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Step changes in meat production systems from dual-purpose crops in the feed-base

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Abstract

A research project at three sites has found that under good management, incorporating dual-purpose crops into livestock systems can both increase returns and reduce production and financial risk. In a four-year systems experiment near Canberra (2013-2016), incorporating dual-purpose crops into a breeding Merino ewe production system on permanent pastures increased meat and wool production and ewe live weights during spring. Lamb production (live weight turn-off per hectare) and gross margin returns were increased by including dual-purpose crops in the system and prioritising grazing of crops for weaners (11% and 56% respectively). Livestock can graze crops for a significant period of the year when two crops are grazed in sequence (e.g. canola then wheat); the main feed gap shifts to late summer and autumn, when the crops are being established. Extrapolation of the systems experiment using simulation modelling supported these conclusions.

Experiments in the Riverina found there were minimal advantages in terms of improved metabolic and reproductive efficiencies for a non-wool breed (White Dorpers) compared to Merinos on a mixed-farming feedbase, although the weaning weight per head of lambs born to White Dorper ewes joined to a terminal sire could be higher.

In suitable environments such as south-west Victoria, spring-sown canola (*Brassica napus*) can be used to increase growth rates of ewe lambs for joining in autumn, and grazing the brassica crops has no negative impacts on maiden ewe reproductive performance. Timely sowing of crops was important for minimising establishment risk and maximising the grazing opportunity. Studies near Canberra and Wagga Wagga also showed that canola can be grazed safely by ewes during the lambing period.

Executive summary

Dual-purpose crops have become an important part of farming systems in parts of southern Australia, but there remains scope to increase the area sown to dual-purpose crops, particularly in the high rainfall zone. Dual-purpose crops can be a valuable addition to the feed base, providing a high quality forage at times when pasture availability may be restricted. There remains, however, the opportunity to explore the use of these crops for increasing livestock production in systems where they may be introduced. This project had the objective of exploring novel uses of dual-purpose crops to increase meat production and subsequently increase farm income and lower risk by incorporating dual-purpose crops into systems to address the overarching question: "Over the long term, does the addition of an extra feed supply of high-quality feed and an extra source of income from grain increase or decrease the reliability of year-round feed supply and business risk?".

For dual-purpose crops to be advantageous in farm systems they need to do one or more of the following;

- Increase the total feed produced in terms of quantity and quality
- Reduce the need for supplementary feeding of livestock
- Increase the performance of grazing animals
- Produce temporal/seasonal shifts in the distribution of the feed supply that reduce the risks of animal production in relation to the three points above.
- Provide benefits that improve crop performance
- Provide a diversified income source that mitigates risk through different price variation or production risk.

To be economically advantageous the additional cost of the inclusion of the dual-purpose cropping in farm systems must be outweighed by the benefits attained through the above means.

A hub and nodes model of experimental sites was used to answer this question. The "hub" was a systems experiment located near Canberra ACT that ran for four years (2013-2016) and considered how much per-ewe productivity of a meat production system can be increased when a proportion of grazing land is converted to dual-purpose crops that are grazed by ewes of their lambs, and also managed for grain production. A comparison was made as to whether prioritising grazing of ewes or weaner lambs was the better use of dual-purpose crops. The study therefore involved 3 treatments: pasture only (Control) and pasture with dual-purpose crops grazed by either Merino ewes (ECG) or weaners (WCG).

Experimental nodes at Wagga Wagga in the NSW Riverina and Hamilton in south west Victoria were designed to answer additional questions not covered by the core systems experiment. The Riverina studies focussed on whether inclusion of crops increased the attractiveness of a non-wool sheep production system and the potential to increase lamb production by using a more diverse feed base in the spring (Wagga). The Hamilton study compared the use of spring sowing of canola with other possible forage system options to increase the reproductive performance of yearling ewe lambs by using them for summer/autumn grazing and then evaluating the impact of that grazing on canola yield the following year. Biophysical and economic modelling was then used at Canberra, Wagga

Wagga and Hamilton to identify the long term impacts on potential profit and business risk of incorporating dual-purpose crops in the feed base.

Increase the total feed produced in terms of quantity and quality

Dual-purpose crops sown in late summer or early autumn can provide a large amount of high quality feed for livestock during autumn and winter. Using a narrower row spacing can increase the amount of forage at the start of grazing: halving the row spacing in a wheat crop from 35 cm to 17.5 cm increased the feed on offer at the start of grazing by 25% at Wagga Wagga (1.268 t DM/ha v. 1.018 t DM/ha). The different sward height:biomass relationship of crops in comparison to pastures allows livestock to graze crops at a biomass that would be considered restrictive in pastures: ewes on the point of lambing safely commenced grazing wheat crops at a mean starting biomass of 0.33 t DM/ha, using moderate stocking rates.

Grazing crops in sequence in a system where one third of the farm was cropped in any year provided a large period when livestock grazed crops near Canberra and mitigated against poor initial production in one crop. Canola was grazed first in sequence in three out of four years, with wheat grazed first in 2015, the year when initial germination of canola was sporadic, demonstrating that sowing a cereal and brassica for grazing provided a hedge against such events.

Spring sowing of canola near Hamilton, Victoria produced 2.0-4.0 t DM/ha during the summer and autumn period.

The metabolizable energy (ME) concentrations of spring-sown canola near Hamilton was 12.0-13.0 MJ/kg DM. Similarly, autumn-sown wheat and canola at Wagga Wagga was also highly digestible (73 - 86 % DM) and had high crude protein contents (19-26 % DM) early in the grazing period, although in wheat crops the digestibility and protein did decline during the grazing period, particularly late in the grazing period when leaf material represented a lower proportion of the forage available. The crude protein levels and digestible organic matter digestibility (DOMD) of canola remained high, and did not vary greatly during the experiment in 2014. Crude protein levels in wheat were initially higher than canola but declined during the grazing period, and were marginal compared to recommended minimum requirements at the conclusion of grazing. Digestibility of wheat declined during the grazing period but remained above requirements for ewes. Calcium and magnesium levels in canola were higher than wheat, sodium levels were similar while potassium levels were lower in canola.

Neutral detergent fibre (NDF) content of wheat increased from 40 to 48% DM during the grazing period while NDF content of canola remained at around 27% DM at Wagga, and was significantly lower than wheat. NDF levels reported for canola forage at Hamilton were often <20% DM.

Reduce the need for supplementary feeding of livestock

Priority grazing of ewes on crop near Canberra reduced supplementary feeding when seasonal conditions were poor. Inclusion of dual-purpose crops changed the pattern of supplementary feeding but did not necessarily reduce the amount of supplement fed to ewes, however supplementary feeding of weaners was lower when crop grazing was prioritised for weaners compared to the pasture-only system in three out of four years. Biophysical modelling of a similar system near Canberra, however, suggested that over the long term grazing systems with dual-purpose crops would need slightly more supplementary feeding if the same farm-level stocking rate was to be maintained, owing to a decrease in forage supply during December-March.

Biophysical modelling of a mixed-farming system near Wagga suggested that for a June lambing system stocked at 8 ewes per hectare pasture, grain feeding was reduced by 37% when ewes were allowed to graze a dual-purpose crop during the winter.

In south west Victoria, high levels of feeding over summer and autumn are required to achieve weight gain in ewe lambs grazing perennial ryegrass pastures in preparation for joining in autumn. The experiment demonstrated that spring-sown canola can reduce reliance on supplementary feeding to achieve the goal of joining ewe lambs.

Increase the performance of grazing animals

Priority grazing of ewes on crop in the core systems experiment near Canberra increased wool production by 16% or 0.7 kg greasy fleece weight (GFW) per head compared to the control; however, sale weight of lambs was not increased compared to the control. Priority grazing of weaners on dual-purpose crops increased wool production by 9% or 0.4 kg GFW per ewe and increased lamb production by 16% or 7.6 kg live weight sold per ewe compared to a pasture-only system. Prioritising crop grazing for weaners also allowed other livestock classes (wethers or ewes) to graze the otherwise under-utilised crops in better seasons. Biophysical modelling of a Canberra grazing system confirmed that the pasture utilization rate and the efficiency of conversion of pasture to lambs for sale both increased substantially when dual-purpose crops were adopted.

Results from south west Victoria indicate that ewe lambs can be safely joined on canola forage with no negative effects on reproductive performance. Ewe lambs on canola showed significant ($P<0.05$) improvements in live weight gain during the joining period in both 2014 and 2016, relative to the ryegrass and pellet supplement treatment. The reproduction rate of ewe lambs grazing canola cultivars were significantly higher ($P<0.05$) than from the perennial ryegrass and pellet treatment in 2014 compared to ewes joined on the ryegrass and pellet treatment (145 and 146 v. 103 foetuses scanned per ewe joined). However, in 2016 there was no statistical differences in reproduction rate between treatments. This may be due to the earlier joining and lower number of ewes cycling overall in 2016.

Experiments near Wagga Wagga (2013-2014) found there were minimal advantages in terms of improved metabolic and reproductive efficiencies for a non-wool breed (White Dorpers) compared to Merinos on a mixed-farming feedbase. Returns from a Merino system joined to terminal sire were higher than for a White Dorper-maternal system if lambs were sold at weaning, even though weaning weights of lambs from the White Dorper system were higher. White Dorper ewes joined to White Suffolk rams would have needed to produce 15-36% more lambs to achieve the same return per ewe as the Merino-maternal system if lambs are sold as store lambs at weaning.

Biophysical modelling demonstrated that, over the longer term, allowing ewes to graze crops at Wagga Wagga increased lamb production per hectare (e.g. 7% for a June lambing system at 8 ewes per hectare pasture), and the proportion of years where lambs reached killable weight was also increased by utilising the dual-purpose crops.

Produce temporal/seasonal shifts in the distribution of the feed supply that reduce the risks of animal production in relation to the three points above.

The systems experiment near Canberra demonstrated that the availability of feed through the year is changed by replacing some permanent pasture with a dual-purpose cropping program. Including dual-purpose wheat and canola in the system and grazing in sequence provided a large number of days during autumn and winter when animals were grazing crops (2338-4519 sheep grazing days per hectare). Feed on offer (FOO; kg DM/ha) in the control treatment was higher overall compared to treatments that included dual-purpose crops at the start of joining, and was significantly higher than treatments that included dual-purpose crops at the end of joining (late March or early April) in 2015 and 2016. FOO of pastures was also higher in control treatments compared to cropping treatments in early May. FOO in late August or early September, corresponding to the period when sheep in relevant treatments ceased grazing of crops, was higher in the treatments that included crop grazing in 2013 compared to the control, which was the year when stocking density in the control treatment were higher per farmlet, but did not differ significantly between crop grazing and control treatments in other years. FOO did not differ significantly between treatments in mid-October or early November, the FOO measurement corresponding most closely to the spring peak in pasture availability. These results suggest that feed availability is lower during late summer and autumn when dual-purpose crops are included in these system, associated with the period when crops are being established (a result that was supported by the biophysical modelling analysis). It also suggests that availability of pasture will not be higher in spring due to pastures being spelled in winter while crops are grazed, but rather grazing dual-purpose crops allows pastures to ‘catch-up’ when compared to pastures from a pasture-only system.

Biophysical modelling was used to determine whether the availability of dual-purpose crops near Wagga changed the optimal time of lambing. June lambing achieved the highest gross margin over the long term for a system with Merino ewes joined to terminal sires, irrespective of whether ewes were able to graze crops. Grazing crops, however increased the long-term gross margin from the livestock enterprise and reduced the volatility of returns.

Provide benefits that improve crop performance

Previous research has found that under some seasonal conditions crop performance can be improved by grazing. There were no improvements in yields as a result of grazing in the current experiments near Canberra and Hamilton, despite crops being managed for grain yield. Nevertheless, it was demonstrated that with good management grazing can have minimal impact on crop yields. Wheat yields near Canberra were not impacted by grazing, however ungrazed canola crops had higher yields than grazed crops (mean 3.6 v. 3.0 t/ha; $P=0.007$). Grazing spring-sown canola near Hamilton during autumn resulted in no yield penalty relative to the ungrazed spring sown canola plots. However, grazing or defoliating the canola in late winter/early spring resulted in significant ($P<0.05$) canola seed yield penalties of up to 80%.

The experiments in south west Victoria have shown that canola can be successfully used as a summer/autumn forage crop in Australia’s southern temperate high rainfall zone. However, there are a number of risks identified during this research, particularly relating to the risk of establishment failure, if sowing occurs during dry spring conditions, as occurred in spring 2014. In that year the sown canola and Winfred brassica failed to establish with sufficient quantities of dry matter produced across all replicates for the experiment to be undertaken.

Provide a diversified income source that mitigates risk through different price variation or production risk.

Dual-purpose crops diversify income by producing both grain and livestock products (meat, wool). In high rainfall areas where the focus has traditionally been on livestock production only, income from grain can significantly increase returns. Further, where the prognosis for grain yield is poor, there is the potential to still derive benefits by sacrificial grazing of crops. For example, grazing in the NSW Southern Tablelands experiment did not affect wheat yields in three years, and wheat crops were sacrificially grazed by ewes in 2015 due to a poor prognosis for grain yield. The biophysical modelling of the Canberra system indicated that yearly crop and meat production will be essentially uncorrelated, owing to the different periods over which yields of grain and of lambs are determined. This means that a mixed farming system can mitigate risk through the construction of a “portfolio” of enterprises, as well as through the biological synergies revealed in the systems experiment.

Economic modelling of the use of ewe lamb mating on a case study farm showed that mating ewe lambs increased profit and reduced financial risk compared to mating ewes to lamb at two years of age. The use of spring-sown dual-purpose canola as the source of feed for ewe lambs reduced the variability around the rate of return in part due to a diversification of income. Of the scenarios modelled, the use of spring sown canola or lucerne forage for ewe lamb mating provided the best returns for the least risk.

“Over the long term, does the addition of an extra feed supply of high-quality feed and an extra source of income from grain increase or decrease the reliability of year-round feed supply and business risk?”

Taken together, the experimental and modelling results in this report clearly demonstrate that dual-purpose crops can increase the reliability of winter feed supply. Incorporating them into a farming system does, however, carry an increased risk of an autumn feed gap emerging. At prevailing prices, however, filling this feed gap with supplements is financially well worthwhile.

Financial analysis of the Canberra systems experiment, the biophysical modelling at Wagga Wagga and the modelling analysis of winter-lambing systems at Canberra all strongly support the conclusion that the inclusion of dual-purpose crops will both increase profitability and decrease business risk. There is likely to be an interaction with lambing time, however: for earlier lambing dates at Canberra, the modelling analysis predicted that the inclusion of dual-purpose crops would increase profit but also modestly increase downside risk.

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1 Background

1.1 Dual-purpose crops in southern Australia

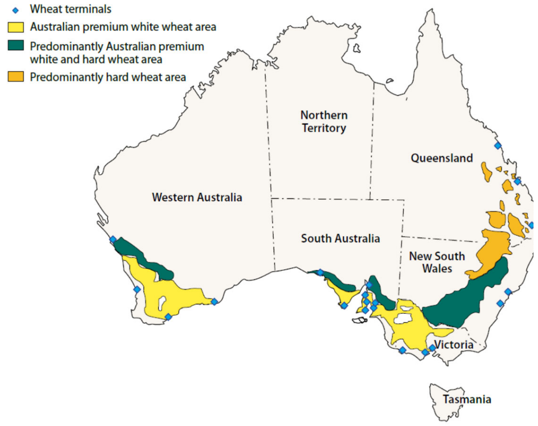

Fig. 1.1. Map of principal wheat growing regions in Australia (ABARES 2011)

A dual-purpose crop is a crop that provides a grazing period for livestock during the vegetative phase, and can then be harvested for grain at the end of the season, thus having the dual purposes of forage and grain production. Many of the winter crops grown in south-eastern Australia can be grazed during the vegetative stage of growth, including oats (*Avena sativa*), triticale (*X Triticosecale*), canola (*Brassica napus*), barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) (Kirkegaard *et al.* 2008; Hennessy and Clements 2009). Varieties that require a vernalisation period, where head initiation does not occur until there has been exposure to periods of cold temperature (Hennessy and Clements 2009), provide an ideal dual-purpose crop for grazing during the winter months in southern Australia, as they can be sown early without inducing early flowering and hence increased risk of exposure to frosts (McMullen and Virgona 2009). Short-season wheat varieties which do not require a vernalisation period for reproductive initiation are usually grown only for grain production and are often referred to as “spring” wheats (McMullen and Virgona 2009; Moore 2009). While spring cultivars can be grazed, these varieties are less suitable for grazing due to their later optimal sowing time and greater risk of grain yield penalty, and the opportunity to graze for any extended period may be restricted in a high proportion of years (Moore 2009).

Early sowing allows these winter crop varieties to be grazed during the vegetative period prior to plants entering the reproductive stage (McMullen and Virgona 2009). The attributes that make grazing of dual-purpose cereal crops attractive to farmers include their potential to fill the winter feed gap in systems where low winter pasture growth rates constrain stocking rates, their high nutritive value, and improved profitability and reduced risk due to income from both livestock production and grain (Harrison *et al.* 2011a).

1.1.1 **History and recent research**

The history of dual-purpose cereals in Australian farming systems has previously been reviewed by Virgona *et al.* (2006) and McMullen and Virgona (2009). While interest in dual-purpose cropping has fluctuated, the practice has been part of farming systems in Australia since at least the 1930s (Forster and Vasey 1931) and was the subject of some research enquiry in the 1970s (Dann *et al.* 1977; Dann *et al.* 1983). The development of short-season and semi-dwarf wheat varieties resulted in interest in dual-purpose cropping being reduced in many farming areas of Australia (Pugsley 1983; Virgona *et al.* 2006). An exception to this was in southern NSW where varieties that required some vernalisation period but with the desirable semi-dwarf habit have been available since the 1970’s

(Virgona *et al.* 2006). The release of several hard grain varieties and reports of higher grain yields in grazed cereal crops have driven a resurgence in use of dual-purpose cereals in the last few decades (Virgona *et al.* 2006). Dual-purpose canola was also investigated in Australia in the 1970's (Dann *et al.* 1977) but there has been renewed interest in the early part of the 21st century (Kirkegaard *et al.* 2008), with rapid adoption in the medium-rainfall zone (Sprague *et al.* 2015b). The recent release of new winter and long-spring canola cultivars provides potential for further expansion of use of dual-purpose canola into the high-rainfall zone (Sprague *et al.* 2015b). The area sown to dual-purpose crops in Australia is estimated to exceed 300,000 hectares (Radcliffe *et al.* 2012).

The renewed interest in dual-purpose cropping has been in conjunction with a large body of research, which has predominantly focussed on management of crops to minimise the impact of grazing on grain yield; however, little research has been undertaken on the optimal use of these crops for grazing. The Tablelands region, for example, is generally focussed on livestock production, therefore it is likely that including dual-purpose crops in the system will replace permanent pasture, rather than replacing a different crop that is sown just for grain as occurs in mixed-farming regions. The Southern Tablelands of NSW are likely to have a restricted area of land that is suitable for cropping (Nix 1971); therefore, it is likely that a smaller area of land in these systems will be devoted to cropping than in the traditional mixed-farming zone. Given the relatively small proportion of the farming system under crop in the Tablelands, it is likely certain livestock classes may need to be prioritised for grazing these crops; therefore, the purpose for the crop in terms of the livestock class that are most likely to graze these crops needs to be identified.

1.2 Exploring the potential of dual-purpose crops to increase meat production

1.2.1 Incorporating dual-purpose wheat and canola into a Tablelands grazing system

The area of land sown to dual-purpose crops in the high rainfall zone (HRZ) of southern Australia (annual average rainfall >500-600 mm) is increasing (Bell *et al.* 2015b). HRZ farming areas such as the Southern Tablelands of NSW were traditionally a pasture-only environment, with dual-purpose crops such as oats sown on small areas to fill winter feed gaps and prepare paddocks for the re-sowing of perennial pastures. These environments are marked by cold winters and mild summers, and areas suitable for cropping are restricted by topography and lack of suitable soils compared to the traditional mixed-farming zones of the slopes and plains (Zhang *et al.* 2006). In the Tablelands systems, the inclusion of more dual-purpose crop typically replaces permanent pasture, in contrast to the grain-producing areas where dual-purpose crops may replace grain-only crops (McMullen and Virgona 2009; Bell *et al.* 2015a).

The potential to expand cropping in the HRZ is well recognized (Bell *et al.* 2015b), and the attributes of dual-purpose crops make them well suited to systems such as those in the Southern Tablelands of south-eastern Australia. Dual-purpose crops such as wheat and canola have high early season growth rates. Forage growth rates for wheat from emergence to first grazing of 22-50 kg DM/ha.day have been reported (Harrison *et al.* 2011b; Sprague *et al.* 2015a). Potential forage growth rates for canola are higher than wheat during autumn, but can be lower than wheat if conditions are dry, with reports ranging from 25-66 kg/ha.day (Sprague *et al.* 2014; Sprague *et al.* 2015a), and winter production of canola is lower than wheat (Sprague *et al.* 2015a). These high forage growth rates during establishment from emergence in early autumn can produce a large bulk of feed for grazing from mid-autumn and during winter for utilisation by livestock. Experiments in the HRZ have consistently demonstrated a high number of sheep grazing days provided by crops during autumn and winter, ranging from 730-2400 grazing days/ha for a single canola or wheat crop (Dove *et al.* 2012; Sprague *et al.* 2014; Dove *et al.* 2015), and up to 3400 grazing days/ha when canola and wheat crops are grazed in sequence (Dove *et al.* 2015). Further, the high nutritive value of forage from dual-purpose crop forage can result in high livestock growth rates. Some studies recorded Merino hoggets and crossbred lambs exceeding mean live weight gains of 0.3 kg/head.day (Dove *et al.* 2002; Kelman and Dove 2007; Dove *et al.* 2012), although these high livestock growth rates have not been achieved in all studies. Attention to rectifying mineral deficiencies has assisted to increase animal growth rates on some cereal crops (Dove and McMullen 2009).

Additional livestock production, reduced supplementary feeding and additional income from grain when dual-purpose crops are included in the system have the potential to increase farm profits in the high rainfall zone. Well-managed dual-purpose crops can achieve high grain yields with little or no penalty compared to ungrazed crops (McMullen and Virgona 2009; Sprague *et al.* 2014). Extrapolation from component experiments has suggested that in the Tablelands environment significant increases in whole farm productivity and profitability can be achieved by incorporating up to 30% of the farm area to dual-purpose crops, although increases in area sown to dual-purpose crops may also result in a reduction in farm stocking rates (Bell *et al.* 2015a). The improved productivity is due to the production of grain as well as increased livestock production while livestock graze the crops and in the period following crop grazing as a result of accumulation of additional pasture biomass. The area sown to crops could consist of a single species such as wheat, or a combination of cereal species or canola.

A common system for Merino producers in the Southern Tablelands is to retain winter-born lambs for sale at approximately 12 months of age. In this production system it might be expected that grazing ewes on high-quality crop forage could improve their body condition at lambing and hence the number of lamb surviving to weaning. On the other hand, carrying lambs over summer and autumn exposes the sale weaners to low pasture availability; this in turn limits their growth rates and therefore meat production, with additional supplementation required to maintain growth rates unless earlier sale of lambs at lower live weights is accepted. An alternative use for dual-purpose crops to grazing by reproducing ewes could therefore be preferential grazing of dual-purpose crops by young livestock. High weight gains are achievable for young livestock when grazing dual-purpose crops, particularly if attention is paid to mineral nutrition (Dove *et al.* 2012). Further, forage consumption of young livestock is low compared to late-pregnant and lactating ewes on a per head basis, therefore a higher stocking density on crops, achieved by running more livestock, reducing the area sown to crop, or allowing other classes of livestock to also graze crops in better seasons, is another potential advantage of prioritising crop grazing for young livestock.

To date, the whole-farm benefit of dual-purpose crops in traditional pasture-based Tablelands systems has not been quantified in a systems experiment that replicates the challenge to provide year-round feed for livestock. The core systems experiment for this project was located near

Canberra and aimed to assess the impact of incorporating dual-purpose crops on livestock production and supplementary feeding and changes in feed availability during the year.

1.2.2 Examining opportunities in mixed-farming systems

Non-wool breeds. More profound changes to the livestock production system may also be possible. One change that has received attention in the cereal-livestock zone is to change to meat-only sheep breeds such as Dorpers. Such livestock production systems are claimed to have lower labour requirements – addressing a significant concern with existing livestock production systems – while preserving the biophysical benefits (N fixation, soil organic carbon maintenance) associated with retaining pastures in the land use mix. To achieve adequate returns, however, systems for non-wool breeds need to produce a significantly higher amount of lamb per hectare or operate at significantly lower cost to compete (in terms of returns) with a dual-purpose system such as Merino ewes joined to terminal sires. This could be achieved, for example, by some combination of increased reproduction rates, higher lamb weight gains, or reduction in supplementary feeding.

Recent research has identified metabolic advantages of Dorpers compared to Merinos (Kilminster and Scanlon 2008; Krebs *et al.* 2014). It was found that when fed a production diet, average dry matter and organic matter digestibilities were higher in Dorper cross sheep than in the Merino sheep. Variations in ruminal parameters could also be attributed to sheep breed. Both heptanoic and hexanoic acid concentrations and molar proportions were higher ($P<0.05$) in the Dorper cross sheep than in the Merinos. Breed differences in the proportions and concentrations of individual volatile fatty acids (VFAs) produced may reflect differences in the microbial population inhabiting the rumen.

Field comparisons of Dorper and more-traditional breeds that are relevant to Australian production systems are limited. Dorper weight gains have been reported in a range of studies in South Africa, but usually on C_4 “native” or “natural” pastures (Cloete *et al.* 2000). Recent Australian research (Kilminster and Greef 2011) indicates that the reproductive efficiency of Dorpers is higher than that of Merinos in young sheep but lower later in development. Limitations to Dorper productivity do exist compared to other breeds but it should be noted that there is the potential for genetic gain as Dorper sheep have had a much shorter history of improvement (Milne 2000). To date there have been no direct comparisons of Dorper-based with conventional livestock production systems; this work is needed in order to both estimate the value of Dorpers and to build knowledge about their production characteristics.

Finishing lambs on pasture. Lamb production systems in southern Australia have traditionally included the use of legume species such as lucerne (*Medicago sativa*) and/or subterranean clover (*Trifolium subterraneum*) (Freer and Jones 1984). Lucerne has many advantages for livestock systems by supplying extended late spring production as well as summer and early autumn production when soil moisture is adequate (Humphries 2012). In comparison, the shallow rooted annual legume subterranean clover (Hamblin and Hamblin 1985) is restricted in growing season length and its future role is less certain, with reports of declining persistence in Australian farming systems brought on by warmer temperatures and more erratic weather patterns (Cullen *et al.* 2009; Revell *et al.* 2012).

The shortcomings of subterranean clover in Australian farming systems have driven breeding and selection programs, including the introduction of a number of new legume species to Australia

(Nichols *et al.* 2007); however, many of these new legume species are yet to be fully assessed for their livestock production potential compared to other finishing options such as brassicas and lucerne. Further, given the possible differences in metabolism for non-wool sheep breeds such as Dorpers in comparison to traditional breeds such as Merinos, there is potential to further explore whether the optimal pasture species to use for lamb finishing may differ between sheep genotypes.

Lambing time. The impact of including dual-purpose crops in mixed-farming systems in southern NSW on the winter feed gap and pasture availability may have potential implications for the optimum lambing time to maximise gross margin returns. Lambing time is an important component of a sheep production system, and the optimal time to commence lambing has been the subject of many studies using both field experiments and modelling. Livestock enterprise, pasture utilisation, the cost of supplementary feeding, stocking rate and lamb weaning weights are all important factors when setting a lambing date (Court *et al.* 2010). Adjusting lambing time to better match pasture availability may increase utilisation of pasture by allowing peak pasture production to meet flock demand (Obst *et al.* 1991; Treacher and Caja 2002)**.** A later lambing generally has advantages over an autumn lambing by allowing a higher winter stocking rate and lamb growth rates, which increases wool and lamb production (McLaughlin 1968; Warn *et al.* 2006a; Court *et al.* 2010). Later lambing can also reduce supplementary feeding costs (Obst *et al.* 1991; Warn *et al.* 2006a; Court *et al.* 2010) and improve reproductive performance, particularly for British breeds of sheep, although lamb survival can be reduced if lambing coincides with periods of cold, wet weather (McLaughlin 1968; Court *et al.* 2010) that occur intermittently during June to August in many regions of southern Australia. The optimal time of lambing is also influenced by the particular enterprise: optimal lambing date for a wool or store lamb enterprise has been suggested to be 3 - 4 months prior to the end of the normal pasture growing season, while a prime-lamb enterprise is recommended to lamb 4 - 5 months prior to the end of the growing season (Warn *et al.* 2006a; Court *et al.* 2010). Warn *et al.* (2006a) concluded that the most profitable time of lambing matches highest production of wool and/or meat with lowest supplementary feeding costs.

Despite many consultants recommending a later lambing date, producers are not necessarily focussed on matching lambing date to feed supply and lambing in autumn is common (Croker *et al.* 2009). The choice of earlier lambing is driven by a focus on meat production by many producers (Sackett and Francis 2006); earlier lambing can increase the number of lambs reaching a finished weight on pasture (Reeve and Sharkey 1980; Freer *et al.* 1994).

Recommendations for later lambing are based on studies in pasture-based systems and do not include the potential contribution of dual-purpose crops to the winter feed base on mixed-farms. Dual-purpose crops can significantly increase the available feed during winter in areas where they can be grown (McMullen and Virgona 2009; Moore *et al.* 2009), and allow stocking rates to increase (Moore 2009). Stocking rate has been shown to have a major impact on gross margins and profit (Warn *et al.* 2006a; Warn *et al.* 2006b), and the greatest advantage of optimising the time of lambing is to increase stocking rate while managing the risk of feeding ewes (Warn *et al.* 2006a). Sackett and Francis (2006) suggested that dual-purpose crops can substantially increase meat production in the cereal-livestock zone, although they provided no supporting data.

1.2.3 **Spring-sown canola**

In the past, only spring-type canola varieties have been commonly grown for seed and oil in Australia. These varieties do not require vernalisation to flower, although vernalisation accelerates flowering. Spring-type canola is usually sown in April-May in southern Australia, following the onset of autumn rains. Crops ripen in late spring or early summer after a 5-7 month growing season. The Australian national average seed yield for canola crops is 1-2 t/ha (Australian Bureau of Statistics 2013; Department of Primary Industries 2010), although these figures include all rainfall environments. Recent research has shown that significant increases in canola seed yields can be achieved in areas that receive greater than 550 mm average annual rainfall by using winter-type canola varieties (Riffkin *et al.* 2012). Riffkin *et al.* (2012) found that winter-type canola, previously not considered suitable for Australian conditions, yielded 1.5-3.5 t/ha at Hamilton, Victoria compared with 1.7-2.9 t/ha from spring cultivars. This was despite the winter-type canola flowering up to 35 days later than the spring types. Although Riffkin *et al.* (2012) focused on canola as a grain crop, significant variety development has occurred recently for late-maturing winter hybrid canola varieties that will not flower until they are exposed to a period of winter vernalisation and that are suitable for both grain and grazing.

Previous research into dual-purpose canola has focussed on using canola sown in autumn and grazed as a winter forage crop (Kirkegaard *et al.* 2008; Kirkegaard *et al.* 2012; McCormick *et al.* 2012). It was found that crops sown in mid-April to early-May provided significant grazing over winter, producing 2.5-5.0 t DM/ha of biomass that provided 0.3-3.5 t DM/ha of high quality forage for grazing by sheep in winter (Kirkegaard *et al.* 2008). At DM intake levels of 1530 g DM/day, Merino hoggets grew at 210 g/day. In other research, Merino hoggets achieved live weight gains of 180-220 g/day over winter on canola (Dove *et al.* 2012).

Kirkegaard *et al.* (2008) found that canola grazed before bud elongation recovered well, though delays in flowering ranged from up to 4 days if heavy grazing occurred before buds were visible, to a 28-day delay if the crop was grazed once flowering had commenced. Delays in flowering associated with grazing did not reduce seed yield or oil content, provided that seasonal conditions were favourable. Gross margins for the grain and grazed canola were $240-$500 higher than for the equivalent grain-only crops. Kirkegaard *et al.* (2012) repeated the finding that winter-type canola can recover from grazing with no canola seed/oil yield penalty if grazing is discontinued before bud elongation commences. Seed yield penalties were found, however, when the canola was grazed to low levels of biomass before bud elongation (<1 t DM/ha residual in July) (Kirkegaard *et al.* 2012).

The vernalisation requirement of winter-type canola also provides the opportunity for canola crops to be sown in spring and grazed as a forage crop during the following summer and autumn, before vernalisation prompts the canola to flower in its second spring. This aspect of canola use has not been scientifically studied. One possible utilisation option for spring-sown canola forage is to improve growth and hence reproductive performance of ewe lambs during the summer and autumn. Modelling analysis by Young *et al*. (2010) suggested that joining ewe lambs to lamb at 1 year of age rather than first joining to lamb at 2 years of age could increase farm profit by up to $100/ha. The benefit gained from joining ewe lambs was contingent on the achievement of weaning rates of at least 83% from the 1 year-old ewes. Thus the modelled system was also dependent on the reproduction rate achieved by the ewes at joining with a 10% reduction in the reproduction rate reducing whole-farm profit by $12/ha. On a per ewe basis, a 10% change in the reproduction rate of the 1-year-old ewes changed profit by $4.80/ewe. This value provides a guide to the amount that could be spent per ewe to increase reproductive performance.

There are a number of factors that can drive the reproduction rate of ewe lambs at their first joining. The primary management requirement is to ensure ewes are on a rising plane of nutrition and gaining weight in the months prior to joining, so that they reach threshold body weight for reproductive maturity (~40 kg) at first joining (Coop 1962, Kenyon *et al*. 2014). A second factor that can increase reproduction rate is nutritional flushing to increase ovulation (Knight *et al*. 1975). Short-term feeding during the luteal phase in the oestrus cycle (days 10-14 of the cycle) (Stewart and Oldham 1986) or during the period six days prior to luteolysis (Nottle *et al*. 1990) increases ovulation rates. These studies have used lupins (*Lupinus angustifolius* L.) as a flushing feed, but forages such as lucerne and chicory can also be used (King *et al.* 2010).

At the start of the project, a number of potential risks of spring-sown canola forage were identified. On the forage production side, it was not known whether spring-sown canola crops could be reliably established, persist over summer and remain in a vegetative state until after they were needed for grazing. Also, the metabolizable energy (ME) concentration and feed on offer from brassica crops can be high and ewes could consume sufficient forage to more than double their energy requirements. Very high levels of nutrition during joining might reduce ewe conception rates (Parr *et al.* 1987, Kenyon *et al.* 2008, Mulvaney *et al.* 2010). Kenyon *et al.* (2008) compared ewe hoggets with live weight gains of 134 and 223 g/day, while Mulvaney *et al.* (2010) compared ewe hoggets with live weight gains of 153 and 208 g/day. Both studies found that a higher proportion of the high weight gain ewes did not conceive in the first cycle, but there was no difference in overall pregnancy scanning data or the percentage of hoggets that subsequently lambed. There therefore appears to be some conflicting evidence around the effect of nutrition on the conception rates of ewe lambs and this was a key consideration for our research.

