plot. At between 2 and 6 week intervals soil moisture readings were taken. A Time Domain Reflectometer (TDR) (Soil Moisture Equipment™) was used for measurements of the top 0.2 m of the soil profile. Below this a neutron probe (Troxler™ and InstroTek™) was used for measurements at 0.2 m intervals from 0.25-2.25 m.

3.7.9 Soil nitrogen

During the winters of 2014, 2015, and 2016 at least 20 soil cores at 0-75 mm and 75-150 mm were taken from each plot and a sub sample was sent to Analytical Research Laboratories, Napier, for analysis. Results on the anaerobically mineralisable nitrogen (AMN) present in these samples were used to compare the pasture treatment effect on soil N status. In February of 2016, an additional 20 cores from each plot (again at two depths) were taken for N and carbon analysis to assess the organic soil profile towards the end of the experiment. A sub sample was separated for drying and grinding for total carbon and total N testing at Lincoln University while a separate sub sample was tested for AMN by Analytical Research Laboratories, Napier.

3.8 Determination of pasture growth response to environmental parameters

3.8.1 Base temperature

Pasture growth was quantified in response to thermal time (TT) above a base temperature. Determination of a base temperature was done by performing regressions of accumulated thermal time with accumulated pasture yield to identify which gave the highest coefficient of determination. Both air and soil (0.1 m) temperatures in the 0-5°C range were tested. There was some variation among treatments and years as to the most appropriate temperature so a base soil temperature of 0°C was used to allow comparison and consistency with previous results from Morris (2011) and Tonmukayakul (2009).

Daily TT is calculated using actual minimum (T_{min}) and maximum (T_{max}) soil temperature measured at Broadfield weather station and the determined base temperature (T_b) using:

Equation 1: $$TT \ (°C \ days) = \frac{Tmax - Tmin}{2} - Tb$$

When T_{min} was below the base temperature, TT was adjusted by dividing the day into eight three hour periods and determining a minimum temperature for each of these periods by way of a sine curve (to allow for the fluctuating daily temperature) and allocating TT accordingly (Jones and Kiniry, 1986).

3.8.2 Growth response to TT

Following the winter 'clean up' graze TT was accumulated over each regrowth period from the date of the post-grazing (or date of removal of non-productive livestock if the preceding grazing was a 'clean-up' graze) to pre-grazing pasture measurements for individual plots

throughout each year. Accumulating pasture yield at each productive grazing was then related to the accumulated TT. Plots did not necessarily accumulate the same amount of TT during periods of yield accumulation within a year due to differences in grazing duration and timing of 'clean-up' grazes.

During the spring of each year, each plot exhibited a period of rapid linear pasture accumulation relative to accumulating TT. This was typically between the first and second grazing but on occasion extended to the third grazing rotation. This period of 'maximum' growth rate occurred when soil water was not limiting to pasture growth. Prior to the first grazing, although soil water was available, the response was suppressed and believed to be associated with slow accumulation of leaf area which limited PAR interception. The growth response to TT was smallest over the summer and autumn. Pasture measurements were infrequent beyond the spring because growth was reduced by the prolonged summer dry periods.

3.8.3   Time of pasture growth initiation

The 'maximum' growth rate was extrapolated to the *x*-axis for each plot. This intercept represented the time when linear pasture growth began in the spring. Pasture growth potentially began prior to this but this allowed a non-subjective method to compare the lag of cool season growth among treatments.

3.8.4   Time of soil water deficit by calculation of a 'break point'

The identification of the time a soil water deficit became limiting to pasture growth on a plot was challenging due to infrequent pasture measurements. As an estimate of this, the 'maximum' growth rate was continued for each plot until pasture accumulation equalled that of the grazing following the linear phase and pasture accumulation was then forced horizontal. The time of this 'break point' indicated a limiting soil water deficit which was compared among treatments. This method did not always exclude growth arising from effective rainfall following a limiting deficit so could not give an accurate indication every year but it allowed treatments to be compared.

3.8.5   Water holding capacity

Soil water measurements from TDR and neutron probe readings taken over the duration of the experiment were used to determine the plant available water holding capacity of each plot. The drained upper limit (DUL) to soil water capacity was calculated by averaging the fourth and fifth largest water content measurement for each layer of soil. The three highest measurements

were excluded to allow for measurements taken prior to the drainage of excess water beyond the capacity of soils. The lowest measurement at each level measured over the duration of the experiment represented the soil water content that was not available to pastures, or lower limit (LL). The difference of the two figures was deemed as PAWC of each layer. The sum of all layers within a plot gave the total PAWC of the soil. Examples are given in Appendix 21.

3.8.6 Potential soil water budget

The identification of available water holding capacity allowed the estimation of a limiting soil water deficit using a potential soil water budget. The potential soil water deficit (PSWD) was calculated from Penman's PET and rainfall measured at Broadfield weather station for each year using:

Equation 2: $PSWD = Yesterdays\ PSWD + PET - Rainfall$

Where all the units are mm. This assumed the PSWD was set to zero on the 1st July each year. Negative PSWD were not allowed. When field capacity was exceeded, this water was assumed to be lost as drainage and did not support PET (Figure 3-9). The point that PSWD equals the mean PAWC indicates the potential exhaustion of plant available soil water when pasture growth can be expected to be restricted.

This provided a more accurate estimate of the date a limiting soil water deficit occurred rather than the calculation of a 'break point' (Section 3.8.4). This method excluded pasture growth arising from rainfall following the limiting soil water deficit.

3.8.7 Water use efficiency

The efficiency of pastures at utilising available water for pasture growth was calculated for the period when soil water was non-limiting to pasture growth. The equation for this was:

Equation 3:   WUE =Pasture yield/Plant available water

Where the units were kg DM/ha/mm, kg DM/ha, and mm for WUE, pasture yield and plant available water, respectively. The water available to pastures prior to becoming limiting to growth was the PAWC (as soils were assumed to be at field capacity as at the 1st July) plus additional rainfall, less drainage when soil was at field capacity. Pasture yield was that determined to have grown as a result of this available water and not from summer rainfall.

During the summer of 2013/14 the separation of pasture yield arising from summer rain was done subjectively but in the remaining years this was easily defined due to the timing of grazings in relation to rainfall events.
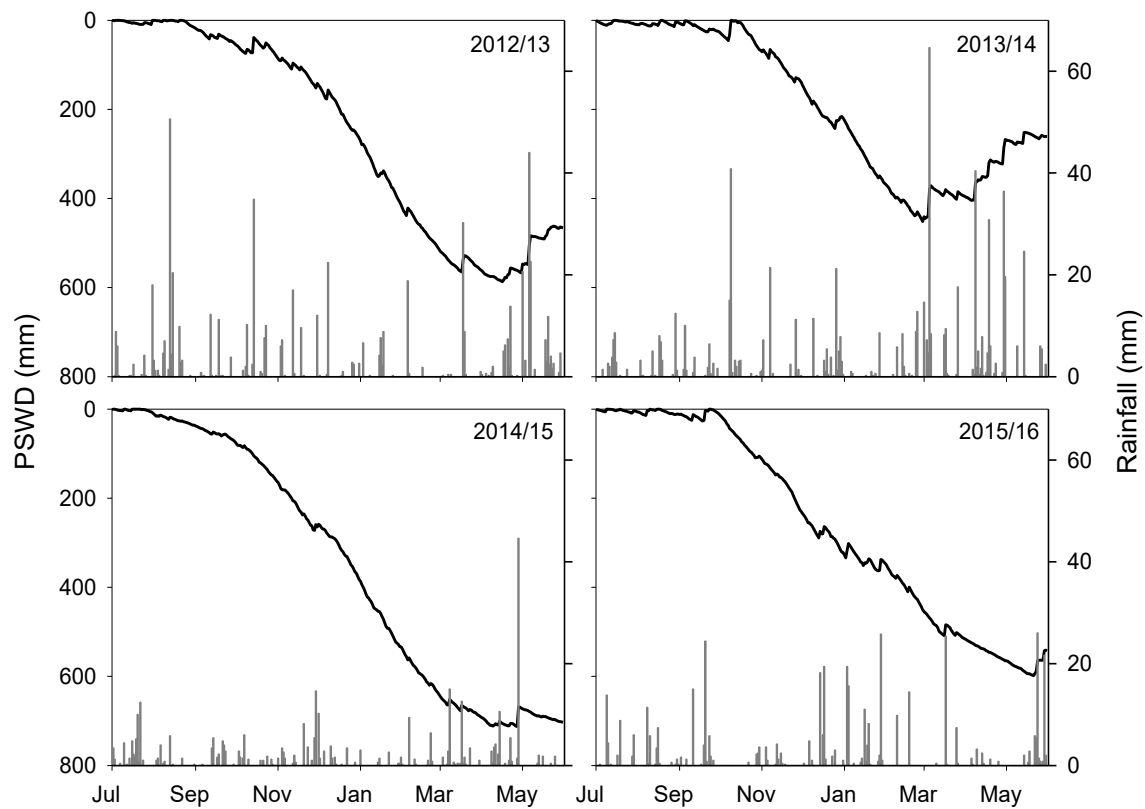
Figure 3-9: Potential soil water deficit (PSWD) for the four years of the experiment using rainfall (bars) and Penman's potential evapotranspiration measured at Broadfield weather station.

3.9 Analysis

Statistical analysis was performed on GenStat (Version 16.1, VSN International Ltd, 2013).

3.9.1 Livestock

One mob of sheep were used for each treatment during each season. As a result there was no independent live weight data within years. To allow analysis, a pseudo replication was created by distributing LWG of live weight rotations among replicates relative to the duration these were grazed by stock. For example, for a live weight rotation of 30 days and an increase in total live weight of a mob of weaned lambs of 120 kg in this period, it was assumed that total LWG was 4.0 kg each day. During this live weight rotation, a mob spending eight days on replicate one, six days on replicate two and four days on each of the remaining replicates was assumed to have grown 32 kg and 24 kg on the first two replicates, respectively, and 16 kg on the remaining replicates. These figures were then divided by the area of each replicate to give a LWG/ha. This LWG pseudo replication data was also used to calculate ME and CP requirement of livestock. This gave six replicates for these measurements and calculations allowing analysis of variation among treatments.

To analyse livestock growth rates, a one way analysis of variance was done using years as replicates.

3.9.2 Reduction of replicates

During the autumn of 2015/16 replicates three and four were dropped from the experiment because they were no longer typical of the pastures in the newly sown treatments. To allow analysis across years, these replicates were allocated the mean of the remaining four replicates as this influenced each treatment equally.

3.9.3 Response to TT

Due to the staggered nature of pasture measurements, the relationship between accumulated pasture yield and accumulated TT was not strictly aligned among replicates. This meant a regression analysis of the data was inappropriate. As an alternative, an analysis of variance was done on the growth rate, intercept, and 'break point' separately. These statistics were calculated independently to grazing rotation pasture yields which were typically the mean of six replicates but occasionally 3-5 if a grazing rotation was not completed within a season.

3.9.4 Pasture composition

A series of two sample t-tests were performed among and within treatments for composition of pasture allocation and calculated pasture intake. This was undertaken for each year during the spring but data for all years were bulked for the summer and autumn, separately. The variance is represented by the largest standard error of the means (S.E.M.) for each pasture component.

3.9.5 Nutritive value of components

A series of two sample t-tests were used on the ME and CP content among pasture components. This was done separately for the pre-grazing and post-grazing content. Measurements from all years were bulked for the spring, summer and autumn periods, separately.

3.9.6 General

When comparing treatments over the duration of the experiment a split plot analysis of variance was performed using treatment as whole plots and year as the sub-plot. Fishers protected least significant differences identified differences in means which are significant to the α=0.05 level. When the p-value was 0.05-0.10 it was considered to be a trend. When an interaction among treatment and year occurred, means within the body of the table followed by a different letter are significantly different. For completeness, interaction tables are presented for all variables but when there was only a main effect, treatment means or year means followed by a different letter are noted as significantly different (treatment in upper case and year in lower case). The associated S.E.M. and p-value are included in tables for treatment, year, and interaction to provide consistency and do not insinuate significance. The significant p-value is highlighted in the table. In the text S.E.M. are reported in parenthesis following the first mean.

RESULTS

4   ANIMAL AND PASTURE PRODUCTION

4.1   Introduction

The ultimate indicator of a dryland pastures performance is the animal productivity it can achieve. This can be related back to pasture yield, which determines carrying capacity, and ME intake/GD.

The aim of Chapter 4 is to explain animal production differences in relation to pasture production, composition, and quality.

The objectives are to:-

- Quantify seasonal and annual LWG of pasture treatments and relate any differences to daily LWG or number of grazing days available.
- Quantify seasonal and annual pasture yields and calculate pasture allocation per grazing day from these.
- Calculate the seasonal and annual metabolisable energy and crude protein yields of pastures measured by near infra-red spectrometry analysis of pasture components and botanical compositions.
- Assess the robustness of seasonal and annual pasture intake estimated independently from pasture and animal measurements, separately.

4.2   Annual live weight gain (LWG)

Over the four years the lucerne monoculture averaged 28% more LWG than the binary mixtures. Specifically, total LWG on the lucerne treatment was higher (p=0.002) than the binary mixtures for the second and fourth years but not different in the other two (Table 4-1). LWG of the binary mixtures was not different to each other in any of the four years. During the 2012/13 year, when lucerne dominated all treatments, total LWG was 780 (± 47.3) kg/ha

and this was the highest annual production for the duration of the experiment. Annual LWG was consistent on the lucerne treatment except for 2014/15 when it was about 30% lower.

Table 4-1: Total annual live weight gain (kg/ha) of productive livestock over four years on three dryland pastures 2012-2016 at Ashley Dene, Canterbury. 'Lucerne' refers to the lucerne monoculture treatment, 'Luc/Brome' refers to the lucerne and brome binary mix treatment, and 'Luc/CF' refers to the lucerne and cocksfoot binary mix treatment.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	808 [a]	792 [a]	560 [b]	755 [a]	729
Luc/Brome	718 [a]	563 [b]	536 [b]	451 [bc]	567
Luc/CF	814 [a]	530 [b]	551 [b]	390 [c]	571
Year mean	780	628	549	532	
	Treatment		**Year**	**Interaction**	
S.E.M.	24.0		26.2	47.3	
P-value	0.001		<0.001	**0.002**	

Note: Means followed by the same letter are not different at the α=0.05 level.

The most productive season of the year was the spring for all pastures. During this season treatments were stocked with ewes & lambs that contributed 57-79% of total annual LWG (Figure 4-1). A loss in ewe live weight occurred on all treatments during the spring of 2013/14 and on the binary mixtures during 2015/16. This negative LWG is depicted as bars extending below the *x*-axis in Figure 4-1. Summer LWG of weaned lambs contributed 5-30% of annual LWG. The autumn was stocked with hoggets for a period each year, and LWG was normally least productive at 2-24% of annual LWG.
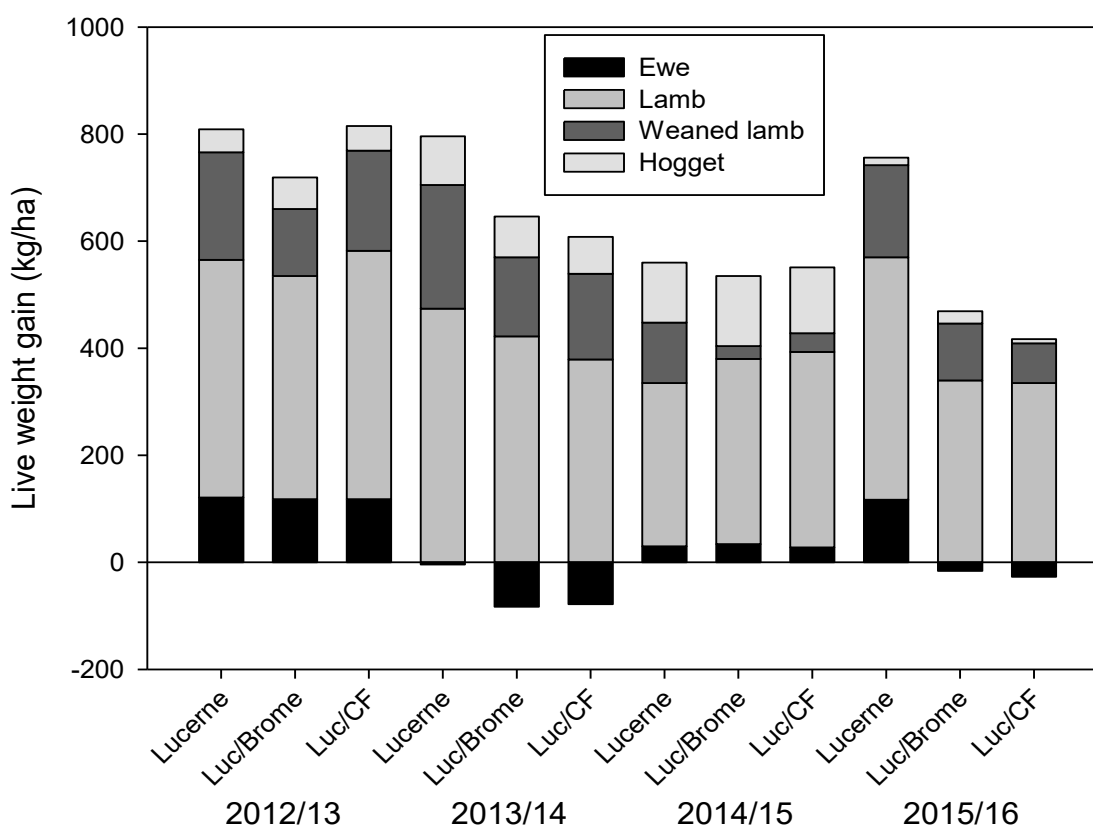
Figure 4-1: Total annual live weight gain (kg/ha) separated into stock classes for sheep grazing three dryland pastures over four years from 2012-2016 at Ashley Dene, Canterbury. Acronyms are reported in Table 4-1.

4.3 Annual pasture yield

Pasture yields did not differ (p=0.445) among treatments over the course of the experiment. Figure 4-2 depicts herbage yield offered to each stock class for each treatment over four years. The first two years of the experiment coincided with higher than average rainfall (670 mm and 883 mm) and mean annual pasture production was 8.8 (±0.28) t/ha in 2012/13 and 10.8 t/ha in 2013/14 (Table 4-2). The 2013/14 year in particular, which received 181 mm of rainfall during October-December and then 133 mm in March (Figure 3-7), experienced a very short period of soil water deficit. In contrast, the final two years pasture yields were 6.5 (± 0.28) t DM/ha and limited by lower than average annual rainfall of 376 mm during 2014/15 and 507 mm during 2015/16.

Table 4-2: Total annual pasture yield (kg DM/ha) of three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	8528	10775	5860	6940	8026
Luc/Brome	8878	10376	6522	6233	8002
Luc/CF	8854	11363	7100	6137	8363
Year mean	8753 [b]	10838 [a]	6494 [c]	6437 [c]	
	Treatment	**Year**	**Interaction**		
S.E.M.	215.6	280.5	472.8		
P-value	0.445	**<0.001**	0.445		

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.
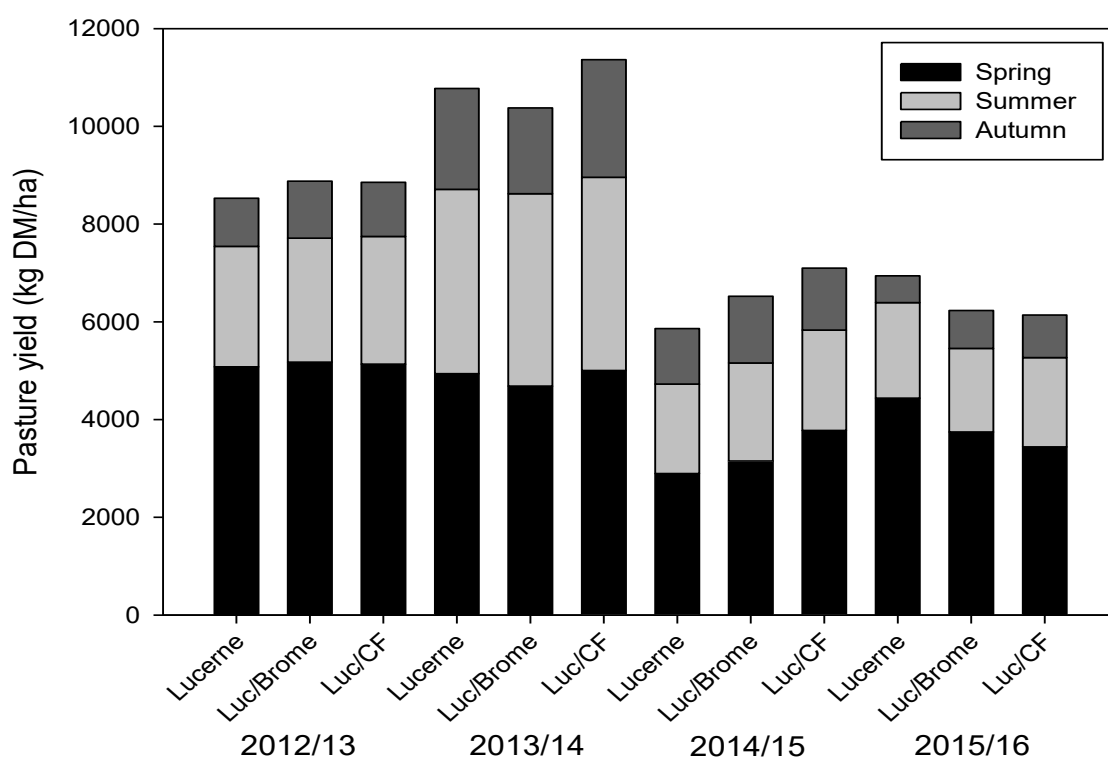
Figure 4-2: Total annual pasture yield (kg DM/ha) of three dryland pastures separated into the seasons grazed from 2012-2016 at Ashley Dene, Canterbury. Treatment acronyms are reported in Table 4-1.

4.4 Spring

4.4.1 Live weight gain

4.4.1.1 Lambs

There was a trend (p=0.086) that showed total LWG of lambs was higher on the lucerne than the binary mixtures. Lamb production was largest in the first year at 441 (±22.4) kg LWG/ha and ~100 kg/ha lower than this in the spring of 2014/15 (Table 4-3). Lambs on the lucerne treatment grew at a faster rate (p=0.048) than those on the lucerne/cocksfoot with the lucerne/brome treatment being intermediate (Appendix 1). Average daily lamb growth rates were 311 (±14.6) g LWG/lamb GD on the lucerne, 269 g LWG on the lucerne/brome, and 245 g LWG/lamb GD on the lucerne/cocksfoot.

Table 4-3: Live weight gain (kg/ha) of lambs at foot on three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	444	474	305	453	419
Luc/Brome	416	422	346	340	381
Luc/CF	464	379	365	335	386
Year mean	441 [a]	425 [ab]	339 [c]	376 [bc]	

	Treatment	Year	Interaction	
S.E.M.	11.6	22.4	35.6	
P-value	0.086	**0.009**	0.215	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.4.1.2 Ewes

There was a treatment by year interaction (p<0.001) with ewe LWG during lactation. This ranged from 121 (±27.4) kg/ha to -83 kg/ha LWG (Table 4-4). There was no difference among treatments in the 2012/13 and 2014/15 years. During the spring of 2013/14, all treatments experienced a live weight loss, this loss was smallest for ewes on the lucerne. In 2015/16 ewes on the lucerne had a LWG of over 100 kg/ha which was similar to that of the first year. In contrast ewes on the binary treatments lost ~22 kg/ha during lactation in the final year. The

four year average daily LWG of ewes was 90 (±23.7) g LWG/ewe GD on the lucerne, 25 g LWG/ewe GD on the lucerne/brome, and 19 g LWG/ewe GD on the lucerne/cocksfoot, but these were not different (p=0.146) due to the variability from year to year (Appendix 1).

Table 4-4: Live weight gain (kg/ha) of lactating ewes on three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	121 [a]	-4 [c]	30 [b]	116 [a]	66
Luc/Brome	118 [a]	-83 [e]	34 [b]	-16 [c]	13
Luc/CF	118 [a]	-78 [de]	28 [bc]	-27 [cd]	10
Year mean	119	-55	31	24	
	Treatment		**Year**	**Interaction**	
S.E.M.	12.9		9.6	27.4	
P-value	0.021		<0.001	**<0.001**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.4.2 Pasture yields

Spring pasture yields were not different (p=0.773) among treatments within years. Pasture yields in the spring of the first two years were 5.0 (±0.32) t DM/ha which was 40% more (p<0.001) than the spring of the third and fourth year (Table 4-5).

Table 4-5: Pasture yield (kg DM/ha) of three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	5080	4939	2896	4439	4339
Luc/Brome	5177	4685	3154	3745	4190
Luc/CF	5136	5004	3776	3439	4339
Year mean	5131 [a]	4876 [a]	3276 [b]	3874 [b]	
	Treatment		**Year**	**Interaction**	
S.E.M.	166.4		315.5	501.7	
P-value	0.773		**<0.001**	0.787	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.4.3 Grazing days

Overall, there were more (p=0.039) spring grazing days (GD) on the lucerne/cocksfoot treatment (2436 (±71.0)) than the lucerne treatment (2145) (Table 4-6). The lucerne/brome treatment was intermediate and not different from the other two. Treatments supported similar stocking rates with the difference occurring due to the timing of livestock introduction (Figure 3-1 to 3-4).

Table 4-6: Grazing days (/ha) of ewes & lambs at foot on three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2249	2875	1427	2031	2145 [B]
Luc/Brome	2104	2888	1895	1975	2216 [AB]
Luc/CF	2262	2987	2284	2209	2436 [A]
Year mean	2205 [b]	2917 [a]	1869 [b]	2072 [b]	
	Treatment		**Year**		**Interaction**
S.E.M.	71.0		143.8		227.1
P-value	**0.039**		**<0.001**		0.669

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Mean pasture allocation per ewe GD over the spring period was not different (p=0.178) among treatments and was 6.2 (±0.31) kg DM/GD on the lucerne treatment, 5.8 kg DM/GD on the lucerne/brome, and 5.4 kg DM/GD on the lucerne/cocksfoot (Appendix 8). Pasture allocation was largest (p=0.002) during the first year at 6.9 (±0.31) kg DM/ha and 5.4 kg DM/ha during the spring of the remaining three years.

4.4.4 Nutritive value

The ME content of pre-grazing pasture components were not different (p=0.070) at 11.1 (±0.12) MJ ME/kg DM during the spring (Table 4-7). As a result, differences in the proportion of pasture components in pasture yield was not expected to influence ME yield. The ME content of the residual lucerne was lower (p<0.001) than sown grass and weed species.

Lucerne had a larger (p<0.001) pre-grazing and post grazing CP content than all the other components being 24.7 (±0.73) % and 17.9 (±0.86) %, respectively. During the spring, all pre-grazing pasture components had a larger (p=0.003) CP content than post-grazing, all except

the brome grasses had larger (p=0.003) ME content pre-grazing than post-grazing. This is consistent with ewes & lambs selecting the more digestible portion of pasture plants (Section 2.4.1.).

Table 4-7: Mean metabolisable energy (MJ ME/kg DM) and crude protein (%) content of pre and post-grazing pasture components of three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Pasture component	ME Pre-graze	ME Post-graze	CP Pre-graze	CP Post-graze
Lucerne	11.1	9.4 [b]	24.7 [a]	17.9 [a]
Brome	10.9	10.6 [a]	17.8 [c]	14.8 [b]
Cocksfoot	11.0	10.5 [a]	19.6 [b]	15.1 [b]
Weed	11.4	10.3 [a]	20.2 [b]	13.8 [b]
S.E.M.	0.118	0.215	0.725	0.862
P-value	0.070	**<0.001**	**<0.001**	**<0.001**

Note: Means within columns followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.4.5 Metabolisable energy and crude protein yield

The total spring ME yield of treatments was not different (p=0.713) but there was a difference (p<0.001) among years (Table 4-8). During the first two springs this averaged 56.4 (±3.46) GJ/ha and during the last two, 39.3 GJ/ha.