This component sought to determine if spring sown canola could be used as a summer-autumn forage to improve the growth and reproductive performance of ewe lambs and to determine the impact of autumn grazing on canola seed yield when the crop was then grown to harvest in the following spring. Additional economic analyses were then conducted to determine the impact on profit and risk of such management practices within a whole farm system in comparison to other management options.

2 Project objectives

This project has carried out a series of interlinked grazing experiments to explore how integration of dual-purpose cereal and brassica crops with a pasture feedbase can be used to achieve significantly more meat production with manageable or lower business risk.

The project objectives were:

- To demonstrate that significantly higher utilisation rates and production of meat per kilogram of pasture eaten (at farm scale) are achievable when winter and summer feed gaps are reduced by grazing dual-purpose crops.

- To rigorously evaluate the changed production risk environment associated with livestock production systems that exploit the higher forage production and potentially greater conversion of pasture to meat that arise from inclusion of dual-purpose crops in the feedbase.

3 Methods

The project used a ‘hub and nodes’ model. The core experimental site was located near Canberra, ACT, consisting of a four-year systems experiment using Merino sheep and investigating benefits of incorporating dual-purpose crops in the feedbase. Focussed experiments were also conducted at ‘nodes’ in other states addressing research questions appropriate to each region. These nodes were located near Wagga Wagga in the Riverina region of southern NSW and near Hamilton in south-west Victoria. In addition, biophysical and/or bio-economic modelling analyses to determine the effect of utilising dual-purpose crops over the longer term were completed at each node.

3.1 Tablelands node – systems experiment

A systems experiment designed to determine how much per-ewe productivity was increased by converting an area of grazing land to dual-purpose crops with grazing prioritised either for ewes or their lambs. This experiment was intended to meet the project objectives of demonstrating the scope for significantly higher production of meat achievable from filling the late autumn and winter feed gap typical of the Southern Tablelands of NSW, and evaluating the effect of incorporating crops on production risk, including supplementary feeding, and feed availability throughout the year.

3.1.1 Experimental treatments, design and layout

The experiment was carried out at Ginninderra Experiment Station (35°11’S, 149°3’E, 600 m elevation, average annual rainfall 665 mm) on a deep Yellow Chromosol soil (Isbell 2002; Table 3.1). An aerial view of the two experimental areas where experiments were carried out is presented in Fig. 3.1.

The experiment comprised of 9 experimental units (‘farmlets’) divided into three treatments with three farmlets per treatment (Table 3.2). Farmlets were composed of non-contiguous sub-paddocks of 0.231 ha each. Three farmlets contained permanent pasture only (the control treatment); in 2013 the control treatment comprised 4 sub-paddocks and in 2014-2016 contained 6 sub-paddocks (Table 3.2) as explained below. The other six farmlets all included six sub-paddocks (0.231 ha per sub-paddock) and were sown to permanent pastures, ley pastures and dual-purpose crops, with the proportion in any one year as shown in Table 3.2. Four of the sub-paddocks formed a 4-year cropping sequence: pasture-pasture-canola-wheat (i.e. in any one year there was a wheat crop, a canola crop, two sub-paddocks of pasture ley and two permanent pasture sub-paddocks; Fig. 3.2). Although longer rotation periods are usually used by farmers, a 4-year rotation was used to accommodate the length of the project. The site was run under a similar regimen in 2012, so that plots in the crop-grazing farmlets had the correct preceding land use.

Each farmlet was grazed by 6 Merino ewes and their progeny, with grazing of the farmlets continuing throughout the year. The experiment compared livestock systems whereby classes of livestock were given first priority to graze crops (wheat or canola) when they were available: a treatment that included dual-purpose crops grazed preferentially by ewes (ECG) and a treatment which included dual-purpose crops that were grazed preferentially by weaners (WCG; Table 3.2). In the third (control) treatment, sheep grazed permanent pasture only. The class of livestock (either ewes or weaners) not assigned to preferentially graze crops in the treatment was permitted to graze the crops when seasonal and crop growth conditions allowed, but with management to protect grain yields.

Fig. 3.1. Aerial photograph of the two experimental areas of the Ginninderra Experiment Station that are being used in these experiments.

Table 3.1. Soil test results from samples collected at Ginninderra Experimental Station

Site	Pasture/crop description	Soil type	pH ($CaCl_2$)	Colwell P (mg/kg)	Organic C (g/kg)
Stockade	Cropping, ley pastures and permanent pastures	Yellow Chromosol	5.1(4.6-5.7)	42(20-57) 2012 44 (32-66) 2013	27 23 (18-28)
Kuringa	Permanent pastures	Red Chromosol	4.5 (4.4-5.5)	21 (16-27) 2012 29 (19-49) 2013 31 (27-42) 2014 35 (28-44) 2015	31 (24-37)

Table 3.2. Experimental design for the control, ewe crop grazing (ECG) and weaner crop grazing (WCG) treatments

System/Treatment	Control	ECG	WCG
Number of replicates (farmlets)	3	3	3
Area per farmlet (ha)	2013: 0.92; 2014-16: 1.39	1.39	1.39
Proportion permanent pasture	1.00	0.33	0.33
Proportion first year ley pasture		0.17	0.17
Proportion second year ley pasture		0.17	0.17
Proportion canola		0.17	0.17
Proportion wheat		0.17	0.17
Ewes per farmlet	6	6	6
Carry-over weaners per farmlet	6	6	6
Crop grazing	no	yes, priority to ewes	yes, priority to weaners

Soil data reported in Table 3.1 are averages from 30 samples per plot, collected using a foot corer from the top 100 mm of soil and bulked. Samples were analysed (CSBP Laboratories, Bilbra Lake WA) for pH ($CaCl_2$ method), Colwell phosphorus and total organic carbon (Table 3.1). Rainfall data were collected by a weather station located on the Ginninderra Experimental Station.

3.1.2 **Pasture and crop management**

Pasture and crop establishment and grazing management

Canola and wheat crops were sown as soon as soil moisture content allowed, with all crop sowing events occurring in February or early March. The specific conditions in each year determined the choice of crop cultivars. For wheat, cv. Revenue was sown in 2013 and cv. Manning 2014-16; all years used a sowing rate of 100 kg/ha with Granulock 15 fertiliser (14% N:12% P:11.0% S) applied at 100 kg/ha. For canola Hyola 971CL was sown in 2013 and Hyola 970CL in 2014-2016 at a sowing rate of 5 kg/ha with Granulock 15 fertiliser at 100 kg/ha. Details of chemical sprays, sowing and harvest dates and fertiliser top-dressing for crops are given in Appendix 3. The crops were managed according to best-practice agronomic advice such that weeds, pests and disease did not impact on forage or grain yield, and nutrients were also supplied at commercial rates targeted to achieve the predicted yield potential in each season. Urea (46% N) was applied by top-dressing to crops post-sowing in 2013 (canola 83 kg/ha in March), 2014 (wheat and canola, 100 kg/ha in April) and 2015 (wheat, 100 kg/ha in April). Top-dressing of crops post-grazing aimed to match the yield potential based on available water and predicted seasonal conditions. Urea was applied to crops post-grazing in 2013 (wheat 200 kg/ha in September; canola 108 kg/ha in July or 100 kg/ha in September) and 2014 (wheat and canola 270 kg/ha in August; Appendix 3); in 2016 wet ground conditions prevented any N applications after sowing.

Sowing of ley pastures immediately followed that of crops in 2013 but was delayed until later in March or April in subsequent years. A high-density grass-legume pasture was used for the ley pastures, which were sown as a mixture of cocksfoot (cv. Porto, sowing rate 3.0 kg/ha) and subterranean clovers (cvv. Rosabrook 4.5 kg/ha, Goulburn 4.5 kg/ha and Leura 3.0 kg/ha) with Granulock 15 fertiliser applied at 100 kg/ha. Details of sowing dates, herbicides and insecticides and top-dressing of pastures are shown in Appendix 3. Second year ley pasture sub-paddocks were cut for hay in 2013 and 2014, as a weed control measure in preparation for the cropping phase in the following years.

The three control farmlets and the permanent pasture utilised an established phalaris, cocksfoot and subterranean clover pasture that was subdivided into 24 x 0.231 ha plots. Additional permanent pasture plots were sown to the same pasture species as the permanent pastures in the cropping farmlets (phalaris cv. Holdfast, cocksfoot cv. Currie and subterranean clover cv. Campeda). Phosphorus levels in the older permanent pastures were not at optimal levels for good legume performance (i.e. Colwell P ≥ 32 mg/kg; Table 3.1). Using soil test results to group plots, 250 or 300 kg/ha of molybdenum superphosphate was applied in 2012 followed by 110 or 120 kg/ha triple superphosphate in 2013. In 2014, 150 kg/ha of single superphosphate was applied (300 kg/ha for sub-paddocks that had a low response to P application) and in 2015 a further 100 kg/ha single superphosphate was applied.

Pasture measurements

Forage dry mass was measured close to the times that grazing mobs (ewes, ewes+lambs or weaners) entered the sub-paddocks. In pasture sub-paddocks, forage within six 0.245 m^2 randomly placed quadrats was cut with electric shears. Cut forage was weighed fresh and sub-samples oven-dried (70°C, 72 h) for determination of dry matter (DM) content, and converted to dry matter per hectare, with feed on offer (FOO, t DM/ha) in each plot calculated from the mean of the six samples.

Forage botanical composition was estimated on one occasion each spring and on a number of other occasions by manually separating pasture samples. In 2016, this occurred at strategic times in the livestock production cycle: the end of joining (March), start of crop grazing (May), end of crop grazing (August), and spring peak/weaning (October). Components for forage botanical composition were green forage (perennial grass and legume species), senescent material (grass and legume species), and green weeds (including annual grasses and other species). Green dry matter proportion for each botanical component was calculated by dividing the dry mass of the botanical component by the total green mass of the sample (i.e. total mass less the senesced component).

Crop measurements

Crop development was carefully monitored to assist in grazing management to avoid significant yield loss. Crop biomass was measured at the start of grazing in all plots, and at the end of crop grazing in cropped plots from 6 quadrats (0.4 m^2) cut at ground level at random sites within the crop sub-paddocks. Crop yields were estimated from 6 quadrats (0.4 m^2) cut at ground level, dried at 70°C and threshed. Grain yields are presented on a dry-weight basis.

3.1.3 **Animal management**

All animal husbandry and experimental procedures were approved by the CSIRO Animal Care and Ethics Committee (Protocol Number AEC 2012-05/AEC 2015-22).

A total of 54 Merino ewes and 54 Merino weaners were selected from the Ginninderra Experiment Station flock in November 2012. Spare ewes and weaners were also selected from the same mob to be used when needed (for example, death of experimental animals). Experimental animals were randomly allocated into 9 groups of 6 ewes and 6 weaners and assigned to the 3 treatments. Following shearing in 2014, the experimental ewes used in 2013 and 2014 (born in 2009) were replaced by a new cohort (born in 2012 and that had already weaned their first lambs). This was to avoid any between-year impact of age on reproductive performance in the first cohort. The replacement ewe cohort was of the same bloodline as the original ewes.

Livestock management

Timing of key livestock production events is shown in Table 3.3. Ewes were joined to Merino rams in February/March to lamb in July/August. During joining, ewes were removed from the experimental plots and replaced by wethers to maintain equivalent grazing pressure. After scanning, ewes were re-allocated to farmlets within their original treatment to balance the number of twin-bearing and single-bearing ewes on each farmlet. Weaning was in October or early November (Table 3.3). Six weaners were retained in each experimental unit for sale as yearlings in the following winter; excess

2014-born and 2016-born weaners were sold in mid-January while excess 2015-born lambs were sold following weaning (there were no excess 2013-born weaners). This system of retaining Merino weaners for sale at approximately 12 months of age is common in the Southern Tablelands. Ewes and weaners were shorn in late October or early November (Table 3.3).

Table 3.3. Key livestock management dates 2013-2016

Year	2013	2014	2015	2016
Joining date	14 Feb–27 Mar	13 Feb–1 Apr	9 Feb– 9 Mar	15 Feb–22 Mar
Scanning	10 May	19-May	30-Apr	5-May
Crutching	3 Jun	8 May (weaners) 28 May (ewes)	2-Jun	20-May
Yearling sheep sold	5 Aug	30 Jul	8 Jul (WCG+ECG) 18 Aug (control)	29 Jul (WCG+ECG) 8 Sep (control)
Lambing period	13 Jul–5 Aug	12 Jul–24 Aug	11 Jul–4 Aug	15 Jul–17 Aug
Lamb marking	4 Sep	29 Aug	2 Sep	7 Sep
Weaning	15 Oct	5 Nov	13 Oct	12 Oct
Shearing	30 Oct	5 Nov	9 Nov	2-3 Nov
Crop grazing dates	10 May–4 Sep	19 May–16 Aug	30 Apr- 2 Sep[a]	12 May–24 Aug
Stubble grazing dates	9 Jan–12 Feb	24 Dec–21 Jan	17 Nov–16 Dec[b]	No stubble grazing due to end of experiment

[a] ewes in one WCG farmlet finished grazing wheat crops on 18 September 2015.

[b] sacrificial grazing of wheat crops prior to harvest.

Ewes and weaners were weighed at irregular intervals during the experiment, with individual weights recorded to the nearest ± 0.1 kg; live weight was measured after an overnight fast with the exception of pregnant and lactating animals, which were weighed straight off the plots and returned immediately. Individual fleeces from ewes were weighed (±0.1 kg) and mid-side samples were tested at a commercial wool testing facility for measurement of fibre diameter and staple strength.

Small windbreaks were erected in lambing sub-paddocks on July 23 following a severe weather event. Subsequently the shelters were also erected during the lambing periods of 2014-2015 to reduce exposure for lambing ewes. Shelters were provided in plots occupied by sheep during heatwave conditions in mid-January 2014 (Fig. 3.3).

Four ewes died or were removed during the experiment. One lactating ewe with single lamb (WCG treatment) grazing wheat crop died following a prolapsed uterus on 31 August 2013; one twin-bearing ewe (WCG treatment) grazing pasture died on 9 July 2014, with the death attributed to pregnancy toxaemia; one single-bearing ewe (control treatment) was euthanized following a prolapsed uterus (prenatal) on 29 July 2014; and one ewe (WCG treatment) grazing wheat was removed from the experiment on 25 July 2016 due to paralysis in rear legs after giving

Fig. 3.3. A view of one of the permanent pasture plots in early March 2014, showing early-season pasture growth and one of the shelters provided to livestock during heatwave conditions in January 2014.

birth to large twin lambs. Weaners in one replicate of the control treatment suffered a dog attack on 22 July 2016, resulting in 5 out of the 6 weaners needing to be euthanized. Replacement weaners were brought in to maintain grazing pressure in this treatment until the control weaners exited the experiment on 8 September.

Ewes were drenched on 21 November 2012, prior to introduction to the experimental plots. Ewes were then drenched (Rametin Combo and Tremacide) and vaccinated (Glanvac 6 in 1) each year prior to the commencement of lambing. Ewes were also drenched when required in spring on 30 August 2013 and 17 November 2015. Tri-Solfen^{TM} (40.6 g/L Lignocaine, 4.2 g/L Bupivacaine, 24.8 mg/L Adrenaline and 5.0 g/L Centrimide) was applied to lambs at marking to provide short and long-term pain relief, reduce blood loss and provide an antiseptic/wound sealing. Lambs were also vaccinated with Gudair vaccine and Glanvac 6^{TM} 6-in-1 vaccine at lamb marking. Lambs were vaccinated with 6-in-1 each year after shearing in the spring and were drenched with Tremacide after crutching in the autumn. “Trade” wethers were drenched for liver fluke (Tremacide) and vaccinated (Glanvac 6) prior to grazing crops in 2014 (see below). When grazing dual-purpose wheat, livestock were supplied *ad libitum* access to mineral supplements consisting of stock lime, Causmag AL4^{TM} and salt in varying ratios (Table 3.4). No mineral supplements were supplied to sheep grazing canola based on results from Dove *et al.* (2012)

Table 3.4. Mineral supplements fed *ad libitum* to sheep grazing wheat during the experiment

Year	Livestock class	Supplement	ratio
2013	ewes	Causmag:lime:salt	1:1:1
	weaners	Causmag:salt	1:1
2014	ewes	Causmag:salt (initially)	5:4
		Causmag:lime:salt (from 2 August)	2:2:1
	weaners	Causmag:salt	1:1
	wethers	Causmag:salt	5:4
2015	ewes	Causmag:salt (initially)	1:1
		Causmag:lime:salt (from mid-pregnancy)	2:2:1
	weaners	Causmag:salt	1:1
2016	ewes	Causmag:lime:salt	2:2:1
	weaners	Causmag:salt	1:1

Grazing management and grain supplementation

Grazing management was conducted flexibly on the basis of forage availability and the nutritional requirements of the animals. Thus animals were moved between permanent pasture sub-paddocks (control) and permanent pasture and ley pasture sub-paddocks (ECG and WCG) based on where the most forage was available. First year ley pastures were not grazed for the first eight months following sowing, and were grazed by weaners at the first grazing.

Crop grazing commenced in the ECG and WCG treatments when withholding periods from crop chemical applications had finished and sufficient biomass was available for grazing. Grazing of crops finished in late-winter/early spring (Table 3.4) to protect grain yield, and always prior to stem elongation. In 2015 wheat crops were sacrificially grazed prior to harvest due to a poor prognosis for grain yield and low forage availability in pasture plots in the crop treatments. Sheep in cropping treatments were able to graze stubble for a short period following each harvest (Table 3.3).

Between 18 June and 9 July 2014, wheat plots in the WCG treatment were grazed by young wethers brought in from outside the experiment ("trade" wethers) to exploit plentiful forage available in these plots that was required neither by the weaners that simultaneously grazed the canola plots, nor by the ewes that grazed adequate pasture. Each wheat sub-paddock in the WCG treatment was grazed during this period by 26 wethers with an initial mean live weight of 40.6 +/- 2.7 kg.

Animals were fed grain in response to low forage availability or forage quality deficiencies. The supplement fed changed during the experiment, and variously included oats:lupins 1:1 in 2013, wheat in 2014/15 and wheat:lupins (2:1), wheat:lupins 1:1 and wheat in 2016. To account for the different supplements used, amount of supplement was compared on a dry matter, energy and crude protein amount fed per head basis. Supplements were introduced to the plots gradually and stock lime was added to supplementary grain (1% w/w). Contingency was made to confinement-feed sheep away from plots if low pasture growth rates were causing ground cover to fall below acceptable levels.

3.1.4 **Statistical analysis – systems experiment**

Data was analysed in Genstat (18th Edition) using linear mixed models to compare plot means. Experimental unit (farmlet) was a random term in each statistical model.

A planned comparison was used for comparison of FOO in pasture plots at joining, start and end of crop grazing and the spring peak in pasture production, with the FOO in pasture plots from the control treatment compared to crop grazing farmlets (i.e. the ECG and WCG treatments were combined). Samples for this comparison only came from plots that sheep were entering at the time and excluded plots sown to dual-purpose crops. Feed on offer at each 'event' was analysed separately with fixed model year x treatment, with a square-root transformation of data prior to analysis and predicted means back-transformed for reporting. The same planned comparison was used to compare the proportion of green in total dry matter on sample dates where samples from both control and at least one crop grazing treatment were collected, and the proportion of green sown perennial grass, legume and weed in green dry matter for samples collected at the spring peak in each year or corresponding to the end of joining (March), start of crop grazing (May), end of crop grazing (August) and spring peak (October) in 2016. For all analyses differences in means were tested using least significant differences (at $P<0.05$).

For the comparison of ewe and lamb weights through time, mean weights in each farmlet were compared using linear mixed models with farmlet (i.e. experimental unit) as a random term and treatment, date and treatment x date (when significant) as a fixed term. Mean weights of ewes and lambs were compared in each farmlet at specific events: the end of joining, scanning, lamb marking, weaning and post-shearing for ewes and birth, weaning, December, start of crop grazing, end of crop grazing and final sale for lambs. Fleece weight per head, fibre diameter and strength and the amount of supplement fed were compared using linear mixed models with farmlet as a random term and treatment, year and treatment x year (when significant) as fixed terms. One ewe with triplets was excluded from the analysis. The end of crop grazing and sale weights for 2016 (i.e. 2015 born carry-over weaners) for the farmlet affected by the dog attack were also excluded.

Predicted means were compared using least significant differences (P<0.05). Data for economic comparisons between systems was analysed as per the biological outputs, using farmlet means. The only dataset analysed using individual animal weights was birth weight, to allow single- and twin-births to be included in the model.

Sheep grazing days

Sheep grazing days (SGD) was used as a measure of the amount of time sheep spent on each forage type. SGD per farmlet was calculated by multiplying the number of sheep by the number of days per year on a particular pasture/forage in that farmlet. Sheep grazing days per hectare on canola and wheat crops was calculated by dividing this by the area sown to that pasture or forage type in the farmlet. To better compare grazing between treatments an estimate of the number of dry sheep equivalent (DSE) grazing days per hectare on crops was calculated by multiplying the number of sheep grazing days by a weighting factor for each livestock class: for ewes April-June (pregnant) 1.5; ewes July/August (lambing) 2.5; ewes August/September (lactation) 3.0; weaners 1.0; and wethers 1.0. To fit with the cropping program and the approximate age of the ley pastures, annual sheep grazing days were calculated for the period from 1 March to 28 February in the following year.

3.2 Tablelands node – additional component experiments

These experiments aimed to quantify the behaviour of livestock grazing canola and supplementation to improve productivity from grazing canola crops. Quantifying the impact of the lag phase when livestock first graze canola and benefits of supplementation strategies was intended to help meet the project objective of increasing utilisation rates and production of meat at a farm scale.

3.2.1 **Intake and grazing behaviour of sheep during introduction to canola**

Behavioural observations and intake measurements were made on weaners grazing canola crops during August 2013. Weaners from the ECG and WCG treatments of the main experiment were used in this study. The ECG canola plots were used; one of them was divided into 2 plots of 0.117 ha, providing 2 replicates for each of 2 treatments, i.e. grazing by (i) “inexperienced” lambs that had only grazed pasture previously, and (ii) “experienced” lambs that had previously grazed canola. The canola plots were set-stocked with weaners at 41 animals/ha for 3 weeks starting on 12 August.

Pasture biomass was assessed by cutting quadrats to ground level (n=6 and n=3 per plot in the large and small plots, respectively). Behaviour was recorded by direct observations on four sheep per group (total 16 sheep) with frequent observations of each animal’s behaviour over 4-5 hours on each measurement day. Behaviours recorded were grazing of canola, grazing of other species, walking, idling, standing and lying. Live weight was measured on all sheep at the same hour of the day in the week before the beginning of the experiment for allocation to experimental groups, and weekly thereafter.

Data on feeding behaviour was analysed across the experimental period by a repeated measurement model, inclusive of treatment, date and treatment x date interaction as fixed effects. Plot within treatment was used as error term for the treatment effect. Feeding behaviour data, expressed as a proportion of total observation times, were submitted to arcsine transformation (arcsine of the square root of the original data) prior to analysis. Back-transformed mean data are shown.

3.2.2 **Feeding value of dual-purpose canola**

Feed analyses (dry matter basis, DM) of brassica and canola forages (18–20% neutral detergent fibre, 18–20% crude protein and 11.5–13.5 MJ metabolizable energy/kg DM; Nichol 2003, Kirkegaard *et al*. 2008, Westwood & Mulcock 2012, Cheng *et al*. 2013) suggest that their feeding value should be extremely high. However, the observed live weight gain (LWG) by livestock is often not as high as expected. For example, Judson *et al*. (2013) reported that lambs grazing forage rape had LWG <200 g/d. Farmers at Goulburn (NSW) have also reported the low performance of sheep grazing DP canola. A replicated grazing experiment was carried out during June-July 2015 in order to address the potential factors limiting the feeding value of DP canola.

A 3.5 ha paddock at the Ginninderra Experiment Station was sown with canola (cv. Hyola 970) on the first week of February 2015. The paddock was irrigated to ensure good and uniform biomass was available for a 2-month study commencing on the 2nd week of June 2015. At the start of the experiment, 18 grazing plots of canola crop were created with temporary wire fences. The size of each plot was set to provide *ad-libitum* feed allowance for 8 sheep over a 20-day period.

The intended experimental design was a three-way factorial, replicated 3 times: time period (3) x ± mineral supplement x ± supplemental fibre. A split-plot design was used within each period. Flocks of 8 Merino wethers were selected from a large flock and allocated to each of 6 plots; half the plots received grass hay, and half the animals in each plot received a single oral dose of mineral supplements. In preparation for the experiment, on 4 June 2015 all the animals (48 experimental + 11 spares) were exposed over three days to a canola crop with plenty of phalaris at one side of the paddock. This plot was sown at the same time as the experimental plot. It was observed that the sheep grazed the canola; hence it was assumed that rumen microbiota had exposure/acclimatisation to the canola chemical entities. Sheep were removed to permanent pasture (grass-dominated) at the end of the third day.

On the afternoon of 10 June 2015 the experimental animals were removed from their grazing paddock, immediately weighed, faecal-sampled and fasted overnight. On the morning of Thursday 11 June 2015 the animals were weighed again and wool was clipped at the mid-side (for wool growth monitoring) and neck (to facilitate blood sampling) of each animal. Subsequently, all the experimental animals were dosed orally with slow release devices containing alkanes (for feed intake estimation). At the same time half of the animals were dosed orally with a mineral mix containing copper, iodine, selenium, cobalt and zinc. Animals were subdivided into flocks and allocated to their experimental plots at approximately 5:30 PM. Drinking water was provided *ad libitum.*

3.3 Tablelands node – financial and biophysical modelling

3.3.1 Financial analysis

A cash flow analysis was carried out of the production systems in each farmlet of the Canberra systems experiment. Incomes and expenditures were accounted for all activities that were actually undertaken on each plot, and so costs of each enterprise varied somewhat from year to year. Costs of cropping activities were accounted for at contract rates, conforming to a situation in which a grazier has recently adopted dual-purpose cropping and has not yet invested in cropping machinery; the financial analysis presented here can therefore be read as a partial budget in which the capital costs of the systems under comparison are the same. In order to keep crop income and costs in the same accounting year, the cash flow calculations were carried out for accounting years commencing immediately before the sowing of crops (i.e. generally from early February to late January). Sales of excess weaners were therefore accounted to the year they were born, while sales of the 6 carryover weaners in each farmlet were accounted to the following year. Weaner sheep were assumed to be sold in-wool, so only wool production from ewes was accounted as income.

Table 3.5. Annually-varying prices used for financial analysis of the Canberra systems experiment (nominal values)

		Year				
Item	**Price**	**2012**	**2013**	**2014**	**2015**	**2016**
Weaner sheep, ~12 months of age	$/kg LW		1.09	1.18	1.25	1.41
Cull ewes	$/head			71.58		
Trade sheep	$/kg LW			1.26		
Wool – ewes	$/kg GFW		9.66	9.11	10.64	11.81
Wheat (farm gate)	$/t	275	285	275	252	209
Canola (farm gate)	$/t	493	467	437	479	498
Oats (farm gate)	$/t	140	176	186	208	183
Lupins (farm gate)	$/t	175	283	288	235	233
Barley (farm gate)	$/t	143	239	229	234	189
Fertiliser - Granulock 15	$/t		690	705	810	780
Fertiliser – urea	$/t		570	560	570	500
Fertiliser – MAP	$/t		690	655	750	720
Fertiliser - triple super	$/t		513	433	509	511
Fertiliser - single super (+molybdenum)	$/t		350	326	350	330

Income from grain and livestock products, expenditure on fertilizers and expenditure on grain for supplementary feeding were calculated using prevailing price values in each year of the experiment. Other expenditures (predominantly costs of contract operations and of animal husbandry activities) were calculated using prices prevailing at the end of the experiment in January 2017. Farm-gate grain prices were computed from ABS data for the free-on-board price by deducting the cost of road transport to Port Kembla, port and handling fees. Livestock prices were taken from those at the Yass saleyard in the week that sheep were removed from the experiment. Actual wool prices recorded for

Table 3.6. Constant prices used for financial analysis of the Canberra systems experiment

Item		Price	Item		Price
Shearing	$/head	6.36	Machinery & operations costs:		
Crutching	$/head	1.89	Cultivation	$/ha	30.00
Marking	$/head	2.65	Wheat sowing	$/ha	45.00
Wool: warehouse & testing charges	$/bale	76.55	Canola sowing	$/ha	45.00
Wool: cartage	$/bale	3.86	Pasture sowing	$/ha	45.00
Wool: packs	$/bale	11.50	Fertilizer application	$/ha	8.50
Ewe scanning	$/head	0.85	Herbicide application	$/ha	10.00
Transport of sale stock	$/head	2.00	Forage cutting	$/ha	45.00
Bucket cubes	$/kg	1.00	Forage baling	$/ha	20.00
Salt+Causmag	$/kg	0.91	Canola windrow	$/ha	35.00
Seed:			Mulch failed crop or stubble	$/ha	40.00
Wheat	$/kg	0.97	Wheat harvest	$/ha	65.00
Canola	$/kg	27.00	Canola harvest	$/ha	95.00
Cocksfoot	$/kg	8.95			
Subterranean clover	$/kg	6.53			
Phalaris	$/kg	20.00			

the Ginninderra Experiment Station ewe flock each year were used. Since supplementary feeding took place in autumn-winter, feed costs were calculated using the previous year's grain price. The historical prices and costs were deflated to real dollars at January 2017 using the Consumer Price Index.

3.3.2 **Biophysical modelling**

A systems model of dual-purpose cropping at Ginninderra was constructed by linking the Agricultural Production Systems Simulator (APSIM) soil water, soil nutrient cycling, annual crop and surface residue simulation models (Holzworth *et al.* 2014) to the GRAZPLAN pasture and ruminant simulation models (Donnelly *et al.* 2002), using the AusFarm® modelling software (Moore *et al.* 2007). Interface logic between the APSIM crop and surface residue models and the GRAZPLAN animal model was included so that the grazing of stubbles and green crops could be modelled. Management systems were described using flexible rules that allocated land to the different crop-pasture sequences and then managed the sowing and killing of the various crop and forage species, N fertilizer applications, the annual cycle of sheep reproduction and sales, and grazing management.

A property of size 1000 ha was modelled, with 600 ha of arable soil (plant-available water content for pastures 72 mm H_2O to 700 mm depth, for crops 120 mm H_2O to 1500 mm depth, soil organic carbon in the surface 100 mm = 21.9 g/kg) and 400 ha of non-arable soil with lower soil organic carbon and a shallower depth to the B horizon. A portion of the arable soil and all the non-arable soil were allocated to permanent pastures (mixtures of phalaris, annual grass and subterranean clover). The remainder of the arable soil was allocated to one of two fixed pasture-crop sequences: a "long" rotation (PPPPCWCW, the standard rotation) or a "short" rotation (PPCWPPCW). In the reference case, 40% of farm area was placed under this rotation, so that 20% of land was in crop in each year.

Both the modelled wheat and canola crops were sown when rainfall over the preceding 5 days exceeded a threshold (25 mm from 1 February to 15 March, 15 mm from 16 March to April 30). Crops were fertilized at sowing with ammonium-N (15 kg N/ha for wheat, 30 kg N/ha for canola) and topdressed with urea (90 kg N/ha for wheat and canola). Ley pastures were sown in the year following the last wheat crop when 5-day total rainfall after 1 March exceeded 15 mm.

A self-replacing Merino ewe flock (standard reference weight 50 kg) was modelled in all simulations, with a simplified version of the management system used in the main grazing experiment at the Canberra node. The reference stocking rate was 4.3 ewes per farm hectare (as in the grazing experiment). All yearling and older ewes were mated to rams of the same genotype. The joining date in the baseline simulations was 1 February. Pregnant ewes were assumed to be scanned, so that twin-bearing and other ewes could be managed as separate mobs. Lambs were born in July-August and weaned on 4 October, with all male lambs being castrated. All weaner sheep were retained over summer and sold on 31 July the following year.

Grazing management was modelled as a flexible short-interval grazing rotation. The priority order for the best forage (in descending order) was: ewes with twin foetuses or suckling lambs, single-bearing ewes, weaner sheep and dry ewes. In the simulations in which crops were grazed, they were made available once the biomass of crop forage exceeded 2.0 t/ha and grazing was ended when crops reached Zadoks stage 30 or crop biomass fell below 1.0 t/ha.

All simulations were run at a daily time step over the period 1970-2016; results are reported for the 42 years from 1973 to 2016 in order to remove any effect of the modelled initial conditions. Weather data recorded at the Ginninderra Experiment station were used as input to the simulations. The soil humus and soil biomass pools were reset at the start of each pasture phase to keep soil organic matter near its starting value, so that each modelled year was directly comparable; otherwise the soil water and biomass dynamics in each phase were allowed to determine resource availability in the next phase of each crop-pasture-fallow sequence.

Two simulation experiments were carried out:

1. Allocating dual-purpose crop to weaners vs ewes with different joining dates. A two-way simulation experiment was carried out, with all combinations of:
    - (i) all land under permanent pasture; (ii) 40% of farm area in the “long” pasture-crop rotation, crop forage allocated to weaners; or (iii) 40% of farm area in the “long” pasture-crop rotation, crop forage allocated to ewes; and
    - Joining commencing on 15 December, 1 January, 15 January, 1 February or 15 February.
2. Changing the proportion of area under crop. A second two-way simulation experiment was carried out, with all combinations of:
    - 0%, 20%, 40% or 60% of farm area in pasture-crop rotation; and
    - Stocking rates set to between 0.80 and 1.20 of the reference stocking rate, in steps of 0.05.

    In these simulations the “long” pasture-crop rotation was used and dual-purpose crop forage was allocated to weaners.

A gross margin calculation was carried out for each financial year of each simulated farming system, taking into account income from crops, wool (19 micron fibre diameter) and sales of livestock together with the costs of growing the crops, pastures and animals. In order to capture business as well as production risks, time-varying grain, livestock and wool prices and costs of N fertilizer were used to compute the gross margins. These cost and price values were derived using techniques described by Ghahramani & Moore (2016). Costs of sowing, windrowing and harvesting crops were set to contract rates, so that the capital requirements of the different farming systems were similar.

The conditional value-at-risk (CVaR) of the annual gross margins at the 20% level was used as a measure of the riskiness of each modelled farming system. As used here, CVaR is the average of the gross margins in the worst 20% of cases. All else being equal, a risk-averse farmer will prefer a system with a high CVaR. When compared with other risk measures such as variance, CVaR has a number of advantages: it is a measure of downside risk, it is defined in readily-understandable terms, it has meaningful units, and it is mathematically coherent (Rockafellar and Uryasev 2002).

3.4 Wagga node – Livestock responses to changes in morphology

Differences in morphology of dual-purpose crops sown in rows in comparison to pastures may mean that livestock are able to more easily harvest forage from crops when biomass is low. This experiment sought to compare sheep growth rates when grazing crops and pastures at different levels of feed on offer, thus evaluating the potential for higher utilisation rates when grazing crops and the potential to mitigate some production risk by grazing crops at low feed on offer.

This experiment was approved by the Charles Sturt University Animal Care and Ethics Committee (protocol number 12/047).

3.4.1 Paddock preparation and experimental design

A paddock located on the Charles Sturt University farm at Wagga Wagga (35°02’S, 147°20’E; elevation 219 m) was used for the experiment. The paddock had been sown to a dual-purpose wheat crop in 2011. The paddock was sprayed with glyphosate and burnt in March 2012, prior to sub-dividing into 12 plots of 0.93 ha. A completely randomised design was used, with three treatments and four replicates. Plots were sown to either wheat (*Triticum aestivum*, cultivar Wedgetail) or tetraploid annual ryegrass (*Lolium multiflorum*, variety Winter Star II). Four plots were sown with wheat at row spacing 35 cm (W35; sowing rate 73 kg/ha) and four sown with wheat at row spacing 17.5 cm (W18; sowing rate 75 kg/ha) on April 23; all were sown with monoammonium phosphate (MAP) fertiliser at 80 kg/ha. The four plots to be sown with annual ryegrass (ryegrass) were pre-drilled with MAP fertiliser on 21 April at a rate of 88 kg/ha. On 22 April ryegrass seed was surface spread at a rate of 40 kg/ha and plots were harrowed to cover the seed. Ryegrass plots were surface spread with urea on 16 June at a rate of 100 kg/ha to encourage pasture growth prior to grazing.

3.4.2 Experimental measurements

Pasture measurements

Feed on offer (kg DM/ha) was measured weekly based on the method of Haydock and Shaw (1975), using a minimum of 3 calibration cuts per plot (i.e. minimum of 12 calibration cuts/treatment, representing high, medium and low biomass in each plot) and 50 visual assessments per plot using a 0.25 m^2 quadrat (70 cm x 35 cm). For calibration and visual assessments on wheat the quadrat was placed across two rows for 35 cm row spacing and four rows for 17.5 cm row spacing. Calibration samples were washed to remove any surface contamination, dried at 80°C and weighed.

Characterisation of wheat swards

Changes in height across wheat rows were measured using a system consisting of nine “drop-disc” devices (based on the drop-disc technique (Stewart *et al.* 2001) held in a rigid frame (Fig. 3.4). Each consisted of a central piece of electrical conduit (height 100 cm; diameter 2 cm) down which a polystyrene “disc” (weight 1.05 g; height 3.0 cm; outer diameter 5.3 cm; internal diameter 2.8 cm) was dropped freely from a height of 50 cm. Graduations were marked on the conduit every 1cm, and readings were made to the nearest graduation at the highest point of the disc each time it was dropped. The pieces of conduit were equally spaced over a distance of 35 cm in two rows (i.e. a row of five and a row of four), offset by 5 cm so that each disc did not inhibit the vertical fall of adjacent discs. The frame was placed so that variation in height was recorded across two rows (35 cm spacing) or four rows (17.5 cm spacing); seventeen consecutive readings were taken across each quadrat. The quadrat was then cut and samples dried at 80°C to determine feed on offer.

Height measurements for three quadrats per plot on 15 August and six quadrats per plot on 22 August were made using this technique. Mean row height (i.e. height in the centre of each sown row) was calculated for each quadrat in wheat plots; for W35 using the mean of heights at position five and thirteen and for W18 using the mean of heights at position seven and eleven. Mean height across the quadrat was calculated from the mean of 17 measurements for W18, W35 or ryegrass.

Fig. 3.4. Device used for measuring changes in height across wheat swards.

Quadrat cuts across the range of measurement dates were blocked by weight and 25 samples from each treatment (a minimum of three samples per treatment per date) were tested for nutritive value using NIR spectroscopy as described by Packer *et al.* (2011).

Sheep management

One hundred and fifty second cross lambs (Poll Dorset x Border Leicester/Merino; mean weight 44.4 ± 5.5 kg) were sourced in May 2012. Lambs were drenched on 26 June (Hat-Trick, Ancare Australia, Parramatta, NSW) and shorn on 27 June. Lambs had been grazing a phalaris, lucerne and clover-based pasture prior to being moved onto the experimental plots on 8 July.

From 8 July lambs were moved between two plots in each treatment to create six plots with a 'low' starting biomass; the six ungrazed plots had a 'high' biomass' at the start of the experiment (Table 3.7). All lambs had the opportunity to graze both wheat and ryegrass plots during this pre-experimental period. Animals were also introduced to a supplement of magnesium oxide (Causmag®) and coarse salt in a 1:1 ratio (as fed) during this preliminary period, and this supplement was provided to lambs *ad libitum* while grazing wheat throughout the experiment (Dove and McMullen 2009). Lambs grazing annual ryegrass were also provided the mineral supplement at the commencement of the experiment. However, due to the low lamb growth rates recorded in ryegrass plots in the first weigh period, no more supplement was fed to lambs grazing ryegrass after that date, in case there was an interaction occurring between the supplement and pasture (e.g. see Dove *et al.* 2012).

Table 3.7. Mean feed on offer (kg DM/ha; FOO) for first week (25 July to 1 August) and final week (29 August to 4 September) of grazing (where live weight gains of lambs were measured) for each treatment group, split by high (ungrazed prior to 19 July) or low (grazed prior to 19 July) starting biomass. Means are for two plots ± s.e.

Treatment	Starting biomass	FOO start kg DM/ha	FOO end kg DM/ha
Ryegrass	high	1949 ± 95	3857 ± 185
	low	1291 ± 68	670 ± 112
W18	high	1472 ± 83	658 ± 15
	low	795 ± 28	301 ± 8
W35	high	1358 ± 160	567 ± 48
	low	710 ± 45	452 ± 54

Lambs were randomly allocated to treatments on 19 July and weighed weekly from 25 July, with changes in lamb growth rates calculated from this date. Lambs were weighed after an overnight curfew (yarding from 4pm; weighing from 9am) each week during the experiment. The stocking rate in each plot (with the exception of two ryegrass plots with high starting biomass which were maintained with only the six "core" lambs) was adjusted at the weekly weighing if necessary by adding or removing some lambs from the plot to maintain a gradual reduction in FOO during the experiment. A core group of six lambs (three wethers and three ewes; mean weight on 25 July 43.8 ± 2.4 kg) was maintained in the same plot for the duration for the experiment, with the exception of two lambs in a plot within the W18 treatment; one lamb had a damaged ear, while the other was showing signs of fleece loss; both were replaced with similar animals during the experiment. Mean live weight changes for each plot were based on the means of these six core lambs in each plot. The final weighing date was 4 September.

Herbage growth during July was higher than anticipated and the number of sheep available was insufficient to reduce feed on offer levels. Therefore, plots (with the exception of the two ryegrass plots with a "high" starting biomass) were subdivided on 4 August to reduce the area to 0.5 ha/plot and allow grazing pressure to be increased.

3.4.3 **Statistical Analysis**

GenStat 15th Edition (VSN International, Hemel Hempstead, UK) was used to analyse the data. Mean plot values (e.g. FOO) for a period were calculated from the average of starting and ending levels for a particular measurement period (i.e. week). Average daily live weight gain was examined on the six core lambs in each plot.

Changes in height across a quadrat in the different treatments were analysed using linear mixed models with fixed model treatment*position (1-17)*FOO and random model plot/quadrat/position. In wheat treatments (W18 and W35), the relationship between row height and biomass was analysed using linear mixed models with random model row height (mean of 2 heights in W35 and W18 quadrats)*FOO, and fixed model of date within quadrat within plot. In all treatments, the relationship between mean quadrat height and biomass was analysed using linear mixed models with random model mean height (17 measurements across quadrat)*FOO, and fixed model of date within quadrat within plot; heights for ryegrass were restricted to below 2000 kg DM/ha for this analysis. Predicted row heights and mean heights at different levels of FOO were generated using the VPredict function in Genstat from the model.

Digestible organic matter in dry matter (DOMD) and crude protein (CP) were analysed using linear mixed models with fixed model terms of treatment, date and quadrat biomass (converted to FOO) and their interactions tested, and random model plot/date. Predicted CP on each date at FOO of 1000 kg DM/ha were generated using the VPredict function in Genstat for reporting. Based on DOMD data, two periods for wheat digestibility were identified for inclusion in analysis of lamb growth rates; digestibility period 1 (high digestibility; periods ending 26 July – 15 August) and digestibility period 2 (low digestibility; periods ending 22 August – 4 September).

Lamb growth rates were analysed using linear mixed models, with random effects of date within lamb tag within plot. The relationship between FOO and lamb growth rates was curvilinear so polynomial regression was used, and as the marked fall in digestibility of wheat was expected to have a significant effect on the growth rates of lambs grazing wheat, separate analyses were applied to wheat and ryegrass. Lamb growth rates on wheat were analysed with fixed effects of row spacing, digestibility period and mean feed on offer for each week (FOOAv) and FooAv^2. Lamb growth rates on ryegrass had fixed effects of $\mathrm{FooAv}+\mathrm{FooAv}^2+\mathrm{FooAv}^3+\mathrm{FooAv}^4+\mathrm{FooAv}^5$. Non-significant terms were sequentially removed from the model. Predicted lamb growth rates and standard errors from this model were generated using the VPredict function in Genstat and the curves were compared at different levels of FOO by calculating the standard error of the difference (s.e.d.).

3.5 Wagga node – maternal genotypes experiment

Sheep genotypes with high reproductive and metabolic efficiencies and high growth rates may be one option to exploit the higher forage production from including dual-purpose crops in the feedbase. Non-wool breeds such as Dorper and White Dorper breeds may require a lower input in terms of labour and infrastructure, however their potential on a mixed-farming feedbase has not been explored. This experiment sought to evaluate the changed production risk environment for a system using White Dorper ewes in comparison to a Merino-maternal system using a feedbase based on dual-purpose crops and lucerne.

3.5.1 Experiment 1

Dual-purpose wheat (cv. EGA Wedgetail) was sown on 18 April 2013 into 9 x 0.93 hectare plots. Plots were sown dry. Emergence and initial growth rates were slow, and plots were spread with urea on 11 June at a rate of 80 kg/ ha to boost production prior to grazing.

White Dorper and Merino ewes were joined for 35 days from 6 February 2013. Forty Merino ewes (born 2008) and 35 White Dorper ewes (born 2011) were joined to three White Suffolk rams, and 35 White Dorper ewes were joined to two White Dorper rams.

Ewes were pregnancy scanned on 2 May and weighed and condition scored. It was identified at scanning that 12 White Dorper ewes were pregnant prior to purchase. In addition, four White Dorper ewes and 11 Merino ewes scanned empty; these ewes were not included in the experiment. Prior to scanning ewes had been rotated between lucerne, stubble and a small area of native pasture. Ewes were re-scanned on 23 May to check for losses following the first scanning and were vaccinated. Faecal egg counts confirmed a low worm burden and ewes were not drenched pre-lambing. On 3 June twin- and single-bearing ewes were separated; the single-bearing ewes remained on lucerne and the twin-bearing ewes were hand-fed rice based pellets (ME 12.2 MJ/kg DM; CP 16% DM) and lucerne hay (ME 10 MJ/kg DM; CP 17.7% DM) to maintain condition until the commencement of crop grazing. One twin-bearing White Dorper ewe and one twin-bearing Merino ewe were found in a recumbent position during this period with evidence of predation and did not respond to treatment; the Merino ewe subsequently died and the White Dorper ewe was euthanized.

Ewes were weighed, condition scored and allocated onto grazing wheat plots on 27 June, with three treatments (White Dorper ewes joined to White Dorper rams, White Dorper ewes joined to White Suffolk rams and Merino ewes joined to White Suffolk rams; genotypes grazing separate plots) and three replicates. Three single-bearing ewes and six twin-bearing ewes were allocated to each plot (stocking rate 10 ewes/ha) based on scanning data, with the exception of one Merino replicate which contained 4 single-bearing ewes due to insufficient twin-bearing ewes being available. The dry matter availability at the commencement of grazing was low and ewes were provided pellets at a rate of 500 g/head on 27 June, 1 July and 3 July (1.5 kg/head total) to assist transition to wheat and to minimise the risk of pregnancy toxaemia. Mineral supplement was also supplied (magnesium oxide, lime and salt in a 2:2:1 mix) at an initial allowance of 25 g/head.day. The warm, wet conditions experienced in winter allowed good biomass production in the crop, and ewes were able to remain grazing the wheat crop until mid-August given the higher than expected crop growth rates. One White Dorper ewe died following lambing while grazing wheat and was replaced by a White Dorper ewe with a single lamb (data not included in analysis), and one recumbent ewe (White Dorper) was injected with Calcigol Plus and subsequently recovered.

Daily lambing rounds commenced from 28 June with the first lamb born on 1 July. All lambs were weighed and tagged within 24 hours of birth, ewe tag noted and ewes allocated a maternal behaviour score. Dead lambs were recorded and removed from the site. Ewes and lambs were yarded weekly with all lambs weighed and ewes weighed and condition scored. Weekly rumen samples were collected from one White Dorper ewe and two Merino ewes per plot using a stomach tube, and bulked faecal samples collected from plots. The last lamb was born on 29 July and only one ewe failed to lamb. Lambs were marked within two weeks of birth during the weekly yarding.

After weighing on 14 August, ewes and lambs were moved to lucerne and clover pasture that had been subdivided into 2.2 ha plots. Replicates were maintained as per the wheat grazing phase. Ewes and lambs continue to be weighed fortnightly and rumen, urine and faecal samples were collected at regular intervals to compare between genotypes on the different feedbases. Lambs were weaned on 2 October at which time they were weighed and ultrasound scanned by a commercial operator (convex scanner HS - 2000 VET, Honda electronics) to measure eye muscle depth and fat depth over the eye muscle.

Feed on offer (kg DM/ha) was measured fortnightly using the technique of Haydock and Shaw (1975). Pluck samples were collected from wheat plots on 9 July and 2 August and from lucerne/clover plots on 29 August and 27 September and tested by in a commercial lab by NIR spectroscopy to estimate diet quality.

The 12-hectare paddock used in the winter crop grazing was divided into two equal portions following harvest. Merino and White Dorper ewes were shorn on 11 December. On 20 December ewes were weighed after an overnight curfew, condition scored and put onto wheat stubble after blocking for ewe genotype and BCS. Rumen liquor samples were collected from a sub sample of ewes during the stubble grazing period. Ewes were weighed after overnight curfew on 21 January and returned to grazing lucerne.

Statistical analysis

Data were analysed using linear mixed models with random effects of plot within replicate and ewe, lamb and date included where required. Treatment (genotype) and birth status (single- or twin-born) and interactions were tested in fixed effects, and lamb sex also tested as a covariate and included when significant. Lamb survival was analysed using Generalized Linear Mixed Model with Logit transformation, with means back-transformed for reporting.

3.5.2 **Experiment 2**

Paddock preparation

Six plots (1.86 ha) were sown to dual-purpose crops in 2014 in a replicated complete block design in the same paddock that had been sown to wheat in 2013. Existing stubble was burnt in March 2014. Dual-purpose canola (Hyola 971CL) was sown in three plots on 8 April at a sowing rate of 4.1 kg/ha and a fertiliser rate (MAP) of 81 kg/ha. The canola was sprayed with Elantra Extreme (200 g/L quizalofop-P-ethyl; 190ml/ha) on 17 May to control grass weeds. Dual-purpose wheat (EGA Wedgetail) was sown in the remaining three plots on 9 April at sowing rate 80 kg/ha and fertiliser rate (MAP) 80 kg/ha. The wheat was sprayed with Monza (750 g/kg sulfosulfuron; 25 g/ha) on 17 May to control grass weeds.

Plant establishment counts were made on 9 May across two transects in each plot. A 0.5 m rule was placed inter-row and the number of seedlings on each side of the rule were counted 62 times in each plot and converted to plants per square meter. Crop biomass was measured at the start and finish of grazing using the method of Haydock and Shaw (1975), with a minimum 17 calibration cuts per species and 60 visual measurements across two transects in each plot. Pluck samples were collected on three occasions during crop grazing, with samples dried at 70°C and tested for digestible dry matter in organic matter (DOMD), crude protein (CP) and neutral detergent fibre (NDF) using near-infrared spectroscopy in a commercial laboratory, with wet chemistry validation on 10% of samples.

Sheep management

White Dorper and Merino ewes were joined on lucerne pasture from 17 February to 31 March 2014. Fifty-four Merino ewes (born 2008) and 49 White Dorper ewes (born 2011) were joined to four White Suffolk rams (lamb genotype designated WSM and WSD respectively), and 49 White Dorper ewes were joined to two White Dorper rams (lamb genotype designated WD). Ewes were vaccinated (5-in-1) on 23 April and 30 May, and worm egg counts identified that drenching was not required. Ewes were scanned as single, twin or empty on 15 May; 8 White Dorper ewes joined to White Suffolks and 7 White Dorper ewes joined to White Dorpers were scanned empty and were subsequently excluded from the experiment.

Ewes were blocked by scanning as single- or twin-bearing and body condition scored (BCS) for allocation to treatment. Initially 18 ewes of each lamb genotype were allocated per treatment (11 single WD, 7 twin WD; 9 single WSD, 9 twin WSD; 9 single WSM, 9 twin WSM) with numbers balanced by replicate. An additional four pregnant and two dry non-experimental ewes were allocated per plot due to high biomass. Therefore 24 ewes were grazing each plot at the commencement of grazing (stocking rate 13 ewes/ha). Due to declining leaf availability in the canola treatment the two dry ewes in replicate one were removed from the canola treatment on 8 July, and from replicate two and three on 24 July. Ewes grazing wheat had access to a loose-lick supplement consisting of magnesium oxide, stock lime and salt in a 2:2:1 ratio (as fed). No supplement was provided to ewes grazing canola, based on the recommendations of Dove *et al.* (2012).

Lambing commenced on 13 July, with all lambs weighed and tagged within 24 hours of birth and ewe tag noted. Lambs were marked on 12 August and ewes and lambs moved to lucerne plots (2.1 ha). Due to declining availability of lucerne in some plots, sheep in all plots were combined into a single mob on 12 September, and continued to graze an alternate lucerne and clover pasture until weaning on 29 September, at which time lambs were weighed again.

Ewe weights and BCS were also recorded at the start and finish of the experiment and on three interim occasions corresponding to three weeks after the commencement of grazing (all ewes still pregnant; 8 July); the end of crop grazing (12 August); the end of grazing individual plots of lucerne (12 September); and weaning (29 September). Average daily weight gain of lambs (ADG; kg/head.day) was calculated using the weight gain for each weigh period divided by the number of days in each weigh period. Only growth rates of lambs that survived until weaning were included, and triplet-born lambs were not included in the analysis.

Statistical analysis

Data for dry ewes, ewes giving birth to triplets and triplet-born lambs was excluded from the analysis. Linear mixed models in Genstat 16th Edition (VSNi, UK) were used to analyse data. The reduced fixed model for ewe live weight included starting weight and whether the ewe was still pregnant or had lambed as co-variates, with random model date within ewe within plot within replicate. The reduced fixed model for lamb birth and weaning data included birth or rearing status (single; twin-born, single-raised; twin-born, twin-raised) and lamb age as co-variates, and plot within replicate as random effects. As with experiment 1, lamb survival was analysed using Generalized Linear Mixed Model with Logit transformation, with means back-transformed for reporting.

3.6 Wagga node – spring forage supply experiment

Using a more diverse feedbase may provide an opportunity to increase meat production through higher utilisation and increased growth rates, for example during late spring when annual pastures based on subterranean clover senesce and decline in quality. This component sought to evaluate a number of traditional and novel forage options for finishing lambs during spring.

3.6.1 **Experiment 1 – 2013**

The experimental site was an existing lucerne stand (cultivar Aurora at 8 plants/m^2) with access to flood irrigation, located at the Wagga Wagga Agricultural Institute (35°3’15”S, 147°18’15”E). The soil type is a Red Kandosol with soil pH 4.85 ($CaCl_2$) in the top 0-10 cm and 5.20 in the 10-20 cm layer. Pasture treatments sown were lucerne (cultivar SARDI 10), subterranean clover (cultivars Riverina and Bindoon (50:50)), biserrula (cultivar Mauro) and a treatment with half the plot area sown to subterranean clover and the other half to biserrula (thus providing lambs with a choice of species). The four treatments were laid out in a randomised complete block design with three replications providing twelve plots, 0.7 ha each.

Pasture establishment

The site was initially irrigated on 29 April 2013 (4.4 ML). On 8 May glyphosate (540 g/L) was applied at 2 L/ha across all plots except plots that were to remain in lucerne. All pasture species were inoculated with appropriate rhizobia two days prior to sowing at twice the commercial recommended rate to ensure effective inoculation. Biserrula and subterranean clover plots were sown on 9 and 10 May 2013 at a sowing rate of 15 kg/ha and phosphorus applied at a rate of 30 kg P/ha to meet minimum requirements for subterranean clover. Lucerne plots were also oversown with lucerne at a seeding rate of 10 kg/ha to increase the density of the stand. On 10 July Bromoxynil (200 g/L) was applied at 1.8 L/ha with Lemat (290 g/L omethoate, Bayer CropScience) to all plots at 200 mL/ha to control broadleaf weeds and red-legged earth mite. Rainfall in spring was below the long-term median and temperature was above average. From 18 September, no daily rainfall totals exceeded 10 mm until 15.8 mm was recorded on 5 December. Given the warm and dry spring conditions, subsequent irrigations occurred on 14 October, 25 October, 7 November, and 21 November (4.4 ML or ~50 mm per irrigation) to allow pastures to continue to produce for a longer period.

Pasture sample collection

Over the experimental period the pastures were measured periodically for green and senesced dry matter yield and botanical composition. Dry matter yield was assessed based on the technique used by Haydock and Shaw (1975), with 60 visual assessments made per plot using a 0.1 m^2 quadrat, and

18 calibration samples cut in each pasture treatment. Botanical composition assessments, using the method of Mannetje and Haydock (1963), were made with each visual assessment. In addition, pluck samples were collected along a transect in each plot by "plucking" herbage that most likely represented the animal diet and avoiding the less digestible plant parts; these were collected on 18 October, 28 October, 15 November, 27 November and 17 December. Pluck samples within each plot were bulked within legume species and dried at 70°C for 72 hours before grinding through a 1 mm sieve. Digestible organic matter in dry matter (DOMD), crude protein (CP) and neutral detergent fibre (NDF) content were determined by proximate analyses using near-infra red spectroscopy (NIR) in a commercial laboratory with a Bruker multi-purpose analyser (Bruker Optik GmbH, Ettlingen, Germany) and Opus software (version 5.1), with calibrations as described by (Packer *et al.* 2011). Wet chemistry was used to validate the NIR analysis.

Animal management

All animal procedures were approved by the Charles Sturt University Animal Care and Ethics Committee (Protocol No. 12/101).

A total of 120 mixed-sex lambs, comprising White Dorper (WD, n=60) and White Suffolk x Merino (WSM, n=60), were randomly allocated to plots after blocking for genotype, source (CSU or commercial farm), sex and weight. In addition, 15 White Suffolk x White Dorper lambs (WSD) were randomly allocated to the three lucerne plots. These 135 core experimental lambs grazed the plots for the duration of the experiment, and only weights for these lambs were used in the statistical analysis. In addition to the core experimental lambs, non-core animals (all lambs) were used in a put-and-take system to assist in maintaining similar total above-ground dry matter (Total DM, measured in units of kg DM/ha) between the forage treatments; stocking rates were always equivalent on the 9 non-lucerne annual pasture treatments. Plots containing annual legumes were initially stocked at 17 sheep per plot (i.e. 10 core and 7 non-core animals) and were reduced to 15 per plot on 25 October, 12 per plot on 14 November and 10 per plot on 21 November (i.e. 5 core WD lambs, 5 core WSM lambs and 0 non-core animals). Stocking rates were always higher in plots containing lucerne compared to the annual pastures. The total DM in lucerne plots was higher than annual pastures at the start of the experiment; therefore, an initial stocking rate in lucerne plots of 33 lambs per plot (i.e. 15 core lambs consisting of 5 WD, 5 WSM and 5 WSD lambs, together with 18 non-core animals) was used to give a similar pasture allowance (kg DM/head) to the other treatments at the start of the experiment. Stocking rate on lucerne was reduced to 20 per plot (i.e. 15 core and 5 non-core animals) on 1 November and was unchanged for the remainder of the experiment.

Lambs were weighed after an overnight curfew on 17 October and drenched with a broad spectrum anthelmintic (Hat-Trick^{TM}, Ancare, Parramatta, NSW). They were also vaccinated against clostridial diseases (Ultravac 5-in-1; Zoetis Australia, Rhodes, NSW) and treated to prevent fly-strike (Vetrazin Spray-On; Novartis Animal Health, North Ryde, NSW). Lambs were subsequently weighed (± 0.1 kg) each week during the experiment after an overnight curfew (yarding from 16:00 hours the previous day; weighing from 09:00 hours the following morning). Lamb weights were affected by rain on 5 December, and these weights were not included in the analysis.

Lambs were not supplemented with additional dried fodder with the exception of one biserrula plot (replicate 1), which was supplied lucerne hay (ME 10 MJ/kg; CP 17.7% DM) on 25 October following observation of clinical signs of photosensitisation. The initial amount fed of 9 kg (as-fed; equivalent to 0.53 kg/head) was quickly consumed and an additional 7 kg (equivalent to 0.42 kg/head) supplied on 26 October; the second allocation was not noticeably consumed and subsequently removed from the plot.

Real-time ultrasound scanning of eye muscle depth and fat depth over the eye muscle, measured at the C site (45 mm from the midline at the thirteenth rib) (Gilmour *et al.* 1994) was conducted by a commercial operator on 11 December (convex scanner HS - 2000 VET, Honda electronics). Lambs were processed at a commercial abattoir on 18 December and individual hot carcase weight and fat depth at the GR site (110 mm from the midline at the twelfth rib) recorded.

The decision-support tool GrazFeed (Freer *et al.* 2010) was used to predict growth rates of WSM lambs grazing lucerne, subterranean clover or biserrula, based on the observed green and senesced dry matter (Table 5.15), digestibility and crude protein (Table 5.16) and lamb weights (Fig. 5.8). Observed average daily gains (ADG) of lambs for comparison to the GrazFeed predictions were calculated for the period most closely aligned with when pluck samples were collected by dividing the average weight gain of WSM lambs by the number of days in that period.

Statistical analysis

Statistical analysis of pasture and lamb data was conducted using Genstat software (version 16.1; VSNi, Hemel Hempstead, UK). Analysis of pasture composition data applied a fixed model where effects were pasture by time; the model for correlation was unstructured with unequally spaced time points. Percentage legume contribution data were logarithmically transformed and data back-transformed for presentation. Pasture nutritive value data were analysed with a linear mixed model with pasture species by time as fixed effects and plots within replicates as random effects. Lamb live weights (for core animals only) were analysed using linear mixed models with the fixed terms tested being lamb genotype, pasture treatment, date and their interactions, and the random model date within lamb within plot within replicate. Lamb weight at the start of the experiment (starting weight) and lamb sex were tested as co-variates in the fixed model and included in the final model when significant. Carcase and fat data for WD and WSM lambs grazing the four pasture treatments were analysed using a linear mixed model, with terms tested in the fixed model of starting weight, sex, pasture treatment and lamb genotype, and random model plots within replicate. Comparison of the three lamb genotypes (WD, WSM and WSD) grazing lucerne was made using a separate linear mixed model analysis. LSD values were calculated at the 5% level in all analyses.

3.6.2 **Experiment 2 – 2014**

Pasture establishment and measurements

The experimental site was located on the Charles Sturt University (CSU) farm at Wagga Wagga, NSW and was sown into good soil moisture on 8-10 April 2014. The experiment included six treatments replicated three times, requiring 18 plots each of area 0.4 ha. Treatments were *Ornithopus sativus* cv. Margurita (French serradella), *Trifolium spumosum* cv. Bartolo (bladder clover), *Brassica napus* cv. Stego (forage brassica), *Medicago sativa* cv. SARDI 10 (lucerne), lucerne + *Phalaris aquatic* cv. Advanced AT (phalaris) and *Trifolium vesiculosum* cv. Arrowtas (arrowleaf clover) + *Cichorium intybus* cv. Choice (chicory) with the latter two treatments sown in 1:1 alternate sowing row (tyne) arrangement. All plots were sown at a rate of 35 kg seed/ha, with the exception of the brassica which was sown at a rate of 9 kg/ha. Phosphorus was applied at sowing to achieve 30 mg/kg Colwell P for all treatments.

Higher than average rainfall was received during autumn 2014 (167 mm cf. 120 mm long-term average) and consequently the site (with the exception of the lucerne + phalaris plots) was grazed in early winter with Merino wethers to reduce the pasture biomass. July-November rainfall totalled 140 mm compared to the long term average of 237 mm (BOM 2015); consequently, all treatments were irrigated between 25 September to 6 October and 29 October to 9 November 2014 to avoid premature pasture senescence in the annual treatments and ensure the experiment could be completed. During each watering period 50 mm total was applied in two irrigation events.

Feed on offer was assessed weekly during the grazing period (15 October to 2 December 2014) and remained above 2000 kg DM/ha in all treatments. Pasture pluck samples were collected weekly to simulate the likely diet quality of lambs. Samples were dried at 70 ºC for 48 hours and digestible organic matter in dry matter (DOMD) and crude protein (CP) tested in a commercial laboratory using near infrared spectroscopy with 10% of samples from each treatment tested by wet chemistry.

Sheep management

Weaned lambs were sourced from the CSU flock and local commercial flocks. Lambs were weighed on 7 October 2014 (allocation weight) and drenched (Hatrick, Ancare), vaccinated (5-in-1; Pfizer Animal Health) and treated to prevent fly-strike (Vetrazin spray-on; Novartis Animal Health). Lambs were yarded at 4pm on 14 October 2014, drafted the following morning into pre-allocated groups, weighed and transported to plots. Allocation to plots within each replicate was based on genotype, source of lambs, sex and weight. Five White Dorper (WD), five WSM and three WSD lambs were allocated to each plot, giving a stocking rate of 32.5 lambs/ha. Lambs were subsequently weighed each week after an overnight fast (curfew weight) throughout the experimental period. Lamb weights on 11 November were discarded due to errors experienced with the scales at that time. French serradella commenced senescence earlier than other annual pasture treatments. Consequently, the lambs grazing this treatment lost a significant amount of weight in the weekly measurement period ending 26 November and were therefore removed from the experiment. The final weighing date for all other treatments was 2 December 2014.

Statistical analysis

Forage quality and lamb weights were analysed using linear mixed models in Genstat 16th edition (VSNi). The random model for lamb weight was date within lamb within plot within replicate. Sex, genotype, treatment, date and their interactions were tested as terms in the fixed model, and start weight was tested as a co-variate and included.

3.7 Wagga node – biophysical modelling

Biophysical modelling was used to determine the impact on production and gross margin returns of the livestock enterprise within a mixed-farming system of allowing ewes to graze crops during winter. Of particular interest was whether the additional winter feed supply would change the optimal lambing time for the sheep production system. Thus this component sought to evaluate the changed production risk environment for the livestock production system of exploiting the additional forage from utilising dual-purpose crops in the mixed-farming systems of southern NSW.

Simulation modelling was conducted using AusFarm® version 1.4.7 (www.grazplan.csiro.au), which allows the GRAZPLAN and APSIM models to simulate grazing and cropping systems, and included crop grazing (Moore *et al.* 2007; Moore 2009). The model was run using weather data for Wagga Wagga, NSW (GRAZPLAN weather database; 35°10'S, 147°27'E) from 1 January 1965 to 31 December 2011, with analysis of lamb birth and weaning data for calendar years 1970 – 2010, and gross margin, supplement feeding and lamb sales data for financial years ending July 1971–2011. Variables used were date of commencement of lambing in monthly increments from April to August and stocking rates of 6, 8 and 10 ewes/ha of permanent pasture. Separate simulations were run in which sheep were or were not allowed to graze the wheat crop.

3.7.1 **Farm**

A self-contained portion of a mixed-farming enterprise was modelled for a site at Wagga Wagga. The system included 400 ha of semi- winter dormant lucerne (*Medicago sativa*) and subterranean clover (*Trifolium subterraneum* cv. Seaton Park) pasture divided into four equal paddocks; cropping and livestock activities occurring on other parts of the farm were not modelled, and for simplicity no rotation of lucerne and crop paddocks was applied. The soil type for all paddocks was a brown chromosol (APSOIL #179; Dalgliesh *et al.* 2012).

An additional 350-ha paddock was added to the system in which a dual-purpose wheat crop was sown annually. The size of the wheat paddock provided a stocking density when grazing crop similar to the average in producer surveys in the district and in local field experiments. Dual-purpose wheat (cultivar EGA Wedgetail) was sown each year during April following a cumulative rainfall total of 25 mm over a 5-day period, or on 30 April if these conditions had not occurred. Wheat was sown at row spacing 17.5 cm and depth 25 mm with plant establishment density of 120 plants/m^2.

3.7.2 **Sheep flock**

The livestock enterprise was a medium Merino ewe flock (breed standard reference weight 50 kg; breed reference fleece weight 4.5 kg) joined to Dorset rams (breed reference weight 55 kg) using a ram ratio of 0.01 and a 44-day joining period. Ewes were culled annually after shearing (before joining) at 6 years of age. Replacement ewes (age 19 months) were purchased annually on the day after cast-for-age ewes were sold to maintain flock size at the target stocking rate.

Lambs were weaned at a median age of 12 weeks. Ewes and weaned lambs grazed crop concurrently if the conditions for crop grazing were met; otherwise ewes and weaned lambs grazed separate pasture paddocks until lambs were sold.

A flexible selling policy was applied for the sale of lambs. Lambs were sold after weaning when the mean weight of lambs reached 45 kg, the mean growth rate of weaned lambs fell below 0.02 kg/head.day or ewes were put in the feedlot, indicating that pasture biomass had declined below the nominated threshold.

Grazing and supplementary feeding rules

Pasture was checked every 14 days and sheep were moved to the pasture paddock with the highest feed on offer (FOO; kg DM/ha, with ewes given priority over lambs), or the crop paddock if conditions for grazing crop were met. If available biomass in the 'best available paddock' fell below 500 kg DM/ha, then ewes were confinement-fed wheat grain (ME 13.8 MJ/kg DM, CP 14% DM) in a feedlot until such time as the available biomass in a paddock increased above this threshold. Maintenance feeding of ewes occurred in the paddock when the lowest ewe body condition score fell below 2.0. To prevent early sale or excessive mortality rates of April- or May-born weaned lambs during winter, maintenance feeding of lambs was introduced up until 24 August if lamb growth rates fell below 0.05 kg/head.day, unless pasture availability was below 500 kg DM/ha, in which case the lambs were sold. No production feeding of lambs was used.

In the simulation that included grazing of the wheat crop, crop grazing commenced when the crop had accumulated 850 kg/ha of green feed and developmental stage was before Zadoks stage 31 (Zadoks *et al.* 1974). When these conditions were met, all sheep grazed the crop paddock to rest pastures (Virgona *et al.* 2008), even if higher FOO was available in other paddocks. Sheep were removed from the crop paddock if the crop reached Zadoks stage 31, above ground biomass of the wheat crop was reduced below 500 kg DM/ha or the date reached 23 August (as few producers in the region would choose to graze beyond this date).

3.7.3 **Commodity and input prices for partial budgets**

A skin price of AU$5/head was applied to all lambs sold, regardless of size, and the same dressing percentage (41%) applied to lambs and cull ewes. Lamb and wool prices were applied as per (Robertson *et al.* 2014) of 361 c/kg for 18 – 22 kg carcass weight, 343 c/kg for 16 – 18 kg and 312 c/kg for carcass weights <16 kg; wool price for 21 – 22 micron wool of 852 c/kg clean, and a wheat price for maintenance feeding of AU$250/tonne was used. Sale of cull ewes was set at AU$1.77/kg carcass weight and replacements purchased at AU$60/head. A pasture maintenance cost of AU$50/ha.year was included; however, no labour cost was included, and income and costs for the cropping operation were excluded. A sensitivity analysis was included to consider the effect on mean gross margins of increasing or decreasing the gross value of lamb or wool sold or cost of supplement by 20%.