Table 4-8: Total metabolisable energy yield (GJ/ha) of three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	57.7	53.5	29.9	47.8	47.2
Luc/Brome	60.2	52.0	35.7	42.1	47.5
Luc/CF	59.3	55.6	41.6	38.6	48.8
Year mean	59.1 [a]	53.7 [a]	35.7 [b]	42.8 [b]	

	Treatment	Year	Interaction
S.E.M.	1.44	3.46	5.38
P-value	0.713	**<0.001**	0.779

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

There was an indication (p=0.085) that the mean spring CP yield differed among treatments being 1000 (±27.7) kg/ha for lucerne and 5-10% lower for the binary mixtures (Table 4-9). Across years it ranged from 742-1131 (±62.4) kg/ha. The mean CP content of pasture yield was not different (p=0.494) among treatments at 22.4 (±6.60) % (Appendix 2).

Table 4-9: Total crude protein yield (kg/ha) of three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1141	1116	671	1072	1000
Luc/Brome	1115	915	716	859	901
Luc/CF	1135	1054	841	757	947
Year mean	1131 [a]	1028 [ab]	742 [c]	896[bc]	
	Treatment		**Year**	**Interaction**	
S.E.M.	27.7		62.4	97.6	
P-value	0.085		**<0.001**	0.445	

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.4.6 Calculated metabolisable energy and crude protein requirement

The calculated ME requirement to meet maintenance and growth of ewes & lambs (Section 3.7.6.3) showed a treatment by year interaction (p=0.001) (Table 4-10). The requirement of treatments was not different in 2012/13 as both the GD and livestock growth rates were similar. Thereafter, the lucerne treatment consistently exhibited greater (p=0.048) livestock growth rates and supported less (p=0.039) GD than the lucerne/cocksfoot treatment (Appendix 1, Table 4-6). The lucerne/brome was intermediate in both respects.

On average, calculated ME requirement/ewe GD averaged 11% higher on the lucerne than the binary mixtures. The calculated ME requirement to meet animal performance came to 47-70% of the measured ME yield. Over the four springs it averaged 62% on the lucerne, 55% on the lucerne/brome, and 58% on the lucerne/cocksfoot.

Table 4-10: Calculated metabolisable energy requirement (GJ/ha) of ewes & lambs, based on Nicol and Brookes (2007), from three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	35.1 [a]	31.0 [abcd]	18.8 [h]	32.3 [abc]	29.3
Luc/Brome	33.2 [ab]	27.2 [cdef]	24.1 [efgh]	20.6 [gh]	26.3
Luc/CF	35.6 [a]	26.3 [defg]	29.3 [bcde]	22.9 [fgh]	28.5
Year mean	34.6	28.2	24.1	25.3	
	Treatment		**Year**	**Interaction**	
S.E.M.	0.75		1.27	2.05	
P-value	0.046		<0.001	**0.001**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

The calculated CP requirement showed a treatment by year interaction (p=0.001). CP requirement was similar among treatments for the first two years at 460 (±29.4) kg/ha and 379 kg/ha for 2012/13 and 2013/14 (Table 4-11). The CP requirement on the lucerne treatment was less (p=0.003) than that of the lucerne/cocksfoot treatment in 2014/15. During the spring of 2015/16 the requirement of ewes & lambs on the lucerne was 50% larger than that on the binary mixtures.

Table 4-11: Calculated crude protein requirement (kg/ha) of ewes & lambs, based on Brookes and Nicol (2007), from three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	466 [a]	421 [abc]	260 [g]	444 [a]	398
Luc/Brome	441 [ab]	364 [bcde]	332 [defg]	283 [fg]	355
Luc/CF	473 [a]	352 [cdef]	397 [abcd]	310 [efg]	383
Year mean	460	379	330	346	
	Treatment		**Year**	**Interaction**	
S.E.M.	10.9		17.0	27.7	
P-value	0.055		<0.001	**0.001**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Calculated CP requirement was 33-47% of measured CP yield, and over four springs averaged 39-40% for all treatments. Given this is lower than the 55-62% of ME requirement, it seemed likely that CP intake was not limiting animal productivity during spring. The CP to ME ratio

of pasture yield was 21 g CP/MJ ME on the lucerne treatment and 19 g CP/MJ ME on both of the binary mixtures. Using the calculated requirements for this stock class, the required ratio in pasture intake was 14 g CP/MJ ME (Brookes and Nicol, 2007; Nicol and Brookes, 2007).

4.4.7 Pasture intake

4.4.7.1 Pasture disappearance

Spring pasture intake estimated by pasture disappearance was largest (p=0.002) during 2012/13 and smallest during 2014/15, at 2416 (±150.6) kg DM/ha and 1584 kg DM/ha, respectively (Table 4-12). There was also a difference (p=0.039) among treatments with ewes & lambs on the lucerne/cocksfoot treatment consuming more than those on the lucerne/brome treatment. Based on this, pasture utilisation was between 38-57%.

Pasture intake/GD was variable among treatments and years, this ranged from 2.0-3.4 (±0.27) kg DM/ewe GD (Appendix 11) and did not relate well to LWG. The minimum intake that could provide the productive and maintenance energy requirement, assuming an ME content of 12 MJ ME/kg DM, was determined. Pasture intake estimated by pasture disappearance was 8-32% lower than this minimum possible intake two thirds of the time during the spring (Table 4-13). During the remaining four periods, this was at the lower end of the potential range indicating that disappearance underestimated pasture intake during the spring.

Table 4-12: Pasture intake (kg DM/ha) of ewes & lambs calculated by pasture disappearance from three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2629	1984	1560	2001	2044 [AB]
Luc/Brome	2234	1783	1256	1617	1722 [B]
Luc/CF	2385	2616	1935	1951	2222 [A]
Year mean	2416 [a]	2128 [ab]	1584 [c]	1856 [bc]	

	Treatment	Year	Interaction
S.E.M.	118.6	150.6	255.1
P-value	**0.039**	**0.002**	0.692

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 4-13: Potential pasture intake (kg DM/GD) of ewes & lambs from three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury. The minimum figure on the range is to meet energy requirement when ME content of pasture intake is 12 MJ ME/kg DM, the maximum figure on the range is 4% of ewe & lamb live weight and the figure in parenthesis is determined via pasture disappearance.

Treatment	2012-13	2013-14	2014-15	2015-16
Lucerne	3.7-4.1, (3.4) [*]	2.7-3.6, (2.3) [*]	2.1-4.4, (3.2)	3.4-4.7, (2.6) [*]
Luc/Brome	3.7-4.1, (3.0) [*]	2.4-3.6, (2.0) [*]	3.1-4.1, (2.1) [*]	2.4-4.0, (2.5)
Luc/CF	3.9-4.2, (3.1) [*]	2.2-3.5, (2.6)	3.2-4.1, (2.5) [*]	2.4-3.8, (2.5)

[*] denotes periods when the measured pasture disappearance lies outside the likely range.

4.4.7.2 Energy requirement

Pasture intake determined by energy requirement was 87-163% of that determined by disappearance. Intake was the same among treatments within years for the first two springs at 2888 ($\pm$171.1) kg DM/ha and 2346 kg DM/ha (Table 4-14). During 2014/15 intake required on the lucerne/cocksfoot was larger ($p<0.001$) than the lucerne treatments, and during the following spring, intake on the lucerne was more than 50% larger than both of the binary mixtures. Using these intakes resulted in pasture intake of 2.2-3.9 ($\pm$0.11) kg DM/ewe GD averaging 3.2 kg DM/ewe GD on the lucerne and 2.9 kg DM/ewe GD on both of the binary mixtures (Appendix 14). Based on these figures, pasture utilisation was 45-67% of pasture yield and averaged 55-57% for all treatments. This is comparable to the measured ME yield relative to the ME requirement calculated in Section 4.4.6.

Calculated energy requirement on the lucerne treatment showed more consistency over the duration of the spring than that on the binary mixtures. Combining the data from four springs, ewes & lambs on the lucerne treatment would have consumed ~3.1 kg DM/ewe GD for the first seven weeks of lactation. In weeks 8-11 pasture intake was ~3.4 kg DM/ewe GD. Intake on the binary mixtures was smaller ($p<0.001$) initially at ~2.5 kg DM/ewe GD despite pasture allocation not being different ($p=0.178$). This increased over the lactation to be similar to the lucerne treatment from the fifth week onwards. Pasture disappearance measurements also suggest an initial 30% larger ($p=0.001$) intake/ewe GD on the lucerne treatment than the binary mixtures, being 2.4 kg DM/ewe GD and 1.9 kg DM/ewe GD, respectively.

Table 4-14: Pasture intake (kg DM/ha) of ewes & lambs calculated by energy requirement to meet maintenance and live weight change from three dryland pastures during the spring from 2012-2016 at Ashley Dene, Canterbury. Metabolisable energy content of intake was estimated at 12 MJ ME/kg DM.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2928 [a]	2579 [abcd]	1563 [h]	2688 [abc]	2440
Luc/Brome	2768 [ab]	2267 [cdef]	2010 [efgh]	1721 [gh]	2191
Luc/CF	2968 [a]	2191 [defg]	2441 [bcde]	1907 [fgh]	2377
Year mean	2888	2346	2005	2105	
	Treatment		**Year**		**Interaction**
S.E.M.	62.6		106.1		171.1
P-value	0.046		<0.001		**0.001**

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.4.8 Metabolisable energy and crude protein intake

ME and CP intake were calculated by subtracting these components remaining in the pasture residual from that in pre-grazing pasture mass. The 2013/14 and 2014/15 years had sufficient pasture measurements to calculate this over the spring. ME intake was 30.1 (±2.48) GJ ME/ha for 2013/14 and 20.3 GJ ME/ha for 2014/15 (Table 4-15). ME intake calculated in this manner was 66-126% of ME requirement over these two years. This raises concerns surrounding the accuracy of estimating ME intake by disappearance. This will be influenced by inaccuracies in calculating pasture DM intake and then further complicated with the decreasing digestibility of pastures between pre and post-grazing measurements.

Spring CP intake was 687 (±54.6) kg/ha in 2013/14 and 477 kg/ha in 2014/15 (Table 4-16), being lowest (p=0.016) on the lucerne/brome both years. When calculated in this manner, CP intake was 119-214% of requirement over the two years that this was calculated. Based on these figures, the CP content of pasture intake was calculated as 28-37%.

Table 4-15: Metabolisable energy intake (GJ ME/ha) of ewes & lambs calculated by disappearance from three dryland pastures during the spring for 2013/14 and 2014/15 at Ashley Dene, Canterbury.

Treatment	2013-14	2014-15	Treatment mean
Lucerne	30.9	17.9	24.4 [B]
Luc/Brome	26.4	16.0	21.2 [B]
Luc/CF	33.1	27.1	30.1 [A]
Year mean	30.1 [a]	20.3 [b]	

	Treatment	Year	Interaction
S.E.M.	1.69	2.48	3.48
P-value	**0.012**	**0.014**	0.717

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

Table 4-16: Crude protein intake (kg/ha) of ewes & lambs calculated by disappearance from three dryland pastures during the spring for 2013/14 and 2014/15 at Ashley Dene, Canterbury.

Treatment	2013-14	2014-15	Treatment mean
Lucerne	738	436	587 [AB]
Luc/Brome	571	395	483 [B]
Luc/CF	752	600	676 [A]
Year mean	687 [a]	477 [b]	

	Treatment	Year	Interaction
S.E.M.	37.9	54.6	76.9
P-value	**0.016**	**0.016**	0.701

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

4.4.9 Spring composition of pre-grazing pasture mass and pasture intake

Ewes & lambs appeared to have an aversion to consuming dead material. A t-test identified a lower (<0.001) dead material proportion of pasture intake compared to allocation of both the binary mixtures but not the lucerne treatment. During the spring, dead material made up 6%, 9%, and 11% of lucerne, lucerne/brome, and lucerne/cocksfoot pre-grazing pasture mass and 4%, 1%, and 2% of intake, respectively.

4.4.9.1 Lucerne

The lucerne content of the monoculture yield remained at 85-90% except in the second year when weeds were unsprayed the weed content increase to 27% (Figure 4-3). Dead material contributed 4-10% of pasture yield over the spring. In this treatment, the proportion of lucerne, weed and dead material intake was not different to allocation (p=0.995, p=0.546, p=0.125).
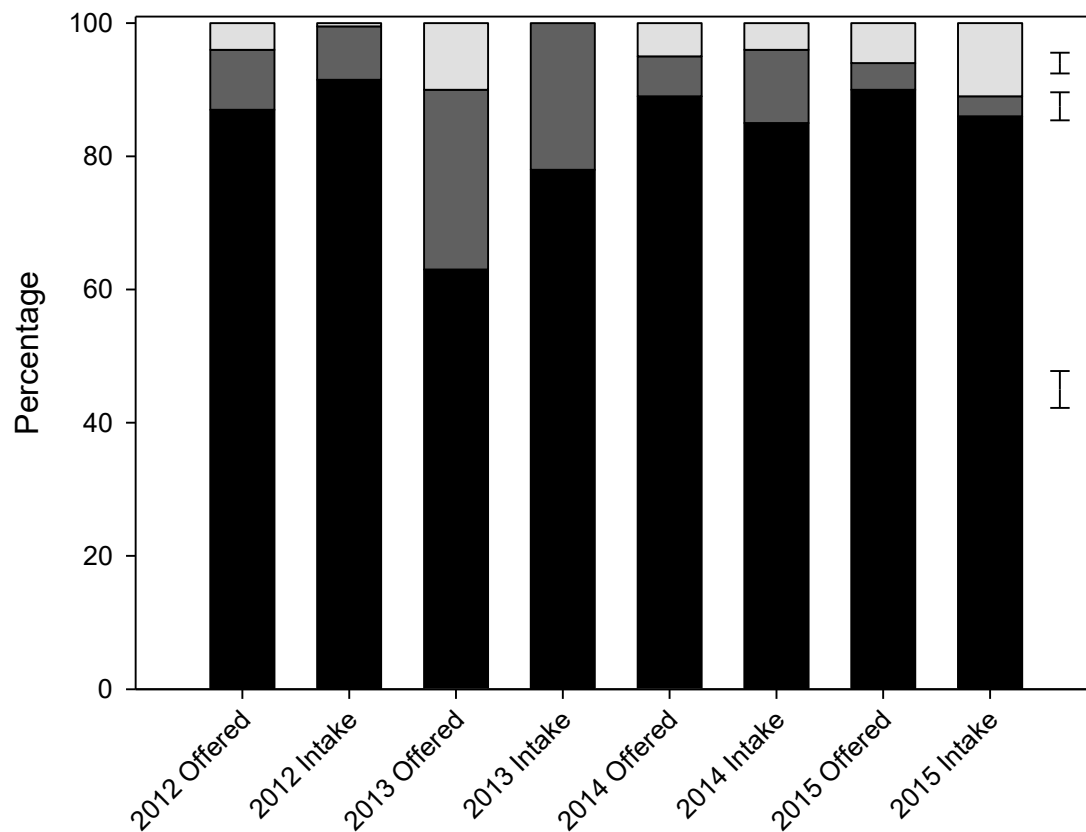
Figure 4-3: Pasture composition of pre grazing pasture mass offered to livestock and calculated intake for the lucerne treatment during the spring from 2012-2016.

Lucerne (■), weed (■), and dead material (▫). Error bars represent the maximum S.E.M. for (from top to bottom) dead material, weed, and lucerne.

4.4.9.2 Lucerne/brome

The spring pre-grazing lucerne content of the lucerne/brome treatment was initially 68% dropping to ~39% for the remaining years (Figure 4-4). The initial fall in lucerne content was largely replaced with brome grass as its composition increased from 21% to ~40% for the

following two years. During the final spring, the sown grass composition fell to 19% as the unsown species increased from ~11% of composition during the first three springs to 28% during 2015/16. On closer inspection it appeared that the 'Atom' sub-treatment (prairie grass) was less competitive than the 'Bareno' (pasture brome). This became apparent during the final two springs. The sown grass content of the 'Atom' was smaller ($p<0.001$) at 17% and 8% compared with the 'Bareno' at 54% and 31% in 2014/15 and 2015/16, respectively (Figure 4-5). The weed content in the 'Atom' plots was larger ($p=0.044$, $p=0.003$) during both of the final springs at 20% and 39% compared with 8% and 15% in the 'Bareno'. The lower competitiveness of 'Atom' benefited the lucerne content during 2014/15 but this was not different among cultivars during 2015/16 when the weed content was at its largest. There was no DM production difference between the 'Atom' and 'Bareno' sub-treatments for any year. This suggests that unsown species substituted for the grass at similar growth rates to the sown species.

Ewes & lambs on the lucerne/brome treatment consumed a larger ($p=0.003$) proportion of lucerne than was offered, being 64% compared with 46% respectively, and a smaller ($p<0.001$) proportion of weed, 2% compared with 16% in pasture yield. Sown grass consumption was in proportion with its composition in the pasture. These trends occurred within sub-treatments but differences among them were not significant in any year.
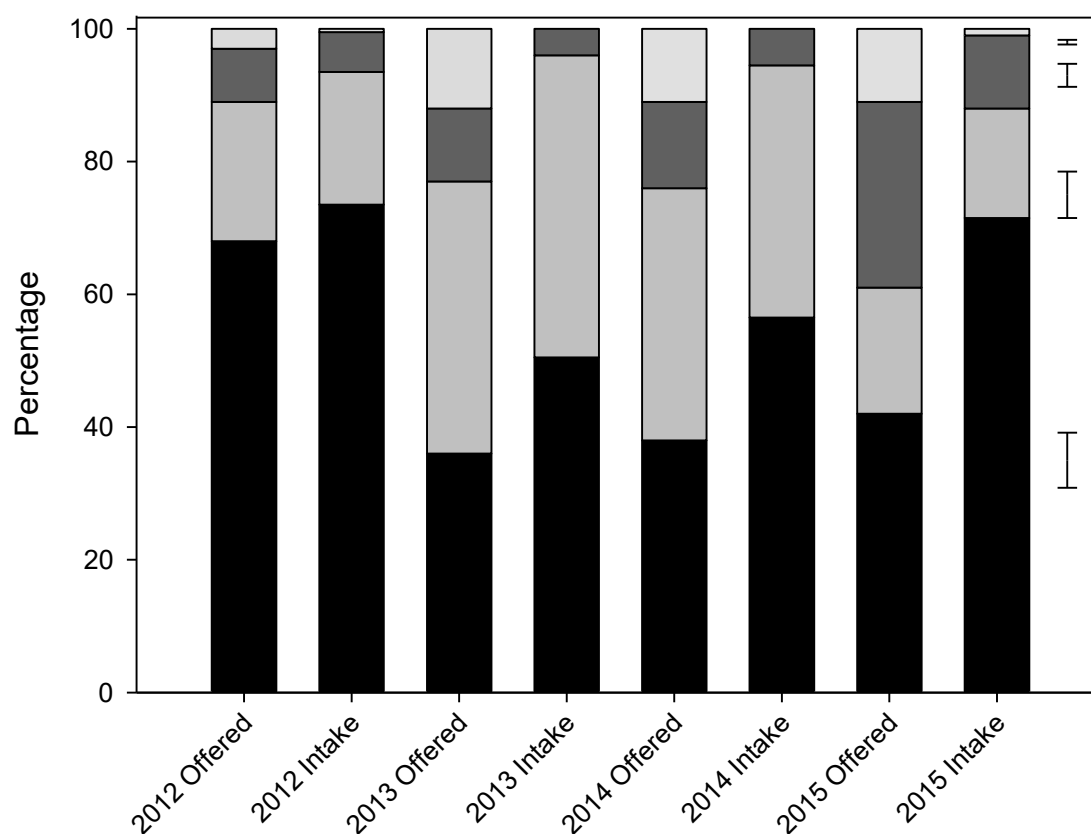
Figure 4-4: Pasture composition of pre grazing pasture mass offered to livestock and calculated intake for the lucerne/brome treatment during the spring from 2012-2016. Lucerne (■), grass (■), weed (■), and dead material (■). Error bars represent the maximum S.E.M. for (from top to bottom) dead material, weed, grass, and lucerne.
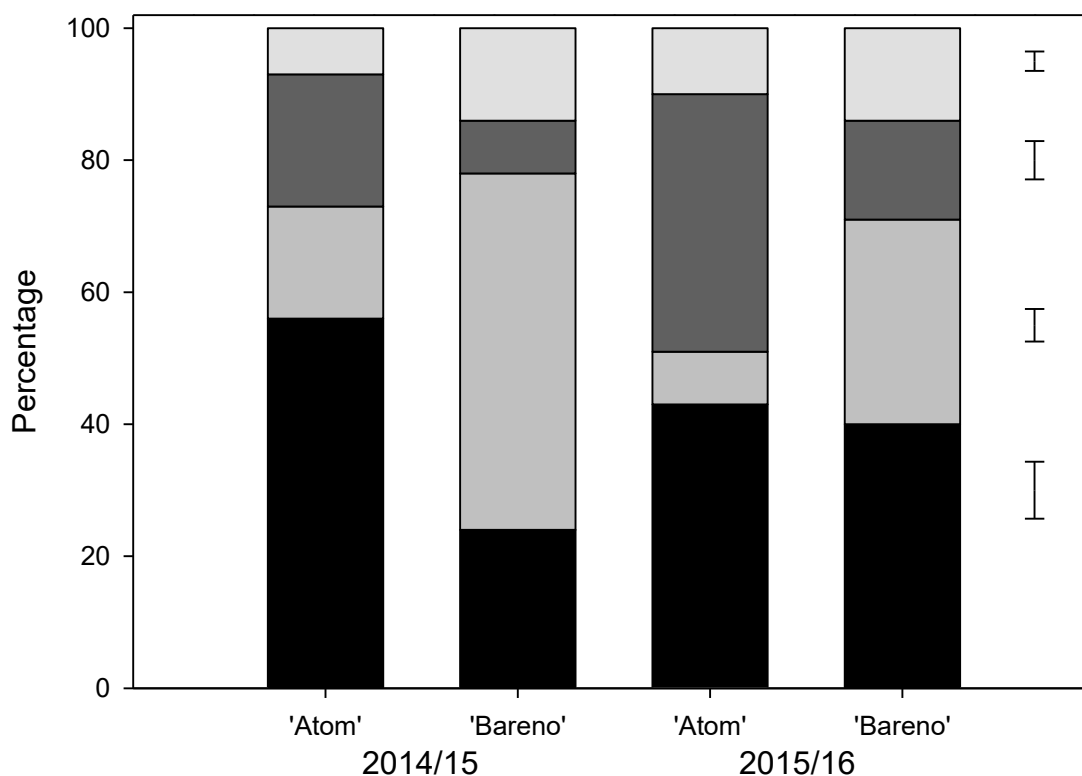
Figure 4-5: Pasture composition of pre grazing pasture mass offered to livestock on the cultivar sub-treatment of the lucerne/brome treatment during the spring of 2014/15 and 2015/16. Lucerne (■), grass (▨), weed (■), and dead material (▨). Error bars represent the maximum S.E.M. for (from top to bottom) dead material, weed, grass, and lucerne.

4.4.9.3 Lucerne/cocksfoot

The lucerne component in the lucerne/cocksfoot treatment was 78% of pasture yield in the first spring (Figure 4-6). This fell to 41% in 2013/14 and then to 31% during the spring of the final two years. The grass content was initially 11% and increased to 42% in 2013/14 and then 50% during the final two years. The low grass composition during the establishment year reflects the low cocksfoot sowing rate of 2-3 kg/ha. This treatment averaged the lowest weed and highest dead material composition of pasture yield (6% and 11%, respectively).

Ewes & lambs consumed a larger (p=0.002) proportion of lucerne than was available in pasture yield, being 61% compared with 44%. The proportion of sown grass and weed species intake was not different (p=0.253, p=0.174) to their proportion in pasture yield. During the first spring the sown grass species made up only 10% of the diet meaning lucerne intake was not different to the monoculture with lucerne making up 85% of the diet in the mixture and 92% in the monoculture (Figure 4-3 & 4-6).
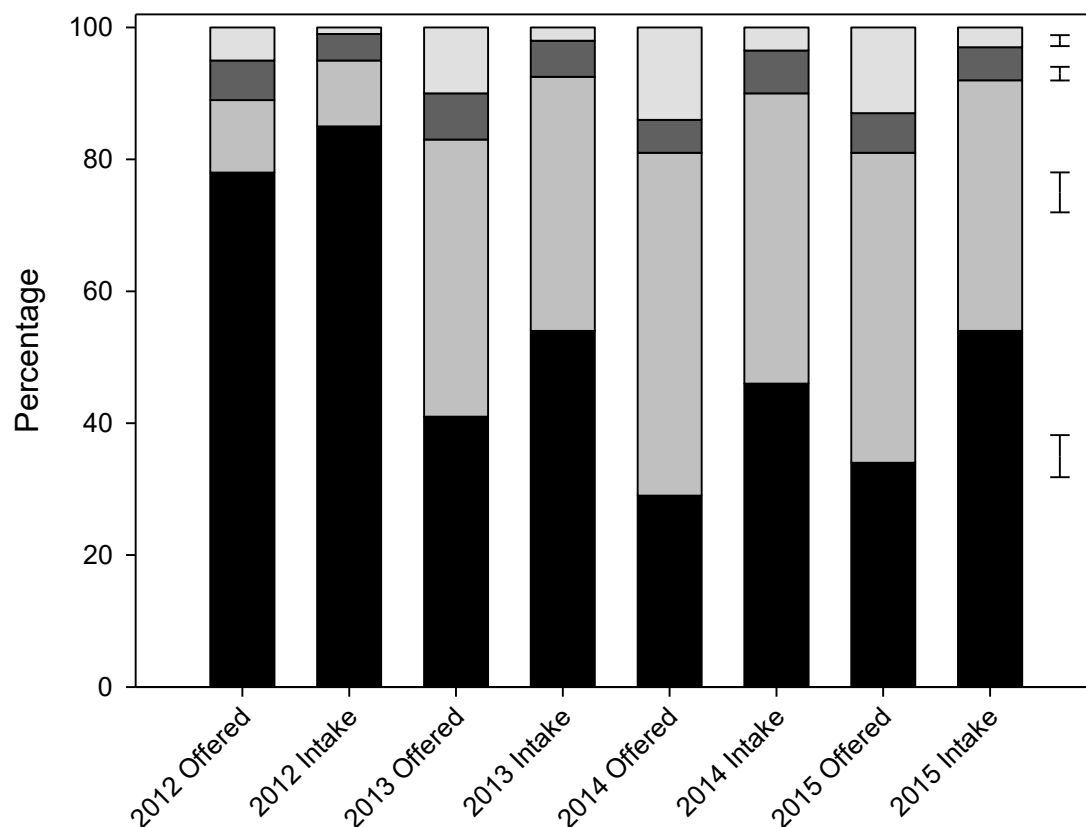
Figure 4-6: Pasture composition of pre grazing pasture mass offered to livestock and calculated intake for the lucerne/cocksfoot treatment during the spring from 2012-2016. Lucerne (■), grass (■), weed (■), and dead material (■). Error bars represent the maximum S.E.M. for (from top to bottom) dead material, weed, grass, and lucerne.

Plate 3: A) Plot 3 (lucerne/brome treatment) 24/10/2012. Notice the lucerne dominance during the initial spring. Pre-grazing pasture mass ~2200 kg DM/ha. B) Plot 1 (lucerne treatment) 30/11/2012. Pre-grazing pasture mass ~ 3000 kg DM/ha.

Plate 4: A) Plot 13 (lucerne/cocksfoot) 24/9/2013. Pre-grazing pasture mass ~2600 kg DM/ha. B) Plot 6 (lucerne/brome) 7/10/2013. Pre-grazing pasture mass ~3800 kg DM/ha. The sown grass composition of the binary mixtures was 40-50% from 2013/14.

4.5 Summer

4.5.1 Live weight gain

LWG of lambs over the summer was variable both among treatments and years. Weaned lamb LWG on the lucerne monoculture was consistently higher (p<0.001) than those on the binary mixtures and averaged 179 (± 9.6) kg/ha and 108 kg/ha, respectively (Table 4-17). LWG was highest (p<0.001) during the first two summers at 176 (± 13.7) kg/ha and lowest at 57 kg/ha during the 2014/15 summer.

Table 4-17: Live weight gain (kg/ha) of weaned lambs on three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	201	231	113	172	179 [A]
Luc/Brome	125	148	24	106	101 [B]
Luc/CF	187	160	35	74	114 [B]
Year mean	171 [a]	180 [a]	57 [c]	117 [b]	

	Treatment	Year	Interaction
S.E.M.	9.6	13.7	22.7
P-value	**<0.001**	**<0.001**	0.544

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

4.5.2 Pasture yields

There was no difference (p=0.742) in pasture yield among treatments during any of the summer periods. Pasture yields over this period ranged from 3887 (±160.5) kg DM/ha in 2013/14 to 1832 kg DM/ha in 2015/16 (Table 4-18) due to differences in soil water availability (Chapter 5).

Table 4-18: Pasture yield (kg DM/ha) of three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2465	3772	1832	1955	2506
Luc/Brome	2535	3937	2003	1713	2547
Luc/CF	2611	3952	2054	1828	2611
Year mean	2537 [b]	3887 [a]	1963 [c]	1832 [c]	

	Treatment	**Year**	**Interaction**
S.E.M.	98.7	160.5	259.0
P-value	0.742	**<0.001**	0.990

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.5.3 Grazing days

GD for all treatments was 1086 (±76.6) for the first two years and 503 (p<0.001) for the last two (Table 4-19). Pasture allocation was 3.1-4.9 (±0.39) kg DM/GD across years and did not differ (p=0.113) among treatments (Appendix 9). Daily lamb growth rates on the lucerne treatments were typically larger than that on the binary mixtures, these were ~190 g LWG/GD for the first three years and 318 g LWG/GD during the final summer. Average annual growth rates on the other treatments were 66-224 g LWG/GD for lucerne/brome, and 70-175 g LWG/GD for lucerne/cocksfoot.

Table 4-19: Grazing days (/ha) of weaned lambs from three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1034	1156	604	540	834
Luc/Brome	908	1099	364	473	711
Luc/CF	1068	1252	495	540	839
Year mean	1003 [a]	1169 [a]	488 [b]	518 [b]	

	Treatment	**Year**	**Interaction**
S.E.M.	47.1	76.6	124.2
P-value	0.146	**<0.001**	0.987

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.5.4   Nutritive value

During the summer, ME and CP content of pasture components were lowest (p<0.001) of all seasons. Sown grass species had a higher (p=0.011) pre-grazing ME content than the legume, at ~10.4 (±0.20) MJ ME/kg DM compared with 9.8 MJ ME/kg DM (Table 4-20). This was due to an increasing proportion of highly lignified stem of the lucerne during the summer. The lucerne had a higher (p=0.001) pre-grazing CP content than the cocksfoot and weed species. The brome content was not different to other species. The difference (p<0.001) between pre and post-grazing ME and CP content of the lucerne suggests a greater ability of livestock to avoid the less digestible stem of this plant relative to the others.

4.5.5   Metabolisable energy and crude protein yield

There was sufficient botanical and NIRS analysis data to calculate the ME and CP yields for the summers of 2012/13 and 2013/14. There was no difference (p=0.229) in summer ME yields among treatments (Table 4-21). The ME yield in 2012/13 was 26.8 (±1.99) GJ ME/ha and 38.5 GJ ME/ha in 2013/14. ME content of summer pasture yields showed a trend (p=0.051) of the lucerne treatment being lower than the binary mixtures. This was 9.7 (±0.27) MJ ME/kg DM, 10.8 MJ ME/kg DM, and 10.4 MJ ME/kg DM on the lucerne, lucerne/brome, and lucerne/cocksfoot, respectively.

Table 4-20: Mean metabolisable energy (MJ ME/kg DM) and crude protein (%) content of pre and post-grazing pasture components of three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Pasture component	ME Pre-graze	ME Post-graze	CP Pre-graze	CP Post-graze
Lucerne	9.8 [b]	6.8 [c]	18.8 [a]	10.3 [b]
Brome	10.3 [a]	10.0 [ab]	16.8 [ab]	13.4 [a]
Cocksfoot	10.5 [a]	10.6 [a]	16.1 [b]	13.4 [a]
Weed	10.0 [ab]	9.7 [b]	15.4 [b]	13.4 [a]
S.E.M.	0.195	0.306	0.969	0.988
P-value	**0.011**	**<0.001**	**0.001**	**0.003**

Note: Means within columns followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 4-21: Metabolisable energy yield (GJ ME/ha) of three dryland pastures during the summer of 2012-13 and 2013-14 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	Treatment mean
Lucerne	24.2	36.4	30.3
Luc/Brome	29.0	38.2	33.6
Luc/CF	27.0	40.8	33.9
Year mean	26.8 [b]	38.5 [a]	

	Treatment	Year	Interaction
S.E.M.	1.54	1.99	2.88
P-value	0.229	**<0.001**	0.799

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

The summer CP yield was 471 (±35.5) kg CP/ha during 2012/13 and 686 kg CP/ha in 2013/14 and was not different (p=0.926) among treatments (Table 4-22). The CP content of pasture yield was ~18.3 (±0.76)% (Appendix 4) during the summer which reflected the high dead material content during this period (Figure 4-7).

Table 4-22: Crude protein yield (kg/ha) of three dryland pastures during the summer for 2012-13 and 2013-14 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	Treatment mean
Lucerne	470	699	584
Luc/Brome	457	686	571
Luc/CF	487	674	581
Year mean	471 [b]	686 [a]	

	Treatment	Year	Interaction
S.E.M.	23.8	35.5	49.6
P-value	0.926	**<0.001**	0.927

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

4.5.6 Calculated metabolisable energy and crude protein requirement

Lambs on the lucerne treatment had a larger (p=0.003) ME requirement than those on the binary mixtures, which were not different from each other (Table 4-23). This was on account of the higher lamb growth rates on the lucerne treatment. This was 11.3 (±0.58) MJ ME/ha compared with 8.1 MJ ME/ha. Based on this requirement, ME utilisation during the first two years averaged 46% on the lucerne treatment, 30% on the lucerne/brome and, and 36% on the

lucerne/cocksfoot. As the ME content of pasture intake is likely to be higher than pasture yield, pasture utilisation can be expected to be lower than these respective figures. During the summer the calculated ME requirement per GD on the lucerne treatment was 30% larger than that of the lambs on the binary mixtures.

Similarly, the calculated CP requirement of weaned lambs was largest (p=0.003) on the lucerne treatment (Table 4-24). The CP requirements on the binary mixtures were not different to each other. During the summer of the first two years, CP requirement was 23-30% of CP yield.

The CP to ME ratio of summer pasture yield was 19 g CP/MJ ME on the lucerne and 17 g CP/MJ ME on the binary mixtures. Using the calculated requirements for this stock class, the required ratio in pasture intake was 13 g CP/MJ ME (Brookes and Nicol, 2007; Nicol and Brookes, 2007).

Table 4-23: Calculated metabolisable energy requirement (GJ ME/ha) of weaned lambs, based on Nicol and Brookes (2007), from three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	12.9	14.8	7.6	9.9	11.3 [A]
Luc/Brome	9.3	11.1	2.8	6.9	7.5 [B]
Luc/CF	12.3	12.4	3.9	5.9	8.6 [B]
Year mean	12.3 [a]	13.4 [a]	4.9 [c]	7.9 [b]	

	Treatment	Year	Interaction
S.E.M.	0.58	0.89	1.45
P-value	**0.003**	**<0.001**	0.879

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 4-24: Calculated crude protein requirement (kg/ha) of weaned lambs, based on Brookes and Nicol (2007), from three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	161	194	98	124	145 [A]
Luc/Brome	116	148	35	87	97 [B]
Luc/CF	154	169	48	74	111 [B]
Year mean	144 [a]	170 [a]	60 [c]	95 [b]	

	Treatment	Year	Interaction	
S.E.M.	7.5	11.8	19.2	
P-value	**0.003**	**<0.001**	0.864	

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.5.7 Pasture intake

4.5.7.1 *Pasture disappearance*

Pasture intake calculated from pasture disappearance indicated weaned lambs on the lucerne monoculture had average summer intake of 750 (±77.3) kg DM/ha compared with 1079 kg DM/ha on each of the binary mixtures (Table 4-25). Pasture intake averaged 1.0 (±0.12) kg DM/GD on the lucerne treatment and 1.6 kg DM/GD on the binary mixtures (Appendix 12). Based on these data pasture utilisation was 28% on the monoculture and ~40% on the binary mixtures.

Table 4-25: Pasture intake (kg DM/ha) of weaned lambs calculated by pasture disappearance from three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	963	1180	405	450	750 [B]
Luc/Brome	1055	1649	658	764	1031 [A]
Luc/CF	1042	1824	797	842	1126 [A]
Year mean	1020 [b]	1551 [a]	620 [c]	685 [c]	

	Treatment	Year	Interaction	
S.E.M.	77.3	85.0	149.2	
P-value	**0.016**	**<0.001**	0.689	

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

A potential daily pasture intake range was determined for weaned lamb GD. This used 4% of lamb live weight, being the potential appetite proposed by Court *et al.* (2010), as the upper limit. The lower limit was that which would supply sufficient ME to sustain maintenance and LWG demand of livestock when intake has an ME content of 12 MJ ME/kg DM. Table 4-26 shows this range followed by pasture intake determined via pasture disappearance in parenthesis for each treatment each summer. During the final summer, daily pasture intake to meet the energy requirements of maintenance and live weight gain of lambs on the lucerne treatment was 4.3% of live weight and pushing the limit of potential appetite.

Table 4-26: Potential pasture intake (kg DM/GD) of weaned lambs from three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury. The minimum figure on the range is to meet energy requirement when ME content of pasture intake is 12 MJ ME/kg DM, the maximum figure on the range is 4% of lamb live weight, the figure in parenthesis is determined via pasture disappearance.

Treatment	2012-13	2013-14	2014-15	2015-16
Lucerne	1.0-1.4, (0.9) [*]	1.1-1.2, (1.0) [*]	1.1-1.2, (0.7) [*]	1.5-1.4, (0.8) [*]
Luc/Brome	0.9-1.3, (1.2)	0.8-1.1, (1.5) [*]	0.7-1.2, (1.8) [*]	1.2-1.3, (1.6) [*]
Luc/CF	1.0-1.4, (1.0)	0.8-1.1, (1.5) [*]	0.7-1.2, (1.6) [*]	0.9-1.2, (1.6) [*]

[*] denotes periods when the measured pasture disappearance lies outside the likely range.

Pasture intake calculated by disappearance on the lucerne treatment is below the determined range each summer, whereas the intake of lambs on the binary mixtures is above this range for the last three summers. This suggests that actual intake of weaned lambs on the lucerne was probably higher than reported, and on the binary mixtures, lower than reported.

4.5.7.2 Calculated energy requirement

Pasture intake calculated to meet the energy requirement of weaned lambs was larger (p=0.003) on the lucerne treatment at 941 (±48.2) kg DM/ha compared with 674 kg DM/ha on the binary mixtures (Table 4-27). This contradicts the measured pasture disappearance results. These figures result in average pasture intake of 1.2 (±0.03) kg DM/GD on the lucerne and 0.9 kg DM/GD on the binary mixtures (Appendix 15). Pasture utilisation is still low, averaging 39% for the lucerne, 25% for lucerne/brome, and 27% for the lucerne/cocksfoot.

Table 4-27: Pasture intake (kg DM/ha) of weaned lambs calculated by energy requirement to meet maintenance and live weight change from three dryland pastures during the summer from 2012-2016 at Ashley Dene, Canterbury. Metabolisable energy content of intake was estimated at 12 MJ ME/kg DM.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1077	1230	634	824	941 [A]
Luc/Brome	778	924	237	574	628 [B]
Luc/CF	1027	1031	327	490	719 [B]
Year mean	961 [a]	1062 [a]	399 [c]	629 [b]	

	Treatment	**Year**	**Interaction**
S.E.M.	48.2	73.9	120.9
P-value	**0.003**	**<0.001**	0.879

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.5.8 Metabolisable energy and crude protein intake

ME and CP intake were calculated for 2012/13 and 2013/14 by subtracting post-grazing ME and CP from pre-grazing pasture mass. Given the inaccuracies in calculating summer pasture intake by disappearance, the likelihood of finding reliable results here are low.

Table 4-28: Metabolisable energy intake (GJ ME/ha) of weaned lambs calculated by disappearance from three dryland pastures during the summer of 2012-13 and 2013-14 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	Treatment mean
Lucerne	13.2	17.3	15.2
Luc/Brome	13.1	18.1	15.6
Luc/CF	12.7	22.1	17.4
Year mean	13.0 [b]	19.1 [a]	

	Treatment	**Year**	**Interaction**
S.E.M.	1.63	1.39	2.36
P-value	0.613	**0.007**	0.518

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

ME intake did not differ (p=0.613) among treatments and averaged 13.0 (±1.39) GJ/ha and 19.1 GJ/ha for consecutive years (Table 4-28). ME intake was 106% of calculated ME requirement during the summer of 2012/13, but was 143% during 2013/14. Based on these figures, the ME content of pasture intake exceeded 12 MJ ME/kg DM each period. This is in excess of what Brown and Moot (2004) and Black and Ryan-Salter (2016) measured in the palatable portions of lucerne and other pasture species. Decreasing digestibility of pastures over a grazing period would result in the overstating of ME content of pasture intake.

CP intake was not different among treatments (p=0.558) being 268 (±33.4) kg/ha in the summer of 2012/13 and 378 kg/ha in 2013/14 (Table 4-29). Determined in this manner the CP content of pasture intake was 26-39% during the first two years. CP intake was 186-222% of requirement on consecutive years.

Table 4-29: Crude protein intake (kg/ha) of weaned lambs calculated by disappearance from three dryland pastures during the summer of 2012-13 and 2013-14 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	Treatment mean
Lucerne	301	375	338
Luc/Brome	231	356	293
Luc/CF	272	403	338
Year mean	268 [b]	378 [a]	

	Treatment	**Year**	**Interaction**
S.E.M.	32.7	33.4	52.3
P-value	0.558	**0.034**	0.867

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.5.9 Summer composition of pre-grazing pasture mass and pasture intake

As the year progressed from spring to summer the most noticeable difference in the composition of pasture yield was the increase in dead material. This averaged 22%, 30%, and 26% for the lucerne, lucerne/brome, and lucerne/cocksfoot treatments, respectively (Figure 4-7). Livestock appeared to show an aversion to this component with the proportion in pasture intake being smaller (p<0.001) at ~8%. The proportion of weed and grass (where applicable) in intake was not different to its proportion in pasture yield for any treatment. The proportion of lucerne in pasture intake was larger (p=0.003, p=0.006) than in pasture yield for both the lucerne (84% compared with 67%) and lucerne/cocksfoot (60% compared with 36%)

treatments, with a trend (p=0.076) for the lucerne/brome treatment at 52% compared with 38%. The lucerne/cocksfoot had a larger (p=0.016) proportion of sown grass in summer pasture yield than lucerne/brome at 33% compared with 22%, respectively. The proportion of sown grass in pasture intake was not different among the binary mixtures.
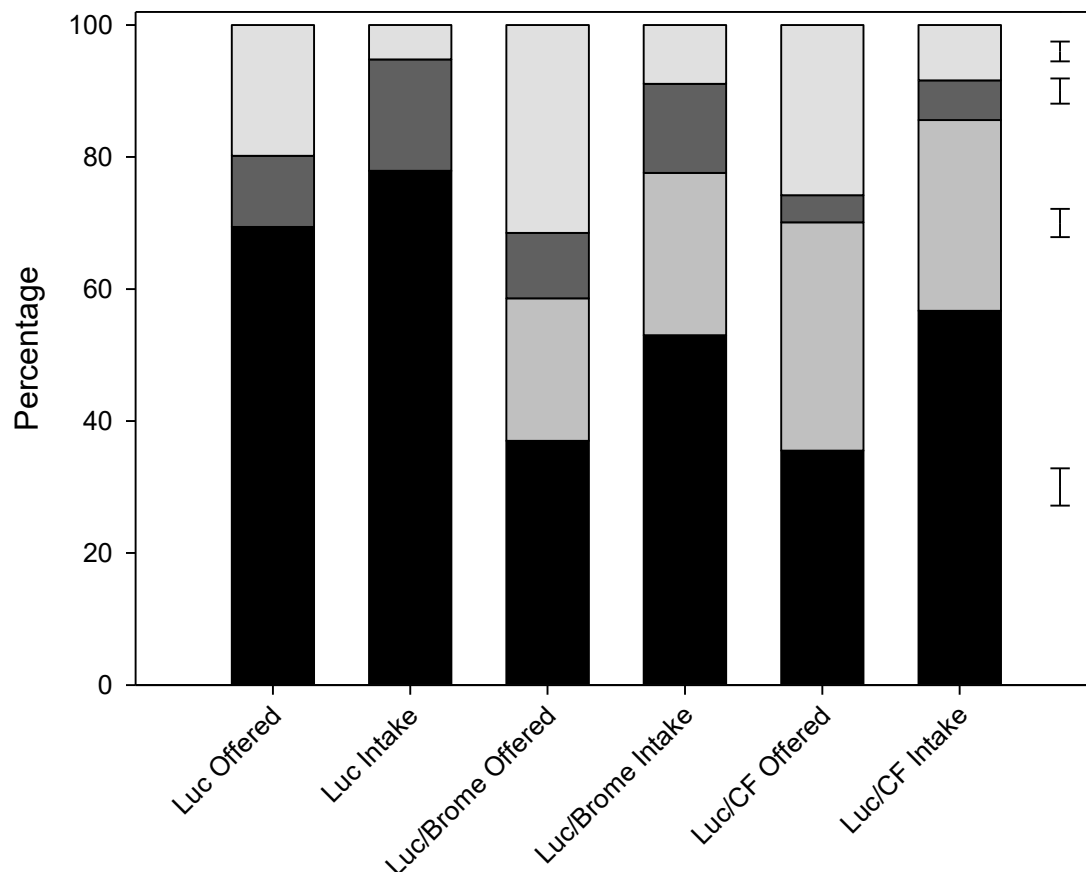
Figure 4-7: Mean pasture composition of pre grazing pasture mass offered to weaned lambs and calculated intake from three dryland pastures during the summer over four years from 2012-2016. Lucerne (■), grass (■), weed (■), and dead material (□). Acronyms reported in Table 4-1. Error bars represent the maximum S.E.M. for (from top to bottom) dead material, weed, grass, and lucerne.

4.6 Autumn

### 4.6.1 Live weight gain

During the autumn period the hoggets on the lucerne/brome treatment had greater (p=0.017) LWG than those on the lucerne/cocksfoot treatment, at 72 (±2.2) kg/ha compared with 62 kg/ha (Table 4-30). The lucerne treatment was intermediate and not different to the other two. LWG was largest (p<0.001) during 2014/15 at 122 (±4.1) kg/ha, and smallest the following year at 15 kg/ha. During the first autumn, ewe hoggets grew ~90 g/GD, the following two years ram hoggets grew 190-290 g/GD. The hogget growth rates during the final year were much lower at ~40 g/GD. Average daily growth rates showed a trend (p=0.051) where hoggets on the lucerne and lucerne/brome grew at 167 (±9.6) g/GD and those on the lucerne/cocksfoot grew 129 g/GD (Appendix 1).

Table 4-30: Live weight gain (kg/ha) of ewe or ram hoggets on three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	43	91	112	14	65 [B]
Luc/Brome	59	76	131	23	72 [A]
Luc/CF	46	69	123	8	62 [B]
Year mean	50 [c]	79 [b]	122 [a]	15 [d]	
	Treatment		**Year**	**Interaction**	
S.E.M.	2.2		4.1	6.6	
P-value	**0.017**		**<0.001**	0.222	

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.6.2 Pasture yield

There was a treatment by year interaction (p=0.032) of pasture yield. During the first and third autumn all treatments grew similar amounts of pasture (Table 4-31). During 2013/14 the lucerne/cocksfoot treatment grew 2407 (±107.1) kg DM/ha, lucerne grew 2064 kg DM/ha, and lucerne/brome grew 1753 kg DM/ha. This was the most productive year for pasture growth resulting from March/April rainfall being 300% of the LTM (Figure 3-7). In contrast, the March/April rainfall of 2015/16 was 50% of the LTM, and pasture yields were 0.5-0.9 t DM/ha.

Table 4-31: Dry matter yield (kg DM/ha) of three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	984 [efg]	2064 [b]	1132 [def]	546 [h]	1181
Luc/Brome	1167 [def]	1753 [c]	1365 [d]	774 [gh]	1265
Luc/CF	1106 [def]	2407 [a]	1270 [de]	871 [fg]	1413
Year mean	1086	2075	1256	730	

	Treatment	Year	Interaction
S.E.M.	39.0	66.5	107.1
P-value	0.006	<0.001	**0.032**

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.6.3 Grazing days

There was a treatment by year interaction (p<0.001) in GD during the autumn period. The only difference among treatments within a year was during 2015/16 when the lucerne treatment supported fewer (p<0.001) GD than both of the binary mixtures, at 162 (±45.0) compared with 587 (Table 4-32). Pasture allocation differed (p<0.001) among years, being 2.4 (±0.30) kg DM/GD during 2012/13, 2014/15, and 2015/16, and 6.3 kg DM/GD during 2013/14 when pasture yields were largest. There was no difference (p=0.169) in pasture allocation among treatments despite during the final autumn the means being 3.5 (±0.20) kg DM/ha on the lucerne treatment and ~1.5 kg DM on the binary mixtures (Appendix 10).

4.6.4 Nutritive value

The ME content of sown and unsown pasture species in pasture allocation were not different (p=0.056) in the autumn at 11.0 (±0.12) MJ ME/kg DM (Table 4-33). The post-grazing content was lowest (<0.001) in the lucerne at 9.4 (±0.25) MJ ME/kg DM, and highest in the brome at 11.0 MJ ME/kg DM. The CP content were the highest (p<0.001) of all seasons during the autumn with the lucerne being 26 (±0.68) % and the other components 22%. The post grazing ME and CP levels are lower (p<0.001) than the pre-grazing content for the lucerne but not for the sown grass species. This indicates the hoggets were more able to discriminate between the high and low digestible portions of the lucerne plant, than sown grasses.

Table 4-32: Total grazing days (/ha) of ewe or ram hoggets on three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	531 [ab]	370 [cd]	425 [bcd]	162 [e]	372
Luc/Brome	545 [ab]	316 [d]	493 [bc]	520 [ab]	469
Luc/CF	529 [ab]	372 [cd]	531 [ab]	654 [a]	522
Year mean	535	353	483	446	

	Treatment	Year	Interaction
S.E.M.	17.6	27.6	45.0
P-value	<0.001	<0.001	**<0.001**

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 4-33: Mean metabolisable energy (MJ ME/kg DM) and crude protein (%) content of pre and post-grazing pasture components of three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Pasture component	ME Pre-graze	ME Post-graze	CP Pre-graze	CP Post-graze
Lucerne	10.9	9.4 [c]	26.1 [a]	19.0 [b]
Brome	11.2	11.0 [a]	22.4 [b]	21.5 [a]
Cocksfoot	10.9	10.6 [ab]	21.7 [b]	20.2 [b]
Weed	11.1	10.2 [b]	22.0 [b]	20.1 [b]
S.E.M.	0.120	0.250	0.681	1.056
P-value	0.056	**<0.001**	**<0.001**	**0.014**

Note: Means within columns followed by the same case are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.6.5 Metabolisable energy and crude protein yield

The ME and CP yields of pastures were determined for the first three autumns. There was no NIRS analysis done in the final autumn so these were not calculated. The ME yield was larger (p=0.032) on the lucerne/cocksfoot than the lucerne treatment being 17.0 (±0.51) GJ ME/ha compared with 14.8 GJ ME/kg DM (Table 4-34). The lucerne/brome treatment was intermediate and not different from either of the other treatments. All treatments produced the largest (p<0.001) autumn ME yield during 2013/14 when pasture yield was also largest. Average ME content of pasture yield of all treatments was 10.8 (±0.08) MJ ME/kg DM (Appendix 7).

The CP yield was not different (p=0.242) among treatments within years. The CP yield was smallest (p<0.001) for all treatments during 2012/13 and 2014/15 at 275 (±14.3) kg/ha and 468 kg/ha during the autumn of 2013/14. The average CP content of pasture yield was 23.6 (±0.48) % for all treatments (Appendix 6) and was the highest of all seasons.

Table 4-34: Metabolisable energy yield (GJ ME/ha) of three dryland pastures during the autumn from 2012-2015 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	Treatment mean
Lucerne	11.1	21.2	12.0	14.8 [B]
Luc/Brome	13.0	18.7	14.8	15.5 [AB]
Luc/CF	12.1	24.6	14.2	17.0 [A]
Year mean	12.0 [b]	21.5 [a]	13.7 [b]	
	Treatment	Year	Interaction	
S.E.M.	0.51	0.71	1.12	
P-value	**0.032**	**<0.001**	0.051	

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 4-35: Crude protein yield (kg/ha) of three dryland pastures during the autumn from 2012-2015 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	Treatment mean
Lucerne	268	469	257	331
Luc/Brome	281	417	294	331
Luc/CF	273	518	277	356
Year mean	274 [b]	468 [a]	276 [b]	
	Treatment	Year	Interaction	
S.E.M.	11.2	14.3	23.1	
P-value	0.242	**<0.001**	0.143	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.6.6 Calculated metabolisable energy and crude protein requirement

There was a treatment by year interaction (p=0.002) of calculated ME requirement (Table 4-36). In 2014/15 ME requirement was the largest of all years for all treatments. This was 9.7

(±0.58) GJ ME/ha for lucerne/brome and lucerne/cocksfoot, and 7.9 GJ ME/ha for lucerne. The ME requirement was ~11 MJ/GD for ewe hoggets during 2012/13 and ~17 MJ/GD for ram hoggets during 2013/14 and 2014/15 on all treatments. During the autumn of the last year ME requirement of ram hoggets was 9.5-12.5 MJ/GD due to much lower hogget growth rates. ME requirement was 25-70% of ME yield over the first three autumns, and averaged ~49% for each treatment.

Table 4-36: Calculated metabolisable energy requirement (GJ ME/ha) of hoggets, based on Nicol and Brookes (2007), from three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	5.4 [c]	6.9 [bc]	7.9 [b]	2.0 [d]	5.5
Luc/Brome	6.2 [c]	5.8 [c]	9.7 [a]	5.6 [c]	6.8
Luc/CF	5.4 [c]	5.9 [c]	9.7 [a]	6.2 [c]	6.8
Year mean	5.7	6.2	9.1	4.6	
	Treatment	**Year**	**Interaction**		
S.E.M.	0.27	0.35	0.58		
P-value	0.010	<0.001	**0.002**		

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

There was also a treatment by year interaction (p=0.006) of calculated CP requirement. This was similar among treatments for the first two autumns at 63 (±6.5) kg/ha in 2012/13 and 69 kg/ha in 2013/14 (Table 4-37). The following two autumns, both of the binary mixtures had a larger CP requirement than the lucerne monoculture.

The CP to ME ratio of pasture yield was 23 g CP/MJ ME on the lucerne treatment and 21 g CP/MJ ME on the binary mixtures. Using the calculated requirements for this stock class, the required ratio in pasture intake was 11 g CP/MJ ME (Brookes and Nicol, 2007; Nicol and Brookes, 2007). Thus in autumn, the requirement ratio was the smallest of all seasons and the yield ratio was the largest. This suggests livestock were most likely to exhibit suppressed pasture intake or reduced livestock productivity due to excessive CP content during the autumn. This would be more pronounced on the lucerne treatment.

Table 4-37: Calculated crude protein requirement (kg/ha) of hoggets, based on Brookes and Nicol (2007), from three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	60 cd	76 bc	91 b	21 e	62
Luc/Brome	69 cd	64 cd	112 a	57 d	76
Luc/CF	61 cd	66 cd	110 a	62 cd	75
Year mean	63	69	104	47	

	Treatment	Year	Interaction
S.E.M.	2.9	3.9	6.5
P-value	0.014	<0.001	**0.006**

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.6.7 Pasture intake

4.6.7.1 *Pasture disappearance*

Pasture intake estimated by pasture disappearance showed a treatment by year interaction (p=0.012). During the first year intake was similar among treatments at ~554 (±58.9) kg DM/ha. During 2013/14 the hoggets on the lucerne/cocksfoot had greater intake than the other two treatments (Table 4-38). In the final two autumns pasture intake was similar among the binary mixtures and greater than the lucerne monoculture. Based on these figures pasture utilisation was variable among years at 30-90% being greatest during 2015/16 when the grazing residual was <350 kg DM/ha. Pasture utilisation averaged 50% on the lucerne and 59% on the binary mixtures. Pasture intake was 1.2 (±0.12) kg DM/GD for the ewe hoggets during the first autumn and 1.4-1.9 kg DM/GD for the ram hoggets during the final three autumns and not different (p=0.493) among treatments.