3.7.4 **Analysis**

Outputs from the model were analysed using Microsoft Office Excel 2007, with box plots produced in GENSTAT 16th edition (VSN International Ltd, Hemel Hempstead, UK).

3.8 Hamilton node – canola as a summer forage for ewe lambs

The research and development question at the Victorian node was "Can reproductive performance of yearling ewe lambs be efficiently increased by the use of a new practice: spring-sown brassica crops (forage canola) that are grazed in summer and autumn and then grown on for seed production?"

3.8.1 Site description

Experiments were conducted at Hamilton, Victoria, Australia (37°50'S, 142°04'E, altitude 200 m). Data from the on-site weather station indicates that the site has a temperate climate with long term (1963-2016) average (LTA) annual rainfall of 683 mm. Rainfall is winter and spring dominant with summer and early autumn usually being hot and dry. The LTA (1965-2016) maximum and minimum daily air temperatures in the warmest month (February) are 26°C and 11°C and in the coolest month (July) are 12°C and 4°C. Climatic conditions, with LTA, are shown in Table 3.8.

Table 3.8. Monthly and annual rainfall (mm) during 2013 to 2016 and long term averages (LTA, 1965-2016) of the maximum and minimum air temperatures at 2 m above ground level (^{o}C) and soil temperatures (^{o}C) at 10 cm depth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						Rainfall (mm)							
2013	13	5	23	18	86	52	88	133	53	93	54	25	644
2014	24	9	20	75	53	76	72	30	39	21	24	32	476
2015	69	16	26	32	86	64	69	31	46	12	27	26	503
2016	43	23	37	48	99	86	106	71	123	85	35	38	794
LTA	36	27	39	51	63	68	83	83	73	61	53	46	683
						Maximum Air Temperature (^{o}C)							
LTA	25	26	23	19	15	13	12	13	15	17	20	23	
						Minimum Air Temperature (^{o}C)							
LTA	10	11	10	8	6	5	4	5	5	6	7	9	
						Soil Temperature (^{o}C)							
LTA	20	20	18	14	11	9	8	8	10	13	15	18	

Table 3.9. Soil fertility (0-100 mm) for each replicate on 19th September 2013

	Replicate 1	Replicate 2	Replicate 3	Replicate 4
Colour	Grey	Grey	Light grey	Light grey
Gravel (%)	5	5	0	5
pH$_{water}$	6.4	6.4	6.0	6.0
pH$_{CaCl2}$	5.7	5.7	5.3	5.4
Conductivity (dS/m^{2})	0.190	0.152	0.216	0.220
Organic carbon (%)	4.88	4.50	4.49	4.46
Nitrate N (mg/kg)	41	30	33	48
Colwell P (mg/kg)	39	34	40	55
Colwell K (mg/kg)	234	90	88	146
KC140 S (mg/kg)	21.7	18.4	26.1	27.0
DTPA Cu (mg/kg)	0.52	1.13	0.70	0.63
DTPA Fe (mg/kg)	211.78	233.60	467.24	450.00
DTPA Mn (mg/kg)	21.78	25.17	24.07	21.65
DTPA Zn (mg/kg)	2.70	4.33	1.87	2.39
Exchangeable Al (meq/100 g)	0.040	0.042	0.066	0.062
Exchangeable Ca (meq/100 g)	14.21	12.26	9.48	9.90
Exchangeable Mg (meq/100 g)	2.19	1.44	2.30	1.86
Exchangeable Na (meq/100 g)	0.35	0.36	0.48	0.35

Soils are of basalt origin and plots were constructed to transect the range in topography within each replicate/block. The soil type varied from well drained grey loam A1 horizon with gravelly loam A2 horizon and heavy clay sub-soil on the crests to more poorly drained valley floors with yellow-grey heavy clay subsoil (Ward *et al.* 2013). Analysis of soil fertility (0-100 mm) was conducted on 19 September 2013 (Table 3.9). There were differences in soil fertility between replicates due to differences in paddock history (e.g. fertiliser, grazing, cropping). For these reasons blocking by replicate was used in the experimental design and stocking rate was independently determined for each block/plot combination according to the feed on offer, the nutritive value of the forage and the predicted feed intake of the sheep.

3.8.2 **Experimental design**

Three consecutive experiments were conducted. Experiment 1 was sown in spring 2013 and was grazed by ewe lambs for a four-week pre-joining period between 25 March to 23 April 2014 followed by a six week joining period with rams between 23 April and 5 June 2014. Experiment 2 was sown in spring 2014 but was never grazed due to poor establishment and below average spring rainfall resulting in inadequate DM production to undertake the experiment. Experiment 3 was sown in spring 2015 and was grazed by ewe lambs for a four-week pre-joining period between 15 February and 11 March 2016 followed by a six week joining period with rams between 11 March and 29 April 2016. The time line for key events in all three experiments is shown in Table 3.10.

The experiment tested seven treatments replicated four times in a complete block design with a restricted randomisation. The treatments were: canola (cv. Hyola 971CL and Taurus [Exp.1 and Exp. 2] or cv. Hyola 971CL and cv. Brazzil [Exp. 3]), forage brassica (*Brassica napus* L. cv. Winfred), lucerne (*Medicago sativa* L. cv. Stamina GT6), chicory (*Cichorium intybus* L. cv. Puna II), plantain (*Plantago lanceolata* L. cv. Tonic) and perennial ryegrass (*Lolium perenne* L. cv. Banquet II Endo5) plus a maintenance pellet allowance.

Table 3.10. Time line of key events for Experiments 1, 2 and 3.

Event	**Experiment 1**	**Experiment 2***	**Experiment 3**
	On the experimental site		
Site preparation commenced	30 July 2013	15 July 2014	26 July to 31 August 2015
Sowing	16, 17,18 and 25 October 2013	21 October 2014	11, 14, 15, 16 September 2015
Start of grazing	25 March 2014		15 February 2016
Start of joining (rams in)	23 April 2014		11 March 2016
End of joining & grazing (rams out)	5 June 2014		29 March 2016
Late winter silage cut /grazing	26-28 August 2014		17 August 2016 12 September 2016
Canola harvest	18 November 2014		6 December 2016
	Off the experimental site		
Pregnancy scanning	14 July 2014		31 May 2016
Lambing			
- Start	27 August 2014		10 August 2016
- End	29 October 2014		20 September 2016
Lamb marking	2 December 2014		11 October 2016

* Experiment 2 was not grazed due to inconsistent establishment and insufficient feed on offer for the grazing experiment to be conducted.

Plot sizes were 1.0 ± 0.1 ha (400-600 m long and 16-18 m wide) within 4 replicate paddocks distributed over approximately 28 ha. The site had been designed, constructed and used in previous experiments (Raeside *et al.* 2017a, Raeside *et al.* 2017b). To determine grazing effects on canola seed/oil yield and oil quality three sub-treatments were imposed on the canola in Exp. 1 and Exp. 3. These were (i) ungrazed, (ii) grazed during autumn for the period of ewe lamb grazing and (iii) grazed during autumn and winter and then cut for silage (Exp. 1) or grazed during autumn and winter and into early spring (Exp. 3). Plots (10m by 10m) were fenced off at the end of each grazing period for each of these canola sub-treatments and they were then harvested. All of the canola plots were harvested at the same time: 18 November 2014 for Exp. 1 and 6 December 2016 for Exp. 3.

3.8.3 Site establishment

The perennial ryegrass treatment was sown in spring 2009 as part of a previous project (Raeside *et al.* 2017a, Raeside *et al.* 2017b) and was retained as it was a dense sward and relatively weed free and represented a perennial ryegrass based pasture system which is typically found on farms within the region. The subterranean clover content in the perennial ryegrass sward was less than 5% of the DM present but this component of the sward would be typically be during summer and autumn.

Site preparation for Exp. 1 commenced on 30 July 2013, with all plots, except for the perennial ryegrass plots, sprayed with 2 L/ha of non-selective herbicide (470 g/L glyphosate), 60 ml/ha of broadleaf herbicide (240 g/L oxyfluorfen) and 100 ml/ha of insecticide (100 g/L alpha-cypermethrin). The Winfred was sown on 16-17 October 2013 and the Hyola 971CL on 18 October 2013 (replicate one) and 25th October 2013 (replicates two, three and four). The remaining plots were power harrowed on 22-24 October 2013 and sprayed with 2 L/ha of non-selective herbicide (540 g/L glyphosate) before being sown on 28 and 29 October 2013. Three plots required re-sowing during December 2013 (Taurus canola in replicate 2, lucerne in replicate 3 and replicate 4) due to poor initial establishment. Sowing rates were: Hyola 971CL 4 kg/ha, Taurus 5 kg/ha, Winfred 4 kg/ha, Stamina GT6 10 kg/ha, Puna II 6 kg/ha and Tonic 8 kg/ha. All plots were sown with 120 kg MAP (10% N, 22% P, 2% S, 0.05% Mo). All plots were sprayed with 100 ml/ha insecticide (120 g/L spinetoram) on 4-10 December 2013 and 100 ml/ha insecticide (290 g/L Omethoate) on 12-13 December 2013. Slug bait was spread across the site at 10 kg/ha on 23 December 2013.

The perennial forage treatments (perennial ryegrass, lucerne, chicory and plantain) were then retained throughout the project, but the annual brassica treatments were re-sown each year. Plots containing the brassica treatments in 2014 (Exp. 2) and 2015 (Exp. 3) were those used for the same treatments in Exp. 1.

On 15 July 2014 the entire experimental site was sprayed with 450 ml/ha of Prosaro foliar fungicide for blackleg prevention. The lucerne plots were also sprayed with SpraySeed® in July 2014 to control annual weeds. On 26-28 August 2014, the brassica plots were cut and baled for silage to remove the herbage from the site in preparation for the sowing of the annual forages for Exp. 2. Regrowth from the brassica plots was then sprayed with 2 l/ha of non-selective herbicide (470 g/L glyphosate) at one week and three weeks after being baled for silage. The annual species were sown at the same sowing rates as were used for Exp. 1.

Site preparation for Exp. 3 commenced on 26-31 August 2015, with the annual treatments sprayed with 1.8 L/ha of non-selective herbicide (glyphosate) and 160 ml/ha of broadleaf herbicide (carfentrazone-ethyl). The Hyola 971CL was sown on 11 and 14 September 2015, Brazzil (cv. Taurus replacement) on 15 September 2015 and Winfred on 16 September 2016. Sowing rates were; Hyola 971CL 4 kg/ha, Brazzil 4 kg/ha and Winfred 4 kg/ha. All plots were sown with 120 kg MAP (10% N, 22% P, 2% S with 0.05% Mo).

3.8.4 **Livestock and grazing management**

Experiment 1

288 maternal composite ewe lambs, 8-9 months of age, were allocated to plots on 25 March 2014. Allocation was based on stratification for live weight, condition score (CS), sire syndicate and birth type (single or twin born). Stocking rate to be applied to each plot was calculated using the GrazFeed decision support tool (Freer *et al.* 1997). These calculations utilised the measured quantity and nutritive value of the available forage on each plot near the start of the experiment. For Exp. 1 these measurements took place on 24 January 2014. The calculations for stocking rate were based on the criterion that the ewe lambs should achieve a predicted live weight gain of 150 g/d over 10 weeks. The perennial ryegrass treatment included the addition of a pellet supplement with 9.8 MJ/kg DM and 11.6% crude protein (CP). Maternal composite rams were randomly allocated to plots on 23 April 2014 at one ram per plot. The rams were fitted with crayon harnesses to record mating activity and were rotated fortnightly using a restricted randomisation within replicate, such that all plots used three different rams over the mating period. The primary aim of this procedure was to ensure all treatments received comparable ram exposure and that possible differences due to ram libido and fertility were minimised between treatments and confounded within the blocks. All livestock were removed from the experimental plots on 5 June 2014. Scanning and lambing for 2014-joined lambs occurred on the dates shown in Table 3.10.

Experiment 2

No livestock were introduced to the plots during Exp. 2 as the establishment of the brassica forages and level of DM production were insufficient to allow grazing for the required length of the experiment.

Experiment 3

189 maternal composite ewe lambs, 8-9 months old, were allocated to plots on 15 February 2016. Allocation was based on stratification for live weight, CS and birth type. The estimation of the applied stocking rate followed the same procedure as Exp. 1, utilising the quantity and nutritive value of the available forage on the 20 January 2016 to set a stocking density where the ewe lambs would achieve a predicted live weight gain of 150 g/d over 10 weeks. The perennial ryegrass treatment included a pellet supplement with 10.0 MJ /kg DM and 11.9% CP. Maternal composite rams were randomly allocated to plots on 11 March 2016 at one ram per plot. The rams were veterinary checked for reproductive fitness prior to mating and were fitted with crayon harnesses to record mating activity. Rams were rotated fortnightly using a restricted randomisation within each replicate, such that all plots used three different rams over the mating period, but there was at least one sire in common, within each group of three, when comparing between treatments within the replicate. All livestock were removed from the experimental plots on 29 April 2016. Scanning and lambing dates for this experiment are reported in Table 3.10.

3.8.5 **Grazing management**

Grazing management for both Exp. 1 and Exp. 3 consisted of dividing the plots into two (or three for some plots) equal sections and rotating the ewe lambs onto fresh pasture at fortnightly intervals to coincide with weighing and condition score measurements.

3.8.6 **Animal health**

All ewe lambs were booster vaccinated with 5-in-1 vaccine prior to grazing experimental plots in both years. Ewe lambs were also vaccinated against campylobacter after the completion of mating in 2014 only. Ewes were drenched before allocation on the plots in 2014. In 2016, ewes had been drenched at their first summer drench and then had a worm egg count measuring 0 eggs/g immediately prior to the 2016 experiment, so no further drenching was undertaken. Worm egg counts (WEC) for strongyles and *Nematodirus*, which are the dominant internal parasites in the area, were monitored from bulk samples of 20 random faecal samples collected across plots within each block during each experimental period.

3.8.7 **Measurements**

Climatic data were collected from an automated weather station which recorded rainfall every 10 minutes and hourly measures of soil temperature (to a depth of 100 mm) and maximum and minimum air temperatures (at a height of 2 m above ground level).

Pre- and post-grazing herbage mass (kg DM/ha) were measured for each grazing rotation using calibrated visual assessments by the procedure of Hodgson *et al.* (1981). Herbage mass was visually estimated from a 0.1 m^2 circular quadrat at 20 random locations per plot. The visual assessments were then calibrated from 20 points of known herbage mass. The calibration equation was determined by estimating the herbage mass in a 0.1 m^2 circular quadrat, then cutting the quadrat at ground level using battery operated shears, washing and drying the sample to constant weight and then converting this weight to kg DM/ha. The actual herbage mass of the calibration cut was then plotted against the estimated herbage mass to give an equation consisting of 20 plotted points. The coefficient of determination for all of the calibration equations was greater than 0.8. Separate calibration equations were developed for each observer and each pasture species at each sampling date.

Pre-grazing forage samples were analysed for crude protein (CP; %DM), neutral detergent fibre (NDF; %DM), *in vitro* dry matter digestibility (IVDMD; %DM), estimated metabolizable energy (ME; MJ/kg DM) and water soluble carbohydrate (WSC; %DM). Forage samples were collected using the procedures of Hodgson *et al.* (1981), where 30 random toe cuts were cut at ground level across each plot using hand held shears and bulked to create a plot sample. The samples were sorted into green and dead and dried at 60°C for 48 h and then ground through a 0.5 mm sieve (Tecator Cyclotec 1093 sample mill, Foss Pacific, North Ryde, NSW, Australia). The dried samples were analysed by near infrared spectroscopy (NIR). The NIR spectra were collected using an XDS Rapid Content Analyser (Foss Analytical AB, Sweden) in conjunction with WinISI II v1.04 software (Infrasoft International, LLC, PA, USA). A generalised NIR calibration was used for all species, derived from sample populations using the procedures of Shenk and Westerhaus (1991). The sample population consisted

of 796 samples. Reference methods were as follows: CP by the Kjeldahl method, NDF by the method of van Soest and Wine (1967), WSC was determined using either the Water Extraction - Anthrone or Alkaline Ferricyanide methodology and IVDMD by using a pepsin-cellulase technique (Clarke *et al.* 1982). Any spectral outliers were analysed by wet chemistry techniques. Estimated ME was calculated in a two-step process using equations from (CSIRO 2007):
DOMD (%) = 7.32 + 0.84 IVDMD (%) and ME (MJ/kg DM) = 0.194 DOMD (%) - 2.577

Botanical composition (%DM) was measured using the dry-weight-rank method of t'Mannetje and Haydock (1963). This involved visually ranking the first, second and third species in 20 circular 0.1 m^2 quadrats per plot according to their contribution to DM production. In the event that there were less than three species present in the quadrat, the cumulative ranking technique of Jones and Hargreaves (1979) was adopted, where more than one rank can be recorded for a given species.

Lamb live weights were measured immediately from the paddock at fortnightly intervals and condition score (CS) was assessed using the methodology described by van Burgel *et al.* (2011) and (Jefferies 1961). Lamb live weight gain was calculated from changes in live weight between consecutive dates. Ultrasound measurements of C-site fat depth (CFAT, measured over the loin) and eye muscle depth (EMD) were made on live animals immediately from the paddock near the start of joining in 2014 (28 April 2014) and at the end of the mating period in 2016 (29 April 2016) using an accredited livestock scanner (Sheep Genetics).

Blood samples were collected by jugular venepuncture from the ewes three times in Experiment 1: (i) at the start of the experiment, (ii) at the start of joining and (iii) at the end of the experiment after joining. The blood samples were collected in 9 ml vacutainers containing EDTA. After collection, the blood samples were placed on ice until centrifugation at 4°C and 3000 rpm. After centrifugation, the plasma was removed and stored at -20°C until required. Plasma samples were then transported frozen to University of Western Australia, Perth.

Plasma progesterone levels were analysed by radioimmunoassay (RIA) at University of Western Australia, using kits supplied by Beckman Coulter. The limit of detection for the assay was 0.16 ng/ml, the intra-assay coefficient of variation 3.6% - 3.7% and the inter-assay coefficient of variation 7.8% - 8.7%.

Plasma prolactin levels were determined at University of Western Australia. They were measured using a homologous double antibody RIA (Miller *et al.* 1995) using a standard (NIADDK-oPrl-I-2) and antiserum (R160) that were kindly donated by Mr. J.A. Avenell of the then CSIRO Division of Animal Production, Prospect, NSW. The samples were assayed in duplicate 10 µl aliquots and the limit of detection was 0.45 ng/ml. The assay included six replicates of three control samples which were used to estimate the intra-assay coefficients of variation of 8.5% at 0.8 ng/ml, 1.4% at 2.1 ng/ml and 3.5% at 4.2 ng/ml.

Blood samples were also collected in Experiment 3 but were lost due to a freezer breakdown prior to analysis.

Endophyte alkaloid analysis of pasture samples collected from Experiment 1 was performed at AgriBio, DEDJTR. Perennial ryegrass pasture samples were ground in a mill mixer MM200 (Retsch, Haan, Germany) and quantification of the alkaloids - lolitrem B, janthitrem, ergovaline and peramine was determined by HPLC analysis (Varian 9100; Varian Inc., Palo Alto, CA, USA).

At harvest, two quadrat cuts, each 1.0 m × 1.0 m, were taken per sub-plot and bulked by plot. The sample was dried at 40°C and then threshed using an electric thresher. An aspirator was used to further separate the seed and non-seed components. A sample of each of these components was oven-dried to determine moisture at 60°C and used to calculate total seed DM/ha. A subsample of 10 plants was divided into leaf, stem and pods and oven-dried at 60°C to a constant weight. One-hundred pods were then selected at random and further separated into silique and seed. The number of seeds from these pods was determined using a Contidor seed counter (Pfeuffer GmbH, Kitzingen) to determine the number of seeds per pod. Weights of the relevant samples were combined to determine total yield per unit area (t ha^{-1} seed yield and biomass kg ha^{-1} DM). Seed from the bulk samples was dried at 40°C and analysed for seed oil and protein, meal protein and fatty acid composition.

3.8.8 Statistical analysis

Plot means of individual animal and forage data were analysed using restricted maximum likelihood (ReML) where the random model contained plot within sub-block (block one = brassicas, block two = chicory, block three = perennial ryegrass, plantain and lucerne), within block (replicate). The fixed model contained treatment within group (group one = brassicas, group two = chicory, group three = perennial ryegrass, plantain and lucerne). This statistical structure accounted for variation between replicates and also accounted for the restricted randomisation required due to the use of the already established perennial ryegrass plots within the trial site. Residuals were checked for normality. The prolactin data were log-transformed to normalise the data. Mean plot growth stage, crop data and seed analyses were analysed by ANOVA or ReML, with the random model containing plot within block (replicate) and the fixed model containing the grazing sub-treatment within the canola variety treatment at the plot level. Statistical comparisons were made using least significant differences (LSD, P=0.05) calculated for the appropriate forage group-by-forage treatment or variety-by-grazing treatment comparisons.

3.9 Hamilton node – economic analysis of canola as a summer forage

The impact of ewe lamb joining with different feeding/forage options on farm production, risk and profit was assessed by a case study economic analysis of six different scenarios for a prime lamb farm in south west Victoria. The modelled base farm (1,000 ha) consisted of perennial ryegrass and sub-clover pastures. The analysis compared incorporating the forages: brassica, canola or lucerne into the feedbase, to grow out ewe lamb replacements for mating at seven months of age. Animal production was simulated using GrassGro® (version 3.3.7; Moore *et al.* 1997), which models the interacting processes of pasture growth and animal production (sheep) subject to historical climate. The biophysical outputs were then combined with price and cost information to build whole farm budgets in Microsoft Excel, with @Risk (version 6.1.1) used to incorporate variability (production and prices) into the economic analysis.

The six different on-farm scenarios that were analysed were:

1. **PR & Sub - Lamb at 2 y.o.:** Perennial ryegrass and sub-clover; first lambing at 2 years of age. Farm 1,000 ha of perennial ryegrass and sub-clover pastures, with 100 ha renewed annually (10-year pasture improvement rotation). Approximately 7,140 mature and 1-2 y.o. ewes lamb each year in late July, with an average lamb marking rate of 129%. Lambs were grown out (finished) on farm to 48 kg LW by the 30th of March. Supplementary feed (barley) was used to maintain ewe and lamb condition and pasture cover levels. Average annual stocking rate was 22 DSE/ha.
2. **PR & Sub - Lamb at 1 y.o.:** Perennial ryegrass and sub-clover; first lambing at 1 year of age. As in option 1, all animals were farmed on perennial ryegrass and sub-clover pastures, however replacement ewe lambs (<1 y.o.) were joined to the ram at seven months of age. Additional supplementary feeding (barley) was used to ensure all replacement lambs were above 40 kg LW (45 kg LW mob average) at joining on 2 March. The target (average) lamb marking rate for ewe lambs was 95% and for mature and 1-2 y.o. ewes 130%. Average annual stocking rate was maintained at approximately 22.4 DSE/ha (due to additional lambs born and farmed).
3. **Brassica - Lamb at 1 y.o.:** Lamb at 1 year of age and use forage brassica to grow out ewe lamb replacements. This option involved farming 950 ha of perennial ryegrass and sub-clover, and annually sowing (in October) 50 ha of forage brassica for replacement ewe lambs to graze over the mid-January to end of March period, to reach the 40 kg minimum live weight required for joining. Target lamb marking for ewe lambs was 100%. Average annual stocking rate was maintained at approximately 22.4 DSE/ha. In total 100 ha of new pasture was renewed annually; 50 ha re-sown after the brassica crop and 50 ha sown direct from old pasture.
4. **Canola - Lamb at 1 y.o.:** Lamb at 1 year of age and graze canola to grow out ewe lamb replacements. This option involved farming 900 ha of perennial ryegrass and sub-clover, and annually sowing (October) 50 ha of canola for grazing by replacement ewe lambs from mid-January to the end of March, in preparation for joining, then again from mid-May to mid-June; the canola would then be allowed to flower and grow for canola seed harvest the following summer – thus a two-year rotation; 50 ha of new canola is planted each year, and a total of 100 ha is in canola each year. Target lamb marking for ewe lambs was 100%. Average annual stocking rate was maintained at approximately 22.4 DSE/ha. In total 100 ha of new pasture was renewed annually; 50 ha re-sown after the canola crop and 50 ha sown direct from old pasture.
5. **Lucerne - Lamb at 1 y.o.:** Lamb at 1 year of age and use lucerne to grow out ewe lamb replacements. This option involved farming 900 ha of perennial ryegrass and sub-clover and 100 ha of lucerne; 90 ha of pasture and 10 ha of lucerne were renewed annually. Lucerne was farmed as part of the annual pasture rotation, with the exception of a heavy grazing by ewes and replacement ewe lambs over the mid-February to mid-March period, and rested either side. Target lamb marking for ewe lambs was 100%. Average annual stocking rate was maintained at 22.5 DSE/ha.
6. **Canola - Higher ewe lamb conception rate:** Lamb at 1 year of age and graze canola to grow out ewe lamb replacements, whilst achieving a higher conception/ lamb marking rate. This option was based on option 4, with a hypothetical target lamb marking for ewe lambs of 110% that was achieved by increasing modelled conception rate.

4 Results from the Tablelands node

4.1 Pasture and crop measurements

4.1.1 Weather conditions

The Canberra systems experiment was notable for between-year variation in weather conditions. The first year (2013) was marked by good rainfall in late-February, a dry and warm March-May period and favourable spring conditions (Fig. 4.1). A dry hot summer in 2013-14 was followed by good rain in mid-February and good plant growth conditions in autumn, winter and spring 2014. The 2015 growing season was less favourable than 2014. There was also limited rainfall at important times in spring 2015, resulting in failure of the wheat crop. There was good rainfall in late January/early February in 2016; after a dry February-April period, 2016 was marked by exceptionally wet and relatively warm conditions from May to November (Fig. 4.1).

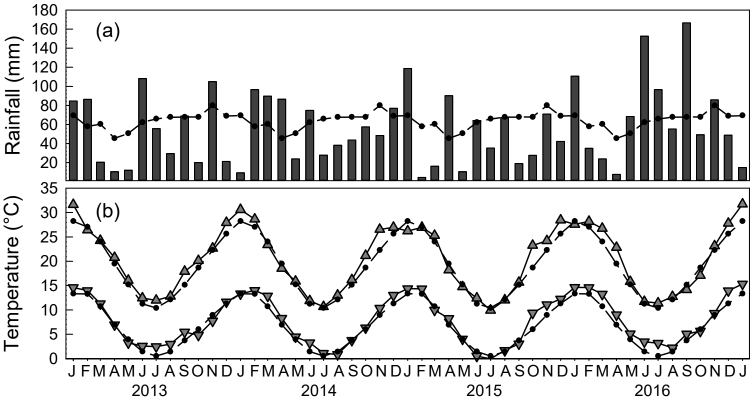

Fig. 4.1. (a) Monthly rainfall at Ginninderra Experimental Station, ACT. Bars show total rainfall recorded in each month. The line shows average monthly rainfall over 1981-2010. (b) Monthly average maximum (▲) and minimum (▼) temperatures recorded at Ginninderra Experimental Station during the experiment, compared to 1981-2010 average monthly values (•).

4.1.2 Crop grazing sequence and sheep grazing days

Crop grazing commenced in all years in late April or May (Table 4.1). In 2013 and 2014, crop grazing was delayed due to withholding periods for chemical applied at sowing. Chemical withholding periods did not delay grazing in 2015 and 2016, with grazing commencing in April in some treatments in these years (Table 4.1).

Ewes in the ECG treatment grazed canola and wheat during late-autumn and winter. In 2013, 2014 and 2016 canola was grazed first in the sequence, while in 2015 wheat was grazed first (Table 4.1) due to the slow germination of canola seed in that year. The initial germination of canola in 2015 was poor despite being sown at the same time as the wheat, however the seed remained viable in the ground and germinated following rainfall in April, and was grazed by sheep from June.

Ewes in the WCG treatment grazed crops in three out of the four years, all during the lambing period; wheat was grazed by ewes in the WCG treatment in 2013 and 2016, and canola followed by wheat in 2015 (Table 4.1). Good growing conditions allowed additional "trade" wethers to graze wheat crops in the WCG treatment in 2014, and this increased the overall number of sheep grazing days in the WCG treatment in 2014 (Fig. 4.2). Both ECG and WCG ewes grazed wheat stubbles in the summers of 2012/13 and 2013/14 (Table 4.1), but stubble grazing only accounted for a small proportion of the sheep grazing days in this experiment (Fig. 4.2). Wheat crops were sacrificially grazed by ewes prior to harvest in November-December 2015 due to a poor prognosis for grain yield and low forage availability in pasture plots in the crop treatments (Fig. 4.3). Weaners in the WCG treatment grazed canola during late autumn/winter 2013, 2014 and 2016, and wheat in 2015 (Table 4.1) but weaners in the ECG treatment did not graze crops in any year.

Table 4.1. Crop grazing dates in the ewe crop grazing (ECG) and weaner crop grazing (WCG) treatments

Year	Treatment	Livestock category	Crop	Grazing dates
2013	ECG	ewes	canola	10 May – 4 July
2013	ECG	ewes	wheat	4 July – 4 September
2013	WCG	ewes	wheat	4 July – 4 September
2013	WCG	weaners	canola	10 May – 2 August
2014	ECG	ewes	canola	15 May – 1 July
2014	ECG	ewes	wheat	1 July – 13 August
2014	WCG	weaners	canola	9 May – 30 July
2014	WCG	wethers	wheat	18 June – 9 July
2015	ECG	ewes	wheat	30 April – 3 June 18 August – 2 September
2015	ECG	ewes	canola	3 June – 18 August
2015	WCG	ewes	canola	2 farmlets: 15 June – 11 August 1 farmlet: 11 August – 18 August
2015	WCG	ewes	wheat	2 farmlets: 11 August – 2 September 1 farmlet: 18 August – 18 September
2015	WCG	weaners	wheat	12 May – 8 July
2016	ECG	ewes	canola	12 May – 28 June
2016	ECG	ewes	wheat	28 June – 24 August
2016	WCG	ewes	wheat	28 June – 24 August
2016	WCG	weaners	canola	28 April – 29 July

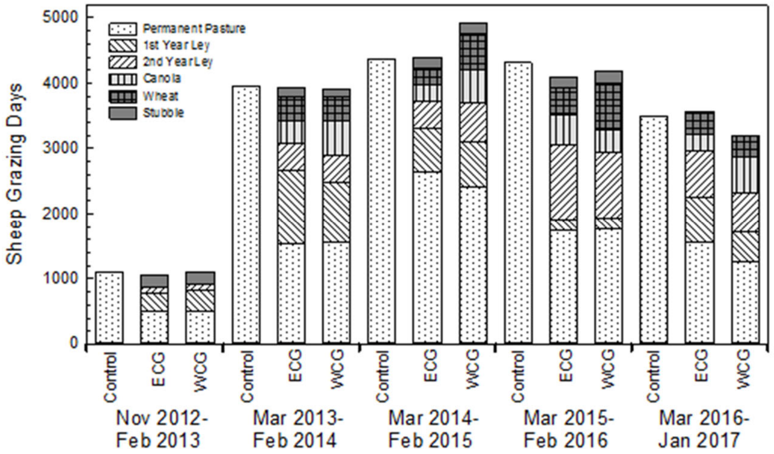

Fig. 4.2. Number of sheep grazing days spent on different pastures and crops in the control, ewe crop grazing (ECG) and weaner crop grazing (WCG) treatments. Days where sheep were not recorded on plots due to being in transition or held elsewhere for animal husbandry or weighing are not included.

Fig. 4.3. Failed wheat crop on 17th November 2015. Grain filling was poor and consequently the crop was grazed between 18 November and 17 December.

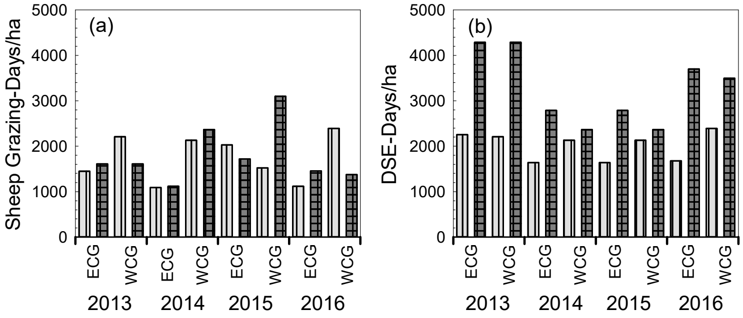

Fig. 4.4. (a) Sheep grazing days per hectare and (right panel) DSE sheep grazing days per hectare in ewe crop grazing (ECG) and weaner crop grazing (WCG) treatments on canola (light bars), wheat (dark bars) during autumn and winter 2013-2016. Values exclude grazing of stubbles and sacrificial grazing of wheat crops.

The higher overall sheep grazing days in the control farmlets in 2015 and 2016 is explained by the weaners being retained longer in the control treatment in those years. In the treatments that included dual-purpose crops, the time spent on first and second year pastures within treatment was similar in 2013, 2014 and 2016. First-year ley pastures were grazed much less than second year pastures in the 2015 cropping year. Sheep spent more time on permanent pastures than other pasture/forage types in the cropping treatments, accounting for 39-60% of SGDs despite only accounting for 33% of the land. Crop grazing plots accounted for 15-30% of sheep grazing days (i.e. sheep grazing days spent grazing canola, wheat or wheat stubble; Fig. 4.2). There were more SGDs on canola in the WCG treatment compared to ECG in 2013, 2014 and 2016 cropping years, which were the years when canola was grazed first in the sequence. This does not necessarily mean there was more grazing pressure on the canola in the WCG treatment, as the DSE rating of ewes is greater than that of weaners.

Total sheep grazing days on crop ranged from 1104 – 2312 sheep grazing days per hectare of crop (canola + wheat) and were 24 – 104% higher in the WCG treatment compared to ECG treatment across years. There were more SGD/ha on canola in the WCG treatment compared to ECG in the 2013, 2014 and 2016 cropping years (Figure 3a), which were the years when canola was grazed first in the sequence. Conversion of sheep grazing days to DSE grazing days showed that total grazing pressure on crops was similar between treatments (<10% in any year), and ranged from 2214 – 3899 DSE-days per crop hectare. There were, however, differences in utilisation of crops between treatments, with higher DSE grazing days per hectare on wheat in the ECG treatment compared to the WCG treatment in 2014, 2015 and 2016, but the reverse effect for canola (Figure 3b). DSE grazing days per hectare were higher on wheat than canola in both treatments in all years (Figure 3b).