Table 4-38: Pasture intake (kg DM/ha) of hoggets calculated by disappearance from three dryland pastures during the autumn from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	520 ^{d}	553 ^{cd}	485 ^{d}	416 ^{d}	494
Luc/Brome	561 ^{cd}	567 ^{cd}	804 ^{a}	756 ^{ab}	672
Luc/CF	581 ^{bcd}	763 ^{ab}	712 ^{abc}	788 ^{a}	711
Year mean	554	628	667	653	

	Treatment	Year	Interaction
S.E.M.	32.2	32.9	58.9
P-value	0.002	0.086	**0.012**

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

A range of potential hogget pasture intake was determined and compared to that estimated via pasture disappearance. The lower limit of the range is the minimum pasture intake required to meet hogget ME requirements assuming an ME content of pasture intake of 12 MJ ME/kg DM. The upper limit is the potential appetite of the hogget according to live weight. For this, 3.5% of live weight was chosen which was less than that of weaned lambs and reflects the relative reduction in potential appetite as animals increase in size (Court *et al.*, 2010). The range is shown in Table 4-39 for each treatment of the four years. The figure in parenthesis is the pasture intake/GD calculated through pasture disappearance.

Figures that fall outside of the associated range indicate irregularities of pasture intake measured through disappearance.

Table 4-39: Potential pasture intake (kg DM/GD) of hoggets from three dryland pastures over four autumns from 2012-2016 at Ashley Dene, Canterbury. The minimum figure on the range is to meet energy requirement when ME content of intake is 12 MJ ME/kg DM, the maximum figure on the range is 3.5% of hogget live weight, the figure in parenthesis was determined via pasture disappearance.

Treatment	2012-13	2013-14	2014-15	2015-16
Lucerne	0.9-1.3, (1.0)	1.6-1.6, (1.5) *	1.6-1.6, (1.1) *	1.0-1.6, (2.6) *
Luc/Brome	0.9-1.3, (1.0)	1.5-1.6, (1.8) *	1.6-1.6, (1.6)	0.9-1.6, (1.5)
Luc/CF	0.9-1.3, (1.1)	1.3-1.6, (2.0) *	1.5-1.6, (1.3) *	0.8-1.6, (1.2)

* denotes periods when the measured pasture disappearance lies outside the likely range.

4.6.7.2 Energy requirement

Pasture intake calculated by energy requirement when intake has an ME content of 12 MJ ME/kg DM, had a treatment by year interaction (p=0.002). Pasture intake was not different among treatments during the first two years and larger in the binary mixtures than the lucerne monoculture in the final two years (Table 4-40). Differences among treatments were predominantly related to the GD each pasture supported. Pasture intake of ewe hoggets in the first year was 0.9 kg DM/GD. Pasture intake of ram hoggets during 2013/14 and 2014/15 was 1.3-1.6 kg DM/GD, but only 0.8-1.0 kg DM/GD during the final autumn which coincided with the period where the lowest pasture residuals were achieved. If the ME content of pasture intake during the final autumn was 10 MJ ME/kg DM, pasture intake was 1.0-1.2 kg DM/GD and more comparable to the previous two autumns. Based on these figures, pasture utilisation was 20-64% and averaged 41% for the lucerne treatment and ~47% for the binary mixtures. With ME utilisation over the first three years being only 5-10% larger than this indicates that the ME content of intake of 12 MJ ME/kg DM was probably accurate. Averaged over four years, autumn pasture intake/GD among treatments was within 10% of each other.

Table 4-40: Calculated pasture intake (kg DM/ha) of hoggets based on energy requirement to meet maintenance and live weight change from three dryland pastures over four autumns from 2012-2016 at Ashley Dene, Canterbury. Metabolisable energy content of intake was estimated at 12 MJ ME/kg DM.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	450 [c]	573 [bc]	658 [b]	166 [d]	462
Luc/Brome	513 [c]	486 [c]	809 [a]	466 [c]	569
Luc/CF	453 [c]	488 [c]	807 [a]	514 [c]	565
Year mean	472	516	758	382	

	Treatment	Year	Interaction	
S.E.M.	22.2	28.4	48.5	
P-value	0.010	<0.001	**0.002**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

4.6.8 Pasture composition

The autumn period saw a reduction (p<0.001) in dead material relative to the summer to a level similar (p=0.757) to the spring of ~12%. The proportion of grass in the binary mixtures was higher (p=0.006, p<0.001) than during the summer at 37% and 53% for the lucerne/brome and lucerne/cocksfoot treatments (Figure 4-8). Lucerne made up 37% and 31% of pasture yield for these treatments, respectively. Lucerne content of the lucerne treatment was 77% during the autumn. The proportion of lucerne in pasture intake appeared larger than that in pasture yield for all treatments at 88%, 55%, and 57% for lucerne, lucerne/brome, and lucerne/cocksfoot, but this difference was only significant (p=0.039) in the lucerne/cocksfoot treatment.
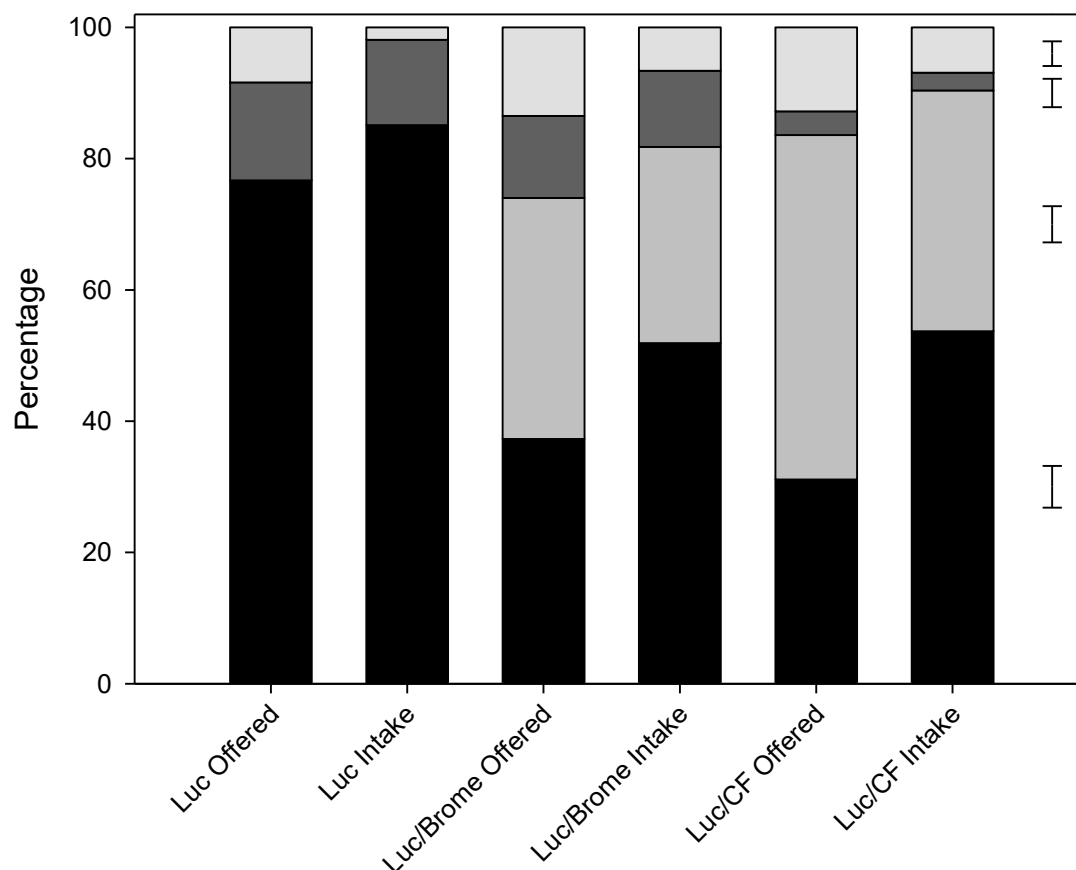
Figure 4-8: Mean pasture composition of pre grazing pasture mass offered to hoggets and calculated intake for all treatment during the autumn over four years from 2012-2016. Lucerne (■), grass (■), weed (■), and dead material (■). Acronyms reported in Table 4-1. Error bars represent the maximum S.E.M. for (from top to bottom) dead material, weed, grass, and lucerne.

4.7   Summary of results

The mean annual LWG of the lucerne treatment was 28% larger than the binary mixtures. This was achieved mainly through higher per head growth rates, however, the lucerne/cocksfoot tended to support more GD than the lucerne treatment. Pasture yields were not different among treatments for any season. Differences in treatments became apparent from the second year when the lucerne composition of the binary mixtures levelled off at ~37% compared with ~80% in the monoculture. The lucerne monoculture supported greater ME intake of ewes & lambs during the first four weeks of lactation, and of weaned lambs in the summer, by ~30% compared with the binary mixtures. This ME intake advantage was not as pronounced from the fifth week of lactation and not apparent during the autumn when grazed by hoggets. At the onset of lactation, the delay of introduction of ewes & lambs to the lucerne treatment essentially resulted in a larger pasture allocation which confounded the results for this period. During the summer, weaned lambs on the lucerne treatment achieved greater ME intake when pasture allocation was the same among treatments.

Pasture disappearance measured in this research was a poor predictor of pasture intake. In the spring this was typically lower than required to meet the measured levels of ewe & lamb productivity and could be in part due to intake of pasture growth occurring during a grazing event. In the summer and autumn the lack of consistency among pasture intake by disappearance and the potential range calculated by animal live weight and levels of productivity indicated that pasture measurements and/or regression equations were unsatisfactory to estimate pasture mass.

The difference between the pre and post-grazing nutritive value of the lucerne component relative to the grass species suggested an enhanced ability of livestock to differentiate the palatable from unpalatable portions of this plant.

Increasing ME intake per head increased the efficiency that this was converted to LWG. Livestock have an obligatory ME requirement for maintenance, as ME intake increases beyond this the fraction apportioned to maintenance decreases. A ~30% increase in ME intake resulted in closer to a ~60% increase in livestock growth rates during early spring and summer. The implications of these results are discussed further in Chapter 6.

5 ENVIRONMENTAL PARAMETER EFFECT ON PASTURE GROWTH

Pasture yield of the lucerne monoculture, lucerne/brome and lucerne/cocksfoot can be related to their ability to source and utilise the limited water resource. Species composition could be influential in both the duration of pasture growth and the rate of pasture growth. Differences in cool season activity among species may extend pasture growth further into the winter when soil water is typically plentiful. The different root structure of these species may influence the amount of soil water they can source and therefore how long into late spring and summer they will grow before exhausting the sub-soil reservoir. While both water availability and soil temperature are conducive to pasture growth, differences in shoot structure and CP content can influence the rate of pasture growth. In addition, variation in legume yield of pastures may be influential on soil nitrogen status with the potential for this nutrient to accumulate and represent an environmental concern.

The objectives of Chapter 5 are:

- Quantify pasture treatment effect on the duration of growth during the spring. This was done by estimating the onset of pasture growth at the end of the winter and the time of cessation of growth in late spring/summer as a result of a soil water deficit.
- Quantify pasture growth rates against TT accumulation when water was non-limiting.
- Quantify pasture treatment effect on anaerobically mineralisable nitrogen and organic matter status in soil over time.

5.1 Spring growth initiation

The initiation of a phase of pasture growth where, when related to accumulating TT, the response is linear, was determined. Relative to the 1st July (approximate time of the last 'clean-up' graze in the winter) this was not different (p=0.133) among treatments. This was latest (p<0.001) during 2012/13 at 434 (±24.8) °C days (20th August), and earliest during 2014/15 at 241 °C days (2nd August) (Table 5-1). Based on these figures, pasture growth began 50-73 days following the mean preceding clean up graze and averaged ~59 days for all treatments.

5.2 Maximum growth response to thermal time

The growth response to TT prior to a limiting soil water deficit did not differ (p=0.202) among treatments. This was highest at 6.1 (± 0.23) kg DM/ha/°C day during the first two years, and 4.3 kg DM/ha/°C day during the spring of years three and four of the experiment (Table 5-2).

Table 5-1: Estimated thermal time (°C days) after 1st July of initial dry matter accumulation of three dryland pastures over four years from 2012-2016 at Ashley Dene, Canterbury. Tb=0°C soil at 100 mm depth.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	420	285	233	331	317
Luc/Brome	452	390	274	326	360
Luc/CF	431	405	216	286	335
Year mean	434 [a]	360 [b]	241 [c]	314 [bc]	

	Treatment	**Year**	**Interaction**
S.E.M.	13.7	24.8	39.6
P-value	0.133	**<0.001**	0.617

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 5-2: Growth response to thermal time (kg DM/ha/°C day) during the spring prior to soil moisture deficit limiting pasture growth of three dryland pastures over four years from 2012-2016 at Ashley Dene, Canterbury. Tb=0°C soil at 100 mm depth.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	5.8	5.8	3.7	4.5	4.9
Luc/Brome	6.1	6.3	4.3	4.4	5.3
Luc/CF	5.9	6.8	4.8	4.2	5.4
Year mean	5.9 [a]	6.3 [a]	4.3 [b]	4.3 [b]	

	Treatment	**Year**	**Interaction**
S.E.M.	0.18	0.23	0.39
P-value	0.202	**<0.001**	0.648

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

5.3 Timing of a limiting soil water deficit

5.3.1 Identifying a limiting soil water deficit by calculation of a 'break point'

The calculation of a 'break point' to estimate when the growth of pasture treatments became restricted by a limiting soil water deficit showed no difference (p=0.345) among treatments within any year (Table 5-3). The units used are degree days after 1st July and translate to 14th December, 13th December, 24th November, and 8th December in consecutive years. The potential soil water deficit associated with these dates was 184 mm in 2012/13, 198 mm in 2013/14, and ~257 mm in 2014/15 and 2015/16. In the 2012/13 year this was the occurrence of the PSWD as there was no effective rainfall measured following this until all summer grazing was completed (Figure 5-1). Effective summer rainfall following the PSWD in 2013/14-2015/16 delayed this 'break point'.

Table 5-3: Calculated time of limiting soil water deficit (°C days after 1st July) by 'break point' of three dryland pastures over four years from 2012-2016 at Ashley Dene, Canterbury. Tb=0°C soil at 100 mm depth.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1989	2009	1809	1953	1940
Luc/Brome	1975	2136	1680	1958	1937
Luc/CF	2004	2061	1617	1928	1902
Year mean	1990 [a]	2069 [a]	1702 [b]	1946 [a]	

	Treatment	Year	Interaction
S.E.M.	19.3	44.9	70.0
P-value	0.345	**<0.001**	0.666

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

5.3.2 Plant available water holding capacity

The PAWC of treatments within the top 2.3 m of soil was not different (p=0.924) at 184 ($\pm$9.6) mm (Table 5-4). The range among plots was 153-209 mm and reflected the variability in soil type and depth across the experimental area (Appendix 21). This is in agreement of the calculation of a 'break point' in 2012/13 which estimated the timing of a limiting soil water deficit when the corresponding PSWD was 184 mm (Section 5.3.1).

Table 5-4: Calculated mean plant available water holding capacity (mm) of soils for three dryland pastures at Ashley Dene, Canterbury.

Treatment	Treatment mean
Lucerne	183
Luc/Brome	187
Luc/CF	182
Grand mean	184
S.E.M.	9.6
P-value	0.924

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

5.3.3 Potential soil water deficit

The time of a limiting soil water deficit was calculated by following a potential soil water deficit until this equalled the available water holding capacity. This was synchronised among treatments as their water holding capacity was not different (Table 5-4) but was weather dependent each year. The date that the PSWD reached 184 mm was 14th December during 2012/13, 11th December during 2013/14, much earlier on the 8th November during 2014/15, and 23rd November during 2015/16 and is depicted in Figure 5-1 to 5-4.

5.4 Water use efficiency

The water available for pasture growth prior to the potential limiting soil water deficit was calculated as 374, 328, 259, and 263 mm for consecutive springs. The WUE of pastures was 12.7-24.3 kg DM/ha/mm across years but not different (p=0.210) among treatments (Table 5-5). This is the equivalent to 1.27-2.43 kg DM/t water.

5.5 Annual pasture accumulation

Annual pasture accumulation related to thermal time accumulation is depicted in the top graph of Figure 5-1 to 5-4 for consecutive years of the experiment. In the bottom graph of each figure, corresponding soil water availability is represented by calculated potential soil water deficit to a maximum of 184 mm on the same thermal time scale.

Table 5-5: Water use efficiency (kg DM/ha/mm) during the spring prior to soil moisture deficit limiting pasture growth of three dryland pastures over four years from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	20.2	23.1	11.2	16.9	17.8
Luc/Brome	20.6	23.9	12.2	14.9	17.9
Luc/CF	20.7	26.0	14.6	13.7	18.8
Year mean	20.5 [b]	24.3 [a]	12.7 [d]	15.2 [c]	

	Treatment	**Year**	**Interaction**
S.E.M.	0.39	0.62	1.01
P-value	0.210	**<0.001**	0.083

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

During each spring, the 'maximum' growth response to thermal time is represented by a stepped solid line. This is stepped as it was assumed pastures did not accumulate pasture yield during grazing. The dotted line extending down to the *x*-axis is a continuation of the 'maximum' pasture growth rate each year to indicate the initiation of linear pasture growth late in the winter.

The points represent actual pasture yield at the time of the mean rotation date. These are typically the mean yield of six replicates but are occasionally 3-5 if a grazing rotation is not completed within a particular season.

The long dashed line tracking pasture yield through summer and autumn is speculative. Over these seasons pasture measurements were intermitted due to prolonged periods of destocking. It reflects a potential growth response following rainfall that gave soil water recharge that lasted for more than three days. Durations of three days or less appeared insufficient to elicit a growth response due to high levels of water loss to soil evaporation. When the budgeted soil water deficit reached 184 mm pasture growth was assumed to have ceased. The growth response to available soil water relative to accumulating thermal time during the autumn was expected to be suppressed due to lower rates of PET compared with the spring and summer so the gradient of this line reflects this. The summer pasture yield of 2014/15 appeared disproportionately large relative to the volume of summer rainfall measured following the limiting soil water deficit but

otherwise, soil water recharge appeared to be a reasonable predictor of pasture yield through the summer and autumn.

Towards the top of the upper graph in each figure, arrows indicate the duration of each season and gaps at either end and between these seasons indicate periods where the experimental area was destocked of all productive livestock.
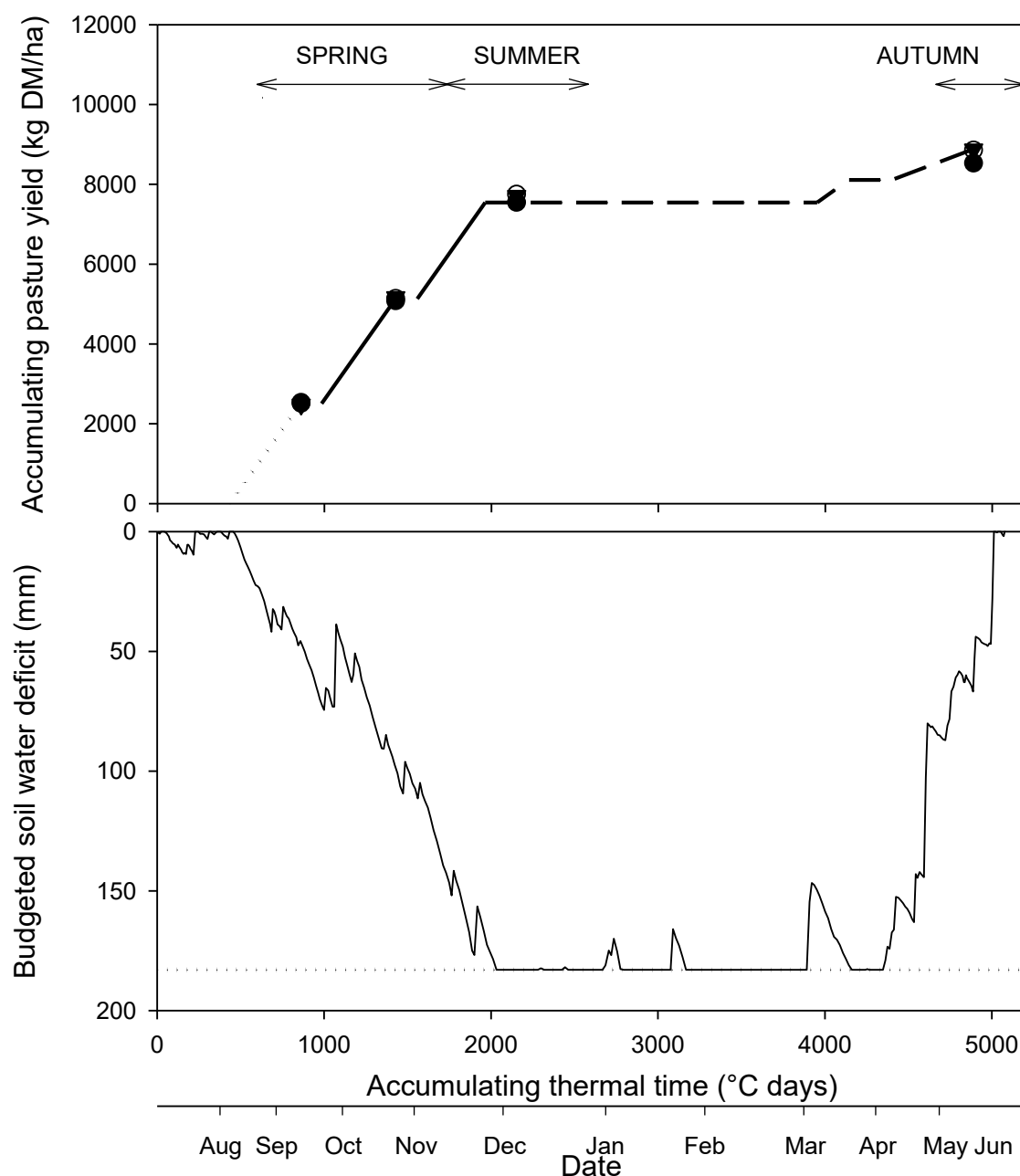
Figure 5-1: Accumulated yield against thermal time for three dryland pastures, lucerne (●), lucerne/brome (▼), lucerne/cocksfoot (○) (Top); and corresponding potential soil water deficit to a maximum of 184 mm (Bottom) for 2012/13 at Ashley Dene, Canterbury. Equation for non-limited spring growth for all treatments was: Pasture yield = 5.9 (±0.14) x – 2589 (±136.8). x intercept = 434 (±15.5) °C days. Tb=0°C soil at 100 mm depth. The spring period was grazed by ewes & lambs, summer period was grazed by weaned lambs, and the autumn period was grazed by hoggets.
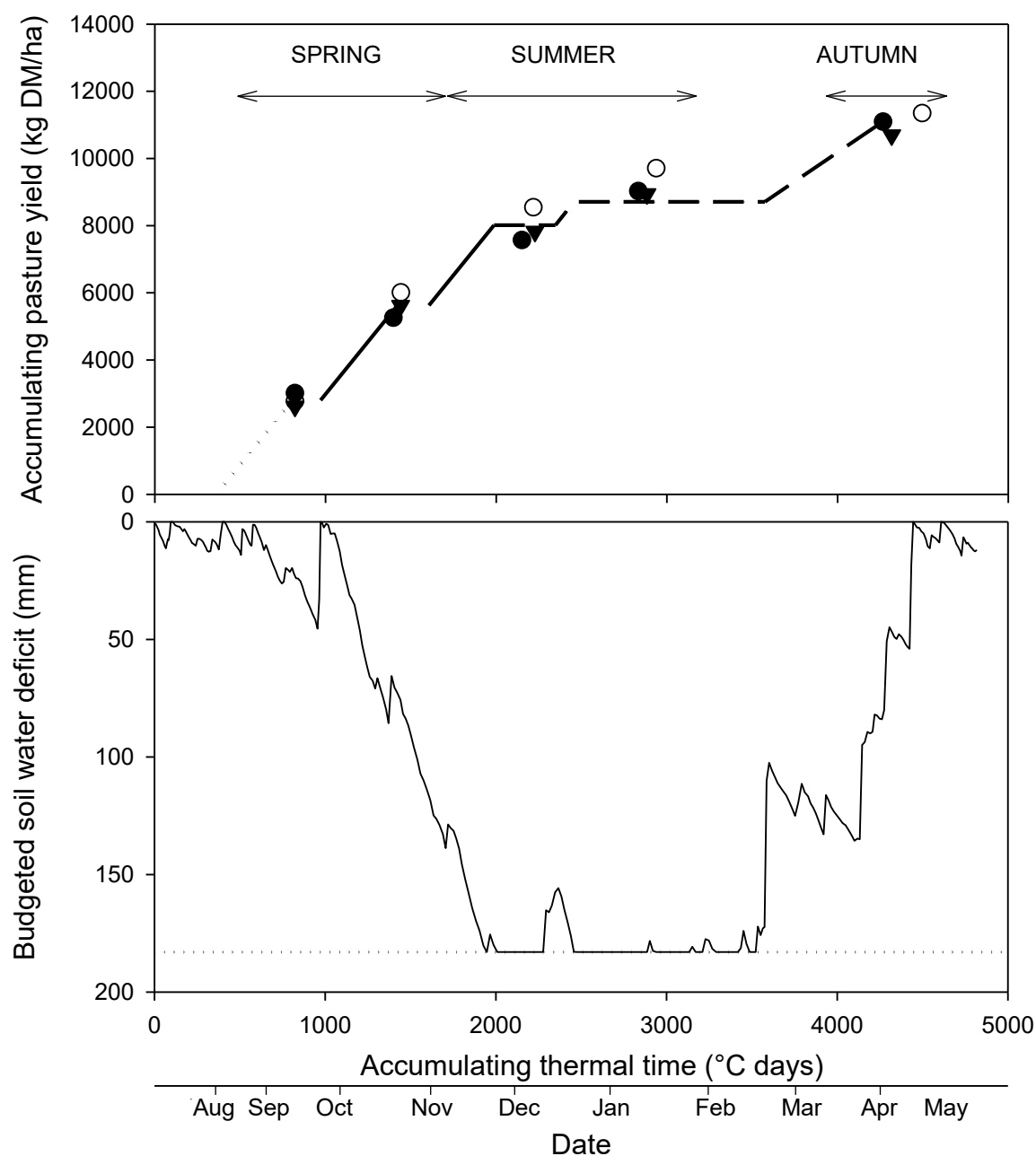
Figure 5-2: Accumulated yield against thermal time for three dryland pastures, lucerne (●), lucerne/brome (▼), lucerne/cocksfoot (○) (Top); and corresponding potential soil water deficit to a maximum of 184 mm (Bottom) for 2013/14 at Ashley Dene, Canterbury. Equation for non-limited spring growth for all treatments was: Pasture yield = 6.3 (±0.47) x – 2357 (±468.3). x intercept = 360 (±42.4) °C days. Tb=0°C soil at 100 mm depth. The spring period was grazed by ewes & lambs, summer period was grazed by weaned lambs, and the autumn period was grazed by hoggets.
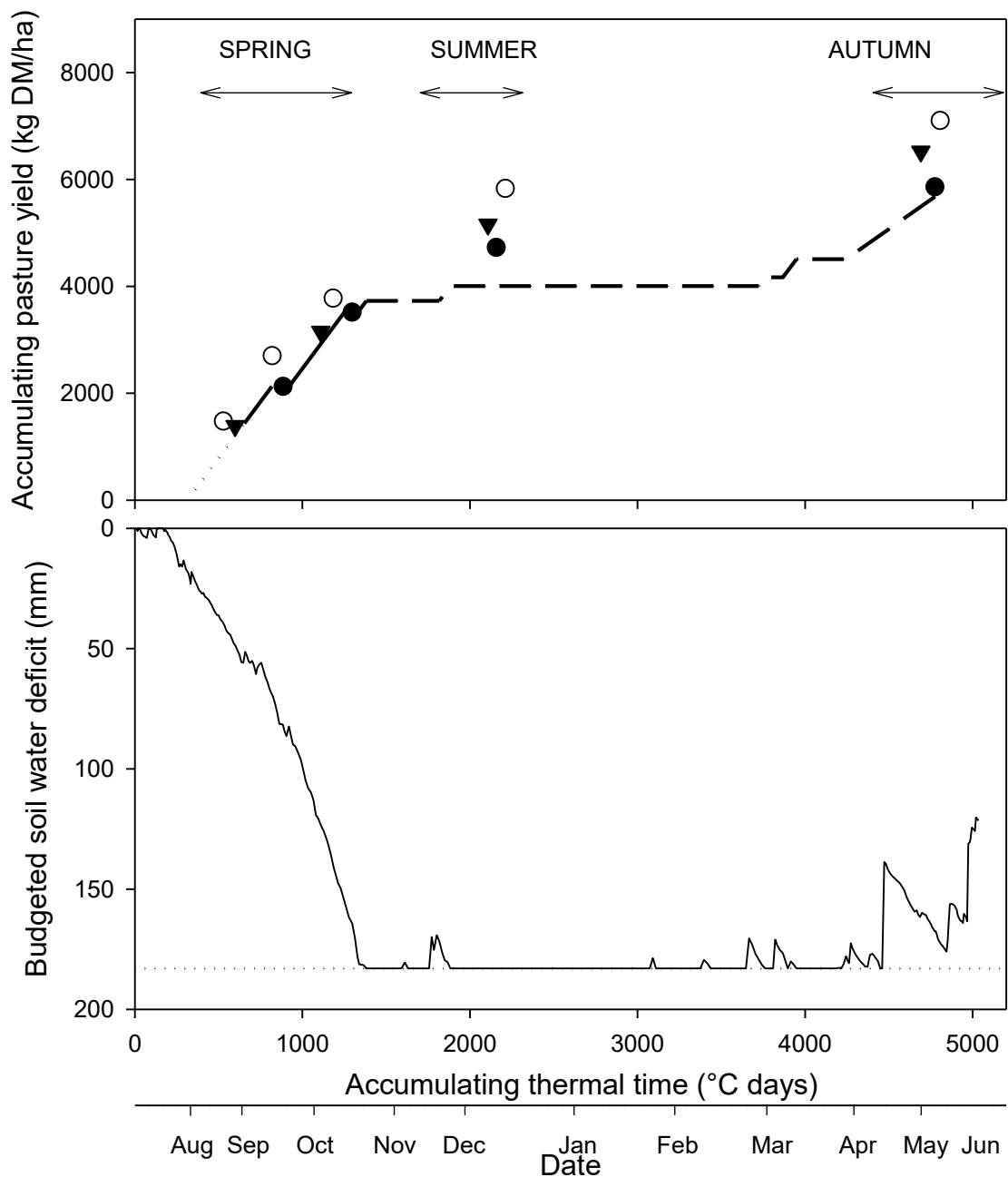
Figure 5-3: Accumulated yield against thermal time for three dryland pastures, lucerne (●),
lucerne/brome (▼), lucerne/cocksfoot (○) (Top); and corresponding potential soil
water deficit to a maximum of 184 mm (Bottom) for 2014/15 at Ashley Dene,
Canterbury. Equation for non-limited spring growth for all treatments was:
Pasture yield = 4.2 (±0.28) x – 983 (±173.2). x intercept = 232 (±33.0) °C days.
Tb=0°C soil at 100 mm depth. The spring period was grazed by ewes & lambs,
summer period was grazed by weaned lambs, and the autumn period was grazed
by hoggets.
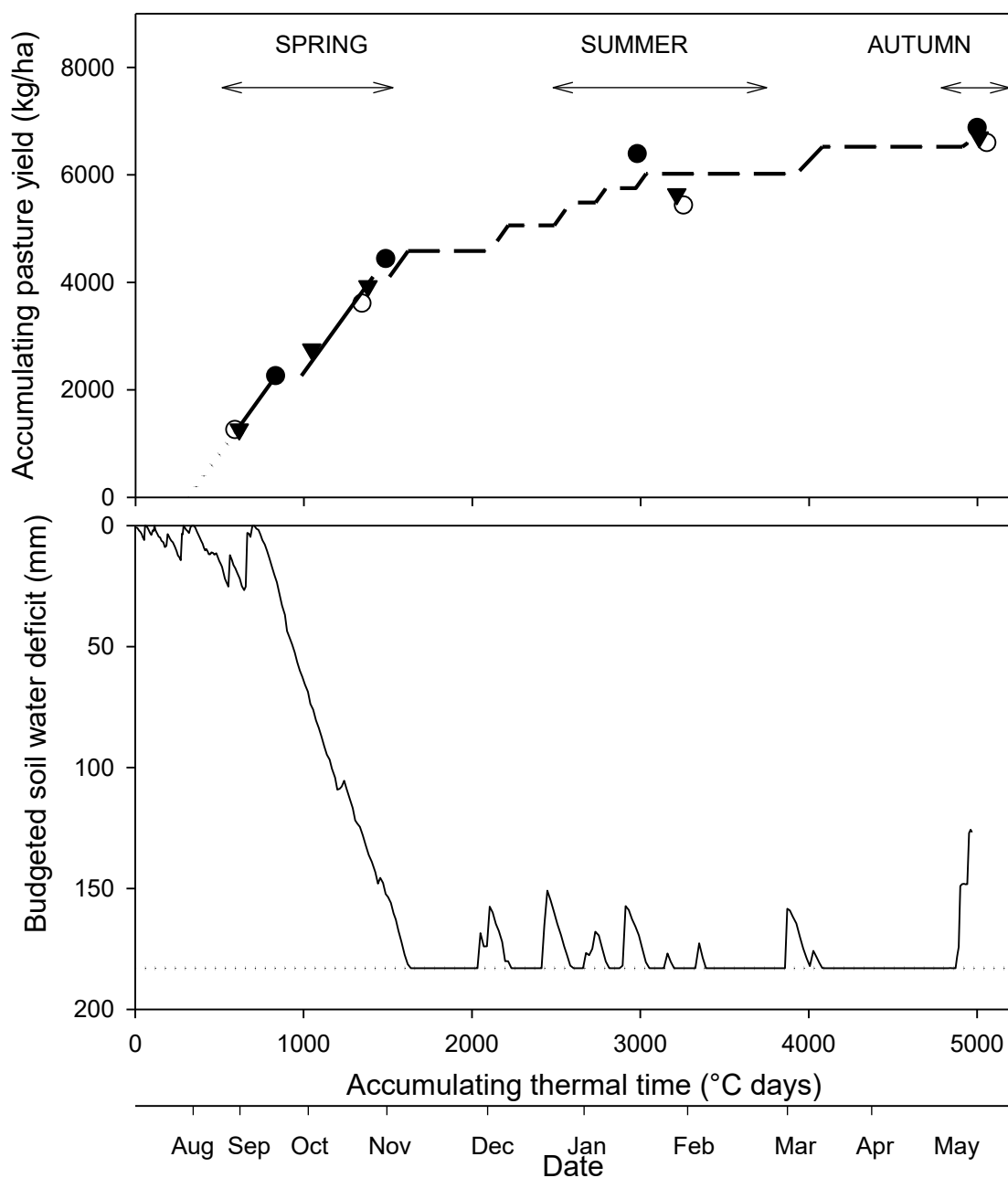
Figure 5-4: Accumulated yield against thermal time for three dryland pastures, lucerne (●), lucerne/brome (▼), lucerne/cocksfoot (○) (Top); and corresponding potential soil water deficit to a maximum of 184 mm (Bottom) for 2015/16 at Ashley Dene, Canterbury. Equation for non-limited spring growth for all treatments was: Pasture yield = 4.3 (±0.26) x – 1423 (±227.7). x intercept = 314 (±38.3) °C days. Tb=0°C soil at 100 mm depth. The spring period was grazed by ewes & lambs, summer period was grazed by weaned lambs, and the autumn period was grazed by hoggets.