4.1.3 **Feed on offer**

Feed on offer from pastures

Pasture FOO in the control treatment was higher than treatments that included dual-purpose crops at the start of joining (3.3 v 2.0 t/ha; P<0.001), and FOO differed between years (P<0.001), being highest in 2015 (3.5 t/ha), intermediate in 2013 (2.7 t/ha) and 2016 (2.6 t/ha), and lowest in 2014 (1.8 t/ha). FOO in the control was significantly higher than treatments that included dual-purpose crops at the end of joining (late March or early April) in 2015 and 2016 (Table 4.2). FOO of pastures was higher in control treatments compared to cropping treatments in early May, corresponding to the period when crop grazing commenced, across the four years (2.3 v. 1.4 t/ha; P<0.001), and differed significantly between years (P<0.001), being highest in 2014 (3.0 t/ha), intermediate in 2015 (2.0 t/ha), and similar in 2013 and 2016 (both 1.3 t/ha). The interaction of treatment and year was not significant for FOO at the commencement of crop grazing.

Table 4.2. Comparison of feed on offer (t/ha) presented to livestock in pasture plots associated with systems with pasture only ("control") or which included dual-purpose crops ("crop"). Different letters on the same line indicate significant differences between treatments in that year (P<0.05). Where interaction of P-value is not significant (P>0.05), P-values for main effects are reported. Note that all FOO values were recorded for plots that sheep were about to enter.

Year	**2013**		**2014**		**2015**		**2016**			**P-value**	
treatment	**control**	**crop**	**control**	**crop**	**control**	**crop**	**control**	**crop**	**Trt*year**	**Trt**	**Year**
start of joining	3.2	2.1	2.3	1.3	5.1	2.5	2.5	2.2	0.09	<0.001	<0.001
end of joining	3.8	4.0	2.3	1.9	5.6a	1.2b	4.6a	1.1b	<0.001		
start of crop grazing	1.6	0.9	3.6	2.4	2.7	1.4	1.8	1.0	n.s.	<0.001	<0.001
end of crop grazing	2.0a	4.2b	4.8	4.2	4.4	3.6	2.6	2.6	<0.001		
spring peak	2.9	3.2	8.7	7.3	5.8	7.0	3.7	5.2	n.s.	n.s.	<0.001

Pasture FOO in late August or early September, corresponding to the period when sheep in relevant treatments ceased grazing of crops, was higher in the treatments that included crop grazing in 2013 compared to the control, but did not differ significantly between crop grazing and control treatments in other years (Table 4.2). In 2013, ewes in the control treatment were removed from plots and confinement fed from just before lambing until lamb marking as a result of low feed availability and concerns that ground cover would not be adequate.

Pasture FOO did not differ significantly between treatments in mid-October or early November, the FOO measurement corresponding most closely to the spring peak in pasture availability, and the interaction of treatment and year was not significant (Table 4.2). FOO for the spring peak differed significantly between years (P<0.001), being highest in 2014 and 2015 (7.8 and 6.6 t/ha respectively), intermediate in 2016 (4.6 t/ha) and lowest in 2013 (3.1 t/ha) (Table 4.2).

Feed on offer from dual-purpose crops

The feed on offer of canola did not differ significantly between ECG and WCG treatments at first grazing (3.9 v. 3.5 t/ha; P>0.05) and the interaction of treatment and year was not significant (Table

4.3). Availability of canola did differ significantly between years (P<0.001), being highest in 2014 (5.1 t/ha), intermediate in 2016 (4.0 t/ha) and did not differ significantly between 2013 and 2014 (2.9 t/ha and 2.8 t/ha respectively). It should be noted that canola was grazed second in the sequence in 2015, so this measurement was made in June instead of April-May. FOO at the commencement of grazing of wheat was highest in in 2014 (4.9 t/ha) and intermediate in 2016 (3.0 t/ha). FOO of wheat at the commencement of grazing was lowest in 2013 and 2015 (1.8 t/ha), although grazing of wheat crops commenced earlier (May) in 2015 compared to June in 2013 and 2016 and July in 2014; wheat FOO did not differ significantly between 2013 and 2015 (Table 4.3). The interaction of year and treatment was significant for FOO in wheat plots at the start of grazing (Table 4.3; P=0.045), being higher in ECG plots compared to WCG plots in 2013, and higher in WCG plots compared to ECG plots in 2015.

FOO of wheat at the end of grazing did not differ significantly between treatments, and unlike the FOO at the start of grazing it was significantly (P<0.001) higher in 2015 compared to 2013.

Table 4.3. Feed on offer (t/ha) in dual-purpose wheat and canola crops measured close to the start of grazing 2013-2016 and residual biomass measured close to end of grazing in wheat in 2013 and 2015. Treatment means with different letters on the same line are significantly different (P<0.05) on that measurement date. LSD reported at P<0.05 level.

	Year	**2013**		**2014**		**2015**		**2016**		**LSD**	**P-Value**
	Treatment	**ECG**	**WCG**	**ECG**	**WCG**	**ECG**	**WCG**	**ECG**	**WCG**		
Start of grazing	Canola	2.9	3.0	5.3	5.0	3.6	2.1	4.1	4.0	1.5	n.s.
	Wheat	2.2a	1.9b	5.0	4.7	1.6a	2.1b	3.0	2.9	0.5	0.045
End of grazing	Wheat	1.3	1.0	-	-	2.4	2.0	-	-	0.9	n.s.

4.1.4 Proportion of green in FOO and botanical composition of pastures in plots on entry

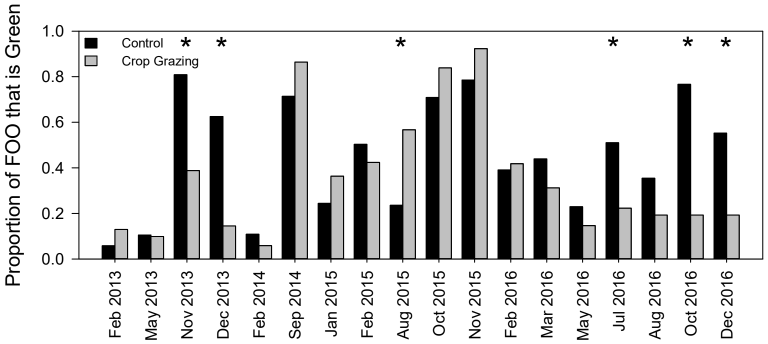

Fig. 4.5. Green plant material as a proportion of feed on offer in pastures from control (black bars) and crop grazing (grey bars) plots. Significant differences between treatments (P<0.05) are denoted by asterisks.

The interaction of treatment and sample date was significant for the proportion of green dry matter in the total dry matter (P<0.001; Figure 4). The proportion of green in dry matter was higher in control plots compared to crop treatments in November and December 2013. Notably the proportion of green in dry matter was higher in the crop treatment samples in August 2015 and 2016, at about the time that crop grazing was finishing in the relevant treatments.

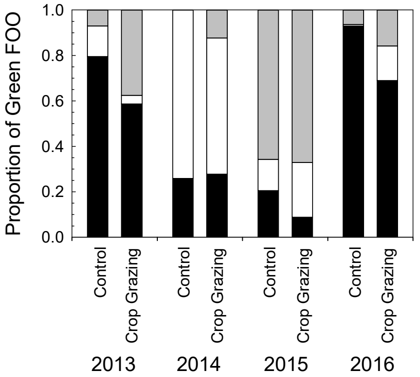

Fig. 4.6. Proportion of sown perennial grass (black bars), legume (white bars), and weed (grey bars) in feed on offer measured at the spring peak 2013-2016.

The 4-year average proportion of perennial grass in green dry matter at the time of the spring biomass peak was significantly higher in control farmlets compared to pastures in the crop-grazing farmlets (0.56 v. 0.41; P=0.002), and the proportion differed between years (P<0.001), being highest in 2013 and 2016, intermediate in 2014, and lowest in 2015 (Fig. 4.6). The average proportion of legume in green dry matter at the spring peak did not differ significantly between treatments but did differ significantly between years (P<0.001), being highest in 2014 (Fig. 4.6). The average proportion of weeds in green dry matter at the spring peak was significantly higher in treatments that included dual-purpose cropping compared to the control treatment (0.33 v. 0.20; P=0.04) and was significantly higher (P<0.001) in 2015 compared to other years (Fig. 4.6). One permanent pasture sub-paddock in the WCG treatment was removed from the experiment in spring 2015 due to a barley grass (*Hordeum vulgare*) infestation and replaced by a different plot (Fig. 4.7).

Fig. 4.7. Plot of permanent pasture (ECG treatment) on 24 November 2015, showing significant presence of invasive weed grasses (*Hordeum* spp. and *Lolium rigidum* among others).

In 2016, the proportion of sown perennial grasses as a proportion of green FOO in pasture plots was significantly higher in the control treatment compared to the crop-grazing treatments in March and August but not in May or October; the proportion of legume did not differ significantly between treatments. The proportion of weeds in green dry matter was significantly higher in the crop-grazing treatments in both March and August 2016, with the contribution being predominantly from dicotyledonous weeds (mainly *Chenopodium* spp. and *Rumex* spp.) in the autumn and annual grasses (*Lolium rigidum*, *Hordeum* spp. and *Vulpia* spp.) in the spring (Table 4.4). Proportions of perennial grasses, legumes and weeds did not differ significantly between treatments.

Table 4.4. Proportion of perennial grass, legume, annual grasses and weed material within the green component of feed on offer collected at selected times in 2016. Treatment means with different letters in the same row are significantly different (P<0.05) on that sampling date.

	March 2016		**May 2016**		**August 2016**		**December 2016**	
	pasture	**crop**	**pasture**	**crop**	**pasture**	**crop**	**pasture**	**Crop**
perennial grass	0.88a	0.32b	0.89	0.83	0.82a	0.34b	0.93a	0.69b
legume	0.01	0.16	0.01	0.10	0.13	0.12	0.01a	0.15b
annual grasses	0.07	0.14	0.00	0.02	0.04a	0.52b	0.02a	0.15b
other weeds	0.04a	0.38b	0.10	0.05	0.01	0.02	0.04	0.01
total weeds	0.11a	0.52b	0.10	0.07	0.05a	0.54b	0.06	0.16

4.1.5 Grain yields

Mean canola yield was significantly higher in ungrazed compared to grazed crops (3.6 v. 3.0 t/ha; P=0.007). Yield from grazed canola crops did not differ significantly between ECG (3.1 t/ha) and WCG (2.9 t/ha) treatments but did differ significantly between years (Table 4.5). Mean wheat yield did not differ significantly between ungrazed compared to grazed crops (3.9 v. 3.7 t/ha; P>0.05). Yield from grazed wheat crops did not differ significantly between ECG (3.8 t/ha) and WCG (3.9 t/ha) treatments or with year (Table 4.5). Interactions between treatment and year were not significant for canola or wheat yields.

Table 4.5. Mean yield (t/ha) from grazed canola and wheat crops 2013-2016. LSD reported at P<0.05 level. Wheat crops were not harvested in 2015.

Crop	**Year**				**LSD**	**P-value**
	2013	**2014**	**2015**	**2016**		
Canola	1.3a	3.9b	2.4a	4.4b	0.7	<0.001
Wheat	3.4	3.8	–	4.5	1.9	n.s.

4.2 Ewe weight changes, condition scores and wool production

4.2.1 Ewe live weights

The starting weight of the second ewe cohort, introduced in November 2014, was similar to the starting weight of the first cohort in November 2012 (Fig. 4.8). As expected, ewe live weights were lower after lambing and shearing (Fig. 4.8). The live weight of the first cohort of ewes tended to be higher in 2014 compared to 2013 (Fig. 4.8), while annual cumulative weight changes of ewes were relatively small in 2015 and 2016. Ewe live weight at specific times differed significantly between years (P<0.001); ewes were heavier at the start and end of joining, pregnancy scanning and lamb marking and weaning in 2014 compared to the other years. Ewe weights of the 2009-born cohort

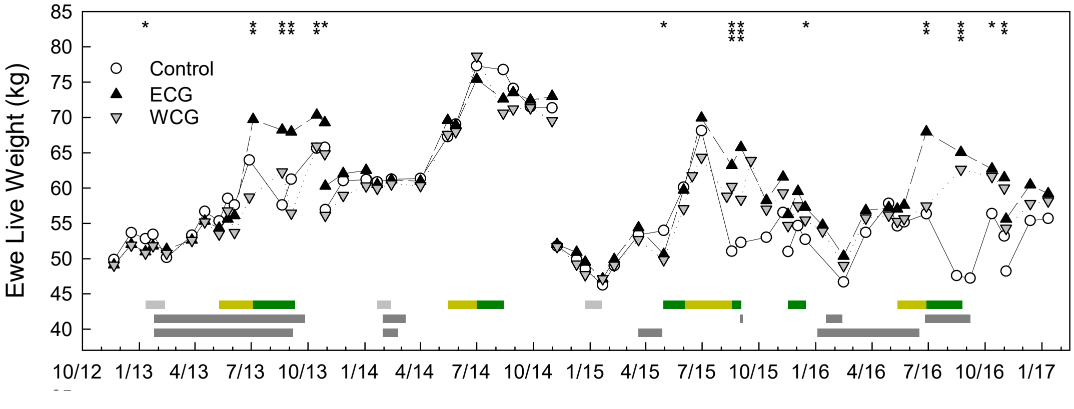

Fig. 4.8. Mean weight of ewes November 2012 – January 2017. Treatments were pasture-only (control; open diamonds), ewes prioritised to graze dual-purpose crops in autumn/winter (ECG; open circles) and weaners prioritised to graze dual-purpose crops during autumn and winter (WCG; closed circles). Periods when ECG and WCG treatments grazed crops are marked by horizontal bars representing vegetative canola (closed bars), vegetative wheat (open bars) or wheat stubble (grey bars). Periods during which supplements were fed to ewes in control or crop grazing treatments are represented by horizontal bars with strike-through. Statistical significance of treatment effects at each measurement are: not significant (P>0.05), not shown in graph; *, P<0.05; **, P<0.001.

were heavier at weaning in 2014 compared to 2013, and live weights for the 2012-born cohort were heavier at weaning in 2016 compared to 2015, reflecting better seasonal conditions in those two years.

Differences between treatments in 4-year average ewe live weight at the start of joining approached significance (P=0.055), with ewes in the ECG treatment (53.2 kg) tending to be heavier than control ewes (51.8 kg). The interaction of treatment and year was not significant (P>0.05) for live weight at the start of joining (Table 4.6). The interaction of treatment and year was significant for ewe live weight at pregnancy scanning (P=0.004), with control ewes being heavier compared to other treatments in 2015; however, there were no significant differences between treatments in other years (Table 4.6).

The interaction between treatment and year was significant for ewe weight at lamb marking (P<0.001), with ewes in the ECG treatment significantly heavier than ewes in the control in three out of four years, and ewes in the WCG treatment significantly heavier than control ewes in 2 years (Table 4.6). Differences in ewe live weight at weaning approached significance (P=0.055) with ewes in the ECG treatment (66.1 kg) tending to be heavier than WCG (63.5 kg) and control (61.6 kg) treatments. The interaction of treatment and year approached significance at weaning for ewe live weight (Table 4.6).

Table 4.6. Comparison of mean ewe live weights and body condition scores between control, ewe crop grazing (ECG) and weaner crop grazing (WCG) treatments at livestock management events 2013-2016. LSD values reported at P<0.05.

	Live Weight						Body Condition Score				
Year	Treatment					Year	Treatment				
	Control	ECG	WCG	LSD	P-Value^		Control	ECG	WCG	LSD	P-value
					Start of joining						
2013	50.2	51.3	50.7	2.3	n.s.	2013	-	-	-		
2014	61.2	61.2	60.6	2.3		2014	2.8	3.0	2.9	0.3	n.s.
2015	49.0	49.9	49.1	2.3		2015	2.8	2.7	2.9	0.3	
2016	46.7	50.3	49.0	2.3		2016	2.6	2.9	2.8	0.3	
					Pregnancy scanning						
2013	58.5	55.6	56.8	3.2	0.004	2013	2.8	2.8	3.1	0.5	n.s.
2014	67.3	69.6	67.6	3.2		2014	3.6	3.7	3.6	0.5	
2015	54.0a	50.6b	49.8b	3.2		2015	3.2	2.7	2.9	0.5	
2016	54.6	57.0	55.3	3.2		2016	2.9	3.3	3.2	0.5	
					Lamb marking						
2013	61.2a	68.0b	62.6[#]a	5.0	<0.001	2013	-	-	-		
2014	74.1	73.5	71.2	4.7		2014	4.0	4.0	3.4	0.6	0.001
2015	52.3a	65.8b	58.4c	4.7		2015	2.2a	3.6b	3.1b	0.6	
2016	47.2a	65.0b	62.7b	4.7		2016	2.1a	3.7b	3.4b	0.6	
					Weaning						
2013	65.6	70.3	66.0	5.0	0.099	2013	-	-	-		
2014	71.3	73.0	69.6	5.0		2014	-	-	-		
2015	53.0	58.3	57.0	5.0		2015	2.4	3.1	3.1	0.6	n.s.
2016	56.4	62.7	61.7	5.0		2016	2.8	4.2	3.9	0.6	
					Post-shearing						
2013	56.9ab	60.3a	56.2b	3.9	0.032	2013	-	-	-		
2014[*]	-	-	-	-		2014	-	-	-		
2015	51.0a	56.3b	54.7ab	3.9		2015	-	-	-		
2016	48.2a	55.6b	54.3b	3.9		2016	3.0a	4.5b	4.4b	0.5	<0.001

one replicate excluded as an outlier

^ treatment x year; n.s. = not significant

[*] ewe cohort replaced, no post-shearing weights

Over the three years measured, mean post-shearing weight of ECG (57.4 kg) and WCG (55.0 kg) ewes were significantly heavier (P=0.013) than control ewes (52.0 kg). The interaction of treatment and year was significant for post-shearing weight of ewes (P=0.032), with ECG ewes being heavier than WCG in 2013 and compared to control ewes in 2015 and 2016, and WCG being heavier than control in 2016 (Table 4.6). Condition score of ewes post-shearing was higher in the crop grazing treatments compared to the control in 2016 (P<0.001; Table 3).

4.2.2 **Wool production**

Mean greasy fleece weight from ECG (5.2 kg) and WCG (4.9 kg) ewes was significantly greater (P<0.001) than from control ewes (4.5 kg). There was a significant difference in GFW between years (P<0.001) with GFW heaviest in 2014 and lightest in 2016. Mean CFW was also significantly heavier (P<0.001) in the ECG (3.8 kg) and WCG (3.7 kg) treatments compared to the control treatment (3.4 kg). CFW also differed significantly between years (P<0.001), again being highest in 2014 and lowest in 2016.

Fibre diameter did not differ between treatments and was significantly higher (P<0.001) in 2014 compared to other years. Interactions between treatment and year were not significant for greasy fleece weight (GFW), clean fleece weight (CFW) or fibre diameter (Table 4.7). The interaction of treatment and year was significant for wool staple strength, with ewe wool from the ECG treatment being significantly stronger compared to other treatments in 2016; however, all treatments had high staple strength in 2016 and no price penalties would have been incurred. Mean fibre strength in 2014 was significantly higher compared to other years (P<0.001).

Table 4.7. Mean greasy fleece weight (GFW) and clean fleece weight (CFW) per head, fibre diameter (micron) and tensile strength of wool cut from ewes during the experiment. LSD values (reported at P<0.05) allow for treatment and year comparisons.

			Treatment				**P-Value**	
	Year	**Control**	**ECG**	**WCG**	**LSD**	**Treatment x year**	**Treatment**	**Year**
GFW (kg/head)	2013	4.5	5.2	4.8	0.4	n.s.	<0.001	<0.001
	2014	5.3	5.6	5.9	0.4			
	2015	4.4	5.2	5.0	0.4			
	2016	3.9	54.8	4.6	0.4			
CFW (kg/head)	2013	3.4	3.7	3.5	0.3	n.s.	<0.001	<0.001
	2014	4.0	4.1	4.4	0.3	(P = 0.055)		
	2015	3.4	3.9	3.5	0.3			
	2016	2.9	3.6	3.3	0.3			
Fibre diameter (µm)	2013	18.5	18.4	18.4	1.0	n.s.	n.s.	<0.001
	2014	19.4	19.5	19.5	1.0			
	2015	18.7	18.5	18.1	1.0			
	2016	18.3	18.4	18.1	1.0			
Fibre strength (N/ktex)	2013	41.8	35.0	41.1	11.3	0.021	n.s.	<0.001
	2014	53.3	50.5	57.1	11.3			
	2015	34.9	32.3	30.1	11.3			
	2016	42.7a	57.5b	46.3a	11.3			

4.3 Reproduction

The mean number of foetuses scanned per ewe and lambs born per ewe were significantly higher in control and ECG treatments compared to WCG in 2013 and 2016 (Table 4.8). 2016 was the only year where some ewes were scanned as non-pregnant, and the WCG treatment also had fewer twin-bearing ewes compared to other treatments in 2016.

Weather during lambing and scanning rates had an effect on lamb mortalities. Severe weather conditions on 19-21 July 2013 coincided with a spike in lamb mortalities. Weather conditions during lambing were more favourable in 2014 and there were more single-born lambs compared to the previous year. In 2015 weather was also favourable during lambing and no lamb deaths were attributed to weather; lamb deaths all occurred within 24 hours post-lambing and deaths were ascribed to fox predation, mismothering, ill-thrift and dystocia. In 2016 most deaths prior to lamb marking also occurred within 24 hours of birth and with a similar range of causes, with no deaths ascribed to weather conditions.

The small number of sheep used in this study meant it was unlikely statistical differences in survival would be detected between treatments. The number of lambs marked per ewe and lamb survival did not significantly differ between treatments or years, and the treatment x year interactions were not significant. Survival of lambs was numerically highest in the WCG treatment (90%), intermediate in the ECG treatment (82%) and lowest in the control (78%). Number of lambs marked per ewe was also numerically highest in the ECG treatment (1.35) but was intermediate in the control (1.24) and lowest in the WCG treatment (1.19). Survival of lambs to marking was numerically highest in 2014 (87%), intermediate in 2013 and 2016 (both 79%) and lowest in 2015 (76%). Number of lambs marked per ewe was numerically highest in 2015 (1.37), intermediate in 2014 (1.33) and lowest in 2013 and 2016 (both 1.17). Survival of single-born lambs was higher than twin-born lambs (92% v. 75%; P=0.002), and the results indicate that lamb survival and number of lambs marked per ewe was at least in part due to differences in the number of twins and singles in each treatment.

Table 4.8. Reproductive performance of ewes recorded during experiment 2013-2016. LSD values reported at P<0.05). P-values are for the treatment x year interaction.

Parameter^	Year	Control	ECG	WCG	LSD	P-value^
No. foetuses scanned per ewe	2013	1.61a	1.67a	1.06b	0.44	0.003
	2014	1.72	1.56	1.67		
	2015	1.78	1.61	1.83		
	2016	1.61a	1.67a	1.06b		
No. lambs born per ewe	2013	1.66a	1.60a	1.16b	0.31	<0.001
	2014	1.28a	1.67b	1.72b		
	2015	1.83	1.78	1.78		
	2016	1.66a	1.60a	1.16b		
Lamb survival to marking	2013	0.69	0.88	0.81	0.31	n.s.
	2014	1.00	0.80	0.81		
	2015	0.73	0.71	0.84		
	2016	0.69	0.88	0.81		
No. lambs marked per ewe	2013	1.17	1.39	0.94	0.53	n.s.
	2014	1.28	1.33	1.39		
	2015	1.33	1.28	1.50		
	2016	1.17	1.39	0.94		

4.4 Lamb weights

The pattern of lamb growth rates was similar in all years, with weight gain tending to increase steadily to weaning, slow or stop during the summer and early autumn and increase again during the late autumn and winter. The increase in weight gain during winter was particularly notable in the WCG treatment (Figure 4.9).

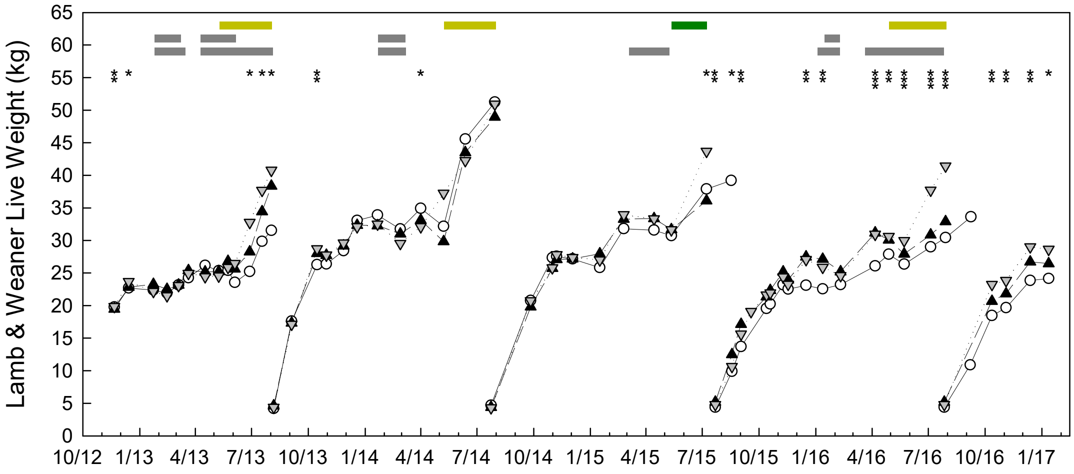

Figure 4.9. Mean weight of lambs November 2012 – September 2016. Treatments were pasture-only (control; open diamonds), ewes prioritised to graze dual-purpose crops in autumn/winter (open circles) and weaners prioritised to graze dual-purpose crops during autumn and winter (WCG; closed circles). Periods when WCG treatments grazed crops are marked by horizontal bars representing canola (closed bars) or wheat (open bars). Periods during which supplements were fed to weaners in control, ECG or WCG treatments are represented by horizontal bars with strike-through. Arrows identify weaning date in each year. Statistical significance of treatment effects at each measurement are: not significant (P>0.05), not shown in graph; *, P<0.05; **, P<0.001.

Birth weight of singles was significantly heavier than twin-born lambs (5.0 v. 4.1 kg; P<0.001) and male lambs had significantly heavier birth weights than female lambs (4.8 v. 4.4 kg; P<0.001). Sex and scanning status were consequently included in the statistical model for birth weight. There was a significant interaction between treatment and year for birth weight, with lambs born in the crop-grazing treatments being significantly heavier (P=0.034) than the control treatment in 2015 (Table 4.8); there were no differences between treatments in any other year.

At weaning, lambs from the ECG (24.3 kg) and WCG (25.3 kg) treatments were significantly heavier than lambs from the control treatment (23.0 kg; P=0.003). Weaning weights in 2013 and 2014 (27.7 kg and 27.5 kg respectively) were significantly greater (P<0.001) than weaning weights in 2015 and 2016 (both 20.8 kg). The interaction between treatment and year was not significant for weaning weight. Total weight of lambs at weaning did not differ significantly between treatments, but was significantly higher (P<0.001) in 2014 compared to other years (Table 4.9). The interaction of treatment and year was significant for live weights of weaners in December, with weaners in crop-grazing treatments being significantly heavier compared to control in December 2015, and WCG weaners significantly heavier than control weaners in December 2016 (Table 4.9).

At the start of crop grazing, the mean weights of weaners in the ECG (31.8 kg) and WCG (31.4 kg) treatments were significantly higher (P=0.02) than in the control treatment (29.2 kg). Year effects were significant (P<0.001) with weaners being heaviest in 2014 and lightest in 2013. The interaction of treatment and year approached significance at this time (Table 4.9). At the end of crop grazing, the interaction of treatment and year was significant for weaner weights (Table 4.9). Weaners from the WCG treatment were significantly heavier than control lambs in three years at the end of the crop grazing period, and significantly heavier than ECG weaners in two years (Table 4.9).

Table 4.9. Comparison of mean live weight of lambs at particular events between birth and the end of the crop grazing period 2013-2016. LSD values reported at P<0.05. P-values are for treatment x year interaction. Note that weights at start of crop grazing and end of crop grazing are for animals born in the preceding calendar year.

Parameter	Year	Control	ECG	WCG	LSD	P-value
Birth weight (kg/head)	2013	4.2	4.6	4.4	0.5	0.034
	2014	4.7	4.4	4.3	0.5	
	2015	4.2a	4.8b	4.8b	0.4	
	2016	4.4	5.2	4.8	0.9	
Weaning weight (kg/head)	2013	26.3	28.0	28.7	3.0	n.s.
	2014	27.6	27.1	27.8	3.0	
	2015	19.6	21.3	21.6	3.0	
	2016	18.5	20.7	23.3	3.0	
Weight of lambs weaned (kg per farmlet)	2013	131	136	163	48	n.s.
	2014	209	204	206	48	
	2015	156	162	188	48	
	2016	118	172	124	48	
Live weight December (kg/head)	2013	33.1	32.3	32.1	2.8	0.025
	2014	27.1	27.2	27.4	2.8	
	2015	23.1a	27.5b	27.1b	2.8	
	2016	23.8a	26.7ab	29.0b	2.8	
Live weight at start of crop grazing period (kg/head)	2013	25.3	25.2	24.5	3.4	0.074
	2014	32.2	38.3	37.2	3.4	
	2015	31.6	33.4	33.3	3.4	
	2016	27.9	30.1	30.6	3.4	
Live weight at end of crop grazing period (kg/head)	2013	31.5a	38.4b	40.8b	3.3	<0.001
	2014	51.2	48.9	50.9	3.3	
	2015	37.9a	36.1a	43.7b	3.3	
	2016	32.1a	32.9a	41.4b	3.7	

The interaction of treatment and year was significant for weaner weights at the end of crop grazing (P<0.001). Weaners from WCG treatment were significantly heavier at the end of the crop grazing period compared to control lambs in three years, and significantly heavier than ECG weaners in two years (Table 4.9).

4.5 Meat production

Retained weaners from the WCG treatment were significantly heavier at sale compared to control lambs in three years, and significantly heavier than ECG weaners in two years (Table 4.10).

The mean sale weight of WCG retained weaners (44.3 kg) was significantly heavier (P<0.001) than for the control (39.2 kg) or ECG (39.1 kg) treatments over the four years of the experiment. The interaction of treatment and year was significant for final sale weight of carry-over weaners (P<0.001). Sale weights of weaners from ECG treatment were significantly heavier compared to the control in 2013, where control weaners growth rates were significantly restricted during winter due to low pasture growth and confinement feeding was necessary, but were lighter compared to the control in 2015 (Table 7), where pasture availability in the control treatment was higher. The only year where sale weights of weaners were not significantly heavier in the WCG treatment compared to both ECG and control was 2014, where the season was marked by an early break and good pasture growing conditions throughout.

Table 4.10. Mean live weight of lambs at sale as yearlings, and total sale weight of lambs for each treatment 2013-2016. LSD values reported at P<0.05). P-values are for treatment x year interaction.

Parameter	Year	Control	ECG	WCG	LSD	P-value
Sale weight of yearlings (kg LW/head)	2013	31.5a	38.4b	40.8b	3.1	<0.001
	2014	51.2	48.9	50.9	3.1	
	2015	39.2a^	36.1b	43.7c	3.1	
	2016	34.6a^	32.9a	41.4b	3.1	
Total sale weight of lambs (kg LW/ha)*	2013	222a	180b	191ab	37	0.005
	2014#	227	221	239	37	
	2015	203a	240b	233ab	37	
	2016	169a	181a	246b	37	

^ excludes one replicate in the Control treatment following a dog attack

* Includes weights of excess weaners sold during November-January and retained weaners sold at approximately 12 months of age.

The 4-year average live weight of weaners sold per hectare was significantly higher (P=0.001) in the WCG treatment (238 kg) compared to the ECG and control (both 205 kg) over the four years of the experiment. The 16% increase in weaners sold per hectare between the WCG and control treatments was due to both a higher number of weaners sold per hectare (including both excess and retained animals) and a higher average sale weight, with half the increase arising from each component. The increase in live weight of weaners sold per hectare in the WCG treatment over the ECG treatment was entirely due to a higher average weight of weaners at sale.

Sale weight per hectare was significantly higher (P<0.001) in 2014 and 2015 (243 kg and 225 kg respectively) compared to 2013 and 2016 (198 kg and 199 kg respectively). The interaction of year and treatment was significant (P<0.001; Table 4.10). The sale weight per hectare was numerically higher in the control treatment compared to the two crop-grazing treatments in 2013 due to the smaller area of grazing land in the first year in the control, although it did not differ significantly from the WCG treatment.

There were no significant differences between treatments for total sale weight of lambs per hectare in 2014 (Table 4.10), which was a year of high pasture production, although WCG plots also produced live weight gain from trade wethers in that year which is not included in this result. Average exit weight of trade wethers from the WCG wheat plots in 2014 was 42.9 ± 3.0 kg, representing a mean average daily gain of 109 ± 44 grams/head.day. This equated to additional production of 259 kg LW per sub-paddock hectare or 43 kg LW per farmlet hectare.

4.6 Supplementary feeding

Substantial amounts of supplementary feed were required in all treatments during 2013 (Table 4.11). Feeding of both ewes and carryover weaners commenced on 25 January 2013 in their respective experimental sub-paddocks. Ewes in the control treatment were removed from their plots and confinement-fed with a lupin/oat mixture from just prior to lambing until 4 September 2013 due to a lack of pasture availability and growth in these farmlets; ewes in the crop-grazing treatments remained on their plots Control ewes were returned to their plots but grain feeding of these animals continued until 25 September; feeding of ewes in the crop-grazing treatments ceased on 6 September.

Supplementary feeding also extended longer into autumn in 2014 in the control treatment compared to the crop grazing treatments. There was minimal supplementary feeding to ewes in the control treatments in 2015, whereas supplements were fed to ewes in the crop-grazing treatments during the autumn 2015. The patterns of feeding were again different in 2016, with crop-grazing treatments being supplementary fed during summer and autumn, whilst in the control treatment supplements were predominantly fed during winter. There was some feeding of supplements to ECG and WCG ewes during the crop grazing period in 2013 and early in the crop grazing period in 2016 (Figure 4.8).

Table 4.11. Amount of grain per head (kg/head) fed to ewes and weaners during the period 2013 to 2016, and equivalent values per head of energy and protein supplied to ewes and weaners.

Year	Ewes					Weaners				
	Control	ECG	WCG	LSD	P-value	Control	ECG	WCG	LSD	P-value
Dry weight of supplement fed (kg DM per ewe unit)										
2013	79.8a	25.6b	47.6c	1.1	<0.001	42.5a	39.8b	6.2c	0.3	<0.001
2014	6.8a	2.6b	2.6b			8.6	8.6	8.6		
2015	0.6a	6.4b	6.7b			0.0a	10.9b	11.1b		
2016	11.7a	12.7a	17.7b			1.2a	18.4b	2.5c		
Metabolizable energy in supplement fed (MJ per ewe unit)										
2013	1100a	352b	656c	15	<0.001	583a	541b	83c	13	<0.001
2014	94a	36b	36b			118	118	118		
2015	8a	88b	92b			0a	151b	153b		
2016	158a	173a	242b			17a	241b	35c		
Crude protein in supplement fed (kg CP per ewe unit)										
2013	11.6a	4.0b	7.1c	0.3	<0.001	6.5a	6.5a	1.3b	0.2	<0.001
2014	1.0a	0.4b	0.4b			1.2	1.2	1.2		
2015	0.1a	0.9b	0.9b			0.0a	1.5b	1.5b		
2016	2.7a	2.3b	3.3c			0.2a	3.5b	0.5c		

The interaction of treatment and year was significant for the amount of supplement fed and energy and crude protein supplied in supplements to ewes (all P<0.001; Table 4.11). The amount of supplement fed per head was significantly higher in the control treatment compared to the ECG treatment in 2013 and 2014, but lower than the ECG treatment in 2015; there was no difference between control and ECG treatments in 2015 (Table 4.11). In 2016 supplementation in the crop grazing treatments occurred in summer and autumn, whereas supplementation of ewes in the control treatment was sporadic, occurring mainly during lactation (Figure 4.8).