5.5.1   Daily pasture growth rates

The daily pasture growth rate of the lucerne treatment preceding the autumn grazing rotation was lower than the binary mixtures in 2012/13 (p=0.008) and lower than the lucerne/cocksfoot treatment in 2015/16 (p=0.036) (Figure 5-5). Growth rates at this time were 6-16 kg DM/ha/day so differences had only a small influence on annual pasture yield. Pasture growth rates peaked leading up to the second or third grazing rotation during the spring. This growth rate was not different (p=0.333, p=0.484) among treatments during the first two years at 85 (±8.78) and 99 kg DM/ha/day. During the following two years, grazing rotations were not synchronised so growth rates could not be compared but these averaged at 59 and 68 kg DM/ha/day on consecutive years.
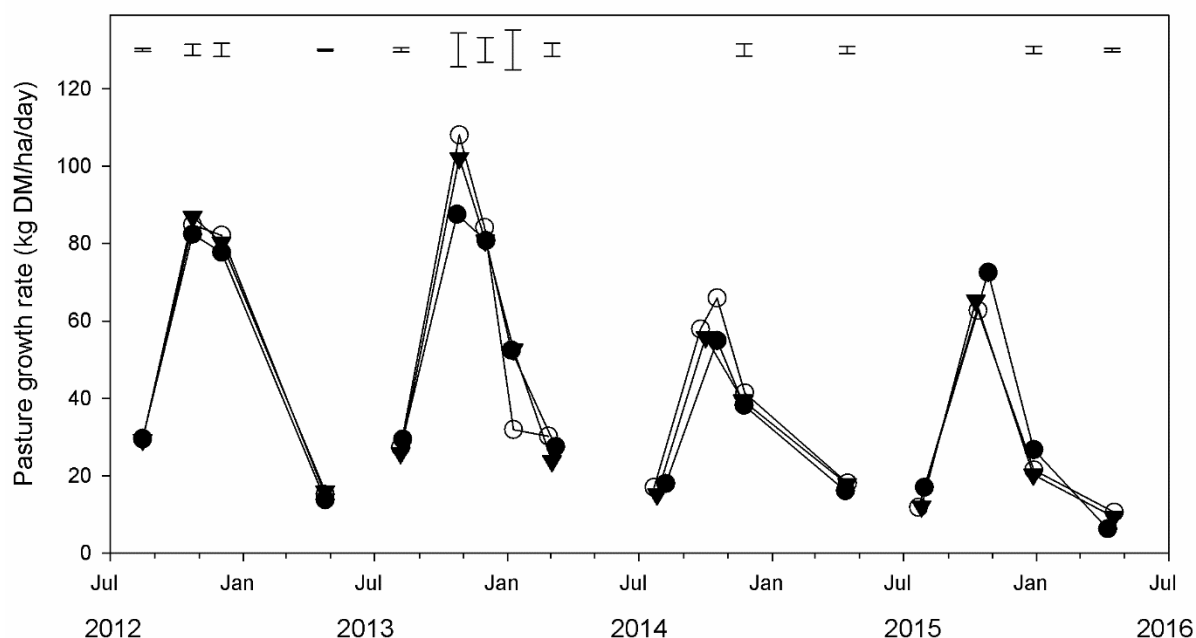
Figure 5-5: Mean daily pasture growth rates of three dryland pastures; lucerne (●), lucerne/brome (▼), lucerne/cocksfoot (○) over four years from 2012-2016 at Ashley Dene. Error bars represent the maximum S.E.M. when grazing rotations were synchronised among treatments.

5.6 Soil nitrogen

Within the top 75 mm of soil, the AMN was higher (p=0.015) within the binary mixtures during 2015/16 than the monoculture of the same winter (Table 5-6). This was not different among treatments during the previous two winters. At 75-150 mm depth the AMN was not different (p=0.358) among treatments within any of the three years this was measured. The AMN was lowest (p<0.001) at 45 (±2.1) μg/g during the 2014/15 and 2015/16 years (Table 5-7). Over the duration of the experiment, each treatment had a 'medium' level of AMN (Hill Laboratories, 2017), being 50-80 μg/g over the top 150 mm of soil. This equates to 150-250 kg of available N within this zone when soil conditions were ideal for mineralisation.

Table 5-6: Anaerobically mineralisable nitrogen (μg/g) in the 0-75 mm depth of soil under three dryland pastures at Ashley Dene measured in the winter from 2013-2016.

Treatment	2013-14	2014-15	2015-16	Treatment mean
Lucerne	78 [bc]	72 [c]	66 [c]	72
Luc/Brome	75 [c]	72 [c]	92 [ab]	83
Luc/CF	79 [bc]	75 [c]	103 [a]	82
Year mean	77	73	87	
	Treatment	**Year**	**Interaction**	
S.E.M.	3.8	4.8	7.8	
P-value	0.015	0.021	**0.022**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Table 5-7: Anaerobically mineralisable nitrogen (µg/g) in the 75–150 mm profile of soil under three dryland pastures at Ashley Dene measured in the winter of three years from 2013-2016.

Treatment	2013-14	2014-15	2015-16	Treatment mean
Lucerne	56	40	41	46
Luc/Brome	60	49	45	51
Luc/CF	55	47	47	49
Year mean	57 [a]	45 [b]	44 [b]	
	Treatment	**Year**	**Interaction**	
S.E.M.	2.7	2.3	4.2	
P-value	0.358	**<0.001**	0.835	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

5.7 Soil organic matter status

The soil carbon levels were not different (p=0.460) among treatments being 2.65 (±0.092) % in the summer of 2015/16 (Table 5-8). This is considered low, consistent with organic matter levels of 4-5%. The total soil nitrogen was not different (p=0.517) among treatments at 0.256 (±0.0088) % which is within the 'medium' range. The AMN was higher in the summer than measured during the winter. This was 92 (±1.9) µg/g over the top 150 mm of soil and not different (p=0.906) among treatments. The AMN to total N ratio was again not different (p=0.634) among treatments. At 3.57 (±0.102) this is considered a 'medium' level with average reserves of partially decomposed organic matter (Hill Laboratories, 2017).

Table 5-8: Organic soil parameters sampled in the summer of 2015/16 at Ashley Dene, Canterbury.

Treatment	Total Carbon (%)	Total Nitrogen (%)	C/N	AMN/N
Lucerne	2.57	0.252	10.2	3.64
Luc/Brome	2.65	0.252	10.5	3.58
Luc/CF	2.74	0.265	10.4	3.50
Average	2.65	0.256	10.4	3.57
Level	Low	Medium	Medium	Medium
S.E.M.	0.092	0.0088	0.08	0.102
P-value	0.460	0.517	0.099	0.634

Note: Means within columns are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

5.8   Summary of results

Pasture treatment was not influential to pasture growth response to soil water and temperature. The initiation of linear pasture growth began in early to mid-August of each year at Ashley Dene. The mean available water holding capacity of soils was 184 mm. When this was supplemented with 200-300 mm of rainfall during July-November of 2012/13 and 2013/14 (Figure 3-7), the maximum pasture growth rate when not limited by a soil water deficit continued into the second week of December. Rainfall over July-November during 2014/15 and 2015/16 of ~150 mm, resulted in pasture growth being limited by a soil water deficit during November. The rate of maximum pasture growth while soil water was non-limiting was 6.1 kg DM/ha/°C day during 2012/13 and 2013/14. This fell to 4.3 kg DM/ha/°C day during 2014/15 and 2015/16. The corresponding WUE fell from ~22 kg DM/ha/mm to ~14 kg DM/ha/mm between these same periods. Effective in season rainfall was a reasonable predictor of summer and autumn pasture growth.

There was no indication that a higher lucerne composition in pastures increased the organic matter or nitrogen status of soils. In fact the lucerne monoculture had a lower AMN level than the binary mixtures in the 2015/16 year. This may be an anomaly and requires continued monitoring to determine if this trend is maintained. All treatments had low levels of organic matter, which is consistent with drought prone soils, and medium levels of mineralisable nitrogen.

6 DISCUSSION

The aim of this research was to determine if the strategy of companion planting a grass species with lucerne increased LWG production through extended lactation. Differences in the productivity of treatments were related to the botanical composition of these pastures. Therefore, the results of this research are specific to the management and environmental conditions experienced at Ashley Dene which potentially influenced this composition. For example, the soils of the experimental area are variable in depth but unlikely to exceed the rooting depth of the grass species (Section 3.1.1). This means water access in this research is expected to be independent of treatment and therefore unlikely to promote the lucerne composition. None-the-less, this research has identified the key drivers of these respective pastures.

In this chapter, the composition of these pastures will be discussed and then their interaction with nitrogen, temperature, and water, related to this. This will be followed by discussion on how livestock responded to this pasture production and why botanical composition has been influential.

6.1 Pasture composition

The establishment of pastures deliberately favoured lucerne composition and was reflected in the small grass contribution in the first spring. Both, lower grass seeding rate and drilling grass into established lucerne ensured a high lucerne composition following establishment (Section 2.5.1). Pasture yield was lucerne dominant for all treatments, contributing 68% and 78% of the lucerne/brome and lucerne/cocksfoot treatments, and 87% of the lucerne treatment (Section 4.4.9). Thereafter, lucerne composition of the binary mixtures equilibrated at ~37%, with sown grass species making up 40-50% of these treatments. Except for the second year, when it did not receive herbicide control for weed ingression, the lucerne treatment maintained a lucerne content of ~80% (Figure 4-3).

Grasses typically dominate legume/grass mixtures over time. The competitive nature of cocksfoot especially, was expected to suppress the lucerne performance as it has done in previous research. Cullen (1960) and Vartha (1973) reported that, following the establishment year, cocksfoot was more dominant than up to seven other temperate grass species when grown in binary mixtures with lucerne. The lucerne composition of this mixture following four years in this research could be considered a success as cocksfoot is renowned for eliminating white

clover when sown together (Moloney, 1993; Mills *et al.*, 2015a). The cocksfoot was also successful at maintaining weed ingression to ~6% of pasture yield. This was lower than that achieved by annual herbicide application in the monoculture (Section 4.4.9) which is considered best practice to prolong stand longevity (Moot *et al.*, 2003). This provides an indication of how successful the companion planting of cocksfoot with lucerne may be on erosion control.

Including a less resilient grass species with lucerne did not promote a higher lucerne composition in pastures, instead it allowed increased weed ingression. Prairie grass, the 'Atom' cultivar sub-treatment of the lucerne/brome, is subject to a larger proportion of tiller death in the summer than the other grass species included in this research (Kemp *et al.*, 1999). From the spring of 2014/15, this species maintained a smaller composition in its respective pasture than the pasture brome ('Bareno'). Initially, this benefited both the lucerne and unsown species but by the spring of 2015/16 the lucerne composition was the same as the pasture brome treatment at ~40%. The 'Atom' sub-treatment comprised of 8% prairie grass and 39% unsown species whereas the 'Bareno' sub-treatments comprised of 31% pasture brome and 15% unsown species (Figure 4-5).

6.2   Pasture yield

Pasture yield regulated the carrying capacity of these pasture treatments, as management aimed to match pasture allocation per GD among treatments. Under dryland conditions the seasonality of pasture growth is also important. This is limited by soil temperature during the winter and by soil water and N availability in late spring or summer. The spring provided the most reliable and abundant pasture supply (Figure 4-2). Lactation was aligned to this period to maximise the opportunity of growing lambs to a killable weight within this window of feed availability.

Spring pasture yield was not different among treatments within any year (Table 4-5). This was 5.0 t DM/ha during the first two years and much lower at 3.6 t DM/ha when the duration of spring growth was reduced by a limiting soil water deficit (Figure 5-3 & 5-4). This was further compounded by reduced pasture growth rates (Table 5-2).

Summer pasture production was variable and unreliable over the duration of this research but consistent among treatments. Dryland farms in this region cannot depend on summer pasture growth which emphasises the importance of spring pasture production while soil water is

available. Summer pasture yield ranged from 1.9-3.9 t DM/ha (Table 4-18). The occurrence of a limiting soil water deficit and additional effective summer rainfall was a strong predictor of this (Figure 5-1 to 5-4). During 2012/13 and 2013/14 weaned lambs completed a grazing rotation on the experimental area directly following weaning. However, due to a feed shortage in 2014/15 and 2015/16 all treatments had to be destocked until summer rainfall had resumed pasture growth (Figure 3-1 to 3-4). On a commercial farm this would have required provision of supplementary feed, or selling store lambs.

Following autumn rainfall, pastures were allowed a period of six weeks growth to recharge lucerne root reserves to provide for spring growth (Moot *et al.*, 2003). The shoot growth arising from this was 0.7-2.1 t DM/ha each year (Table 4-31) and was grazed with 6-9 month old hoggets. During this season the lucerne/cocksfoot treatment tended to have a larger pasture yield than the lucerne, with the lucerne/brome being intermediate. Teixeira (2006) measured a ~20 kg DM/ha/day increase in the root yield of lucerne monocultures between mid-summer and autumn. The root yield was not measured in this research but this was expected to be positively related to lucerne composition and probably explains the lower shoot yield of the lucerne treatment relative to grass based pastures.

6.3 Nitrogen

Nitrogen is an important component of both pasture and livestock production, however, little is actually removed in the end product of dryland pasture systems. The nitrogen composition of livestock is ~3% by weight (Maeno *et al.*, 2013), so 15-25 kg/ha N was removed in animal product each year during this research. In addition, there was the opportunity for additional N loss through volatilisation and leaching of mineral N in excreta. This was probably <10 kg/ha given the stock class and level of inputs (Cameron *et al.*, 2013). With the ability to fix ~2.5% of dry weight in N (Peoples *et al.*, 1998; Carlsson and Huss-Danell, 2003; Yang *et al.*, 2011; Taraken, 2014), fixation from a lucerne yield of 1200 kg DM/ha would have been sufficient to maintain this N balance. This is complicated by the nutrient transfer of livestock which results in two very different areas within a paddock in regards to N availability. Under a urine patch, N is non-limiting to pasture growth and pasture yield is often visually more than the surrounding N deficient areas. The remaining grazing area is dependent on soil mineralisable N and biological fixation.

Legume crops can be used to improve the N and organic matter status of soils through the contribution of decaying rhizobia and plant material of high N content (McLaren and Cameron, 1996). This increases the N availability over time which can enhance pasture growth. In this research there was no indication that a higher lucerne composition in pastures resulted in increased N availability or an improvement in organic matter status (Table 5-8). There was no apparent accumulation of N within the soil resulting from double the lucerne yield in the monoculture. This is consistent with the occurrence of similar shoot CP yields among treatments for each season (Table 4-9, 4-22 & 4-35).

The mean AMN content of the top 150 mm of these soils was 60-65 µg/g (Table 5-6 & 5-7), meaning under ideal conditions this would have provided ~190 kg mineral N/ha (Hill Laboratories, 2017). Assuming minimal mineral N availability from below this profile, without fixation, this could have supported 5-6 t DM/ha pasture yield (21% CP content) between the urine patches. To produce pasture yields >6 t DM/ha required N contribution from fixation. The monoculture had a much larger capacity to fix N than the binary mixtures during the final three years of this research due to producing a larger lucerne yield. The N fixation capacity of the binary mixtures was potentially 70-120 kg/ha each year depending on total DM yield, half of the monocultures capacity. Given that CP yield was not different among treatments (Table 4-9, 4-22 & 4-35) it would appear that ~37% legume composition was sufficient to provide the necessary N fixation of these pastures. It is likely that total fixation was similar among treatments. Lucerne is recognised to downscale fixation, to potentially <20% of total shoot N (0.6% of lucerne shoot dry weight), when the availability of mineral N allows (Armstrong *et al.*, 1999). This is likely to have occurred beneath the urine patches but also in the monoculture between the urine patches. During the final three years of this research, the grasses' ability to scavenge available soil N essentially doubled the rate of fixation of the lucerne component compared to when this was grown as a monoculture.

Legumes are recognised as maintaining a higher shoot CP content than grass species. This increases leaf extension rate (Belanger, 1997) and photosynthesis (Peri *et al.*, 2002), both of which promote pasture growth rate. The higher lucerne composition of the monoculture could be expected to promote pasture growth rate of this treatment. In this research, the spring shoot CP content of lucerne was 25% compared to 18-20% for the grass species (Table 4-7). However, as pasture yield contained a mixture of components, the average spring CP content of pasture yield was intermediate to these, being 22-23% on all treatments (Appendix 2). The

higher lucerne composition of the monoculture potentially provided little advantage to pasture growth rates in this environment.

6.4 Temperature

To allow comparison through each spring period when soil water was non-limiting pasture growth was quantified by TT. A base temperature of 0°C of soil temperature at 0.1 m depth was used to allow comparison with the results of Tonmukayakul (2009) and Morris (2011). These authors reported that cocksfoot/subterranean clover pastures grew at a 20-30% higher rate than lucerne monocultures prior to a limiting soil water deficit. This was attributed to more cool season growth. The point of this research was centred on an expectation the grass based pastures would allow earlier stocking of pastures. However, the initiation of spring pasture growth could not be separated among treatments. This occurred about two months following the preceding grazing which fell between the 2nd and the 20th of August (Table 5-1). More frequent pasture measurements over this period could have identified a difference among pasture treatments here. During the final two years the binary mixtures were stocked in the last week of August, 2-3 weeks earlier than the monoculture (Figure 3-3 & 3-4). Rather than being due to earlier pasture growth, this could be explained by management recognising that growth of grass based pastures continues when set stocked as the growing tip is protected from grazing damage. If the grass based pastures did experience more cool season growth, the lucerne treatment appeared to compensate for this with higher growth rates when temperatures allowed. An indication of this was apparent in 2014/15 with a separation in the growth response to TT among treatments appeared. The lucerne treatment grew at 3.7 kg DM/ha/°C day compared with ~ 4.5 kg DM/ha/°C day on the binary mixtures (Table 5-2). During this spring the time of a limiting soil water deficit was the 8th November (Figure 5-3), resulting in the duration of lucerne growth being insufficient to negate the effect of an increased lag in early spring pasture growth compared with other years.

The growth response to TT measured in this research was 6.1 kg DM/ha/°C day during the first two springs and 4.3 kg DM/ha/°C day during the following two and not different among treatments (Table 5-2). Tonmukayakul (2009) and Morris (2011) measured a response of 4.2-4.9 kg DM/ha/°C day on lucerne monocultures and 5.7-5.9 kg DM/ha/°C day on cocksfoot/subterranean clover pastures. The pastures in these authors' research were 6-8 years old and the lucerne would have been subject to natural thinning (Moot *et al.*, 2012) which may explain the lower response than was initially measured in their research.

The difference in spring pasture growth rates between the first and the second half of the experiment may be related to the pasture covers that were maintained in respective years. Increasing pasture cover can be related to increasing LAI of the pasture canopy which in turn increases PAR interception during regrowth periods. During the spring of 2012/13 and 2013/14 the average pre-grazing pasture mass of all treatments was ~2900 kg DM/ha (Appendix 18) and coincided with the initial growth response to TT of 6.1 kg DM/ha/°C day (Table 6-1). During the spring of 2014/15 and 2015/16 the average pre-grazing pasture mass was ~1750 kg DM/ha and the corresponding response to TT was 4.3 kg DM/ha/°C day.

6.5 Water

Dryland farms are subject to a limiting soil water deficit each year. Ashley Dene experienced this late in November or December in this research (Figure 5-1 to 5-4). The soils of the experimental area had a plant available water holding capacity of 184 mm (Table 5-4). Composition of pastures did not affect this. This made spring pasture yield highly dependent on effective spring rainfall. During the first two years of the experiment this was 200-300 mm (Figure 3-7) which maintained pasture growth into the second week of December. During 2014/15 and 2015/16 ~150 mm of rain fell each spring. A soil water deficit occurred on the 8th November and 23rd November in these two years (Section 5.3.3). Even during 2012/13 and 2013/14 the duration of pasture growth was insufficient to finish lambs to a killable weight at Ashley Dene. Management would have needed to provide additional feed each year to finish lambs, spring and summer rainfall dictated when this was required and how much.

All treatments exhibited the same WUE prior to a limiting soil water deficit. This was ~22 kg DM/mm/ha during the first two years and ~14 kg DM/mm/ha during the final two (Table 6-1). McKenzie *et al.* (1990) and Moot *et al.* (2008) reported that the WUE of legume pastures was ~25 kg DM/mm/ha with binary mixtures being lower at ~21 kg DM/mm/ha. The difference is attributed to lower canopy CP content of the grass component. During the final two years the WUE calculated here is comparable to that of a grass monoculture (Moot *et al.*, 2008), despite having higher CP content than the spring of 2012/13 and 2013/14 (Table 6-1). With the reduced canopy size of all treatments during the final two springs, transpiration rate of pastures will have been suppressed. However, this was potentially offset by higher soil water evaporation due to reduced ground cover. This was observed by Sim (2014) who maintained contrasting pasture covers on lucerne through grazing management. He measured similar total water use despite differences in transpiration and soil evaporation.

Summer pasture yields (Table 4-18) suggested the response to effective in season rainfall was not different among treatments. The WUE of pastures during the summer appeared lower than during the spring (Figure 5-1 to 5-4). This is in part due to the loss of tillers in the grass component following heading but higher levels of soil evaporation while rainfall infiltrated beyond the soil surface also probably contributed. Moot *et al.* (2008) suggested that rainfall comparable to one weeks PET was probably required to elicit a pasture growth response following a limiting deficit. It is speculated that it may have been four days in this research.

Table 6-1: Pasture parameters during the spring period when water was non-limiting, from 2012-2016 at Ashley Dene, Canterbury.

Year	CP content (%)	Pasture mass (kg DM/ha)	Response to TT (kg DM/ha/°C day)	WUE (kg DM/ha/mm)
2012/13	22.0	2698	5.92	20.5
2013/14	21.1	3127	6.27	24.3
2014/15	22.6	1684	4.25	13.5
2015/16	23.1	1833	4.34	15.2

6.6   Pasture allocation

As well as pasture composition, pasture allocation is recognised as influencing livestock productivity. Increasing pasture allocation from 2 to at least 8 kg DM/ewe/day has been shown to increase pasture intake (Rattray *et al.*, 1982). In addition, a larger pasture allocation can increase the nutritive value of intake due the increased ability of livestock to select a preferential diet (Bhargava *et al.*, 1988).

In this research the lucerne/cocksfoot treatment supported 14% more GD during the spring than the lucerne treatment with the lucerne/brome treatment being intermediate (Table 4-6). This effectively reduced pasture allocation on the binary mixtures compared with the lucerne treatment. Given spring pasture yield was not different within years among treatments (Table 4-5), the increased duration of spring grazing on the binary mixtures should have been offset with a lower stocking rate relative to the lucerne treatment to ensure equivalent pasture allocation. This was not the case, and average pasture allocation was 6.2 kg/ewe GD on the lucerne, 5.8 kg/ewe GD on the lucerne/brome, and 5.4 kg/ewe GD on the lucerne/cocksfoot (Appendix 8). Despite the difference in pasture allocation, pasture utilisation was typically low

during this research as management prioritised per head production. Whereas Moot *et al.* (2016) reported pasture utilisation of ~75% for this stock class on a lucerne monoculture, here it was ~55% on all treatments so potentially reducing the effect of allocation.

Pasture treatments supported the same number of grazing days each summer and pasture allocation averaged 3.9 kg DM/ha over the duration of the experiment (Appendix 9). This pasture allocation deliberately allowed a high level of pasture refusal as ME content of pasture species was lowest and dead material content was highest of all seasons (Table 4-20, Figure 4-7). This was in order to support high growth rates of lambs to enable them to meet killable weights quickly.

The number of GD supported in the autumn was lowest on the lucerne treatment and highest on the lucerne/cocksfoot treatment (Table 4-32). This was consistent with pasture yield and resulted in mean pasture allocation of 3.4 kg DM/GD for all treatments (Appendix 10).

6.7 Pasture intake

There are a number of constraints to pasture intake in addition to pasture allocation. Pasture intake of productive livestock is limited by bite frequency, bite size and grazing duration (Cosgrove and Edwards, 2007). Livestock are reluctant to graze for longer than 10-12 hrs each day but if the rate of pasture intake is sufficiently low they are reported to operate in this range (Champion *et al.*, 2004). The composition of pasture allocation will have been influential in both the cost of foraging and the rate of digestion.

Livestock typically showed a preference for legumes over grasses and an aversion to dead material in this research (Figure 4-4, 4-5 & 4-6) which is consistent with the findings within the literature. The cost of selecting a preferential diet is smaller bite size therefore, as pasture allocation deviated from the preferred diet, there was an expectation that bite frequency and/or grazing duration would increase or pasture intake would reduce. In this research, the lucerne monoculture provided pasture allocation with a ~75% legume component which fits well with the preferential diet exhibited by livestock. (Figure 4-3, 4-5 & 4-6). The legume component was about half as much as this in the binary mixtures during years 2-4. In addition, dead material content was typically lower in the monoculture compared with the lucerne/cocksfoot treatment. Livestock actively selected palatable portions within these pasture components which is demonstrated by the decreasing nutritive value over a grazing (Table 4-7, 4-20 & 4-

33). This selection intensity would have increased over the duration of each grazing as remaining pasture allowance would have been modified by progressive selection. Livestock on the binary mixtures appeared to exhibit more selection intensity (Figure 4-4, 4-5 & 4-6) and therefore expected to have lower pasture intake than livestock on the monoculture.

In addition, the higher lucerne composition of the monoculture was expected to support larger bite size, reduced requirement for mastication and rumination, and promote passage of digesta therefore supporting smaller reticulorumen fill (McLean *et al.*, 1967; Cosgrove and Edwards, 2007).

6.7.1 Determining pasture intake

The measurements of pasture intake by disappearance during this research were difficult to interpret. Due to the experimental scale, relative to the number of pasture measurements and lack of pasture uniformity, there was potential for inaccuracy. This appeared most pronounced in determining post-grazing pasture mass. Some measurement periods were associated with pasture intake that exceeded the potential appetite of livestock (Court *et al.*, 2010) and other periods that could not provide the nutrition required to meet measured levels of livestock productivity (Nicol and Brookes, 2007).

As an alternative, livestock productivity was used to calculate pasture intake. This was based on the assumption that ME intake was the most limiting component to livestock productivity (Nicol and Brookes, 2007). This was calculated from Nicol and Brookes (2007) and then divided by a consistent estimate of ME content of pasture intake. The ME content used was 12 MJ ME/kg DM as this was deemed to be the highest content the palatable portion of these pasture species could provide (Brown and Moot, 2004; Black and Ryan-Salter, 2016). This reflected the typically low grazing intensity of the productive livestock over the duration of the experiment which would have supported the ability of livestock on all treatments to select an intake of high nutritive value (Bhargava *et al.*, 1988). This calculated pasture intake would have been the least that could have supported levels of livestock productivity.

The ME content of pasture intake among treatments was potentially different. The ME content of the components of spring pasture were 11.0 MJ ME/kg DM (Table 4-7) with the post-grazing content being lower. This is consistent with livestock selecting the more palatable portion of these. However, the difference between pre and post-grazing ME content was greater on the

lucerne component compared with the grass and unsown species. This was 9.4 MJ ME/kg DM for the lucerne and 10.5 MJ ME/kg DM for grass and unsown species. This suggests the ME content of intake was higher for lucerne plants. This is probably due to the enhanced ability of livestock to discriminate between the higher palatability of the leaves and the lower palatability of the stem as observed by Jagusch *et al.* (1971). Similar trends were noticed in the summer and the autumn (Table 4-20 & 4-33). As the proportion of lucerne in pasture allocation increased, the ME content of pasture intake potentially did too. This method potentially underestimated actual pasture intake on the binary mixtures to a larger degree than on the monoculture.

6.8   Ewe & lamb growth rates

During the spring, there were a number of livestock components that influenced ME requirement/GD but the most influential among treatments was LWG of lambs and ewes.

The lucerne treatment maintained higher lamb growth rates than the binary mixtures during the spring through greater ME intake of ewes & lambs. Mean lamb growth rates on the lucerne were 311 g/day compared with 269 g/day and 245 g/day on the lucerne/brome and lucerne/cocksfoot (Appendix 1). These growth rates compare well to the ~300 g/day and ~250 g/day on similar lucerne and ryegrass/white clover allocations, respectively, measured by Rattray *et al.* (1982). Lucerne has again shown its superiority in achieving higher growth rates of lambs at foot compared with grass based pastures.

There was a positive relationship (R^2=0.749) between ewe and lamb LWG during lactation (Appendix 17). It is likely that ewe milk and live weight production were equally influenced by the level of pasture intake. Ewes that were supporting lamb growth rates of over 300 g/day were typically growing more than 100 g/day themselves, whereas ewes that were losing weight were probably supporting lamb growth rates of less than 250 g/day. The LWG of lactating ewes was variable but those on the lucerne monoculture were on average 5 kg heavier at weaning than those on the binary mixtures (Figure 4-1).

To meet the levels of productivity, ewes & lambs on the lucerne had an ~11% larger per head pasture intake than those on the binary mixtures (Appendix 14). This was 3.2 kg/DM/ewe GD compared with 2.9 kg DM/ewe GD. Larger pasture intake resulted in increasing efficiency of converting this to LWG as all livestock had an obligatory maintenance requirement (although,

this was increasing at a faster rate on more rapidly growing stock). Taking into account ewe and lamb LWG, an ~11% increase in ME intake/GD on the lucerne resulted in a ~32% increase in LWG/GD.

6.8.1 Stage of lactation

The higher pasture intake of ewes & lambs on the lucerne treatment was most pronounced during the early stages of lactation. During the first four weeks, the calculated pasture intake was ~32% greater than on the binary mixtures. This was confounded by a 9% larger pasture allocation on the lucerne treatment over this period. Ewes on the lucerne treatment were able to consume ~3.3 kg DM/day from early in lactation whereas those on the binary mixture appeared limited to ~2.5 kg DM/day (Appendix 19). This is the equivalent of 4.4% and 3.6% of ewe live weight at the time. This appears to be in excess of the potential appetite of ewes on the lucerne treatment but may have been supplemented with some lamb pasture intake. The ability to transition from pregnancy to lactation pasture intake requirement is suppressed by reticulorumen capacity (Stanley *et al.*, 1993) and may have been enhanced here by the lower NDF content the lucerne monoculture provided, which supported faster passage of digesta (Waghorn *et al.*, 2007). From week five, this advantage appeared much reduced with pasture intake increasing from ~3.1 to ~3.3 kg DM/ewe GD from week 5 to 11 of lactation on all treatments. This was the equivalent of ~4.3% to ~4.6% of ewe live weight with lamb intake obviously becoming more important as lactation progressed.

The increased pasture intake at the beginning of lactation was potentially supported by 10-15% larger pasture allocation on the lucerne treatment but these ewes & lambs also achieved higher utilisation of allocation, being 64% compared with ~55% on the binary mixtures.

6.8.2 Establishment year

The binary mixtures maintained lamb growth rates in excess of 300 g/day in the spring following pasture establishment. During this spring the lucerne composition of pasture yield was 68% and 78% for the lucerne/brome and lucerne/cocksfoot treatment (Section 4.4.9). Thereafter, when lucerne composition settled at ~37% and lamb growth rates averaged ~240 g/day on the binary mixtures.

6.9 Weaned lamb growth rates

During the summer, lambs on the lucerne treatment grew at a faster rate than those on the binary mixtures as these had a 30% larger ME intake. Average growth rates of weaned lambs in the summer were 225 g/day on the lucerne treatment (Appendix 1) which is midway in the 180-270 g/day range measured by Wang *et al.* (2009) and McLean *et al.* (1967). The lambs on the binary mixtures were growing at 134 g/day, 40% lower than on the monoculture. Cruickshank (1986) reported that weaned lambs grew at a 27% lower rate when grazing grass compared to legumes when pasture allocation was not limiting. This author estimated that a non-limiting pasture allocation for weaned lambs was 4.5 kg DM/GD on lucerne and 6.0 kg DM/GD on prairie grass. This suggests pasture allocation was probably more limiting on the binary mixtures compared with the monoculture in this research.

The pasture intake to achieve lamb growth rates in this research, assuming an ME content of 12 MJ ME/kg DM, was 1.2 kg DM/GD on the lucerne treatment and ~0.9 kg DM/GD on the binary mixtures (Appendix 15). This is ~4.0% and ~3.2% of mean live weight, respectively. This would suggest lambs on the lucerne treatment were consuming their potential appetite (Court *et al.*, 2010). These levels of pasture intake were supported by 67% lucerne composition in the monoculture and ~37% in the binary mixtures with about 25% dead material in each pasture (Figure 4-7). In the summer, differences in pasture intake among treatments were not confounded by pasture allocation.

6.10 Hogget growth rates

During the autumn there was a trend for the hoggets on the lucerne and lucerne/brome treatment to grow 29% faster than on the lucerne/cocksfoot (Appendix 1). Over four years, this averaged 167 g/day and 129 g/day, respectively. These appear low in comparison to the growth rates of 250-260 g/day of young sheep grazing lucerne measured by Black and Ryan-Salter (2016). Mean growth rates here were suppressed by hogget performance during the final autumn due to low pasture allocation and lower grazing residuals. During the autumn of the first three years mean hogget growth rate across treatments was ~200 g/day.

Based on 12 MJ ME/kg DM content of pasture intake, this ranged from 0.8-1.6 kg DM/GD and appeared dependent on pasture allocation and grazing residual. Pasture allocation of 2.5-3.0 kg DM/GD was sufficient for hoggets to consume >3.5% live weight so long as they were not

required to graze below ~550 kg DM/ha (Appendix 10 & 16). This appeared independent of pasture treatment.

In the spring and the summer, livestock on the lucerne treatment were able to consume up to 36% more dry matter than on the binary mixtures. In the autumn, the benefit of higher lucerne composition had disappeared. This is despite a similar NDF advantage and presumably similar ease of discrimination between palatable and unpalatable portions. The limitations to pasture intake experienced during the spring and summer on the binary mixtures may have lessened during the autumn. The fact that calculated pasture intake was ~3.8% of hogget live weight during 2013/14 and 2014/15 on the binary mixtures suggests they were consuming close to their potential appetite. The benefit acquired from a high proportion of lucerne in the diet during the autumn may have been countered by another limitation to pasture intake during this season. CP content of pasture yield was 200% of the requirement of hoggets (Section 4.6.6). The tendency of livestock to select the most palatable portion of pasture allocation would result in this being even higher in pasture intake. This will have increased the metabolic cost to process excessive rumen ammonia build up and suppressed pasture intake (Pacheco and Waghorn, 2008). The shoot structure of lucerne, that enhances the discrimination of more and less palatable components, may have suppressed the ability of hoggets to dilute CP intake. The accessibility of the grass component in the binary mixtures may have been beneficial here (Chapman *et al.*, 2007).

6.11 Practical implications

Providing a lucerne monoculture enables up to 60% faster growth rates of young sheep compared with the alternative binary mixtures examined here, despite these maintaining a 37% lucerne composition. An allocation of 6 kg DM/ewe & her twin lambs appeared sufficient to achieve growth rates of 100 g/LWG/day for the lactating ewe and 300 g/LWG/day for each of the lambs. However, the practice of delaying introduction of ewes & lambs in the spring until lucerne is 15 cm in height (~1350 kg DM/ha) reduces the practicality of this crop. The primary advantage of lucerne occurs during the first four weeks of lactation where this facilitates greater pasture intake during the transition from pregnancy diet to lactation diet. Compared with grass based pastures, this delays lucerne availability by ~20 days in the spring, aligning well with ewes lambing to the second oestrus cycle. The lamb growth advantage allows these late lambs to meet or exceed weights achieved by the early lambs by mid to late November. Transferring ewes lambing to the first cycle from grass based pasture to lucerne (once 15 cm in height is

attained) would offer little advantage. It appears any benefit lucerne provides to increasing pasture intake is negligible from mid lactation. This is potentially a result of increasing ewe reticulorumen capacity as well as increasing lamb pasture consumption.

There are indications that livestock can be introduced to lucerne prior to attaining 15 cm in height with little adverse effect on pasture yield (Black A. D., pers. comm, 2017). This research revealed a strong positive association between growth response to thermal time and pre grazing pasture mass on all treatments. The risk of early introduction of livestock is reduced mean spring pasture covers resulting in reduced interception of PAR. However, this opportunity requires further investigation and should recognise that late October and early November lucerne yield could be sacrificed to maximise the number of lactating ewes grazing this species during the transition period. Assuming ewes & lambs could adapt quickly to a change in diet, grass based pasture could be used during mid and late lactation to maintain LWG.

The alternative of delaying lambing to align with a 15 cm pre grazing pasture height is undesirable as this would reduce the time available to grow out lambs during the more reliable spring period prior to a limiting soil water deficit restricted pasture growth.

Grass based pastures, including more winter active species, can be used to provide increased early spring feed supply to support an early lambing date. The inclusion of these in a mixture with lucerne requires the compromise of the requirements for each species. In this research there was no indication that increased biodiversity would increase pasture yield although comparisons to monocultures of the sown grass species was not examined. The inclusion of a pasture legume with grass increases ME intake through providing a more preferential diet and reduced NDF levels. In addition, lucerne appeared to facilitate increased ME intake through improved discrimination between portions of palatable and unpalatable shoot. The legume component is also important to maintain the N balance of grass based pastures in the absence of nitrogenous fertilisers. In this research, a 37% lucerne component was sufficient to uphold the N status of these pastures relative to a lucerne monoculture. To maximise legume allocation at the onset of lactation the use of more winter active species, like subterranean clover, is potentially preferential to lucerne in binary mixtures.

Post weaning, lucerne monocultures should be provided to lambs in preference to grass based pastures to support earlier killable weights. Pasture allocation should allow for the high dead

material composition and depressed ME content during the summer and higher pasture residuals should be expected compared with the spring. Pasture allocation of ~4.0 kg/lamb/day during this research supported lamb growth rates of 225 g/day on the lucerne, which was ~60% higher than on the grass based pastures. The unreliability of summer pasture growth at this site required alternative feed supply to maintain lamb growth rates through this season. Here, off farm grazing was the alternative feed supply but crops that can utilise spring soil water for growth and maintain feed quality into the summer (like brassica crops) may be a more sustainable option.

During the autumn there appeared to be little advantage in LWG from feeding a lucerne monoculture over a grass dominant pasture. Hoggets in this research consumed close to their potential appetite on all treatments when pasture allocation was above 2.5 kg DM/GD and grazing residual was above 550 kg DM/ha. As a result, hogget growth rates were >200 g/day. If pasture intake was suppressed due to high lucerne CP content, this could be remediated through supplementation of a low CP alternative like hay or grain. Alternatively, the lucerne can be mown and allowed to wilt before stock are introduced. If sufficient grass based pastures are available, these should be utilised to ensure lucerne pastures receive a period of regrowth to recharge root reserves.

6.12 Conclusions

- Over four years the live weight production of the lucerne treatment averaged 28% more than the binary mixtures.
- At Ashley Dene, the lucerne composition of the binary mixtures equilibrated at ~37% following the year of establishment allowing a sown grass component of 40-50%. The lucerne treatment maintained a lucerne composition of ~80%.
- Pasture yield was independent of pasture composition during each year.
- The inclusion of a companion grass species with lucerne supported the introduction of ewes & lambs 2-3 weeks earlier than the lucerne treatment in this research.
- ME intake per GD was ~30% larger on the lucerne treatment than the binary mixtures during the first four weeks of lactation and in the summer.
- Higher lucerne composition supported larger ME intake through the enhanced ability of livestock to discriminate between the more and less digestible portions of lucerne

compared to sown grasses. In addition, the lower NDF content of lucerne potentially supported a faster rate of pasture intake and digestion.

- Higher lucerne composition did not promote pasture intake during the autumn. The limitation to intake of grass based pastures may have lessened during the autumn or the advantage of lucerne plant structure and low NDF was countered, perhaps, due to an excessively high CP content during this season.

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APPENDICES

Appendix 1: Livestock growth rates (g LWG/GD) of four stock classes grazing three dryland pastures from 2012-2016. Years are used as replicates.

Treatment	Lactating ewe	Lamb at foot	Weaned lamb	Hogget
Lucerne	90	311 [a]	225 [a]	169
Luc/Brome	25	269 [ab]	140 [b]	165
Luc/CF	19	245 [b]	128 [b]	129
S.E.M.	23.7	14.6	18.6	9.6
P-value	0.146	**0.048**	**0.020**	0.051

Note: Means within columns followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 2: Crude protein content (%) of spring pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	22.7	22.3	23.0	24.2	23.0
Luc/Brome	21.9	20.9	22.6	22.9	22.1
Luc/CF	22.3	21.8	22.1	21.9	22.0
Year mean	22.3	21.7	22.5	23.0	

	Treatment	Year	Interaction
S.E.M.	6.60	6.49	11.76
P-value	0.494	0.516	0.962

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 3: Metabolisable energy content (MJ ME/kg DM) of spring pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	11.4	10.7	10.3	10.8	10.8 [B]
Luc/Brome	11.6	11.4	11.3	11.3	11.4 [A]
Luc/CF	11.5	11.3	11.0	11.2	11.3 [A]
Year mean	11.5 [a]	11.1 [ab]	10.9 [b]	11.1 [ab]	

	Treatment	Year	Interaction
S.E.M.	0.15	0.16	0.29
P-value	**0.036**	**0.050**	0.911

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 4: Crude protein content (%) of summer pasture yield from three dryland pastures from 2012-2014 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	Treatment mean
Lucerne	18.5	18.5	18.5
Luc/Brome	18.0	17.9	18.0
Luc/CF	18.6	18.0	18.3
Year mean	18.4	18.1	
	Treatment	Year	Interaction
S.E.M.	0.76	0.89	1.33
P-value	0.892	0.860	0.984

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 5: Metabolisable energy content (MJ ME/kg DM) of summer pasture yield from three dryland pastures from 2012-2014 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	Treatment mean
Lucerne	9.7	9.7	9.7
Luc/Brome	11.7	9.8	10.8
Luc/CF	10.4	10.4	10.4
Year mean	10.6	10.0	
	Treatment	Year	Interaction
S.E.M.	0.27	0.24	0.39
P-value	0.051	0.086	0.067

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 6: Crude protein content (%) of autumn pasture yield from three dryland pastures from 2012-2015 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	Treatment mean
Lucerne	27.4	23.2	22.8	24.5
Luc/Brome	23.9	24.2	21.5	23.2
Luc/CF	24.5	22.0	22.4	23.0
Year mean	25.2 [a]	23.1 [ab]	22.2 [b]	
	Treatment	Year	Interaction	
S.E.M.	0.48	0.73	1.14	
P-value	0.113	**0.021**	0.462	

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 7: Metabolisable energy content (MJ ME/kg DM) of autumn pasture yield from three dryland pastures from 2012-2015 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	Treatment mean
Lucerne	11.3	10.4	10.6	10.8
Luc/Brome	11.1	10.8	10.8	10.9
Luc/CF	10.9	10.3	11.3	10.8
Year mean	11.1[a]	10.5 [b]	10.9 [a]	

	Treatment	Year	Interaction
S.E.M.	0.08	0.11	0.18
P-value	0.521	**0.001**	0.052

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

Appendix 8: Pasture allocation (kg DM/ewe GD) of spring pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	6.68	6.23	6.00	6.07	6.24
Luc/Brome	7.12	5.16	5.21	5.61	5.78
Luc/CF	6.94	5.16	4.96	4.40	5.37
Year mean	6.91 [a]	5.52 [b]	5.39 [b]	5.36 [b]	

	Treatment	Year	Interaction
S.E.M.	0.305	0.306	0.551
P-value	0.178	**0.002**	0.561

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

Appendix 9: Pasture allocation (kg DM/GD) of summer pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2.83	3.97	3.23	3.81	3.46
Luc/Brome	3.36	3.77	7.00	3.85	4.49
Luc/CF	3.09	3.50	4.38	3.68	3.66
Year mean	3.09 [b]	3.75 [b]	4.87 [a]	3.78 [ab]	

	Treatment	Year	Interaction
S.E.M.	0.332	0.385	0.666
P-value	0.113	**0.019**	0.086

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

Appendix 10: Pasture allocation (kg DM/GD) of autumn pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2.21	6.28	2.89	3.48	3.72
Luc/Brome	2.51	5.94	2.90	1.51	3.22
Luc/CF	2.48	6.67	2.37	1.40	3.23
Year mean	2.40 [b]	6.30 [a]	2.72 [b]	2.13 [b]	

	Treatment	Year	Interaction
S.E.M.	0.195	0.296	0.485
P-value	0.169	**<0.001**	0.155

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 11: Pasture intake by disappearance (kg DM/ewe GD) of spring pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	3.44	2.30	3.18	2.62	2.89
Luc/Brome	3.01	1.98	2.06	2.49	2.39
Luc/CF	3.12	2.61	2.52	2.49	2.69
Year mean	3.19 [a]	2.30 [b]	2.59 [b]	2.53 [b]	

	Treatment	Year	Interaction
S.E.M.	0.127	0.157	0.268
P-value	0.055	**0.002**	0.449

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 12: Pasture intake by disappearance (kg DM/GD) of summer pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1.11	1.25	0.66	0.88	0.98 [B]
Luc/Brome	1.51	1.53	2.08	1.68	1.70 [A]
Luc/CF	1.19	1.51	1.72	1.67	1.52 [A]
Year mean	1.27	1.43	1.49	1.41	

	Treatment	Year	Interaction
S.E.M.	0.115	0.146	0.247
P-value	**0.003**	0.744	0.273

Note: Means followed by the same letter across treatments or among years are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 13: Pasture intake by disappearance (kg DM/GD) of autumn pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1.14 [e]	1.64 [bcde]	1.21 [de]	2.65 [a]	1.66
Luc/Brome	1.19 [de]	1.88 [bc]	1.75 [bcd]	1.47 [cde]	1.57
Luc/CF	1.30 [cde]	2.07 [b]	1.31 [cde]	1.25 [de]	1.48
Year mean	1.21	1.86	1.42	1.79	
	Treatment		**Year**	**Interaction**	
S.E.M.	0.100		0.119	0.204	
P-value	0.493		<0.001	**<0.001**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 14: Pasture intake by calculated energy requirement (kg DM/ewe GD) of spring pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	3.74 [ab]	2.67 [e]	3.07 [d]	3.44 [bc]	3.23
Luc/Brome	3.68 [ab]	2.39 [ef]	3.13 [d]	2.39 [ef]	2.90
Luc/CF	3.85 [a]	2.18 [f]	3.18 [cd]	2.42 [ef]	2.91
Year mean	3.76	2.41	3.13	2.75	
	Treatment		**Year**	**Interaction**	
S.E.M.	0.056		0.063	0.110	
P-value	0.003		<0.001	**<0.001**	

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 15: Pasture intake by calculated energy requirement (kg DM/GD) of summer pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	1.06 [bc]	1.06 [bc]	1.05 [bc]	1.55 [a]	1.18
Luc/Brome	0.86 [d]	0.84 [d]	0.66 [e]	1.20 [b]	0.89
Luc/CF	0.99 [cd]	0.82 [de]	0.66 [e]	0.91 [cd]	0.84
Year mean	0.97	0.91	0.79	1.22	
	Treatment		**Year**	**Interaction**	
S.E.M.	0.030		0.037	0.064	
P-value	<0.001		<0.001	**0.003**	

Note: Means followed by the same letter are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

Appendix 16: Pasture intake by calculated energy requirement (kg DM/GD) of autumn pasture yield from three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	0.85	1.55	1.55	1.02	1.24
Luc/Brome	0.94	1.54	1.64	0.90	1.25
Luc/CF	0.86	1.31	1.52	0.79	1.12
Year mean	0.88	1.47	1.57	0.90	
	Treatment		**Year**	**Interaction**	
S.E.M.	0.0001		0.0001	0.0003	
P-value	<0.001		<0.001	**<0.001**	

Due to only one live weight rotation each autumn, every mean is different.