In mid-winter 2013 the weaners in the control farmlets were failing to grow towards a saleable weight and weaners were therefore confinement-fed until they exited the experiment on 5 August. Patterns of supplementary feeding of weaners were similar for ECG and control treatments in 2013 and 2014, however supplementary feeding ceased on 24 May for the WCG treatment in 2013, soon after weaners commenced crop grazing (Figure 4.9). The amount of supplement fed to WCG weaners in 2013 was significantly lower than other treatments as a result (Table 4.11). During summer and early autumn of 2015, animals in the ECG and WCG treatments were supplemented with wheat grain, whereas animals in the control treatment did not require supplementation. WCG and ECG weaners were fed for the same amount of time on 2015, whilst there was no feeding of weaners in the control treatment in that year. The period of supplementary feeding of weaners was longer in the ECG treatment compared to WCG or control treatments in 2016, with control weaners only requiring a short period of supplementation during summer (Figure 4.9). In 2016 grain supplementation in the crop-grazing treatments started slightly earlier than in the control treatment (4 January v. 15 January). The amount of supplement fed to weaners was lowest in the WCG treatment in 2013 and highest in the control treatment, while weaners in the control treatment had significantly less supplement fed to them in 2015 and 2016 compared to the two crop grazing treatments (Table 4.11).

The low biomasses in pastures of cropping treatments in autumn and winter 2015 resulted in slightly earlier grazing of wheat crops in that year (30 April 2015- although this isn't that early). Similarly, projections for feed availability in late-spring 2015 were a consideration in choosing to sacrificially graze wheat crops in late spring/early summer 2015 (combined with low expectation for grain yields) and an earlier start to supplementation.

Overall, the amount of grain supplement (dry) fed per farmlet hectare was significantly higher in the control compared to the treatments that included crop grazing (P<0.001). The treatment by year effect was significant (P<0.001) however, with grain feeding significantly higher in the control treatment compared to the crop grazing treatments in 2013 and 2014, and significantly lower in the control in 2015 and 2016 (Table 4.12). The amount of grain fed in the WCG treatment was either similar too (2014 and 2015) or lower than the amount fed within the ECG treatment on a per hectare basis (Table 4.12)

Table 4.12. Amount of grain per head (kg/farmlet hectare) fed to ewes and weaners during the period 2013 to 2016, and equivalent values per hectare of energy and protein supplied to ewes and weaners.

Year	Control	ECG	WCG	LSD	P-value
Dry weight of supplement fed (kg DM per farmlet hectare)					
2013	794a	283b	233c	5	<0.001
2014	67a	49b	49b		
2015	3a	75b	77b		
2016	56a	135b	88c		
Metabolizable energy in supplement fed (GJ per farmlet hectare)					
2013	10.93a	3.86b	3.20b	0.72	<0.001
2014	0.92	0.67	0.67		
2015	0.04a	1.03b	1.06b		
2016	0.76a	1.80b	1.20ab		
Crude protein in supplement fed (kg per farmlet hectare)					
2013	117.6a	45.4b	36.3c	1.1	<0.001
2014	9.3a	6.8b	6.8b		
2015	0.4a	10.5b	10.7b		
2016	12.8a	25.1b	16.3c		

4.7 Financial analysis of the systems experiment

Partial budget analysis of the production and management data from the Canberra systems experiment identified that gross margin returns were significantly higher (P<0.05) overall for treatments that included dual-purpose crops compared to the control treatment. Gross margin returns were significantly higher in the WCG compared to the control every year, and were significantly higher in the ECG treatment compared to the control in three out of four years (Table

4.13). The gross margin for the WCG treatment was significantly higher than for the ECG treatment in 2014 and 2015, mainly due to higher returns from meat in the WCG treatment; this was despite slightly higher expenses in the WCG treatment in those years.

Expenses were significantly higher in the control treatment in 2013 due to higher feeding costs and the small farm area in the control treatment in that year, but were significantly lower in the control treatment compared to ECG and WCG in subsequent years (2014-2016) due to no expenses associated with cropping and pasture renovation.

Total income was significantly higher in the cropping treatments compared to the control in 2014-16, but not in 2013, again due to the smaller farmlet area in the control in that year. Total income was significantly higher in the WCG compared to the ECG treatment in 2014 and 2015, but did not differ between the cropping treatments in the other years. Income from grain did not differ significantly between ECG and WCG treatments in any year.

Table 4.13. Income, expenses and gross margins ($/ha) 2013-2016 at Ginninderra. LSD values significant at P<0.05. Where letters differ within row the values differed significantly (P<0.05)

	Treatment			
	Control	**ECG**	**WCG**	**LSD**
2013				
Meat income	474a	400b	438ab	53
Wool income	329a	242b	232b	21
Grain income	*	253	228	111
Total income	803	895	898	122
Total expenses	583a	560b	542c	13
Gross margin	221a	335b	356b	113
2014				
Meat income	601a	574a	703b	53
Wool income	231a	244ab	257b	21
Grain income	*	456	493	111
Total income	832a	1274b	1453c	122
Total expenses	233a	478b	538c	13
Gross margin	599a	796b	916c	113
2015				
Meat income	670a	632a	830b	53
Wool income	238a	280b	251a	21
Grain income	*	191	188	111
Total income	908a	1103b	1307c	122
Total expenses	282a	471b	493c	13
Gross margin	627a	632a	776b	113
2016				
Meat income	415a	462a	581b	53
Wool income	231a	280b	254c	21
Grain income	*	565	486	111
Total income	646a	1307b	1321b	122
Total expenses	189a	431b	396c	13
Gross margin	457a	876b	925b	113
4-year summaries				
Mean gross margin	476	660	743	
S.D. of gross margin	186	239	267	

The inter-year standard deviations of the farmlet gross margins were higher in the ECG treatment than in the control, and higher again in the WCG treatment (Table 4.13). When expressed as a coefficient of variation, however, the inter-annual variability of the gross margins was very similar between treatments (0.39, 0.36 and 0.36 for the control, ECG and WCG treatments respectively).

4.8 Biophysical modelling

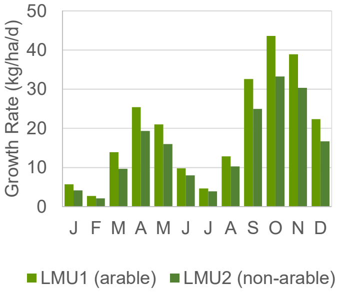

Fig. 4.10. Long-term average pasture growth rates in the reference pasture-only simulation.

Permanent pastures in the simulation showed the expected long-term average pattern of growth rates (Figure 4.10), with a marked slowing of growth during winter and a pronounced spring peak of growth. In the pasture-only simulation with 4.3 ewes per hectare, the arable land yielded 7.1 t DM/ha.year and the non-arable land 5.4 t DM/ha.year. When crop rotations occupied 20% of the land, annual yields of the permanent pastures decreased slightly (to 6.6-6.7 t DM/ha.year on the arable land) owing to the increased grazing pressure; the ley pastures yielded about 5.3 t DM/ha.year but had much higher legume content (49-64% compared to 6-20% for the permanent pastures in the same systems). The modelled average legume content in the pasture-only grazing system was 20%; the weighted average legume content in the crop-grazing systems was 26%. The condition-score-based feeding rules resulted in feeding of twin-bearing ewes in nearly all years, but the median annual feeding amount was only 2 kg/ewe in the pasture-only system and the mean amount was 9 kg/ewe.

As can be seen in Figure 4.11, the addition of dual-purpose crops to the feedbase significantly altered the sources of energy utilised by livestock. Where ewes grazed the crops, 13% of metabolizable energy was derived from winter wheat and canola forage and another 2% from stubbles; where weaner sheep grazed the crops the corresponding proportions were 10% and 2%. The number of DSE-days per hectare derived from crops in the simulated systems was high (Table 4.14), but no higher than found in earlier experimental studies at Ginninderra (Dove et al. 2015). The supply of ME to livestock during December-March was 5% lower in the simulations with crop grazing than in the pasture-only system (Fig. 4.11), which was consistent with dynamics of sheep live weights during the field experiment.

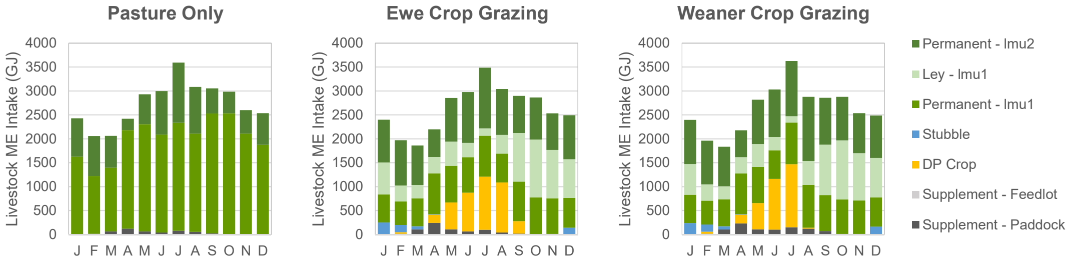

Fig. 4.11. Sources of metabolizable energy intake by livestock in three simulated farming systems at Ginninderra. The “ewe crop grazing” and “weaner crop grazing” systems had 20% of land area under grain crops and 20% under ley pastures, in a PPPPCWCW sequence. Ewes were joined on 1 February and the stocking rate was 4.3 ewes/farm ha.

Table 4.14. Comparison of the long-term performance of three simulated farming systems at Ginninderra. The "ewe crop grazing" and "weaner crop grazing" systems had 20% of land area under grain crops and 20% under ley pastures, in a PPPPCWCW sequence. Ewes were joined on 1 February and the stocking rate was 4.3 ewes/farm ha.

	Farming System		
	Pasture-Only	**Ewe Crop Grazing**	**Weaner Crop Grazing**
Lamb sold (kg LW/farm ha)	146	134	139
Mean wheat yield (t/ha)		3.8	3.8
Mean canola yield (t/ha)		2.8	2.8
Lamb sold per unit pasture consumed (kg LW/t DM)	50	55	56
Pasture utilization rate (kg/kg)	0.46	0.54	0.55
Mean winter crop grazing (DSE-days/crop ha.year)		2310	1820
Mean supplementary feeding (kg wheat/ewe.year)	9	14	18
Long-term average gross margin ($/farm ha)	395	431	434
S.D. of gross margin ($/farm ha)	119	154	153
CVaR of gross margin ($/farm ha)	238	237	240

Given the important role of crop forage in the modelled animals' diet when it was made available, it was not surprising that the efficiency with which pasture intake was converted to lamb live weight increased by 9-12% (Table 4.14) when crops were made available as an additional source of forage. Pasture utilization rates increased by 19-21%, and these two changes together almost compensated for the 33% lower area of pasture in the crop-grazing systems.

As found in the field experiment, canola yields in the simulations were high relative to wheat yields (averaging 73% of the wheat yields in the simulations). The ratios were similar for the canola-wheat sub-sequences that followed pasture and those that followed wheat, suggesting that the departure from the typical 50% ratio may be more due to higher frost-sensitivity of the wheat than to water and nitrogen supply effects.

Financial results from the simulations confirmed key results of the financial analysis of the field experiment. Over a long run of years, the crop-grazing systems were substantially more profitable than the pasture-only system, with higher variability (measured as the standard deviation of gross margin) but lower risk (measured as CVaR). One difference between simulations and experiment was that the simulated system in which weaners grazed the crops did not turn off a greater weight of lamb per farm hectare than the pasture-only system, as was found in the 4 years of the systems experiment (Table 4.14; Table 4.10). Another difference was that supplementary feeding requirements in the modelled crop-grazing systems were slightly higher than in the pasture-only system.

Figure 4.12 shows that the production of wheat and of lambs in each year from 1973 to 2016 is uncorrelated in the simulated results. This can be readily explained by the fact that much of the variation in the weight of lambs sold in July has been induced by conditions prevailed as far back as the previous January, when the body condition score of ewes prior to conception of the sale weaners was determined. Figure 4.13 shows gross margins per hectare calculated for the cropping and livestock enterprises separately in each year from 1973 to 2016. (For simplicity, all crop growing costs were allocated to the cropping enterprise). The correlation between the two enterprise gross margins is not zero (due to November-shorn fleece weights and crop yields being determined over the same time period) but is relatively low. This lack of correlation between the production – and

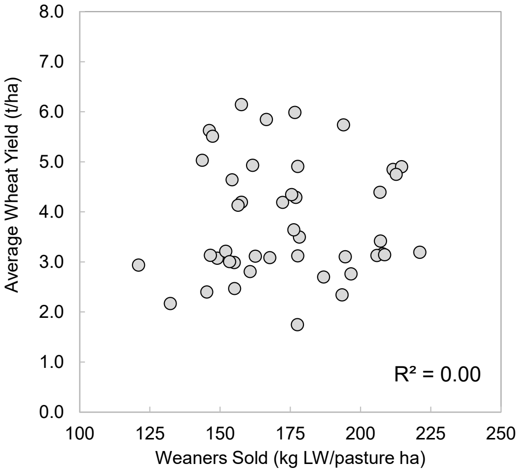

Fig. 4.12. Weight of weaners sold and average wheat yield in each year of the reference "weaner crop grazing" systems simulation.

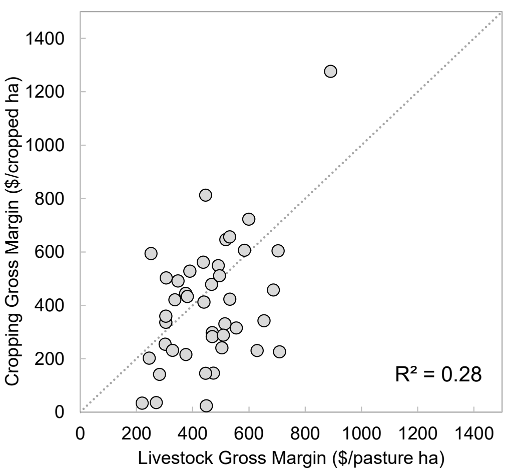

Fig. 4.13. Cropping and livestock gross margins in each year of the reference "weaner crop grazing" systems simulation. The dashed line is the 1:1 line; in years that fall to the right of it, the livestock enterprise has higher gross margin than the cropping enterprise and *vice versa*.

hence financial – outcomes of the two enterprises means that a mixture of the two can be found which will be more profitable at a given level of risk that can be achieved for either enterprise alone, even in the absence of biophysical synergies (Bell & Moore 2012).

The farming systems modelled in the simulation experiments are *not* directly comparable to those implemented in the systems experiment in the field. The simulations modelled a self-replacing flock that included maiden ewes, while all ewes in the experiment were 2 years or older; also, the Merino sheep genotype that was modelled had a lower fecundity that is more typical of the region and the supplementary feeding rules used in the simulations allowed the ewes to fall to lower body condition. As a result, an average of 0.86 lambs were weaned per ewe joined in the reference pasture-only simulation, compared with 1.24 in the pasture-only (control) treatment of the experiment. In the simulations in which weaners grazed the crops, ewes did not graze excess crop forage as was done in the field experiment. As a result of these differences, the gross margins presented in this section were considerably lower than those reported for the field experiment across all treatments, and the modelled mean sale weights of yearling lambs – a higher proportion of which were single-born, and fewer of which occupied the pastures – were higher than in the field experiment.

4.8.1 **Joining dates**

Figure 4.14 shows that earlier joining dates resulted in more variable financial outcomes in the simulated farming systems, regardless of whether or not dual-purpose crops were grown or how they were allocated to livestock. In the pasture-only system, the standard deviation of gross margin was 18% higher with a 15 December joining relative to the reference case (1 February). Earlier joining times were also much more profitable, however, and as a result they exhibited less downside risk as measured by CVaR. When modelled at the same overall stocking rate, the ewe crop grazing and weaner crop grazing systems fell on nearly identical risk-return curves (Figure 4.14), with the weaner crop-grazing system slightly more profitable and slightly less risky at each joining date. As joining was carried out progressively earlier, however, the profitability advantage of the crop-grazing systems over the pasture-only system became smaller (from $39/farm ha for the 1 February joining date to $20/farm ha for the 15 December joining date). At the 15 December and 1 January joining dates the modelled pasture-only system became less risky than the corresponding crop grazing system; in fact, the pasture-only system with 4.3 ewes/ha and a 15 December joining date had the highest CVaR of all the systems modelled in this analysis.

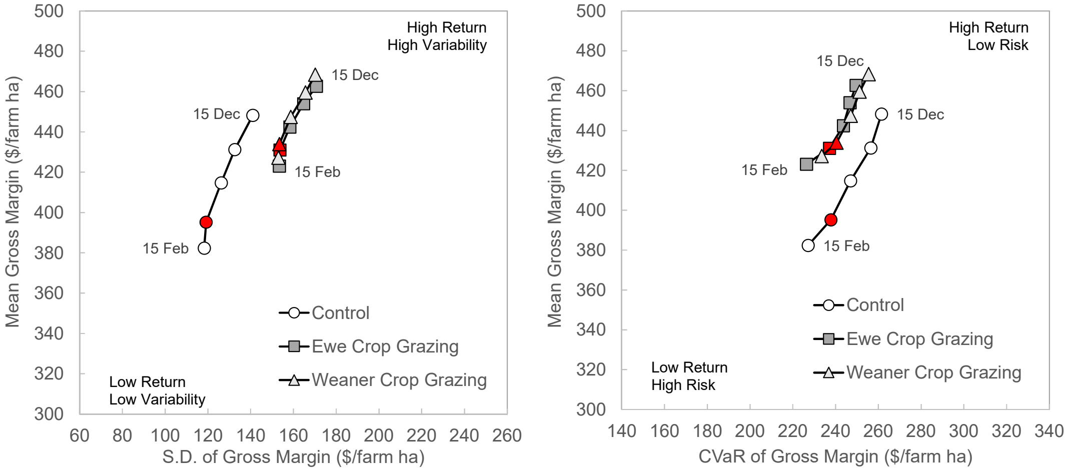

Fig. 4.14. Variability (measured as standard deviation), risk (measured as CVaR) and expected gross margin in simulated dual-purpose cropping systems at Ginninderra when the joining date was varied for each of 3 farming systems with different approaches to the growing and allocation of dual-purpose crops. The “ewe crop grazing” and “weaner crop grazing” systems had 20% of land area under grain crops and 20% under ley pastures, in a PPPPCWCW sequence. The stocking rate was 4.3 ewes/farm ha in all systems shown. The red symbols show the farming systems presented in Table 4.14.

Table 4.15. Changes in long-term mean simulated values of key ewe production system characteristics when the joining date was varied in the “weaner crop grazing” farming system.

Joining date:	15 Dec	1 Jan	15 Jan	1 Feb	15 Feb
Lambs conceived per ewe joined	1.23	1.29	1.32	1.35	1.36
Lamb survival to weaning	0.75	0.69	0.66	0.63	0.62
Lambs weaned per ewe mated	0.92	0.90	0.87	0.84	0.84
Lamb sold (kg LW/farm ha)	157	151	145	139	137
Mean winter crop grazing (DSE-days/crop ha.year)	1930	1940	1840	1820	1810
Mean supplementary feeding (kg wheat/ewe.year)	29	25	22	18	16
Long-term average gross margin ($/farm ha)	468	459	447	434	427
CVaR of gross margin ($/farm ha)	255	251	247	240	233

As can be seen in Table 4.15, the higher predicted gross margin of the earlier joining dates is driven by higher modelled rates of lamb survival for lambs born in May-June instead of June-July, which outweigh lower conception rates. This tradeoff is likely to be strong in a ewe production system where weaners are retained into their second winter, putting maximum pressure on the feedbase during early winter when February-conceived lambs are being born (Figure 4.13). Earlier joining dates also slightly increase the quantity of dual-purpose crop forage that can be exploited by the weaner sheep, because the older weaners can consume more per head.

4.8.2 Proportion of land in the cropping rotation

When 0%, 10% or 20% of the farm area was devoted to dual-purpose crops (and hence 0%, 20% or 40% to the pasture-crop rotation), there was an intermediate stocking rate in the modelled weaner crop grazing systems that was both more profitable and less risky than all lower stocking rates (Figure 4.15). For the particular circumstances modelled here, that stocking rate was 4.5 ewes/ha for zero crop; 4.3 ewes/ha (4.8 ewes/pasture ha) for 10% of land under crop; and 4.1 ewes/ha (5.1 ewes/pasture ha) for 20% of land under crop. Above this threshold stocking rate, the modelled results showed a tradeoff between expected long-term gross margin and the financial risk.

At each stocking rate, increasing the area under crop from 0% to 10% was predicted both increase gross margin and lower downside risk. The financial choice between 10% and 20% of land under crop was less straightforward: a producer seeking a low-risk system would select 10% of land under crop and an intermediate stocking rate, while a less risk-averse producer could maximize profit by choosing 20% of land under crop and a high stocking rate.

All strategies in which 30% of the farm area was allocated to crop were dominated by strategies in which a lower area was allocated to crop, i.e. there were strategies with 10% or 20% crop that had both higher expected gross margin and higher CVaR. It appears likely that 20% is an upper bound for the area that should be allocated to cropping under the climate, soil and sheep management circumstances that were modelled.

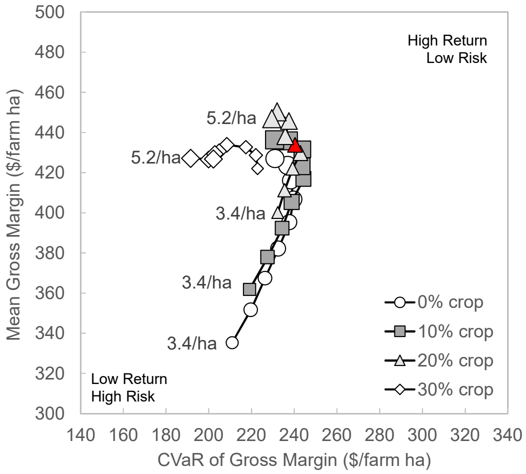

Fig. 4.15. Risk and reward in simulated dual-purpose cropping systems at Ginninderra when the proportion of land under crop and the stocking rate are both varied. All simulations are for “weaner crop grazing” systems in which weaners are allocated the dual-purpose crops, prior to sale as yearling animals in July. Each curve shows the variation in mean and CVaR of farm gross margin at a particular proportion of land area under cropping (canola + wheat) as the stocking rate is changed. The red symbol shows the farming system presented in Table 4.14.

4.9 Additional studies at Ginninderra Experiment Station

4.9.1 Intake and grazing behaviour of sheep during introduction to canola

“Inexperienced” sheep coming from pasture plots showed a sharp decrease in the proportion of time devoted to grazing on the day of transition (Fig. 4.16; day 0) which was opposite to the trend shown by their experienced counterparts (0.05<P<0.10). Grazing times were similar thereafter.

Overall, no treatment effect was found on this variable, considering either the whole or the post-transition dataset. After the weaners began grazing the canola crops, the time they devoted to grazing species other than canola was affected by their level of experience ($P < 0.05$), with a significant treatment x date interaction ($P<0.05$). Animals with experience of canola spent a higher proportion of time grazing other species on the transition day, while inexperienced animals spent more time grazing other species on day 4 after the transition (Fig. 4.16). These results suggest that experienced sheep tried to diversify their mono-specific diet at turnout, while inexperienced sheep reduced their grazing time at the transition and only started to search for other species after tasting the new forage. Other behavioural variables under focus (walking, idling, standing and lying, meal duration and frequency) showed no differences between treatment groups across the experimental period.

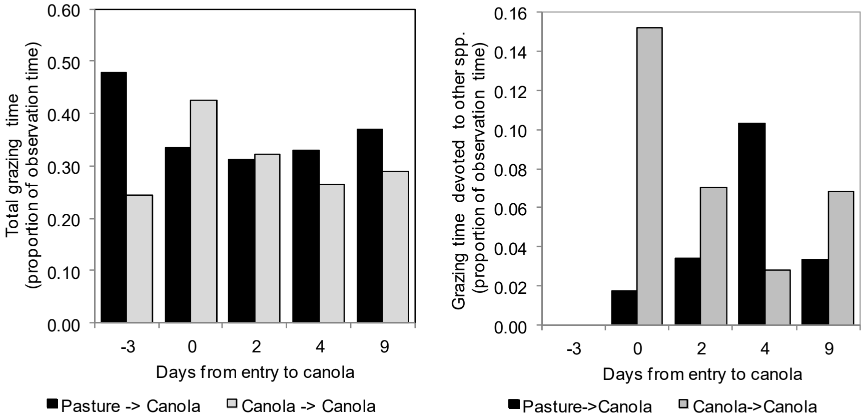

Fig. 4.16. Grazing behaviour of weaner sheep grazing canola crops either without prior experience of canola ("Pasture -> Canola") or with prior experience ("Canola->Canola")

4.9.2 **Feeding value of canola**

Animal welfare monitoring at the start of the experiment

The wellbeing of the experimental animals was monitored on Friday 12 June almost all day (daylight hours) by the project personnel. No apparent problems occurred during Friday 12 June and animals were observed to behave normally.

Monitoring of experimental animals continued over the weekend. Animals on each plot were observed to flock at one corner of their plots (a normal behaviour), but they approached the feeding bins where the hay supplement was provided. Hay supplement was provided (once a day) to flocks in the supplementary feeding treatment. The approximate consumption of the supplementary hay (cubes) was about 70%, except that one mob ate the entire allocated amount.

Fig. 4.17. Plot 1 at CR-6 (Ginninderra Experiment Station) showing the canola crop after the experimental animals were removed following the adverse event. Material eaten was predominantly leaf.

Grazing of the crop was observed to increase on days 3 and 4, but grazing was still located at one corner of the plots, probably due to the height of the crop. Material grazed was mostly leaves, leaving the petioles (Fig. 4.17).

Adverse event (sheep deaths)

On Monday 15 June 2015, at approximately 0900 h, two sheep belonging to two different plots were found dead. From the consistency of mouth secretions, it was estimated that deaths occurred 4-5 hours earlier. Two sheep were found in prostrated (ventrally) positions, and a third was found with clear signs of compromised health, but in a standing position. Based on the fact that mortalities or symptoms were observed across all the experimental treatments, it seems unlikely the incident was related to experimental treatments (mineral and capsule dosing or hay supplementation). An immediate decision was made to remove the animals from the canola crop. They were moved to a paddock of old grass. By approximately 11:00 AM the two sheep that were found prostrated died; and the one that was found standing showed signs of recovery. The rest of animals did not show any apparent symptoms of ill health. On Tuesday 16 June, at approximately 0900 h, two other sheep were found dead on the grass paddock. The deaths occurred overnight and despite no apparent symptoms the day before.

A veterinarian was called following the initial deaths and based on symptoms gave a diagnosis of nitrate poisoning. The laboratory analysis of the samples collected immediately before (12th June) and after (16th June) the sheep deaths had NO_3-N concentrations far below levels considered toxic for cattle. Plant samples collected on 16 June to simulate the leaf-predominant diet of sheep had low nitrate levels (<30 mg NO_3-N/kg DM). The stem portion of samples contained higher amounts of NO_3-N (1000-1400 mg/kg DM). Further plant samples collected on 20 July were subdivided into leaves, petioles and stems, and as expected leaves had the lowest concentrations of NO_3-N, whereas the stems the highest. Nevertheless, even the concentrations of NO_3-N in stems were well below the critical level to cause toxicity.

At the same time that these deaths occurred, there were late-pregnant ewes and weaners grazing canola in the separate system experiment at Ginninderra Experiment Station, for which the canola sowing was at the same date. There were no cases of compromised animal health or welfare in these flocks. Lactating ewes and lambs involved in the separate system experiment (ECG and WCG treatments) grazed quite heavily on canola crop and at the later stages of grazing the ewes utilised the stems, yet without apparent signs of toxicity.

This adverse event seems to be the first report of its kind in sheep. The laboratory analyses of forage samples do not support a diagnosis of nitrate poisoning. The observed symptoms did not match the symptoms involving acute ruminal acidosis and the deaths also occurred in flocks supplemented with grass hay.

5 Results from the Wagga Wagga node

5.1 Livestock responses to changes in forage morphology

Morphology of annual ryegrass and wheat swards

Annual ryegrass swards formed a continuous pasture with minimal variation in height across the sward, while wheat swards were characterised by "peaks" in the middle of each sown row and "troughs" between rows (Fig. 5.2). Bare ground (measured as zero height) was usually visible inter-row in W35 swards at all levels of FOO; in contrast W18 swards did not typically have bare ground between rows until FOO levels were low (Figure 5.1).

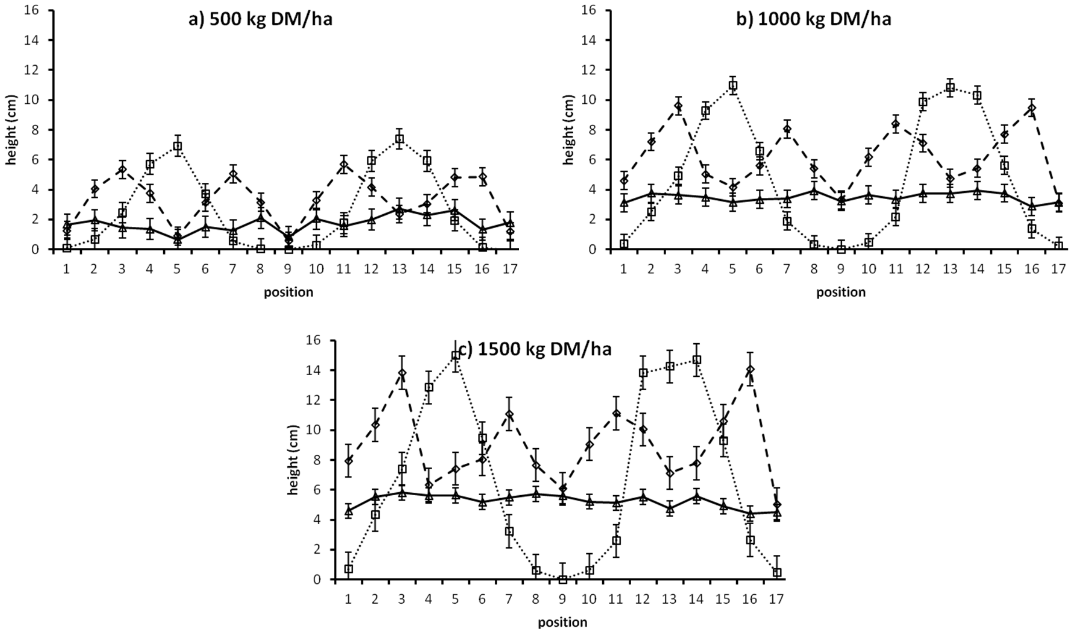

Fig. 5.1. Changes in height across quadrats in grazed swards of annual ryegrass (solid line) and wheat at row spacings of 17.5 cm (dashed line) and 35 cm (dotted line) at above-ground biomass in quadrats equivalent to a) 500 kg DM/ha, b) 1000 kg DM/ha and c) 1500 kg DM/ha.

Row height was significantly higher in W35 quadrats compared to W18 quadrats ($P<0.001$) and row height increased with the above-ground biomass ($P<0.001$; Table 5.1); there was no interaction between row spacing and FOO. Mean height differed significantly ($P<0.001$) between all three treatments with W18 treatment having the highest mean height at any given FOO (Table 5.1) and the interaction between treatment and above-ground biomass was also significant ($P<0.001$).

The interaction between date and treatment was significant ($P<0.001$) in the model for DOMD (Table 5.2). FOO approached significance as a term in the model ($P=0.050$) and was subsequently excluded from the model. The interaction between date and treatment was significant ($P<0.001$) in the model for crude protein (Table 5.2). Feed on offer was significant as a covariate ($P<0.001$) with a 0.002 % CP per kg decrease in FOO.

Table 5.1. Predicted row height of wheat forage and predicted mean height of wheat forage and annual ryegrass (± standard error) at varying levels of FOO

		Feed on offer (kg DM/ha)				
Measurement	**Treatment**	**500**	**750**	**1000**	**1250**	**1500**
row height (cm)	W18	5.4 ± 0.4	7.0 ± 0.4	8.7 ± 0.4	10.3 ± 0.5	12.0 ± 0.6
	W35	7.4 ± 0.4	9.0 ± 0.4	10.7 ± 0.4	12.3 ± 0.5	14.0 ± 0.6
mean height (cm)	ryegrass	1.9 ± 0.2	2.7 ± 0.1	3.4 ± 0.1	4.1 ± 0.1	4.8 ± 0.2
	W18	3.3 ± 0.1	4.9 ± 0.1	6.4 ± 0.1	8.0 ± 0.2	9.5 ± 0.2
	W35	2.6 ± 0.1	3.6 ± 0.1	4.6 ± 0.1	5.6 ± 0.2	6.6 ± 0.2

Table 5.2. Predicted means for digestible organic matter in dry matter (DOMD; % DM,) and crude protein[A] (CP, % DM)

	Date						
	26 Jul	**2 Aug**	**8 Aug**	**15 Aug**	**22 Aug**	**29 Aug**	**4 Sep**
	DOMD (s.e.d.[B] = 2.0)						
Ryegrass	78.2	77.0	80.7	82.2	77.2	76.6	77.0
W17	77.2	75.1	75.5	74.3	63.9	63.2	60.8
W35	77.2	77.6	78.2	73.0	66.8	65.0	64.0
	CP (s.e.d. = 2.1)						
Ryegrass	25.5	20.7	16.4	20.7	16.0	22.2	16.9
W17	19.6	19.2	13.6	15	12.9	10.3	10.8
W35	19.3	16.2	13.5	10.9	12.2	14.9	13.8

[A] at pasture mass 1000 kg DM/ha

[B] average standard error of the difference

Plot level analysis

Mean FOO on 16 July (day 84 after sowing and prior to experimental grazing) in ungrazed plots was 1018 ± 31 kg DM/ha in W35 plots, which was significantly lower (P=0.041) than in W18 (1268 ± 35 kg DM/ha) and ryegrass (1352 ± 48 kg DM/ha) treatments. Ranges of FOO for each treatment during the grazing period are included in Table 5.3. Live weight gains for lambs grazing wheat did not differ significantly between narrow or wide row spacing, so the reduced model used for growth rates of lambs grazing wheat was digestibility period+FooAv+FooAv^{2}. Live weight gains for lambs grazing wheat were significantly higher (0.071 kg/hd.day; P=0.016) in the high digestibility period compared to the low digestibility period. The model used for lambs grazing ryegrass was FooAv+FooAv^{2}+FooAv^{3} FooAv^{4}+ FooAv^{5}. Smoothed curves of lamb growth rates when grazing wheat in digestibility period 1 and digestibility period 2 or annual ryegrass within relevant ranges of FOO are displayed in Fig. 5.2, and this was used to identify FOO levels at which to look for significant differences in Table 5.3. Average daily live weight gain did not differ significantly for lambs grazing wheat compared to annual ryegrass at a given FOO over the range of feed on offer used in this experiment (Table 5.3).