Note: Means followed by the same letter across treatments or among years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.
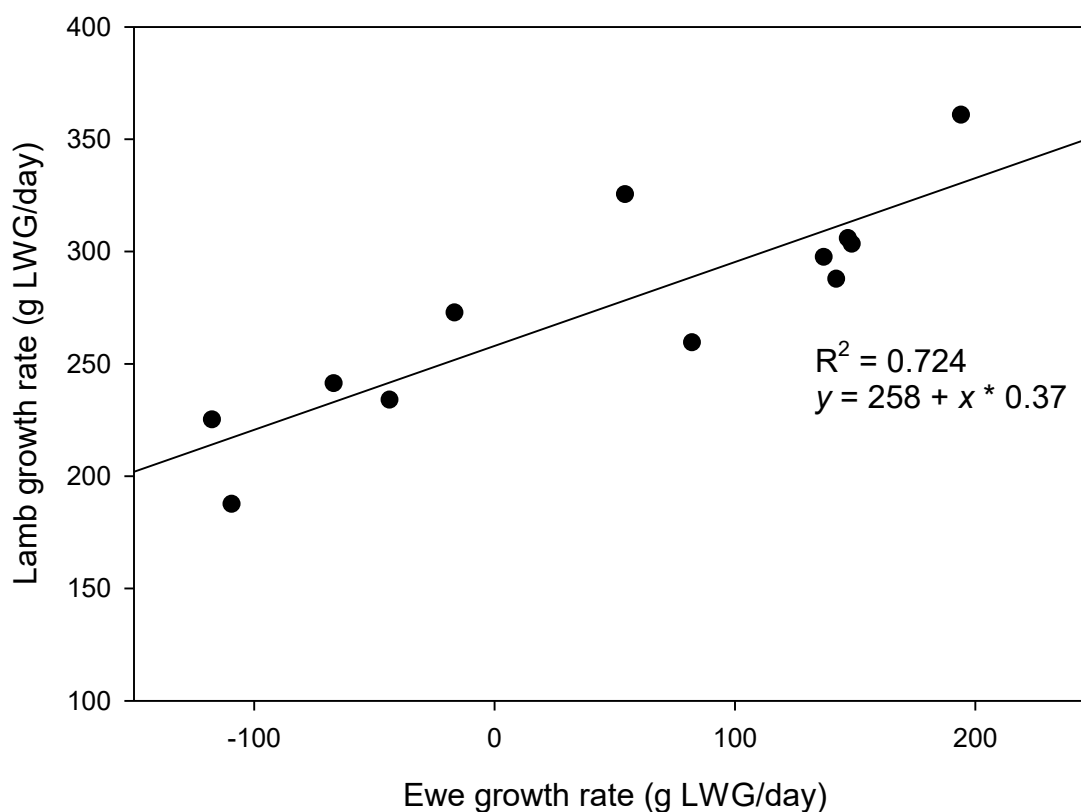
Appendix 17: Relationship between spring ewe and lamb growth rate on three dryland pastures from 2012-2015 at Ashley Dene, Canterbury.

Appendix 18: Mean pre-grazing pasture mass (kg DM/ha) during the spring of three dryland pastures from 2012-2016 at Ashley Dene, Canterbury.

Treatment	2012-13	2013-14	2014-15	2015-16	Treatment mean
Lucerne	2601 [c]	2922 [bc]	2018 [de]	2125 [d]	2416
Luc/Brome	2757 [c]	3142 [ab]	1459 [f]	1644 [ef]	2251
Luc/CF	2736 [c]	3318 [a]	1575 [f]	1731 [ef]	2340
Year mean	2698	3127	1684	1833	

	Treatment	Year	Interaction
S.E.M.	63.8	79.7	135.8
P-value	0.234	<0.001	**0.015**

Note: Means followed by the same letter are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 19: Calculated mean pasture intake (kg DM/ewe GD) based on energy requirement to meet level of productivity of three periods during the spring from three dryland pastures from 2012-2015 at Ashley Dene, Canterbury.

Treatment	Weeks 1-4	Weeks 5-8	Weeks 9+
Lucerne	3.29 [a]	3.13	3.39
Luc/Brome	2.50 [b]	3.08	3.15
Luc/CF	2.48 [b]	3.13	3.27
Period mean	2.76	3.11	3.25
S.E.M.	0.154	0.168	0.222
P-value	**<0.001**	0.979	0.689

Note: Means followed by the same letter within columns years are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.

Appendix 20: Mean pasture allocation (kg DM/ewe GD) for three periods during the spring from three dryland pastures from 2012-2015 at Ashley Dene, Canterbury.

Treatment	Weeks 1-4	Weeks 5-8	Weeks 9+
Lucerne	5.14	5.87	9.34
Luc/Brome	4.62	4.86	9.90
Luc/CF	4.40	4.77	7.26
Period mean	4.72	5.17	8.83
S.E.M.	0.393	0.406	1.214
P-value	0.382	0.093	0.114

Note: Means followed by the same letter within columns are not different at the $\alpha=0.05$ level. Treatment acronyms are reported in Table 4-1.
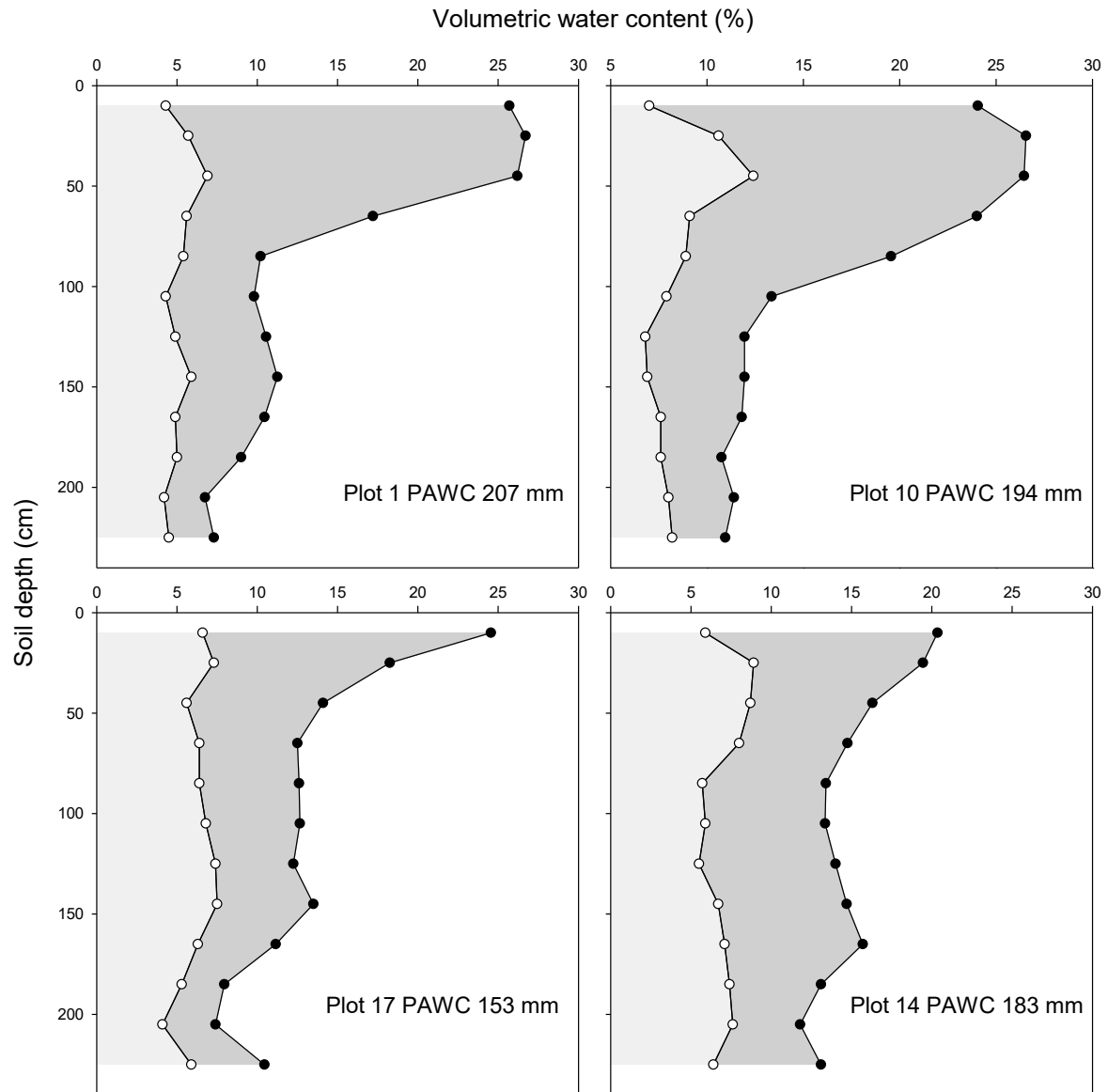
Appendix 21: Plant available water holding capacity (PAWC) (%), being the difference between drained upper limit (●) and lower limit (○), measured to a depth 2.3 m from 2012-2016 of four plots of the experimental area at Ashley Dene Canterbury.

Appendix 22: Mean live weight (kg) of stock classes at the time of introduction to the experimental area.

Stock class	Treatment	2012/13	2013/14	2014/15	2015/16	Treatment mean
Ewes	**Lucerne**	64	63 [b]	75 [a]	78 [a]	70
	Luc/Brome	65	69 [a]	70 [ab]	74 [b]	69
	Luc/CF	67	67 [ab]	69 [b]	70 [b]	69
	S.E.M.	1.3	1.6	2.4	1.5	
Weaned lambs	**Lucerne**	30	25 [a]	27	27	27
	Luc/Brome	29	24 [b]	28	26	27
	Luc/CF	29	22 [c]	28	26	26
	S.E.M.	0.4	0.4	0.4	0.9	
Hoggets	**Lucerne**	36	41	39	46	40
	Luc/Brome	35	42	38	46	40
	Luc/CF	35	41	39	46	40
	S.E.M.	0.9	0.9	0.9	1.3	

Note: Means followed by the same letter within columns within a stock class are not different at the α=0.05 level. Treatment acronyms are reported in Table 4-1.

Appendix 23: Summary of grazing periods for the lucerne treatment from 2012-2016. E&L refers to ewes & lambs over lactation, WL refers to weaned lambs, hgt refers to hoggets. The status is productive (Prod) when weight gain is recorded, or unproductive (Unprod) when livestock are used to reduce the grazing residual. SR refers to the stocking rate over the entire treatment area.

Year	Rep	Stock	Status	Date on	Date off	Ewe SR/ha	Lamb SR/ha	Other SR/ha
2012/13	1	E&L	Prod	5/09/2012	18/09/2012	2.3	4.6	
2012/13	1	E&L	Prod	18/09/2012	21/09/2012	10.1	18.7	
2012/13	6	E&L	Prod	21/09/2012	26/09/2012	10.1	18.7	
2012/13	2	E&L	Prod	26/09/2012	3/10/2012	10.1	18.7	
2012/13	5	E&L	Prod	3/10/2012	8/10/2012	10.1	18.7	
2012/13	3	E&L	Prod	8/10/2012	16/10/2012	10.1	18.7	
2012/13	4	E&L	Prod	16/10/2012	24/10/2012	10.1	18.7	
2012/13	1	E&L	Prod	24/10/2012	31/10/2012	10.1	18.7	
2012/13	6	E&L	Prod	31/10/2012	5/11/2012	10.1	18.7	
2012/13	2	E&L	Prod	5/11/2012	8/11/2012	10.1	18.7	
2012/13	2	E&L	Prod	8/11/2012	12/11/2012	10.1	18.7	
2012/13	5	E&L	Prod	12/11/2012	17/11/2012	10.1	18.7	
2012/13	3	E&L	Prod	17/11/2012	24/11/2012	10.1	18.7	
2012/13	4	E&L	Prod	24/11/2012	28/11/2012	10.1	18.7	
2012/13	1	WL	Prod	28/11/2012	10/12/2012		18.7	
2012/13	6	WL	Prod	10/12/2012	17/12/2012		18.7	
2012/13	2	WL	Prod	17/12/2012	24/12/2012		18.7	
2012/13	5	WL	Prod	24/12/2012	29/12/2012		18.7	
2012/13	3	WL	Prod	29/12/2012	5/01/2013		18.7	
2012/13	4	WL	Prod	5/01/2013	8/01/2013		18.7	
2012/13	4	WL	Prod	8/01/2013	11/01/2013		13.3	
2012/13	1	WL	Prod	11/01/2013	19/01/2013		10.8	
2012/13	3	Ewes	Unprod	18/01/2013	22/01/2013			35.3
2012/13	4	Ewes	Unprod	18/01/2013	22/01/2013			18.6
2012/13	6	WL	Prod	19/01/2013	22/01/2013		10.8	
2012/13	1	Ewes	Unprod	22/01/2013	25/01/2013			26.5
2012/13	2	Ewes	Unprod	22/01/2013	28/01/2013			18.6
2012/13	5	WL	Prod	22/01/2013	25/01/2013		10.8	
2012/13	5	Ewes	Unprod	25/01/2013	28/01/2013			35.3
2012/13	6	Ewes	Unprod	25/01/2013	30/01/2013			26.5
2012/13	1	Ram hgt	Unprod	5/03/2013	8/03/2013			27.7
2012/13	3	Ram hgt	Unprod	10/03/2013	13/03/2013			37.1
2012/13	4	Ram hgt	Unprod	14/03/2013	16/03/2013			37.1
2012/13	5	Ram hgt	Unprod	19/03/2013	21/03/2013			37.1
2012/13	2	Ram hgt	Unprod	20/03/2013	26/03/2013			13.8
2012/13	6	Ram hgt	Unprod	23/03/2013	24/03/2013			37.1
2012/13	3	Ram hgt	Prod	15/05/2013	24/05/2013			9.4
2012/13	4	Ram hgt	Prod	24/05/2013	30/05/2013			9.4
2012/13	1	Ram hgt	Prod	30/05/2013	7/06/2013			11.8

2012/13	3	Ewes	Unprod	3/06/2013	4/06/2013			33.6
2012/13	4	Ewes	Unprod	6/06/2013	7/06/2013			33.6
2012/13	1	Ewes	Unprod	7/06/2013	10/06/2013			33.6
2012/13	2	Ewe hgt	Prod	7/06/2013	12/06/2013			11.8
2012/13	2	Ewe hgt	Prod	12/06/2013	17/06/2013			15.4
2012/13	5	Ewe hgt	Prod	17/06/2013	22/06/2013			15.4
2012/13	2	Ewes	Unprod	20/06/2013	21/06/2013			29.2
2012/13	6	Ewe hgt	Prod	22/06/2013	26/06/2013			15.4
2012/13	5	Ewes	Unprod	24/06/2013	25/06/2013			29.2
2012/13	6	Ewes	Unprod	27/06/2013	28/06/2013			29.2
2013/14	1	E&L	Prod	6/09/2013	13/09/2013	1.1	2.1	
2013/14	1	E&L	Prod	13/09/2013	16/09/2013	5.3	10.6	
2013/14	1	E&L	Prod	16/09/2013	18/09/2013	7.8	15.5	
2013/14	1	E&L	Prod	18/09/2013	24/09/2013	11.7	23.3	
2013/14	5	E&L	Prod	24/09/2013	30/09/2013	11.7	23.0	
2013/14	4	Ewe hgt	Unprod	24/09/2013	30/09/2013			31.1
2013/14	6	E&L	Prod	30/09/2013	3/10/2013	11.7	23.3	
2013/14	6	E&L	Prod	3/10/2013	7/10/2013	11.7	23.3	
2013/14	2	E&L	Prod	7/10/2013	14/10/2013	11.7	22.6	
2013/14	3	E&L	Prod	14/10/2013	23/10/2013	11.7	23.3	
2013/14	1	E&L	Prod	23/10/2013	31/10/2013	11.7	23.3	
2013/14	5	E&L	Prod	31/10/2013	5/11/2013	11.7	22.3	
2013/14	6	E&L	Prod	5/11/2013	11/11/2013	11.7	23.3	
2013/14	2	E&L	Prod	11/11/2013	13/11/2013	11.7	22.3	
2013/14	2	E&L	Prod	13/11/2013	19/11/2013	11.7	22.3	
2013/14	3	E&L	Prod	19/11/2013	25/11/2013	11.7	23.3	
2013/14	4	E&L	Prod	25/11/2013	30/11/2013	11.7	22.3	
2013/14	1	WL	Prod	3/12/2013	12/12/2013		21.9	
2013/14	5	WL	Prod	12/12/2013	16/12/2013		20.5	
2013/14	6	WL	Prod	16/12/2013	19/12/2013		21.9	
2013/14	2	WL	Prod	19/12/2013	24/12/2013		20.5	
2013/14	3	WL	Prod	24/12/2013	29/12/2013		21.9	
2013/14	4	WL	Prod	29/12/2013	2/01/2014		20.5	
2013/14	1	WL	Prod	6/01/2014	16/01/2014		16.6	
2013/14	5	WL	Prod	16/01/2014	20/01/2014		16.6	
2013/14	6	WL	Prod	20/01/2014	23/01/2014		16.6	
2013/14	2	WL	Prod	23/01/2014	28/01/2014		16.6	
2013/14	3	WL	Prod	28/01/2014	31/01/2014		16.6	
2013/14	4	WL	Prod	31/01/2014	3/02/2014		16.6	
2013/14	3	WL	Unprod	5/02/2014	7/02/2014		20.7	
2013/14	4	WL	Unprod	7/02/2014	11/02/2014		20.7	
2013/14	1	Ram hgt	Prod	24/03/2014	4/04/2014			8.0
2013/14	5	Ram hgt	Prod	4/04/2014	10/04/2014			8.0
2013/14	6	Ram hgt	Prod	10/04/2014	14/04/2014			8.0
2013/14	2	Ram hgt	Prod	17/04/2014	25/04/2014			8.0
2013/14	3	Ram hgt	Prod	25/04/2014	6/05/2014			8.0

2013/14	4	Ram hgt	Prod	6/05/2014	9/05/2014			15.7
2013/14	1	Ewes	Unprod	7/05/2014	22/05/2014	10.2		
2013/14	5	Ewes	Unprod	22/05/2014	29/05/2014	10.2		
2013/14	1	Ewes	Unprod	25/05/2014	26/05/2014	53.0		
2013/14	6	Ewes	Unprod	29/05/2014	4/06/2014	10.2		
2013/14	5	Ewes	Unprod	1/06/2014	2/06/2014	53.0		
2013/14	3	Ewes	Unprod	4/06/2014	10/06/2014	10.2		
2013/14	6	Ewes	Unprod	8/06/2014	9/06/2014	53.0		
2013/14	4	Ewes	Unprod	10/06/2014	18/06/2014	10.2		
2013/14	3	Ewes	Unprod	11/06/2014	12/06/2014	53.0		
2013/14	2	Ewes	Unprod	19/06/2014	24/06/2014	15.2		
2014/15	1	E&L	Prod	18/09/2014	27/09/2014	8.1	14.8	
2014/15	5	E&L	Prod	27/09/2014	30/09/2014	8.1	14.8	
2014/15	5	E&L	Prod	30/09/2014	2/10/2014	9.9	17.7	
2014/15	6	E&L	Prod	2/10/2014	7/10/2014	9.9	17.7	
2014/15	2	E&L	Prod	7/10/2014	14/10/2014	9.9	17.7	
2014/15	3	E&L	Prod	14/10/2014	21/10/2014	9.9	17.7	
2014/15	4	E&L	Prod	21/10/2014	28/10/2014	9.9	17.7	
2014/15	1	E&L	Prod	28/10/2014	2/11/2014	9.9	17.7	
2014/15	5	E&L	Prod	2/11/2014	5/11/2014	9.9	17.7	
2014/15	6	E&L	Prod	5/11/2014	7/11/2014	9.9	17.7	
2014/15	2	WL	Prod	26/11/2014	2/12/2014		10.6	
2014/15	2	WL	Prod	2/12/2014	5/12/2014		15.5	
2014/15	3	WL	Prod	5/12/2014	15/12/2014		15.5	
2014/15	2	Ewe hgt	Unprod	11/12/2014	20/12/2014			8.8
2014/15	4	WL	Prod	15/12/2014	24/12/2014		15.5	
2014/15	3	Ewe hgt	Unprod	20/12/2014	27/12/2014			8.8
2014/15	1	WL	Prod	24/12/2014	31/12/2014		15.5	
2014/15	4	Ewe hgt	Unprod	27/12/2014	31/12/2014			8.8
2014/15	5	WL	Prod	31/12/2014	5/01/2015		15.5	
2014/15	1	Ewe hgt	Unprod	31/12/2014	4/01/2015			8.8
2014/15	6	WL	Prod	5/01/2015	7/01/2015		15.5	
2014/15	5	Ewe hgt	Unprod	5/01/2015	7/01/2015			8.8
2014/15	6	Ewe hgt	Unprod	7/01/2015	9/01/2015			8.8
2014/15	6	WL	Unprod	18/02/2015	20/02/2015			10.6
2014/15	5	WL	Unprod	20/02/2015	22/02/2015			10.6
2014/15	1	WL	Unprod	26/02/2015	2/03/2015			9.9
2014/15	6	Ewes	Unprod	28/02/2015	1/03/2015	47.7		
2014/15	5	Ewes	Unprod	2/03/2015	3/03/2015	47.7		
2014/15	4	WL	Unprod	5/03/2015	9/03/2015			5.3
2014/15	1	Ewes	Unprod	6/03/2015	7/03/2015	35.3		
2014/15	2	Ewes	Unprod	7/03/2015	9/03/2015	35.3		
2014/15	4	Ewes	Unprod	13/03/2015	14/03/2015	35.3		
2014/15	3	WL	Unprod	16/03/2015	2/04/2015			5.3
2014/15	6	Ram hgt	Prod	1/05/2015	7/05/2015			9.0
2014/15	5	Ram hgt	Prod	7/05/2015	13/05/2015			9.0

2014/15	1	Ram hgt	Prod	13/05/2015	22/05/2015			9.0
2014/15	2	Ram hgt	Prod	22/05/2015	31/05/2015			9.0
2014/15	3	Ram hgt	Prod	31/05/2015	9/06/2015			9.0
2014/15	4	Ram hgt	Prod	9/06/2015	15/06/2015			9.0
2015/16	1	E&L	Prod	17/09/2015	25/09/2015	8.8	13.4	
2015/16	5	E&L	Prod	25/09/2015	29/09/2015	11.0	18.0	
2015/16	6	E&L	Prod	29/09/2015	4/10/2015	11.0	18.0	
2015/16	2	E&L	Prod	4/10/2015	11/10/2015	11.0	18.0	
2015/16	3	E&L	Prod	11/10/2015	21/10/2015	11.0	18.0	
2015/16	4	E&L	Prod	21/10/2015	29/10/2015	11.0	18.0	
2015/16	1	E&L	Prod	29/10/2015	4/11/2015	11.0	18.0	
2015/16	5	E&L	Prod	4/11/2015	9/11/2015	11.0	18.0	
2015/16	6	E&L	Prod	9/11/2015	13/11/2015	11.0	18.0	
2015/16	2	E&L	Prod	13/11/2015	17/11/2015	11.0	18.0	
2015/16	3	E&L	Prod	17/11/2015	21/11/2015	11.0	18.0	
2015/16	4	E&L	Prod	21/11/2015	23/11/2015	11.0	18.0	
2015/16	1	E&L	Prod	23/11/2015	25/11/2015	11.0	18.0	
2015/16	3	WL	Prod	7/01/2016	21/01/2016		5.3	
2015/16	3	WL	Prod	21/01/2016	25/01/2016		10.6	
2015/16	4	WL	Prod	25/01/2016	4/02/2016		10.6	
2015/16	5	WL	Prod	4/02/2016	10/02/2016		10.6	
2015/16	5	WL	Prod	10/02/2016	12/02/2016		10.6	
2015/16	6	WL	Prod	12/02/2016	18/02/2016		10.6	
2015/16	1	WL	Prod	18/02/2016	26/02/2016		10.6	
2015/16	2	WL	Prod	26/02/2016	3/03/2016		10.6	
2015/16	1	Ram hgt	Prod	17/05/2016	23/05/2016			9.5
2015/16	2	Ram hgt	Prod	23/05/2016	27/05/2016			9.5
2015/16	5	Ram hgt	Prod	27/05/2016	31/05/2016			9.5
2015/16	6	Ram hgt	Prod	31/05/2016	3/06/2016			9.5

Appendix 24: Summary of grazing periods for the lucerne/brome treatment from 2012-2016. Acronyms are reported in Appendix 23.

Year	Rep	Stock	Status	Date on	Date off	Ewe SR/ha	Lamb SR/ha	Other SR/ha
2012/13	1	E&L	Prod	5/09/2012	18/09/2012	2.4	4.9	
2012/13	1	E&L	Prod	18/09/2012	21/09/2012	9.6	17.0	
2012/13	6	E&L	Prod	21/09/2012	26/09/2012	9.6	17.0	
2012/13	2	E&L	Prod	26/09/2012	3/10/2012	9.6	17.0	
2012/13	5	E&L	Prod	3/10/2012	8/10/2012	9.6	17.0	
2012/13	3	E&L	Prod	8/10/2012	16/10/2012	9.6	17.0	
2012/13	4	E&L	Prod	16/10/2012	24/10/2012	9.6	17.0	
2012/13	1	E&L	Prod	24/10/2012	31/10/2012	9.6	17.0	
2012/13	6	E&L	Prod	31/10/2012	5/11/2012	9.6	17.0	
2012/13	2	E&L	Prod	5/11/2012	8/11/2012	9.6	17.0	
2012/13	2	E&L	Prod	8/11/2012	12/11/2012	9.6	17.0	
2012/13	5	E&L	Prod	12/11/2012	17/11/2012	9.6	17.0	
2012/13	3	E&L	Prod	17/11/2012	24/11/2012	9.6	17.0	
2012/13	4	E&L	Prod	24/11/2012	28/11/2012	9.6	17.0	
2012/13	1	WL	Prod	28/11/2012	10/12/2012		17.0	
2012/13	6	WL	Prod	10/12/2012	17/12/2012		17.0	
2012/13	2	WL	Prod	17/12/2012	24/12/2012		17.0	
2012/13	5	WL	Prod	24/12/2012	29/12/2012		17.0	
2012/13	3	WL	Prod	29/12/2012	5/01/2013		17.0	
2012/13	4	WL	Prod	5/01/2013	8/01/2013		17.0	
2012/13	4	WL	Prod	8/01/2013	11/01/2013		11.6	
2012/13	1	WL	Prod	11/01/2013	19/01/2013		7.3	
2012/13	3	Ewes	Unprod	18/01/2013	22/01/2013			26.1
2012/13	4	Ewes	Unprod	18/01/2013	24/01/2013			18.2
2012/13	6	WL	Prod	19/01/2013	22/01/2013		7.3	
2012/13	1	Ewes	Unprod	22/01/2013	25/01/2013			34.7
2012/13	5	WL	Prod	22/01/2013	25/01/2013		7.3	
2012/13	2	Ewes	Unprod	23/01/2013	28/01/2013			26.1
2012/13	5	Ewes	Unprod	25/01/2013	30/01/2013			34.7
2012/13	6	Ewes	Unprod	28/01/2013	4/02/2013			18.2
2012/13	3	Ram hgt	Unprod	5/03/2013	8/03/2013			36.5
2012/13	1	Ram hgt	Unprod	10/03/2013	13/03/2013			24.7
2012/13	4	Ram hgt	Unprod	13/03/2013	14/03/2013			36.5
2012/13	2	Ram hgt	Unprod	16/03/2013	18/03/2013			36.5
2012/13	5	Ram hgt	Unprod	21/03/2013	23/03/2013			36.5
2012/13	6	Ram hgt	Unprod	24/03/2013	26/03/2013			36.5
2012/13	3	Ewe hgt	Prod	15/05/2013	23/05/2013			9.6
2012/13	4	Ewe hgt	Prod	23/05/2013	30/05/2013			9.6
2012/13	3	Ewes	Unprod	30/05/2013	1/06/2013			33.0
2012/13	1	Ewe hgt	Prod	30/05/2013	7/06/2013			12.2
2012/13	4	Ewes	Unprod	5/06/2013	6/06/2013			33.0