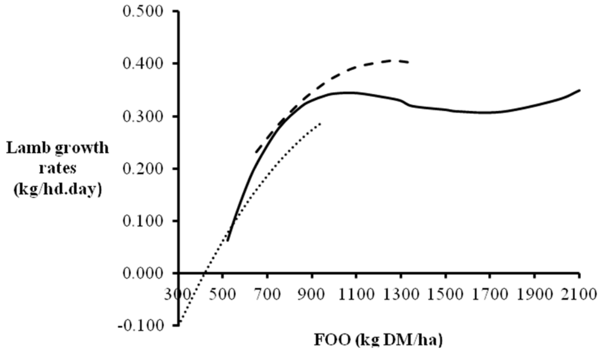

Fig. 5.2. Changes in predicted lamb growth rates with FOO for lambs grazing annual ryegrass (solid line) or wheat at high (dashed line) or low (dotted line) digestibility

Table 5.3. Comparison of lamb growth rates (kg/hd.day) grazing wheat and annual ryegrass at different levels of FOO

	FOO range (kg DM/ha)		**FOO (kg DM/ha)** **520**	**650**	**850**	**1000**	**1250**
wheat (high digestibility)	640-1555	prediction	*	0.231	0.327	0.374	0.406
		s.e.[A]	*	0.023	0.017	0.016	0.019
wheat (low digestibility)	292-894	prediction	0.077	0.160	0.256	*	*
		s.e.	0.016	0.018	0.025	*	*
ryegrass	519-4042	prediction	0.063	0.209	0.319	0.344	0.335
		s.e.	0.049	0.047	0.051	0.049	0.043
s.e.d.[B] (wheat high digestibility vs. ryegrass)			*	0.052	0.054	0.052	0.047
s.e.d. (wheat low digestibility vs. ryegrass)			0.052	0.050	0.057	*	*

[A] standard error

[B] standard error of the difference

5.2 Maternal genotypes experiment

5.2.1 Experiment 1

The feed on offer at the commencement of grazing wheat was low but increased during the wheat grazing period (Table 5.4). Feed availability was high during the period when sheep grazed the lucerne and clover pasture and would not be considered to be at a level that could restrict intake. Differences in feed on offer did not differ significantly between genotypes at the conclusion of grazing.

Table 5.4. Changes in feed on offer of dual-purpose wheat and lucerne/clover pasture during winter and spring grazing by ewes and lambs. Values are means for three replicates, and treatment differences were not significant.

Date	**28 Jun**	**10 Jul**	**23 Jul**	**1 Aug**	**14 Aug**	**s.e.d.**
Wheat (t DM/ha)	0.33	0.35	0.48	0.71	0.64	0.05
Date	**19 Aug**	**29 Aug**	**12 Sep**	**27 Sep**		
Lucerne/clover (t DM/ha)	2.39	2.86	4.94	4.40		0.04

The DOMD of wheat forage was significantly higher (P=0.004) early in the grazing period (9 July; DOMD = 79% DM) compared to later in the grazing period (2 August; DOMD = 75% DM). Crude protein content of wheat forage was significantly higher on the second sampling date (30.5% v. 34.3%; P<0.001) but both values were very high. DOMD of clover was significantly higher (P<0.001) at the first sampling date (29 August; DOMD = 76% DM) compared to the second sampling date (27 September; DOMD = 66% DM). Crude protein content of clover was significantly higher on the first sampling date (29.3% v. 18.1%; P<0.001). DOMD of lucerne did not vary with sampling date (DOMD = 72% DM), however CP of lucerne was significantly higher at the first sampling date compared to the second sampling date (34.1 v. 27.4%; P<0.001). There was no interaction of nutritive value of forage with plots grazed by the different sheep genotypes, and digestibility and crude protein content of diets were unlikely to have restricted production.

Body condition score of White Dorper ewes was significantly higher than Merino ewes from the start of crop grazing until end of crop grazing (3.5 v. 2.9; P<0.001) and there was no breed x date interaction. Mean body condition score of ewes was slightly higher at the end of grazing the crop compared to at the start (3.2 v. 3.1; P=0.042). White Dorper ewes were significantly heavier than Merino ewes (81.2 v. 75.2 kg; P=0.009) and live weight of ewes was greater at the start compared to the end of grazing crops (81.3 v. 75.1 kg; P<0.001) due to ewes giving birth during this period.

Single-born lambs had higher birth weights than twin-born lambs (5.5 v. 4.6 kg; P<0.001), WD lambs had significantly lighter birth weights than other genotypes (Table 5.5; P=0.012), and there was no genotype x birth status interaction. The genotype x birth status interaction was significant (P=0.039) for the survival of lambs to weaning, with the percentage of single-born WD lambs surviving being lower than other genotypes (Table 5.5).

Single-born lambs were heavier than twin-born lambs at weaning (39.8 v. 35.0 kg; P<0.001) and the difference in weaning weight between twin-born lambs raised as singles or twins was not significant. Age at weaning was also a significant covariate (P=0.005). WSD lambs were significantly heavier at weaning than WD or WSM lambs (P<0.001; Table 5.5). Eye muscle depth at weaning was significantly greater for WSD lambs (P=0.005), however when eye muscle depth was analysed per unit weight, birth status was significant but the breed difference only approached significance (P=0.079; Table 5.5), suggesting this parameter was associated with the weight of lambs. Fat depth over the eye muscle at weaning was higher for single-born than twin-born lambs (4.2 v. 3.3 mm; P=0.002) and approached significance for genotype (P=0.059, Table 5.5). Genotype approached significance when fat depth was calculated per unit body weight (P=0.094; Table 5.5) and was greater for single-born lambs than twin-born lambs (0.105 v. 0.091; P=0.025).

There were no genotype differences in VFA proportions for sheep grazing dual-purpose wheat or a lucerne/clover pasture in 2013 (Table 5.6, Table 5.7).

Table 5.5. Comparison of birth weight, survival and weaning weights for White Dorper (WD), White Suffolk x White Dorper (WSD) and White Suffolk x Merino (WSM) lambs when ewes grazed dual-purpose wheat and lucerne from lambing to weaning in 2013.

		WSD	WSM	DD	s.e.d.	P-value
Birth weight (kg)		5.2	5.2	4.7	0.2	0.012
Survival to weaning	single-born	0.78	0.90	0.38		0.039
	twin-born	0.81	0.74	0.88		
Weaning weight (kg)		40.3	36.4	35.4	1.0	<0.001
Eye muscle depth	(mm)	30.8	27.1	27.4	0.7	.005
	(mm/kg LW)	0.786	0.752	0.812	0.025	0.079
Fat over eye muscle	(mm)	4.2	3.3	3.7	0.3	0.059
	(mm/kg LW)	0.103	0.090	0.104	0.005	0.094

Table 5.6. Least squares mean (± SE) molar proportions (%) of volatile fatty acids in White Dorper and Merino ewes grazing dual-purpose wheat.

	White Dorper	Merino	P-value
Acetic acid	64.0 (± 1.28)	62.7 (± 1.32)	n.s.
Propionic acid	18.4 (± 1.06)	18.6 (± 1.09)	n.s.
Butyric acid	9.2 (± 0.61)	10.1 (± 0.62)	n.s.
Iso-butyric acid	3.26 (± 0.18)	3.31 (± 0.18)	n.s.
Iso-valeric acid	3.55 (±0.29)	3.62 (± 0.30)	n.s.
Valeric acid	1.34 (± 0.065)	1.33 (± 0.067)	n.s.
Hexanoic acid	0.29 (± 0.029)	0.27 (± 0.030)	n.s.
Heptanoic acid	0.05 (± 0.0067)	0.04 (± 0.0069)	n.s.
Propionic:Acetic+2xButyric	0.22 (± 0.014)	0.23 (± 0.014)	n.s.
Acetic:Propionic	3.98 (± 0.42)	3.65 (± 0.44)	n.s.

Table 5.7. Least squares mean (± SE) molar proportions (%) of volatile fatty acids in White Dorper and Merino ewes grazing a lucerne and clover pasture.

	White Dorper	Merino	P-value
Acetic acid	63.3 (± 0.97)	61.7 (± 0.97)	n.s.
Propionic acid	21.0 (± 0.69)	21.5 (± 0.69)	n.s.
Butyric acid	10.4 (± 0.40)	11.2 (± 0.40)	n.s.
Iso-butyric acid	1.83 (± 0.096)	2.03 (± 0.096)	n.s.
Iso-valeric acid	1.69 (±0.100)	1.83 (± 0.100)	n.s.
Valeric acid	1.46 (± 0.063)	1.33 (± 0.063)	n.s.
Hexanoic acid	0.37 (± 0.04)	0.37 (± 0.04)	n.s.
Heptanoic acid	0.06 (± 0.007)	0.05 (± 0.007)	n.s.
Propionic:Acetic+2xButyric	0.25 (± 0.009)	0.29 (± 0.009)	n.s.
Acetic:Propionic	3.17 (± 0.21)	2.93 (± 0.21)	n.s.

Table 5.8. Least squares mean (± SE) molar proportions (%) of volatile fatty acids in White Dorper and Merino ewes grazing wheat stubble.

	Dorper	Merino	P-value
Acetic acid	75.8 (± 0.51)	73.1 (± 0.52)	P<0.001
Propionic acid	16.8 (± 0.37)	17.6 (± 0.37)	n.s.
Butyric acid	6.35 (± 0.40)	8.07 (± 0.40)	P<0.01
Iso-butyric acid	0.33 (± 0.027)	0.32 (± 0.027)	n.s.
Iso-valeric acid	0.25 (±0.04)	0.26 (± 0.04)	n.s.
Valeric acid	0.38 (± 0.026)	0.47 (± 0.026)	n.s.
Hexanoic acid	0.08 (± 0.011)	0.10 (± 0.011)	n.s.
Heptanoic acid	0.015 (± 0.0015)	0.015 (± 0.0015)	n.s.
Propionic:Acetic+2xButyric	0.19 (± 0.005)	0.20 (± 0.005)	n.s.
Acetic:Propionic	4.57 (± 0.14)	4.18 (± 0.14)	n.s.

Stubble samples collected during the stubble grazing period had mean DOMD 42% DM (ME 5.6 MJ/kg DM) and CP 2.4% DM. Live weight of Merino ewes was significantly lighter than Dorper ewes at both the commencement and end of the stubble grazing period Fig. 5.3; (P<0.001); however, the interaction of genotype and date was not statistically significant (P=0.122), although Merino ewes lost more weight than Dorpers during the grazing period.

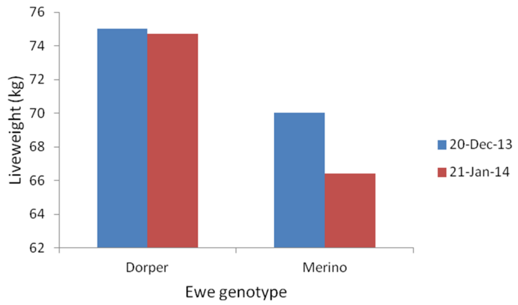

Fig. 5.3. Mean live weight of White Dorper (Dorper) and Merino ewes at start and end of stubble grazing (average s.e.d. = 1.5 kg).

Proportions of acetic acid in rumen liquor were found to be significantly higher (P>0.05) in the Dorper compared to the Merino ewes when grazing stubble, while both butyric and valeric acid levels in the rumen fluid were significantly higher in Merino ewes compared to Dorpers (Table 5.8). In all other VFA proportions there were no differences between the sheep genotypes grazing stubble, although the ratio of acetic:propionic acid approached significance (Table 5.8). The differences observed on stubble may relate to between-breed differences in energy metabolism when grazing a low quality diet, although more research is required to confirm this.

5.2.2 **Experiment 2**

Wheat and canola

Mean plant establishment counts (± s.d.) were 134 ± 38 plants/m^2 for wheat and 49 ± 17 plants/m^2 for canola. The interaction between treatment and date was significant for feed on offer (FOO; P=0.009); FOO was significantly higher in wheat compared to canola crops at the start of grazing (2600 vs 2300 kg DM/ha) but did not differ significantly at the end of grazing (1500 vs 1300 kg DM/ha).

The interaction of date and crop was highly significant for CP, DOMD and NDF (all P<0.001). CP concentrations in wheat were initially higher than canola but were lower at the conclusion of grazing. DOMD was similar between crops early in the grazing period, with digestibility of wheat declining throughout the grazing period, while canola maintained a higher digestibility. The NDF content of wheat was higher than canola and increased during the grazing period, while NDF content of canola pluck samples did not differ significantly between sample dates (Table 5.9).

Table 5.9. Nutritive value of wheat and canola forage

	Crop	Sampling date		
		26 Jun 2014	11 Jul 2014	14 Aug 2014
Crude protein (% DM)	Wheat	25.7	22.8	14.5
average s.e.d. = 0.7	Canola	22.8	19.5	18.7
DOMD (% DM)	Wheat	85.7	77.7	73.0
average s.e.d. = 0.7	Canola	86.3	83.0	83.0
NDF (% DM)	Wheat	40.3	46.7	48.3
average s.e.d. = 0.1	Canola	26.3	26.7	27.0

Calcium and magnesium concentrations in canola leaf appeared adequate to meet the requirements of late-pregnant and lambing ewes (Fig. 5.4). Potassium levels in canola were lower than wheat while sodium concentrations were similar in the two forages.

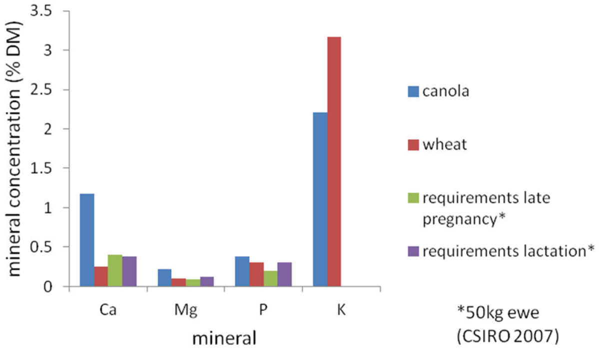

Fig. 5.4. Mineral concentrations of calcium (Ca), magnesium (Mg), phosphorus (P) and potassium (K) in dual-purpose canola and wheat forage compared to ewe requirements.

Ewes

Lambing was characterised by a high number of ewes requiring assistance to lamb (21% assisted births), due to the higher BCS of ewes at the commencement of lambing (following excellent seasonal conditions through autumn). Four ewes died during the experiment and were autopsied; one Merino (grazing wheat) and one White Dorper (grazing canola) ewe died on 21 July from likely toxaemia/septicaemia associated with mastitis; one White Dorper ewe (grazing canola) died on 6 August from acute peritonitis, secondary to uterine rupture; and one White Dorper ewe (grazing lucerne) died on 4 September from suspected enterotoxaemia.

Ewe body condition score and live weight

The fixed model for BCS was crop x ewe genotype x date x single/twin (triplet-bearing and empty ewes were excluded) and the random model date within ewe within plot within replicate. The interaction of crop, ewe genotype, number of lambs and date was significant (Fig. 5.5, P=0.019). Body condition score of White Dorper ewes did not differ significantly between crop type on any date, and the condition score of White Dorper ewes with twins was significantly lower than those with single lambs at the conclusion of crop grazing. Body condition score of twin-bearing Merino ewes was lower when grazing canola compared to wheat at the conclusion of crop grazing, but this difference was not significant.

For ewe live weight, the interactions of number of lambs born per ewe, ewe breed and crop grazed were significant with date (Table 5.10). Ewes grazing wheat were heavier than ewes grazing canola at the end of crop grazing (12 August) but not at weaning (29 September).

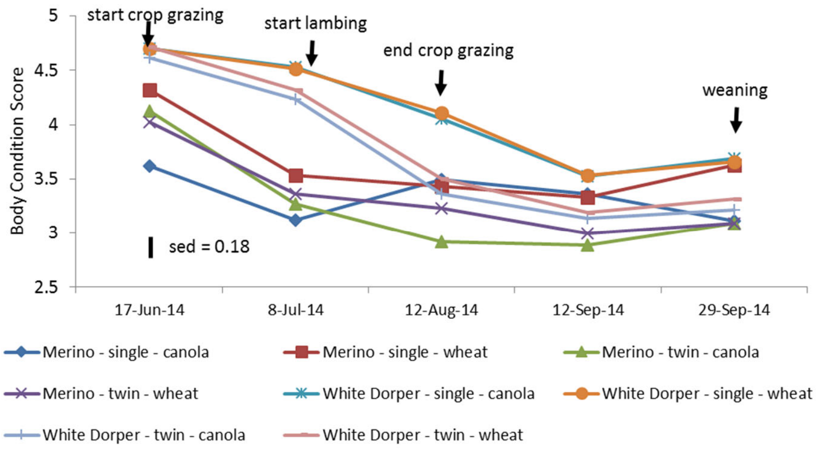

Fig. 5.5. Changes in body condition score of late-pregnant and lactating single- (S) and twin- (T) bearing ewes grazing dual-purpose crops (17 June- 12 August) and lucerne pasture (12 August-29 September).

Table 5.10. Mean ewe live weights from the start of crop grazing to weaning

Factor		Date					s.e.d.	P-value
		17 Jun	8 Jul	12 Aug	12 Sep	29 Sep		
Number of lambs	single-bearing	76.9	83.0	89.8	83.8	84.3	1.0	<0.001
	twin-bearing	77.4	83.9	82.6	74.8	75.5		
Ewe genotype	White Dorper	77.2	84.1	88.7	79.8	80.4	1.0	<0.001
	Merino	77.1	82.7	83.7	78.8	79.3		
Crop grazed	canola	76.9	82.4	84.7	79.3	80.3	1.0	0.001
	wheat	77.4	84.5	87.7	79.4	79.5		

Lamb birth weight

The birth weight of lambs was not significantly affected by the crop grazed by ewes (P=0.84). Differences in mean birthweight between genotypes approached significance (P=0.06; Table 5.11). Birth weight of single born lambs were significantly heavier than twin-born lambs (5.4 kg v. 4.8 kg; P<0.001) and birth weight of male lambs was significantly heavier than female lambs (5.3 kg v. 5.0 kg; P=0.018).

Table 5.11. Mean lamb birth weight, survival, weaning weight and muscle and fat scanning data at weaning in 2014

		Crop	WD	WSD	WSM	s.e.d.
Birth weight (kg)			5.0	5.3	5.2	0.1
Survival to weaning[a]	single-born	canola	0.56	0.57	0.50	
	single-born	wheat	0.88	0.92	0.86	
	twin-born	canola	0.90	0.70	0.71	
	twin-born	wheat	0.75	0.79	0.64	
Weaning weight (kg)		canola	29.4	30.8	28.5	0.1
		wheat	26.5	30.9	28.8	
Eye muscle depth	mm		23.9	23.8	22.5	0.4
Eye muscle depth	(mm/kg LW)	canola	0.82	0.82	0.81	0.03
		wheat	0.85	0.79	0.75	
Fat over eye muscle	(mm)[b]	canola	0.75	0.66	0.71	0.08
		wheat	0.70	0.68	0.60	
	(mm/kg LW)	canola	0.078	0.073	0.071	0.006
		wheat	0.073	0.074	0.065	

[a] back-transformed means; [b] transformed on natural log scale

Lamb survival

The proportion of lambs surviving to weaning did not differ significantly between genotypes and the interaction of genotype x crop was not significant (Table 5.11); however, there was a significant interaction between crop type and birth status of lambs (P=0.019), with survival being lower in single-born lambs on canola compared to wheat (0.53 v. 0.89), but no difference in lamb survival between crop treatments for twin-born lambs (0.75 v. 0.74).

Weaning weight, ewe muscle depth and fat over eye muscle of lambs at weaning

Weaning weight differed significantly between lamb genotypes (P=0.021), being higher for WSD lambs (30.9 kg) compared to WSM (28.9 kg) and WD (28.0 kg), which did not differ significantly from each other. There was a significant interaction between crop and lamb genotype for weaning weight (P=0.027; Table 5.11), with WD lambs being significantly lighter at weaning from the wheat treatment compared to the canola treatment, but there were no significant differences between crop treatments for WSD or WSM lambs.

Sex and weight were significant as co-variates for eye muscle depth at weaning (both P<0.001). Eye muscle depth of WD and WSD lambs was significantly higher than WSM lambs (P<0.001, Table 5.11). Neither the crop grazed by ewes nor the interaction between crop and ewe genotype were significant effects for eye muscle depth. Sex and age were significant (P<0.001) as co-variates when eye muscle depth was expressed per kg LW, and the interaction of crop and ewe genotype was significant (P=0.024; Table 5.11), being higher for WSM lambs from the canola treatment compared to the wheat treatment. Sex (P=0.033) and age (P=0.007) were significant co-variates for fat depth per kg LW; genotype, crop and their interaction were not significant.

Ewe colostrum quality and passive transfer of immunity

Neither ewe breed nor crop type had any effect (P > 0.05) on ewe serum and colostral IgG concentrations for ewes grazing dual-purpose canola and wheat crops. The serum IgG concentration of ewes was significantly (P < 0.05) associated with their live weight and body condition score one-week pre-partum, although their colostral IgG concentration was not (P > 0.05). The colostral IgG concentration was also not associated (P > 0.05) with serum IgG concentrations in either the ewes or their lambs, indicating that neither the immune status of the ewe (serum IgG concentration) nor the quality of the colostrum she produces can be used to predict the success (or failure) of transfer of passive immunity to lambs. However, when fitted to a linear model, the interaction of colostral IgG concentration modified by lamb birth weight did significantly affect (P < 0.05) lamb serum IgG concentration.

Rumen fluid samples

Molar proportions of acetic, iso-butyric and iso-valeric acids were significantly higher in the animals grazing wheat compared to those grazing canola (Table 5.12). Molar proportions of propionic, butyric and valeric acid were higher in animals grazing canola compared to wheat. The molar ratio of propionate:(acetate + 2 x butyric acid) was significantly higher in sheep fed the canola diet compared

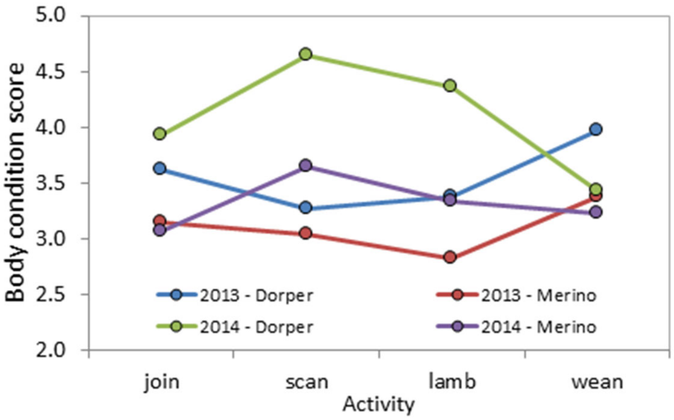

Fig. 5.6. Mean body condition score of White Dorper and Merino ewes during 2013 and 2014 (s.e.d. = 0.07)

to the winter wheat diet. The molar ratio of acetate:propionate was significantly lower in animals grazing canola compared to wheat. There were no genotype differences in molar proportions or molar ratios (Table 5.12).

Table 5.12. Least squares mean (± SE) molar proportions (%) of volatile fatty acids in sheep grazing wheat or canola.

	Canola		Wheat		P-values			
Ewe type	Merino	Dorper	Merino	Dorper	Breed	Diet	Weeks	Breed x Diet
Acetic acid	58.64	58.03	66.91	66.79				
	(± 0.97)	(± 0.97)	(± 0.97)	(± 0.97)	0.71	<0.0001	0.005	0.37
Propionic acid	23.73	24.89	19.93	19.85				
	(± 0.66)	(± 0.66)	(± 0.66)	(± 0.66)	0.42	<0.0001	0.69	0.37
Butyric acid	14.22	13.27	9.84	10.09				
	(± 0.60)	(± 0.60)	(± 0.62)	(± 0.62)	0.49	<0.0001	0.0002	0.23
Iso-butyric acid	0.52	0.53	0.62	0.76				
	(± 0.05)	(± 0.05)	(± 0.05)	(± 0.05)	0.15	0.004	0.039	0.21
Iso-valeric acid	0.64	0.75	1.28	1.23				
	(±0.16)	(± 0.16)	(± 0.17)	(± 0.17)	0.79	<0.0001	0.019	0.50
Valeric acid	1.55	1.62	0.76	0.64				
	(± 0.20)	(± 0.20)	(± 0.20)	(± 0.20)	0.89	<0.0001	0.37	0.54
Hexanoic acid	0.29	0.45	0.22	0.17				
	(± 0.18)	(± 0.18)	(± 0.18)	(± 0.18)	0.70	0.29	0.24	0.50
Heptanoic acid	0.047	0.070	0.038	0.037				
	(±0.018)	(± 0.018)	(± 0.018)	(± 0.018)	0.54	0.28	0.99	0.58
Pr:(Ac + 2 x Bu)	0.26	0.29	0.22	0.22				
	(± 0.009)	(± 0.009)	(± 0.009)	(± 0.009)	0.25	<0.0001	0.87	0.20
Ac:Pr	2.48	2.35	3.37	3.42				
	(± 0.13)	(± 0.13)	(± 0.13)	(± 0.13)	0.73	<0.0001	0.31	0.52

Analysis of body condition score across years

Body condition score of ewes was analysed over the two years using linear mixed models with random model ewe/year. The interaction of breed, management activity (joining, scanning, start of lambing and weaning) and year was highly significant (Fig. 5.6; P<0.001). The condition score of White Dorper ewes was always higher than Merino ewes, and ewe condition scores at scanning and lambing were higher in 2014 compared to 2013.

5.3 Biophysical systems modelling of crop grazing and lambing times

Pasture growth rates of lucerne and subterranean clover pastures were compared with those reported by (Hall *et al.* 1985) at Wagga Wagga for the period 1975–77 and considered acceptable. Pasture growth rates tended to peak in the spring, the lucerne component was able to respond to rainfall and soil moisture in the summer and autumn, and winter was typified by low pasture growth rates. Mean daily growth rates for wheat in the crop grazing model (July lambing flock at 8 ewes/ha) were 16, 22 and 15 kg DM/ha.day for June, July and August, respectively, which is lower than some other suggested growth rates (Anonymous 2008a). The growth rate of ungrazed wheat in 2004 was 75 kg DM/ha.day in the model, compared with 71 kg DM/ha.day reported by (Virgona *et al.* 2006) for a site north of Holbrook during the same period and with the same cultivar. The mean day that grazing of crops commenced was 30 June (median 9 July) in years when crop grazing occurred; no crop grazing occurred in 1983 and 2007. The mean number of days grazing crop ranged between 49–50 days, except for April and May lambing at a stocking rate of 10 ewes/ha where crop grazing days averaged 44 days.

The ratio of lambs weaned:ewes joined ranged between 0.82 – 0.89 across lambing months, stocking rates and whether or not crops were grazed, and tended to be highest for May and June lambing. Lamb mortality rates to weaning were highest when lambing commenced in July and August (both 21%), lowest when lambing commenced in April (7%) and May (12%), and were not substantially affected by stocking rate or whether ewes had wheat crop available to graze. Mean weaning weight across years was increased when crop grazing was available, with the effect greater for May and June lambing dates; however, mean weaning weights remained higher when lambing commenced later (data not presented).

The amount of grain fed was reduced with later lambing months and when ewes were able to graze the wheat crop and, as expected, increased at higher stocking rates; the proportion of years when more than 50 kg was fed per ewe followed a similar trend (Table 5.13).

The mean number of lambs sold annually increased and the mean sale weight of lambs across years was reduced as stocking rate increased. The increase in amount of lamb produced when crop grazing was permitted was proportionally greater for autumn lambing compared with later lambing at stocking rates of 8 or 10 ewes/ha (Table 5.13). The proportion of years when mean sale weight of lambs exceeded 39 kg live weight increased at lower stocking rates and generally increased when crop grazing was permitted, with the effect being greatest for autumn lambing at the higher stocking rates (Table 5.13). In general, the mean sale date was not changed substantially by the inclusion of crop grazing for a given lambing month and stocking rate combination, although the sale date was slightly earlier for June lambing and slightly later for April and May lambing at higher stocking rates when crop grazing occurred compared with when it did not (Table 5.13).

The median gross margin was highest when lambing took place in June at a stocking rate of 8 ewes/ha regardless of whether crop was grazed or not (Fig 5.7). Optimal stocking rate (in terms of median gross margin) was 6 ewes/ha for April and May lambing when no crop grazing was permitted, and the median gross margin was similar for 6 or 8 ewes/ha for July and August lambing

Table 5.13. Effect on median gross margin, grain feeding and lamb production of varying lambing month, stocking rate and access to dual-purpose wheat grazing. Data are means of 41 modelled years

Stocking rate (ewes/ha)	Lambing month	Change in gross margin (%)[A]	Grain fed (kg/ha)[B]		Proportion years >50 kg/head grain[C]		Sale date		Lamb production (kg/ha)		Proportion years lambs >39 kg/head[D]	
			No crop	Grazed	No crop	Grazed	No crop	Grazed	No crop	Grazed	No crop	Grazed
6	April	15	349	283	0.49	0.41	21 Oct	22 Oct	193	211	0.78	0.83
	May	11	343	257	0.46	0.37	16 Nov	12 Nov	206	218	0.78	0.80
	June	21	322	218	0.41	0.29	4 Dec	5 Dec	201	210	0.71	0.76
	July	14	292	191	0.41	0.20	31 Dec	1 Jan	195	202	0.59	0.68
	August	8	261	177	0.32	0.20	23 Jan	24 Jan	181	186	0.49	0.49
8	April	67	601	461	0.59	0.51	17 Oct	16 Oct	222	262	0.61	0.76
	May	67	583	428	0.56	0.46	31 Oct	7 Nov	228	273	0.61	0.71
	June	42	567	358	0.56	0.39	5 Dec	30 Nov	248	265	0.59	0.71
	July	28	550	334	0.54	0.39	27 Dec	28 Dec	240	253	0.51	0.56
	August	21	495	323	0.44	0.34	15 Jan	18 Jan	220	232	0.39	0.39
10	April	257	887	701	0.63	0.60	20 Sep	11-Oct	213	295	0.29	0.59
	May	241	894	634	0.66	0.54	16 Oct	27 Oct	229	309	0.37	0.59
	June	95	922	538	0.66	0.49	1 Dec	15 Nov	273	293	0.41	0.49
	July	113	887	541	0.63	0.49	19 Dec	20 Dec	269	292	0.37	0.44
	August	56	810	525	0.56	0.44	7 Jan	9 Jan	248	265	0.27	0.32

[A] Change in median gross margin when crop grazing included.

[B] From total grain fed.

[C] Proportion of years when amount of grain fed exceeded 50 kg/ewe joined (excluding grain fed to lambs).

[D] Proportion of years when mean lamb sale weight exceeded 39 kg/head.

(Fig. 5.7a). The optimal stocking rate increased to 8 ewes/ha for April and May lambing and 10 ewes/ha for August lambing when grazing crops were included, but did not change for June and July lambing (both 8 ewes/ha; Fig. 5.7b). The variability in the gross margins increased with stocking rate; however, this effect was reduced by the inclusion of crop grazing (Fig. 5.7).

Varying the sale price of wool or lamb or the cost of supplement by 20% from the standard values affected mean gross margins, but did not have a major impact on the month with the highest mean gross margin (Table 5.14). The stocking rate at which the highest mean gross margin occurred for a given lambing month was affected by changes in commodity prices for some lambing months.

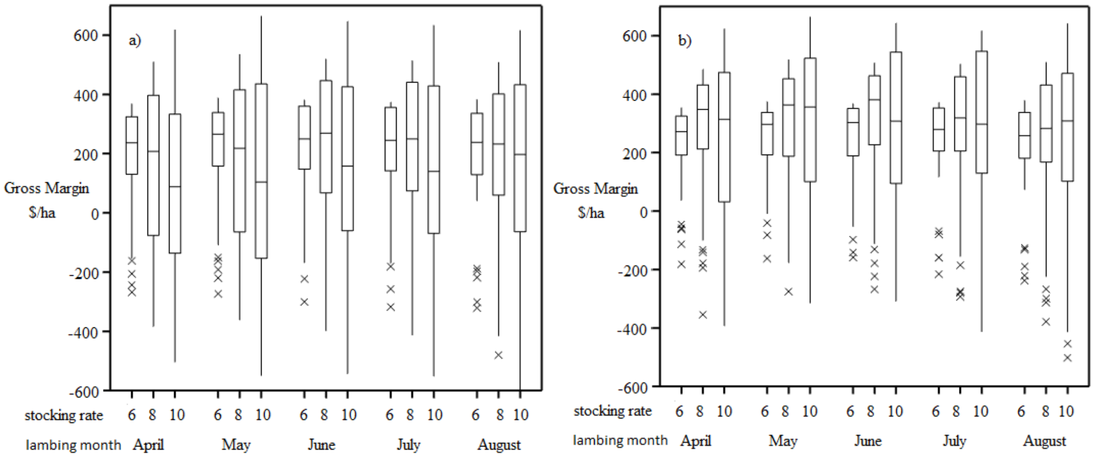

Fig. 5.7. Effect of lambing month on variation in gross margin (1971–2011) at stocking rates of 6, 8 and 10 ewes/ha for lambing months commencing April to August when (*a*) no grazing of dual-purpose wheat occurred, and (*b*) when ewes were able to graze the dual-purpose wheat crop. The box represents interquartile range with the median marked by the central line; whiskers show range of data, with outliers marked if exceeding 1.5 times the interquartile range beyond the quartiles (×).

Table 5.14. Highest mean gross margin (AU$) for each lambing month and crop grazing scenario at commodity prices 20% above or below standard rates and stocking rate at which this occurred (brackets). See text for standard wool, lamb and grain prices used.

Lambing month	Crop grazing	Standard	Commodity					
			Wool		Lamb		Supplement	
			Plus 20%	Minus 20%	Plus 20%	Minus 20%	Plus 20%	Minus 20%
April	No crop	186 (6)	218 (6)	153 (6)	238 (6)	134 (6)	168 (6)	203 (6)
	Grazed	265 (8)	307 (8)	224 (8)	336 (8)	195 (8)	242 (8)	289 (10)
May	No crop	205 (6)	238 (6)	173 (6)	261 (6)	150 (6)	188 (6)	222 (6)
	Grazed	292 (10)	343 (10)	246 (8)	373 (10)	215 (8)	266 (8)	323 (10)
June	No crop	212 (8)	253 (8)	170 (6)	277 (8)	148 (6)	186 (6)	240 (8)
	Grazed	293 (8)	343 (10)	251 (8)	368 (10)	222 (8)	275 (8)	318 (10)
July	No crop	200 (8)	242 (8)	166 (6)	263 (8)	147 (6)	184 (6)	228 (8)
	Grazed	278 (10)	328 (10)	236 (8)	353 (10)	211 (8)	261 (8)	305 (10)
August	No crop	183 (6)	224 (8)	151 (6)	240 (8)	136 (6)	170 (6)	208 (8)
	Grazed	242 (8)	286 (8)	200 (8)	304 (10)	181 (8)	225 (8)	262 (10)

5.4 Spring forage supply experiment

5.4.1 Experiment 1 – 2013

Pasture production and botanical composition

Total pasture dry matter ranged from 2.1 to 4.5 t/ha. Green dry matter (2.0 to 4.5 t/ha) was always significantly greater than senesced dry matter (0.01 to 0.7 t/ha) and green dry matter tended to be lowest at the first and/or last measurement time (Table 5.15). The pasture treatment within time interaction was significant (P<0.001) for green, senesced, total dry matter and percent legume. Green dry matter was generally highest for the annual legumes during the 31 October to 4 December period, while lucerne had its highest green dry matter on 25 October. Senesced dry matter increased at the last measurement date in all treatments (11 December, Table 5.15). Legume proportions were high in all treatments and ranged from 0.84 to 0.99 (Table 5.15).