Year	No	Type	Status	Start	End			
2012/13	2	Ewe hgt	Prod	7/06/2013	12/06/2013			12.2
2012/13	2	Ewe hgt	Prod	12/06/2013	17/06/2013			15.5
2012/13	1	Ewes	Unprod	13/06/2013	16/06/2013			33.0
2012/13	5	Ewe hgt	Prod	17/06/2013	22/06/2013			15.5
2012/13	2	Ewes	Unprod	21/06/2013	23/06/2013			28.7
2012/13	6	Ewe hgt	Prod	22/06/2013	26/06/2013			15.5
2012/13	5	Ewes	Unprod	25/06/2013	27/06/2013			28.7
2012/13	6	Ewes	Unprod	28/06/2013	30/06/2013			28.7
2013/14	1	E&L	Prod	6/09/2013	13/09/2013	0.7	1.2	
2013/14	1	E&L	Prod	13/09/2013	16/09/2013	3.0	5.9	
2013/14	1	E&L	Prod	16/09/2013	18/09/2013	4.0	8.0	
2013/14	1	E&L	Prod	18/09/2013	19/09/2013	7.5	14.9	
2013/14	1	E&L	Prod	19/09/2013	24/09/2013	11.3	22.6	
2013/14	5	E&L	Prod	24/09/2013	30/09/2013	11.3	22.6	
2013/14	4	Ewe hgt	Unprod	24/09/2013	1/10/2013			27.1
2013/14	6	E&L	Prod	30/09/2013	3/10/2013	11.3	22.6	
2013/14	6	E&L	Prod	3/10/2013	7/10/2013	11.3	22.6	
2013/14	2	E&L	Prod	7/10/2013	14/10/2013	11.1	22.4	
2013/14	3	E&L	Prod	14/10/2013	27/10/2013	11.1	22.4	
2013/14	1	E&L	Prod	27/10/2013	7/11/2013	11.1	22.4	
2013/14	5	E&L	Prod	7/11/2013	13/11/2013	11.1	22.2	
2013/14	5	E&L	Prod	13/11/2013	14/11/2013	11.1	22.2	
2013/14	6	E&L	Prod	14/11/2013	20/11/2013	11.1	22.2	
2013/14	2	E&L	Prod	20/11/2013	27/11/2013	11.1	22.2	
2013/14	3	E&L	Prod	27/11/2013	2/12/2013	11.1	22.2	
2013/14	4	WL	Prod	2/12/2013	10/12/2013		20.7	
2013/14	1	WL	Prod	10/12/2013	16/12/2013		20.7	
2013/14	1	WL	Prod	16/12/2013	20/12/2013		20.7	
2013/14	5	WL	Prod	20/12/2013	24/12/2013		20.7	
2013/14	6	WL	Prod	24/12/2013	29/12/2013		20.7	
2013/14	2	WL	Prod	29/12/2013	2/01/2014		20.7	
2013/14	3	WL	Prod	2/01/2014	6/01/2014		20.7	
2013/14	3	WL	Prod	6/01/2014	13/01/2014		17.2	
2013/14	4	WL	Prod	13/01/2014	17/01/2014		17.2	
2013/14	1	WL	Prod	17/01/2014	21/01/2014		10.3	
2013/14	5	WL	Prod	21/01/2014	23/01/2014		10.3	
2013/14	6	WL	Prod	23/01/2014	27/01/2014		10.3	
2013/14	3	WL	Prod	27/01/2014	30/01/2014		10.3	
2013/14	2	WL	Prod	30/01/2014	3/02/2014		10.3	
2013/14	2	WL	Unprod	4/02/2014	5/02/2014		20.3	
2013/14	1	Ram hgt	Prod	24/03/2014	1/04/2014			7.6
2013/14	5	Ram hgt	Prod	1/04/2014	5/04/2014			7.6
2013/14	6	Ram hgt	Prod	5/04/2014	11/04/2014			7.6
2013/14	2	Ram hgt	Prod	11/04/2014	14/04/2014			7.6
2013/14	2	Ram hgt	Prod	17/04/2014	21/04/2014			7.6
2013/14	3	Ram hgt	Prod	21/04/2014	28/04/2014			7.6

2013/14	4	Ram hgt	Prod	28/04/2014	5/05/2014			7.6
2013/14	1	Ewes	Unprod	7/05/2014	22/05/2014	12.2		
2013/14	5	Ewes	Unprod	22/05/2014	29/05/2014	12.2		
2013/14	1	Ewes	Unprod	26/05/2014	27/05/2014	52.1		
2013/14	6	Ewes	Unprod	29/05/2014	4/06/2014	12.2		
2013/14	5	Ewes	Unprod	2/06/2014	3/06/2014	52.1		
2013/14	3	Ewes	Unprod	4/06/2014	12/06/2014	12.2		
2013/14	6	Ewes	Unprod	9/06/2014	10/06/2014	52.1		
2013/14	4	Ewes	Unprod	12/06/2014	18/06/2014	12.2		
2013/14	3	Ewes	Unprod	16/06/2014	17/06/2014	52.1		
2013/14	2	Ewes	Unprod	17/06/2014	18/06/2014	52.1		
2013/14	2	Ewes	Unprod	19/06/2014	23/06/2014	52.1		
2013/14	4	Ewes	Unprod	19/06/2014	27/06/2014	9.0		
2014/15	1	E&L	Prod	26/08/2014	28/08/2014	3.1	5.7	
2014/15	1	E&L	Prod	28/08/2014	4/09/2014	8.0	14.8	
2014/15	5	E&L	Prod	4/09/2014	8/09/2014	8.0	14.8	
2014/15	6	E&L	Prod	8/09/2014	12/09/2014	8.0	14.8	
2014/15	2	E&L	Prod	12/09/2014	19/09/2014	8.0	14.8	
2014/15	3	E&L	Prod	19/09/2014	26/09/2014	8.0	14.8	
2014/15	4	E&L	Prod	26/09/2014	30/09/2014	7.8	14.6	
2014/15	4	E&L	Prod	30/09/2014	3/10/2014	10.1	20.0	
2014/15	1	E&L	Prod	3/10/2014	7/10/2014	10.1	20.0	
2014/15	5	E&L	Prod	7/10/2014	13/10/2014	10.1	20.0	
2014/15	6	E&L	Prod	13/10/2014	16/10/2014	9.9	20.0	
2014/15	2	E&L	Prod	16/10/2014	21/10/2014	9.9	20.0	
2014/15	3	E&L	Prod	21/10/2014	25/10/2014	9.9	20.0	
2014/15	4	E&L	Prod	25/10/2014	29/10/2014	9.7	20.0	
2014/15	1	E&L	Prod	29/10/2014	2/11/2014	9.7	20.0	
2014/15	5	E&L	Prod	2/11/2014	3/11/2014	9.7	20.0	
2014/15	6	WL	Prod	26/11/2014	2/12/2014		6.9	
2014/15	6	WL	Prod	2/12/2014	4/12/2014		8.7	
2014/15	2	WL	Prod	4/12/2014	15/12/2014		8.7	
2014/15	6	Ewe hgt	Unprod	11/12/2014	16/12/2014			10.4
2014/15	3	WL	Prod	15/12/2014	20/12/2014		8.7	
2014/15	2	Ewe hgt	Unprod	16/12/2014	20/12/2014			10.4
2014/15	4	WL	Prod	20/12/2014	28/12/2014		8.7	
2014/15	3	Ewe hgt	Unprod	20/12/2014	28/12/2014			10.4
2014/15	1	WL	Prod	28/12/2014	31/12/2014		8.7	
2014/15	4	Ewe hgt	Unprod	28/12/2014	31/12/2014			10.4
2014/15	5	WL	Prod	31/12/2014	4/01/2015		8.7	
2014/15	1	Ewe hgt	Unprod	31/12/2014	4/01/2015			10.4
2014/15	5	Ewe hgt	Unprod	4/01/2015	7/01/2015			10.4
2014/15	6	WL	Prod	4/01/2015	5/01/2015		8.7	
2014/15	6	Ewe hgt	Unprod	7/01/2015	9/01/2015			10.4
2014/15	6	WL	Unprod	15/02/2015	18/02/2015			10.4
2014/15	3	WL	Unprod	22/02/2015	25/02/2015			10.4

Year	N	Type	Status	Start	End			
2014/15	5	WL	Unprod	22/02/2015	23/02/2015			10.4
2014/15	6	Ewes	Unprod	27/02/2015	28/02/2015	46.9		
2014/15	1	WL	Unprod	28/02/2015	7/03/2015			10.4
2014/15	5	Ewes	Unprod	1/03/2015	2/03/2015	46.9		
2014/15	2	Ewes	Unprod	9/03/2015	11/03/2015	34.7		
2014/15	4	WL	Unprod	9/03/2015	12/03/2015			5.2
2014/15	3	Ewes	Unprod	11/03/2015	12/03/2015	34.7		
2014/15	4	Ewes	Unprod	14/03/2015	16/03/2015	34.7		
2014/15	6	Ram hgt	Prod	1/05/2015	8/05/2015			6.6
2014/15	5	Ram hgt	Prod	8/05/2015	17/05/2015			6.6
2014/15	1	Ram hgt	Prod	17/05/2015	31/05/2015			6.6
2014/15	2	Ram hgt	Prod	31/05/2015	12/06/2015			6.6
2014/15	3	Ram hgt	Prod	12/06/2015	16/06/2015			6.6
2014/15	3	Ram hgt	Prod	16/06/2015	24/06/2015			6.6
2014/15	4	Ram hgt	Prod	16/06/2015	24/06/2015			10.3
2014/15	3	Ram hgt	Unprod	25/06/2015	26/06/2015			25.4
2014/15	4	Ram hgt	Unprod	26/06/2015	30/06/2015			13.2
2015/16	5	E&L	Prod	2/09/2015	4/09/2015	2.4	4.2	
2015/16	5	E&L	Prod	4/09/2015	8/09/2015	4.0	6.8	
2015/16	5	E&L	Prod	8/09/2015	14/09/2015	5.2	8.7	
2015/16	6	E&L	Prod	14/09/2015	15/09/2015	5.2	8.7	
2015/16	6	E&L	Prod	15/09/2015	18/09/2015	8.9	15.6	
2015/16	2	E&L	Prod	18/09/2015	27/09/2015	8.9	15.6	
2015/16	3	E&L	Prod	27/09/2015	2/10/2015	8.9	15.6	
2015/16	3	E&L	Prod	2/10/2015	4/10/2015	10.8	18.8	
2015/16	4	E&L	Prod	4/10/2015	9/10/2015	10.8	18.8	
2015/16	1	E&L	Prod	9/10/2015	12/10/2015	10.8	18.8	
2015/16	1	E&L	Prod	12/10/2015	15/10/2015	10.8	18.4	
2015/16	5	E&L	Prod	15/10/2015	19/10/2015	10.8	18.4	
2015/16	6	E&L	Prod	19/10/2015	24/10/2015	10.8	18.4	
2015/16	2	E&L	Prod	24/10/2015	30/10/2015	10.8	18.4	
2015/16	3	E&L	Prod	30/10/2015	3/11/2015	10.8	18.4	
2015/16	4	E&L	Prod	3/11/2015	6/11/2015	10.8	18.4	
2015/16	1	E&L	Prod	6/11/2015	9/11/2015	10.8	18.4	
2015/16	5	E&L	Prod	9/11/2015	11/11/2015	10.8	18.4	
2015/16	6	E&L	Prod	11/11/2015	12/11/2015	10.8	18.4	
2015/16	2	E&L	Prod	12/11/2015	13/11/2015	10.8	18.4	
2015/16	3	WL	Prod	7/01/2016	21/01/2016		4.3	
2015/16	3	WL	Prod	21/01/2016	25/01/2016		6.9	
2015/16	4	WL	Prod	25/01/2016	9/02/2016		6.9	
2015/16	5	WL	Prod	9/02/2016	10/02/2016		6.9	
2015/16	5	WL	Prod	10/02/2016	20/02/2016		6.9	
2015/16	6	WL	Prod	20/02/2016	29/02/2016		6.9	
2015/16	1	WL	Prod	29/02/2016	4/03/2016		6.9	
2015/16	2	WL	Prod	4/03/2016	11/03/2016		6.9	
2015/16	2	WL	Prod	11/03/2016	14/03/2016		13.0	

2015/16	1	Ram hgt	Prod	17/05/2016	27/05/2016	14.2
2015/16	2	Ram hgt	Prod	27/05/2016	3/06/2016	14.2
2015/16	2	Ram hgt	Prod	3/06/2016	5/06/2016	19.0
2015/16	5	Ram hgt	Prod	5/06/2016	10/06/2016	19.0
2015/16	6	Ram hgt	Prod	10/06/2016	17/06/2016	19.0

Appendix 25: Summary of grazing periods for the lucerne/cocksfoot treatment from 2012-2016. Acronyms are reported in Appendix 23.

Year	Rep	Stock	Status	Date on	Date off	Ewe SR/ha	Lamb SR/ha	Other SR/ha
2012/13	1	E&L	Prod	5/09/2012	18/09/2012	2.4	4.9	
2012/13	1	E&L	Prod	18/09/2012	21/09/2012	9.8	18.8	
2012/13	6	E&L	Prod	21/09/2012	26/09/2012	9.8	18.8	
2012/13	2	E&L	Prod	26/09/2012	3/10/2012	9.8	18.8	
2012/13	5	E&L	Prod	3/10/2012	8/10/2012	9.8	18.8	
2012/13	3	E&L	Prod	8/10/2012	16/10/2012	9.8	18.8	
2012/13	4	E&L	Prod	16/10/2012	24/10/2012	9.8	18.8	
2012/13	1	E&L	Prod	24/10/2012	31/10/2012	9.8	18.8	
2012/13	6	E&L	Prod	31/10/2012	5/11/2012	9.8	18.8	
2012/13	2	E&L	Prod	5/11/2012	8/11/2012	9.8	18.8	
2012/13	2	E&L	Prod	8/11/2012	12/11/2012	9.8	18.8	
2012/13	5	E&L	Prod	12/11/2012	17/11/2012	9.8	18.8	
2012/13	3	E&L	Prod	17/11/2012	24/11/2012	9.8	18.8	
2012/13	4	E&L	Prod	24/11/2012	28/11/2012	9.8	18.8	
2012/13	1	WL	Prod	28/11/2012	10/12/2012		18.8	
2012/13	6	WL	Prod	10/12/2012	17/12/2012		18.8	
2012/13	2	WL	Prod	17/12/2012	24/12/2012		18.8	
2012/13	5	WL	Prod	24/12/2012	29/12/2012		18.8	
2012/13	3	WL	Prod	29/12/2012	5/01/2013		18.8	
2012/13	4	WL	Prod	5/01/2013	8/01/2013		18.8	
2012/13	4	WL	Prod	8/01/2013	11/01/2013		13.4	
2012/13	1	WL	Prod	11/01/2013	19/01/2013		11.5	
2012/13	3	Ewes	Unprod	18/01/2013	22/01/2013			34.9
2012/13	4	Ewes	Unprod	18/01/2013	23/01/2013			26.2
2012/13	6	WL	Prod	19/01/2013	23/01/2013		11.5	
2012/13	1	Ewes	Unprod	22/01/2013	25/01/2013			34.9
2012/13	5	WL	Prod	23/01/2013	25/01/2013		11.5	
2012/13	2	Ewes	Unprod	24/01/2013	28/01/2013			18.3
2012/13	5	Ewes	Unprod	28/01/2013	2/02/2013			26.2
2012/13	6	Ewes	Unprod	28/01/2013	4/02/2013			18.3
2012/13	1	Ram hgt	Unprod	8/03/2013	14/03/2013			13.6
2012/13	3	Ram hgt	Unprod	8/03/2013	10/03/2013			36.6
2012/13	4	Ram hgt	Unprod	8/03/2013	10/03/2013			24.8
2012/13	2	Ram hgt	Unprod	14/03/2013	20/03/2013			13.6
2012/13	5	Ram hgt	Unprod	18/03/2013	19/03/2013			36.6
2012/13	6	Ram hgt	Unprod	26/03/2013	28/03/2013			36.6
2012/13	3	Ewe hgt	Prod	15/05/2013	23/05/2013			9.1
2012/13	4	Ewe hgt	Prod	23/05/2013	30/05/2013			9.1
2012/13	1	Ewe hgt	Prod	30/05/2013	7/06/2013			11.7
2012/13	3	Ewes	Unprod	1/06/2013	3/06/2013			33.1
2012/13	4	Ewes	Unprod	4/06/2013	5/06/2013			33.1

2012/13	2	Ewe hgt	Prod	7/06/2013	12/06/2013			11.7
2012/13	1	Ewes	Unprod	10/06/2013	13/06/2013			33.1
2012/13	2	Ewe hgt	Prod	12/06/2013	17/06/2013			15.2
2012/13	2	Ewes	Unprod	17/06/2013	20/06/2013			28.8
2012/13	5	Ewe hgt	Prod	17/06/2013	22/06/2013			15.2
2012/13	6	Ewe hgt	Prod	22/06/2013	26/06/2013			15.2
2012/13	5	Ewes	Unprod	23/06/2013	24/06/2013			28.8
2012/13	6	Ewes	Unprod	30/06/2013	3/07/2013			28.8
2013/14	1	E&L	Prod	6/09/2013	13/09/2013	0.9	1.7	
2013/14	1	E&L	Prod	13/09/2013	16/09/2013	3.1	5.9	
2013/14	1	E&L	Prod	16/09/2013	18/09/2013	4.2	7.9	
2013/14	1	E&L	Prod	18/09/2013	19/09/2013	7.7	14.8	
2013/14	1	E&L	Prod	19/09/2013	24/09/2013	11.7	22.9	
2013/14	5	E&L	Prod	24/09/2013	30/09/2013	11.7	22.9	
2013/14	4	Ewe hgt	Unprod	24/09/2013	1/10/2013			30.4
2013/14	6	E&L	Prod	30/09/2013	3/10/2013	11.7	22.9	
2013/14	6	E&L	Prod	3/10/2013	7/10/2013	11.7	22.9	
2013/14	2	E&L	Prod	7/10/2013	14/10/2013	11.7	22.7	
2013/14	3	E&L	Prod	14/10/2013	25/10/2013	11.7	22.7	
2013/14	1	E&L	Prod	25/10/2013	4/11/2013	11.7	22.3	
2013/14	5	E&L	Prod	4/11/2013	11/11/2013	11.7	22.3	
2013/14	6	E&L	Prod	11/11/2013	13/11/2013	11.7	22.3	
2013/14	6	E&L	Prod	13/11/2013	18/11/2013	11.7	22.3	
2013/14	2	E&L	Prod	18/11/2013	26/11/2013	11.7	22.3	
2013/14	3	E&L	Prod	26/11/2013	2/12/2013	11.7	22.3	
2013/14	4	WL	Prod	2/12/2013	10/12/2013		22.3	
2013/14	1	WL	Prod	10/12/2013	16/12/2013		22.3	
2013/14	1	WL	Prod	16/12/2013	20/12/2013		22.3	
2013/14	5	WL	Prod	20/12/2013	24/12/2013		22.3	
2013/14	6	WL	Prod	24/12/2013	29/12/2013		22.3	
2013/14	2	WL	Prod	29/12/2013	2/01/2014		22.3	
2013/14	3	WL	Prod	2/01/2014	6/01/2014		22.3	
2013/14	3	WL	Prod	6/01/2014	13/01/2014		15.2	
2013/14	4	WL	Prod	13/01/2014	17/01/2014		15.2	
2013/14	1	WL	Prod	17/01/2014	26/01/2014		15.2	
2013/14	5	WL	Prod	26/01/2014	29/01/2014		15.2	
2013/14	6	WL	Prod	29/01/2014	1/02/2014		15.2	
2013/14	2	WL	Prod	1/02/2014	3/02/2014		15.2	
2013/14	3	WL	Unprod	11/02/2014	17/02/2014		20.4	
2013/14	4	WL	Unprod	17/02/2014	20/02/2014		20.4	
2013/14	1	Ram hgt	Prod	24/03/2014	1/04/2014			8.4
2013/14	5	Ram hgt	Prod	1/04/2014	5/04/2014			8.4
2013/14	6	Ram hgt	Prod	5/04/2014	11/04/2014			8.4
2013/14	2	Ram hgt	Prod	11/04/2014	14/04/2014			8.4
2013/14	2	Ram hgt	Prod	17/04/2014	21/04/2014			8.4
2013/14	3	Ram hgt	Prod	21/04/2014	30/04/2014			8.4

Year	No.	Class	Type	Start	End	V1	V2	V3
2013/14	4	Ram hgt	Prod	30/04/2014	9/05/2014			8.4
2013/14	1	Ewes	Unprod	7/05/2014	22/05/2014	14.0		
2013/14	1	Ewes	Unprod	22/05/2014	25/05/2014	52.3		
2013/14	5	Ewes	Unprod	22/05/2014	29/05/2014	14.0		
2013/14	2	Ewes	Unprod	27/05/2014	29/05/2014	52.3		
2013/14	5	Ewes	Unprod	29/05/2014	1/06/2014	52.3		
2013/14	6	Ewes	Unprod	29/05/2014	4/06/2014	14.0		
2013/14	2	Ewes	Unprod	3/06/2014	8/06/2014	52.3		
2013/14	3	Ewes	Unprod	4/06/2014	12/06/2014	14.0		
2013/14	6	Ewes	Unprod	10/06/2014	11/06/2014	52.3		
2013/14	3	Ewes	Unprod	12/06/2014	16/06/2014	52.3		
2013/14	4	Ewes	Unprod	12/06/2014	18/06/2014	14.0		
2013/14	4	Ewes	Unprod	19/06/2014	24/06/2014	9.8		
2013/14	4	Ewes	Unprod	24/06/2014	27/06/2014	25.1		
2014/15	1	E&L	Prod	19/08/2014	26/08/2014	3.7	6.8	
2014/15	1	E&L	Prod	26/08/2014	29/08/2014	10.5	20.8	
2014/15	5	E&L	Prod	29/08/2014	2/09/2014	10.5	20.8	
2014/15	6	E&L	Prod	2/09/2014	5/09/2014	10.5	20.8	
2014/15	2	E&L	Prod	5/09/2014	11/09/2014	10.5	20.8	
2014/15	3	E&L	Prod	11/09/2014	17/09/2014	10.5	20.8	
2014/15	4	E&L	Prod	17/09/2014	25/09/2014	10.5	20.8	
2014/15	1	E&L	Prod	25/09/2014	30/09/2014	10.5	20.4	
2014/15	5	E&L	Prod	30/09/2014	3/10/2014	10.5	20.4	
2014/15	6	E&L	Prod	3/10/2014	6/10/2014	10.5	20.4	
2014/15	2	E&L	Prod	6/10/2014	7/10/2014	10.5	20.2	
2014/15	2	E&L	Prod	7/10/2014	16/10/2014	6.3	12.6	
2014/15	3	E&L	Prod	16/10/2014	20/10/2014	6.3	12.6	
2014/15	3	E&L	Prod	20/10/2014	23/10/2014	10.3	20.2	
2014/15	4	E&L	Prod	23/10/2014	28/10/2014	10.3	20.2	
2014/15	1	E&L	Prod	28/10/2014	2/11/2014	10.3	20.2	
2014/15	5	E&L	Prod	2/11/2014	4/11/2014	10.3	20.2	
2014/15	6	E&L	Prod	4/11/2014	7/11/2014	10.3	20.2	
2014/15	2	WL	Prod	26/11/2014	2/12/2014		8.7	
2014/15	2	WL	Prod	2/12/2014	5/12/2014		10.5	
2014/15	3	WL	Prod	5/12/2014	20/12/2014		10.5	
2014/15	2	Ewe hgt	Unprod	11/12/2014	20/12/2014			15.7
2014/15	4	WL	Prod	20/12/2014	28/12/2014		10.5	
2014/15	3	Ewe hgt	Unprod	20/12/2014	28/12/2014			15.7
2014/15	1	WL	Prod	28/12/2014	5/01/2015		10.5	
2014/15	4	Ewe hgt	Unprod	28/12/2014	5/01/2015			15.7
2014/15	1	Ewe hgt	Unprod	5/01/2015	12/01/2015			15.7
2014/15	5	WL	Prod	5/01/2015	9/01/2015		10.5	
2014/15	5	Ewe hgt	Unprod	9/01/2015	12/01/2015			19.2
2014/15	6	WL	Prod	9/01/2015	12/01/2015		10.5	
2014/15	6	WL	Prod	12/01/2015	13/01/2015		22.7	
2014/15	6	WL	Unprod	13/02/2015	15/02/2015			10.5

Year	No	Type	Prod	Start	End			
2014/15	5	WL	Unprod	22/02/2015	26/02/2015			9.8
2014/15	3	WL	Unprod	25/02/2015	28/02/2015			10.5
2014/15	6	Ewes	Unprod	25/02/2015	27/02/2015	47.1		
2014/15	5	Ewes	Unprod	3/03/2015	4/03/2015	47.1		
2014/15	1	WL	Unprod	5/03/2015	20/03/2015			5.2
2014/15	3	Ewes	Unprod	12/03/2015	13/03/2015	34.9		
2014/15	4	WL	Unprod	12/03/2015	16/03/2015			5.2
2014/15	4	Ewes	Unprod	16/03/2015	18/03/2015	34.9		
2014/15	2	WL	Unprod	20/03/2015	5/04/2015			5.2
2014/15	6	Ram hgt	Prod	1/05/2015	8/05/2015			8.5
2014/15	5	Ram hgt	Prod	8/05/2015	17/05/2015			8.5
2014/15	1	Ram hgt	Prod	17/05/2015	28/05/2015			8.5
2014/15	2	Ram hgt	Prod	28/05/2015	5/06/2015			8.5
2014/15	3	Ram hgt	Prod	5/06/2015	16/06/2015			8.5
2014/15	3	Ram hgt	Prod	16/06/2015	18/06/2015			8.5
2014/15	4	Ram hgt	Prod	18/06/2015	24/06/2015			8.5
2014/15	4	Ram hgt	Unprod	26/06/2015	30/06/2015			12.2
2015/16	1	Ewes	Unprod	12/08/2015	31/08/2015	3.8		
2015/16	5	Ewes	Unprod	12/08/2015	31/08/2015	2.3		
2015/16	6	E&L	Prod	31/08/2015	2/09/2015	4.4	8.2	
2015/16	6	E&L	Prod	2/09/2015	7/09/2015	5.8	10.6	
2015/16	2	E&L	Prod	7/09/2015	8/09/2015	5.8	10.6	
2015/16	2	E&L	Prod	8/09/2015	15/09/2015	6.6	12.2	
2015/16	2	E&L	Prod	15/09/2015	18/09/2015	8.2	16.0	
2015/16	3	E&L	Prod	18/09/2015	27/09/2015	8.2	16.0	
2015/16	4	E&L	Prod	27/09/2015	2/10/2015	8.2	16.0	
2015/16	4	E&L	Prod	2/10/2015	7/10/2015	10.8	19.0	
2015/16	1	E&L	Prod	7/10/2015	9/10/2015	10.8	19.0	
2015/16	1	E&L	Prod	9/10/2015	15/10/2015	11.0	19.4	
2015/16	5	E&L	Prod	15/10/2015	19/10/2015	11.0	19.4	
2015/16	6	E&L	Prod	19/10/2015	24/10/2015	11.0	19.4	
2015/16	2	E&L	Prod	24/10/2015	30/10/2015	11.0	19.4	
2015/16	3	E&L	Prod	30/10/2015	5/11/2015	11.0	19.4	
2015/16	4	E&L	Prod	5/11/2015	11/11/2015	11.0	19.4	
2015/16	1	E&L	Prod	11/11/2015	16/11/2015	11.0	19.4	
2015/16	5	E&L	Prod	16/11/2015	18/11/2015	11.0	19.4	
2015/16	6	E&L	Prod	18/11/2015	20/11/2015	11.0	19.4	
2015/16	3	WL	Prod	7/01/2016	21/01/2016		3.5	
2015/16	3	WL	Prod	21/01/2016	27/01/2016		8.7	
2015/16	4	WL	Prod	27/01/2016	9/02/2016		8.7	
2015/16	5	WL	Prod	9/02/2016	10/02/2016		8.7	
2015/16	5	WL	Prod	10/02/2016	20/02/2016		8.7	
2015/16	6	WL	Prod	20/02/2016	29/02/2016		8.7	
2015/16	1	WL	Prod	29/02/2016	7/03/2016		8.7	
2015/16	2	WL	Prod	7/03/2016	11/03/2016		8.7	
2015/16	2	WL	Prod	11/03/2016	14/03/2016		4.4	

2015/16	1	Ram hgt	Prod	17/05/2016	27/05/2016	14.3
2015/16	2	Ram hgt	Prod	27/05/2016	3/06/2016	14.3
2015/16	2	Ram hgt	Prod	3/06/2016	7/06/2016	19.0
2015/16	5	Ram hgt	Prod	7/06/2016	14/06/2016	19.0
2015/16	6	Ram hgt	Prod	14/06/2016	17/06/2016	19.0
2015/16	6	Ram hgt	Prod	17/06/2016	20/06/2016	38.1