Pasture quality

In vitro digestible organic matter digestibility (DOMD), crude protein (CP) and neutral detergent fibre (NDF) differed between pasture species and sampling times, with the sampling time within species interaction being significant (P<0.001) for all three traits (see Table 5.16). DOMD of the legume species ranged from 54 to 85 percent and digestibility of lucerne was either not significantly different or higher than other legume species over the experimental period (Table 5.16). Compared with lucerne, DOMD was significantly lower for subterranean clover on 18 and 28 October and lower for both subterranean clover and biserrula from 15 November to 17 December. CP of lucerne pluck samples was greater than 19% and was significantly higher than other species at all time points measured from late-October, whilst subterranean clover had the lowest or equal lowest CP from late-October (Table 5.16). NDF content of subterranean clover was significantly higher than for other pasture species on all sample dates, and NDF in biserrula samples was significantly higher than for lucerne on 15 November and 27 November (Table 5.16). NDF increased markedly in all species between 27 November and 17 December, accompanied by a marked decrease in DOMD.

Table 5.15. Pasture type and green, senesced and total dry matter (DM; t/ha), and the proportion of the legume species (green) in total dry matter over time. LSD values (reported at P<0.05) allow for both pasture type and time interval comparisons. The proportion of biserrula in total dry matter is also shown for the subterranean clover plus biserrula treatment.

	17/10	25/10	31/10	7/11	14/11	19/11	27/11	4/12	11/12	LSD
Green DM										
Lucerne	3.67	4.11	3.55	3.74	3.32	3.43	3.54	3.91	2.70	0.52
Subterranean clover	2.04	2.54	3.47	3.64	3.19	3.70	3.03	3.18	2.33	
Biserrula	2.04	2.62	3.21	3.89	4.48	4.50	3.59	4.19	3.03	
Sub. clover + biserrula	2.21	3.11	3.52	3.76	4.28	4.42	3.63	3.93	2.88	
Senesced DM										
Lucerne	0.39	0.05	0.11	0.17	0.10	0.11	0.20	0.20	0.74	0.6
Subterranean clover	0.14	0.13	0.17	0.22	0.19	0.19	0.20	0.13	0.44	
Biserrula	0.09	0.08	0.11	0.07	0.03	0.03	0.04	0.11	0.21	
Sub. clover + biserrula	0.01	0.04	0.07	0.09	0.06	0.03	0.04	0.04	0.32	
Total DM										
Lucerne	4.06	4.16	3.66	3.90	3.42	3.54	3.74	4.10	3.44	0.54
Subterranean clover	2.18	2.67	3.64	3.85	3.37	3.90	3.23	3.31	2.77	
Biserrula	2.12	3.71	3.32	3.96	4.51	4.52	3.63	4.29	3.23	
Sub. clover + biserrula	2.23	3.15	3.59	3.84	4.34	4.45	3.67	3.97	3.19	
Proportion main legume species										
Lucerne	0.88	0.94	0.91	0.84	0.90	0.91	0.91	0.92	0.91	0.05
Subterranean clover	0.95	0.99	0.94	0.91	0.95	0.96	0.91	0.86	0.88	
Biserrula	0.94	0.95	0.92	0.92	0.95	0.96	0.94	0.92	0.93	
Sub. clover + biserrula	0.94	0.98	0.95	0.91	0.92	0.95	0.90	0.88	0.89	
Proportion of biserrula										
Sub. clover + biserrula	0.37	0.35	0.40	0.39	0.38	0.53	0.46	0.43	0.46	0.09

Table 5.16. Nutritive value of pluck samples collected from lucerne (n = 3), subterranean clover (n = 6) and biserrula (n = 6); means did not differ significantly between choice and monoculture plots. LSD values are reported at P<0.05 and allow for both pasture type and time comparison intervals.

Species	Date					
	18 Oct 2013	28 Oct 2013	15 Nov 2013	27 Nov 2013	17 Dec 2013	LSD
Digestible organic matter digestibility (% DM)						
Lucerne	84	80	81	85	67	3
Subterranean Clover	81	76	73	69	54	
Biserrula	85	80	75	71	61	
Crude protein (% DM)						
Lucerne	22.8	24.4	28.0	27.1	19.7	2.1
Subterranean Clover	21.6	18.9	16.3	15.5	12.1	
Biserrula	23.0	22.1	17.5	15.9	15.5	
Neutral detergent fibre (% DM)						
Lucerne	27	32	30	28	43	3
Subterranean Clover	31	35	36	41	56	
Biserrula	28	30	33	37	45	

Livestock performance

Starting weight, but not sex, was significant (P<0.001) as a co-variate in the analysis of lamb live weight. Lamb weight was significantly affected by the pasture within lamb genotype and date interaction (P<0.001, Fig. 5.8). Live weight of WD lambs grazing lucerne, subterranean clover and subterranean clover plus biserrula were significantly higher than for WD lambs grazing the biserrula monoculture from 1 November, 21 November and 7 November onwards, respectively, while for WSM lambs those grazing biserrula had significantly lower live weights from 7 November onwards (Fig. 5.8).

Final live weight of WD and WSM lambs was highest when grazing lucerne (47.2 and 49.5 kg respectively) and lowest when grazing biserrula (41.7 and 41.4 kg respectively). Final weight of WD lambs grazing subterranean clover plus biserrula was significantly heavier than WD lambs grazing subterranean clover alone; however final weight of WSM lambs grazing subterranean clover plus biserrula did not differ significantly to that of WSM lambs grazing subterranean clover alone. Live weight of WSM lambs was significantly greater than WD lambs on the lucerne (from 1 November), subterranean clover (from 21 November) and subterranean clover plus biserrula (from 28 November) treatments; however final live weights of WD and WSM lambs grazing biserrula did not differ significantly (Fig. 5.8). Live weight of WSD lambs grazing lucerne was significantly higher than Dorper lambs from 14 November but was similar to WSM lambs at all time points (Fig. 5.8).

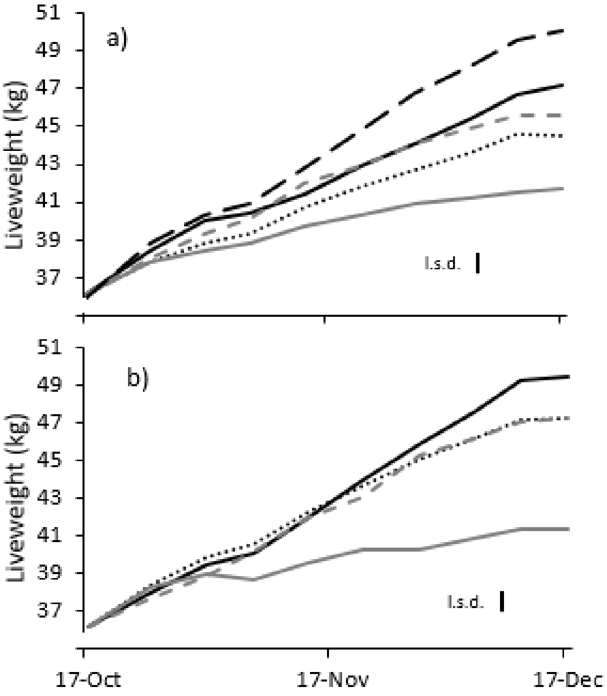

Fig. 5.8. Mean lamb weight (kg) for a) White Dorper (WD; n = 60) and b) White Suffolk x Merino (WSM; n = 60) lambs grazing lucerne (black line), biserrula (grey line), subterranean clover (dotted line) or a choice of subterranean clover plus biserrula (dashed line). Weights of White Suffolk x White Dorper (WSD) lambs grazing lucerne (n = 15) are shown on figure a) (black line, long-dash). LSD values (black bar, significant at P<0.05 level) allow for pasture type, genotype and time interval comparisons.

Observed growth rates of lambs grazing lucerne were similar to those predicted by GrazFeed early in the experiment, higher than predicted in late November and lower than predicted in mid-December (Fig. 5.9). The observed growth rate of lambs grazing subterranean clover were lower than predicted using this tool in the early part of the experiment, but were similar to the GrazFeed prediction from mid-November onwards (Fig. 5.9). Growth rates of lambs grazing biserrula were predicted to be higher than lambs grazing subterranean clover from the middle of November; however, observed lamb growth rate in the biserrula treatment was significantly lower than that of lambs grazing subterranean clover and well below predicted growth rates from late-October (Fig. 5.9).

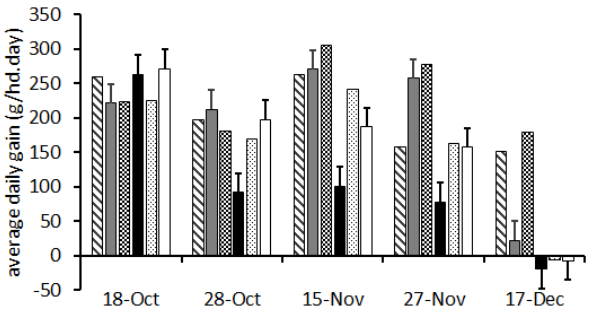

Fig. 5.9. Comparison of predicted growth rates of crossbred lambs grazing lucerne (diagonal stripes), biserrula (checkers) or subterranean clover (dots) compared to observed mean growth rate (± s.e.) of White Suffolk x Merino (WSM) lambs grazing lucerne (grey bar, n = 15), biserrula (black bar, n = 15) or subterranean clover (white bar). Predicted growth rates were calculated using GrazFeed, (Freer *et al.* 2010) with inputs using mean feed on offer, digestibility, crude protein and lamb weights for WSM lambs (refer to Tables 1 – 2, Figure 2) and lamb ages 3 months (October), 4 months (November) and 5 months (December). Observed growth rates were selected for the period closest to the date when pluck samples were collected, with means and standard errors generated using linear mixed models.

Carcase characteristics

Initial weight (P<0.001) and sex (ewes>wethers, 3.3 v. 3.0 mm; P=0.030) were significant co-variates in the analysis of fat depth over the eye muscle measured by real-time ultrasound on 11 December. Fat depth was highest for lambs grazing lucerne and lowest for lambs grazing biserrula (P=0.001; Table 5.17). Lamb genotype differences were not significant, nor was the pasture within genotype interaction.

Table 5.17. Mean fat depth over the eye muscle and eye muscle depth (by ultrasound on live animals on 11 December) and dressed weights and GR fat depth (carcase on 18 December) of White Dorper (WD; n = 60) and White Suffolk x Merino (WSM; n = 60) lambs grazing legume pastures. LSD values are reported at P<0.05. n.s. = not significant

	Lucerne	Subterranean clover	Biserrula	Subterranean clover/ biserrula	LSD	P-value
Fat depth over the eye muscle (mm)	4.2	3.2	2.4	2.9	0.5	0.001
Eye muscle depth (mm)	29.5	27.4	26.6	28.1	3.6	n.s.
Carcase weight (kg)	24.7	21.1	19.1	22.2	0.8	<0.001
GR fat depth (mm)	18	13	11	14	2	<0.001
	WD	WSM				
Fat depth over the eye muscle (mm)	3.3	3.1			0.3	n.s.
Eye muscle depth (mm)	27.0	28.8			2.6	n.s.
Carcase weight (kg)	22.1	21.4			0.5	0.009
GR fat depth (mm)	15	12			1	<0.001

Table 5.18. Mean fat depth over the eye muscle and eye muscle depth (by ultrasound on live animals on 11 December) and dressed weights and GR fat depth (carcase on 18 December) of White Dorper (WD; n = 15), White Suffolk x Merino (WSM; n = 15) and White Suffolk x White Dorper (WSD) lambs grazing lucerne. LSD values are reported at P<0.05. n.s. = not significant

	WD	WSM	WSD	LSD	P-value
Fat depth over the eye muscle (mm)	4.3	4.2	3.7	0.9	n.s.
Eye muscle depth (mm)	28.0	29.8	31.3	6.3	n.s.
Carcase weight (kg)	24.8	24.3	26.3	1.3	0.016
GR fat depth (mm)	19	17	17	3	n.s.

Lamb hot carcase weight was affected by starting weight (P<0.001) but not sex. Carcase weight differed significantly with pasture type (P<0.001) and was highest for lambs grazing lucerne (Table 5.17). Carcase weight of lambs grazing subterranean clover plus biserrula was significantly higher than lambs grazing subterranean clover in monoculture, which was greater than and for lambs grazing biserrula (Table 5.17). WD lambs had a significantly higher mean hot carcase weight than WSM lambs across the pasture treatments (P=0.009, Table 5.18), and carcase weight of WSD lambs were significantly higher than other genotypes on the lucerne treatment (P=0.016, Table 5.18). The interaction between pasture treatment and lamb genotype was not significant for carcase weight.

GR fat depth was affected by starting weight (P=0.018) and differed significantly with pasture type (both P<0.001). GR fat depth was highest for lambs that were grazing lucerne pastures and lowest for lambs that were grazing biserrula monoculture, with no significant difference between lambs from subterranean clover and subterranean clover plus biserrula treatments (Table 5.17). GR fat depth for WD lambs was significantly higher (P<0.001) than for WSM lambs across the pasture treatments (Table 5.19) and the pasture within lamb genotype interaction was not significant.

5.4.2 **Experiment 2 - 2014**

Feed on offer

The feed on offer at the commencement of grazing was high (Fig. 5.10) and was not considered limiting in terms of dry matter availability at any stage during the experiment for any pasture treatment.

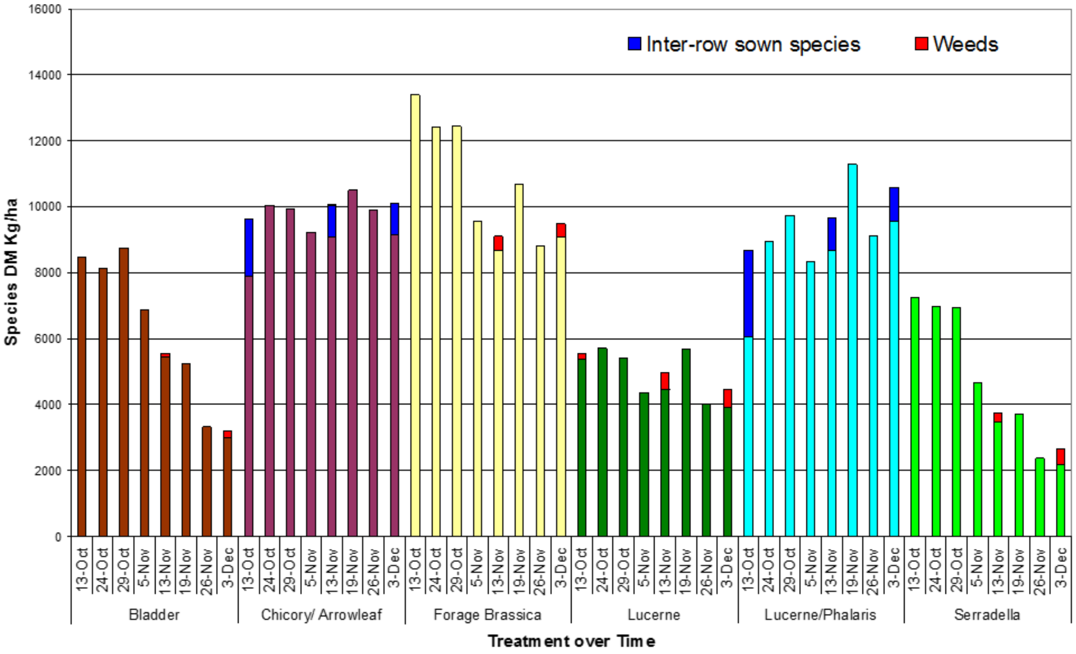

Fig. 5.10. Feed on offer and species composition during grazing period. “Inter-row sown species” refers to chicory in the chicory/arrowleaf clover treatment or lucerne in the lucerne/phalaris treatment.

Forage quality

The interaction of treatment and date was significant (P<0.001) for DOMD and CP content of pluck samples (Table 5.19). At the first measurement (13 Oct) the DOMD of chicory + arrowleaf clover, lucerne and forage brassica treatments were high compared with the other treatments (Table 5.19). DOMD was lower by the end of the experiment (2 December) in all treatments; however, the temporal pattern of DOMD changes differed between treatments (Table 5.19). CP was highest in the lucerne and chicory + arrowleaf clover treatments at the commencement of the experiment and lucerne had the highest at the conclusion. The CP concentration in forage brassica and serradella was lower than other treatments at the end of the experiment.

Table 5.19. Mean digestible organic matter digestibility (DOMD) and crude protein content of pluck samples.

Date	Chicory/ arrowleaf clover	Lucerne	Bladder clover	French serradella	Lucerne/ phalaris	Forage brassica
			Digestible organic matter in dry matter (DOMD, %)			
13 Oct	74	74	62	63	63	72
24 Oct	77	76	65	65	62	75
29 Oct	76	73	63	64	61	74
5 Nov	77	73	60	58	56	69
13 Nov	70	67	54	47	55	59
21 Nov	71	63	51	39	52	56
26 Nov	65	72	49	38	54	59
2 Dec	65	64	49	38	53	47
DOMD average s.e.d. = 2%						
			Crude protein (CP, %)			
13 Oct	29.4	32.3	20.5	23.7	23.2	23.6
24 Oct	30.3	27.9	19.3	20.2	19.0	22.0
29 Oct	28.5	24.9	14.2	19.4	14.7	23.1
5 Nov	24.8	25.8	14.8	15.3	10.4	17.7
13 Nov	17.7	23.3	13.6	10.7	13.0	16.4
21 Nov	19.8	19.5	12.0	7.8	10.0	16.7
26 Nov	13.9	24.4	12.9	8.5	14.1	13.9
2 Dec	15.3	21.9	14.9	9.7	18.1	10.1
CP average s.e.d. = 2.1%						

Lamb weights

The interaction of genotype and sex was significant (P<0.01) for lamb live weight. The interaction between date, pasture treatment and genotype was also significant (P=0.020). Finishing liveweight of lambs was highest for the chicory + arrowleaf clover treatment and lowest for French serradella and lucerne + phalaris across all lamb genotypes. Lucerne, bladder clover and forage brassica had similar finishing weights that were also consistent across lamb genotypes (Table 5.20).

The higher weight gains of lambs grazing chicory + arrowleaf clover resulted in a higher proportion of lambs reaching the target minimum finished weights for slaughter (Table 5.21). Lamb genotype was also a significant effect (P<0.001), with a significantly lower proportion of WSM lambs reaching the minimum slaughter weight at the conclusion of the experiment (Table 5.22). The interaction of genotype x treatment was not significant for the proportion of lambs reaching target liveweight for kill.

Table 5.20. Mean curfew weight of White Suffolk × White Dorper, White Dorper x White Dorper and White Suffolk × Merino lambs grazing pastures from 15 October to 2 December 2014 (s.e.d. = 0.5)

Date	Chicory/ arrowleaf clover	Lucerne	Bladder clover	French serradella	Lucerne/ phalaris	Forage brassica
			White Suffolk x White Dorper			
15-Oct	32.4	32.4	32.4	32.4	32.4	32.4
21-Oct	33.4	33.1	33.1	33.6	33.9	32.9
28-Oct	35.3	35.1	35.5	35.8	35.6	34.3
4-Nov	37.7	37.1	37.1	37.4	37.4	35.7
18-Nov	41.1	38.8	39.6	38.9	39.0	38.6
26-Nov	43.5	41.2	40.8	37.3	38.1	40.0
2-Dec	45.2	42.6	41.0	*	37.9	41.2
			White Dorper x White Dorper			
15-Oct	32.2	32.2	32.2	32.2	32.2	32.2
21-Oct	32.9	32.6	33.2	33.7	33.6	32.8
28-Oct	35.0	34.9	35.7	35.9	35.5	34.2
4-Nov	37.2	36.5	37.5	37.3	37.3	35.8
18-Nov	40.3	38.5	40.2	39.9	39.0	38.8
26-Nov	42.5	40.6	41.4	38.6	38.7	40.3
2-Dec	43.7	41.7	41.4	*	38.8	41.1
			White Suffolk x Merino			
15-Oct	32.3	32.3	32.3	32.3	32.3	32.3
21-Oct	33.3	32.6	33.4	33.9	33.5	32.9
28-Oct	35.0	34.7	35.2	35.6	35.3	34.2
4-Nov	37.4	36.1	37.3	37.5	37.3	35.7
18-Nov	40.8	38.1	38.7	38.4	37.6	38.5
26-Nov	42.9	40.1	40.0	36.2	37.4	39.8
2-Dec	44.0	41.4	39.6	*	37.6	40.5

Table 5.21. Proportion of lambs reaching slaughter weight (back-transformed means) and mean carcase data for each treatment

Pasture treatment	Proportion reaching slaughter weight	Hot carcase weight (kg)	Dressing percentage	GR fat (mm)
Chicory/arrowleaf clover	0.94	24.4	53.1	14
Lucerne	0.80	22.6	52.0	11
Bladder clover	0.70	20.2	47.2	7
French serradella[a]	0.52			
Lucerne/phalaris	0.68	20.8	49.7	7
Forage brassica	0.76	21.8	49.4	11
s.e.d.		0.8	0.8	1

[a] Number of lambs in this treatment reaching slaughter weight on 18 November; lambs not included in carcase data.

Carcase data

There was a significant difference between treatments for hot carcase weight (HCW), dressing percentage and GR fat depth (all P<0.001; Table 5.21). Lambs finished on chicory/arrowleaf clover had significantly heavier carcases, higher dressing percentage and higher GR fat compared to other treatments, while lambs that had grazed bladder clover or lucerne/phalaris had significantly lower GR fat (Table 5.21). WSM lambs had significantly (P<0.001) lighter hot carcase weights, lower dressing percentages and less GR fat compared to other lamb genotypes (Table 5.22). There were no significant genotype x treatment interactions for carcase data.

Table 5.22. Proportion of lambs reaching slaughter weight (back-transformed means) and mean carcase data for each genotype

Ewe Genotype	**Proportion reaching slaughter weight**^{A}	**Hot carcase weight (kg)**	**Dressing percentage**	**GR fat (mm)**
Dorper	0.85	23.0	52.1%	12
WSD	0.84	22.5	51.0%	12
WSM	0.53	20.4	47.8%	7
s.e.d.		0.6	0.50%	1

^{A} includes lambs grazing French serradella that reached minimum slaughter weight on 18 November; these lambs not included in carcase data

Profit per head

The gross profit per head accrued over the spring grazing period was significantly lower for WSM lambs (P<0.001) compared to White Dorper or White Suffolk x White Dorper lambs (Figure 5.11). The gross profit per head also differed significantly with pasture treatment (P<0.001); gross profit for lambs grazing the chicory/arrowleaf clover mixture was significantly higher, and gross profit of lambs grazing French serradella or lucerne and phalaris mixture was significantly lower than the other pasture treatments (Fig. 5.12). The interaction of genotype and treatment was not significant.

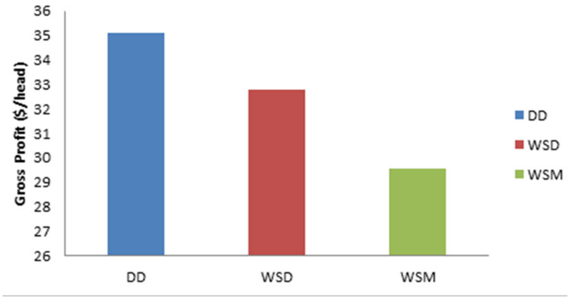

Fig. 5.11. Gross profit per head of White Dorper (DD), White Suffolk x White Dorper (WSD) and White Suffolk x Merino (WSM) lambs (s.e.d. = $0.70)

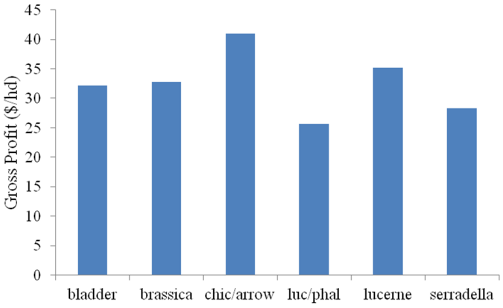

Fig. 5.12. Gross profit per head of lambs grazing finishing treatments (s.e.d. = $1.47)

6 Results from the Hamilton node – canola as a summer forage

6.1 Forage production and nutritive characteristics

Plant establishment

Seedling establishment rates are shown in Table 6.1. The spring 2013 sowing resulted in all sown treatments having acceptable seedling densities, with no differences ($P>0.05$) existing between the annual brassica treatments. The 2014 and 2015 sowings resulted in annual species having lower seedling densities than the 2013 sowing. Plant densities in the 2015 sowing were, however, sufficient to permit adequate herbage mass production (Table 6.2), so the crop failure in 2014-15 cannot be ascribed to poor establishment alone.

Table 6.1. Seedling establishment (seedlings/m^2) for all of the treatments sown in spring 2013, except the perennial ryegrass which was an existing sward, and the annual species sown in spring 2014 and 2015 (Means with different superscripts are statistically different $P<0.05$)

Treatment	2013	2014	2015
Hyola971CL	68.9^a	16.9	16.5
Taurus/Brazzil	40.7^a	17.8	14.1
Winfred	42.4^a	19.4	15.0
Chicory	202.4^b		
Plantain	216.1^b		
Lucerne	94.1^a		
P-value Group	**<0.001**	n/a	n/a
P-value Group.treatment	**0.002**	0.88	0.26
LSD P=0.05	55.0		

Herbage mass

The canola cultivars did not differ in pre-grazing herbage mass from Winfred forage brassica on any date in Exp. 1, except for 17 April 2014 when canola cv. Taurus (but not cv. Hyola981CL) had lower herbage mass than the Winfred (Table 6.2). The canola and the Winfred did not differ in herbage mass from the perennial ryegrass on any sampling date in Exp. 1, except on 17 April 2014 when the Winfred had higher herbage mass than the perennial ryegrass. The lucerne, chicory and plantain treatments did not differ in herbage mass on all but one sampling date in Exp. 1 and were generally lower in herbage mass than the brassicas or perennial ryegrass.

During January and February 2016 in Exp.3, pre-grazing herbage mass did not differ between the three brassica treatments, with the brassicas having lower pre-grazing herbage mass than the chicory and lucerne (on 20 January 2016 only) but not differing from the perennial ryegrass or plantain. On 9 March 2016 there were no differences in pre-grazing herbage mass between forage treatments. On 21 March 2016, the perennial ryegrass treatment had the highest pre-grazing herbage mass, with herbage mass not significantly different between the other treatments. On 21 March 2016, the perennial ryegrass treatment had the highest pre-grazing herbage mass, with herbage mass not differing between the other treatments except for the plantain which was relatively low in herbage mass. On 4 April and 29 April 2016 the perennial ryegrass had higher pre-grazing herbage mass than all of the other treatments which did not differ from each other. On 1 June 2016, following a period of re-growth following grazing, the herbage mass of the Winfred and Brazzil forage brassicas did not differ with the Winfred having higher herbage mass than the Hyola 971CL. The herbage mass of Hyola 971CL canola did not differ from the chicory, plantain, lucerne or perennial ryegrass.

Table 6.2. Pre-grazing herbage mass (kg DM/ha) during the pre-joining and joining periods in summer and autumn 2014 and 2016. Means with different superscripts are statistically different (i.e. P<0.05).

Treatment				Experiment 1 (2014)				
	24 Jan	12 Feb	24 Mar	07 Apr	17 Apr	05 May	19 May	02 Jul
Hyola971CL	4162	3565	3639^{b}	3063^{b}	2385^{bc}	1395	1305^{c}	3695
Taurus	3831	3592	3345^{b}	2445^{b}	1863^{b}	1045	1140^{bc}	2871
Winfred	3824	3968	3612^{b}	2777^{b}	2877^{c}	1433	1371^{c}	3949
Chicory	2260	1445	1369^{a}	1302^{a}	472^{a}	934	798^{ab}	1078
Plantain	1628	1416	1048^{a}	932^{a}	675^{a}	1175	1212^{bc}	2050
Lucerne	1940	1946	1297^{a}	992^{a}	679^{a}	936	558^{a}	1045
Perennial Ryegrass	2211	1689	2941^{b}	2679^{b}	2177^{b}	1251	1288^{c}	1589
P-value Group	<0.001	<0.001	0.005	<0.001	<0.001	0.337	0.096	0.002
P-value Group.treatment	0.29	0.08	<0.001	<0.001	<0.001	0.18	0.033	0.43
LSD P=0.05 (within brassica group)	751	501	772	724	607	479	485	1637
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	751	501	772	724	607	479	485	1637
LSD P=0.05 (max. all other comparisons)	766	527	1197	724	607	608	530	1681
				Experiment 3 (2016)				
	20 Jan	25 Feb	09 Mar	21 Mar	04 Apr	29 Apr	01 Jun	
Hyola971CL	2129^{b}	2232^{ab}	1857	1598^{bd}	1535^{b}	1231^{b}	1831^{c}	
Brazzil	2047^{b}	2394^{ab}	1930	1567^{bd}	1583^{b}	1269^{b}	2352^{b}	
Winfred	2167^{b}	2383^{ab}	2051	1652^{d}	1546^{b}	1321^{b}	2944^{a}	
Chicory	3342^{a}	3346^{a}	2450	1424^{bc}	1559^{b}	1310^{b}	1197^{c}	
Plantain	2237^{b}	1799^{b}	2140	1264^{c}	1469^{b}	1264^{b}	1313^{c}	
Lucerne	3090^{a}	1862^{b}	2267	1540^{bd}	1571^{b}	1262^{b}	1320^{c}	
Perennial Ryegrass	2444^{b}	3189^{a}	2491	2179^{a}	2395^{a}	1548^{a}	1383^{c}	
P-value Group	<0.001	0.131	0.013	0.063	<0.001	0.101	0.005	
P-value Group.Treatment	0.014	0.002	0.52	<0.001	<0.001	0.001	<0.001	
LSD P=0.05 (within brassica group)	456	668	468	195	123	134	359	
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	456	668	468	195	123	134	359	
LSD P=0.05 (max. all other comparisons)	486	1255	468	223	123	134	707	

Metabolizable energy

The ME concentrations of the two canola varieties in Exp. 1 did not differ from the Winfred on any date except for 2 July, when Winfred had higher ME than canola cv. Taurus (Table 6.3). The canola varieties and Winfred forage brassica were higher in ME than all other treatments on all dates in Exp. 1, and remained at high levels (at or above 11.9 MJ/kg) through to the start of July. The perennial ryegrass treatment had ME values of about 11 MJ/kg, intermediate between the brassica treatments and the lucerne or plantain.

Table 6.3. Pre-grazing metabolisable energy (MJ/kg DM) during the pre-joining and joining periods in summer and autumn 2014 and 2016. Data is for the green component only. Means in the same column with different superscripts are statistically different ($P<0.05$).

Treatment	Experiment 1 (2014)						
	22 Jan	21 Mar	10 Apr	17 Apr	5 May	19 May	2 Jul
Hyola 971CL	13.2^{d}	13.0^{c}	12.7^{c}	12.3^{c}	12.3^{d}	11.9^{d}	12.9^{de}
Taurus	13.2^{d}	13.0^{c}	12.8^{c}	12.3^{c}	12.2^{d}	12.2^{d}	12.8^{d}
Winfred	13.3^{d}	13.2^{c}	12.9^{c}	12.6^{c}	12.2^{d}	12.1^{d}	13.1^{e}
Chicory	11.4^{c}	10.8^{b}	11.3^{b}	10.6^{b}	9.4^{bc}	9.3^{b}	10.9^{b}
Plantain	10.7^{b}	10.6^{b}	9.7^{a}	10.4^{b}	8.3^{ab}	8.7^{ab}	10.3^{a}
Lucerne	10.1^{a}	8.8^{a}	9.0^{a}	8.7^{a}	8.0^{a}	8.0^{a}	11.0^{b}
Perennial Ryegrass*	11.1^{c}	11.0^{b}	11.3^{b}	11.1^{b}	10.1^{c}	10.8^{c}	11.8^{c}
P-value Group	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P-value Group.treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD P=0.05 (within brassica group)	0.29	0.72	0.72	0.72	0.87	0.77	0.29
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	0.29	0.72	0.72	0.72	0.87	0.77	0.29
LSD P=0.05 (max. all other comparisons)	0.38	0.77	0.79	0.72	1.10	0.77	0.41
	Experiment 3 (2016)						
	21 Jan	25 Feb	9 Mar	21 Mar	1 Apr	6 Jun	
Hyola 971CL	12.2	12.1^{d}	12.0^{c}	11.5	11.7	11.5	
Brazzil	12.4	12.7^{de}	12.5^{cd}	12.5	12.5	12.5	
Winfred	11.9	13.2^{e}	13.2^{d}	13.1	12.9	12.7	
Chicory	10.9	9.0^{ab}	8.9^{a}	7.9	8.0	7.6	
Plantain	9.5	9.9^{bc}	10.0^{b}	10.9	10.7	10.8	
Lucerne	9.6	8.1^{a}	8.1^{a}	9.9	9.8	9.8	
Perennial Ryegrass	8.2	10.4^{c}	10.6^{b}	10.3	10.0	10.6	
P-value Group	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	
P-value Group.treatment	0.820	0.002	<0.001	0.210	0.437	0.244	
LSD P=0.05 (within brassica group)	2.52	1.03	0.94	1.58	1.63	1.43	
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	2.91	1.03	0.94	1.58	1.63	1.43	
LSD P=0.05 (max. all other comparisons)	2.89	1.03	0.94	1.58	1.63	1.43	

At the start of Exp. 3 there were no differences in ME content between treatments. On 25 February 2016, the chicory, lucerne and plantain had the lowest and the brassicas the highest ME concentrations, with the perennial ryegrass being intermediate. On 9 Mar 2016, the chicory and lucerne still had the lowest and brassicas the highest ME concentrations; thereafter, however, there were no significant differences in ME concentrations between treatments.

Crude protein

Crude protein content of green forage tended to increase over time, more so in Exp. 1 than in Exp. 3 (Table 6.4). At the start of Exp. 1, canola cv. Taurus had higher CP than all other forages except chicory and canola cv. Hyola 971CL. In March 2014, both canola varieties had higher CP than all other treatments, except that Hyola 971CL and plantain did not differ significantly. There were no significant differences in CP concentration between treatments at the next three measurement dates. On 19 May 2014, the Winfred forage brassica had lower CP than the plantain and Taurus canola, but was not different from the other treatments. The canola varieties and the perennial ryegrass did not differ in CP concentration on 19 May 2014. In July 2014, the lucerne had higher CP concentration than all other treatments, with the other treatments not being different from each other.

Table 6.4. Pre-grazing crude protein (% DM) during the pre-joining and joining periods in summer and autumn 2014 and 2016. The data presented is for the green component of the forages only. Means in the same column with different superscripts are statistically different (P<0.05).

Treatment	Experiment 1 (2014)						
	22 Jan	21 Mar	10 Apr	17 Apr	5 May	19 May	2 Jul
Hyola971CL	16.5^{bc}	18.7^{c}	18.8	20.8	21.5	22.2^{ab}	27.9^{a}
Taurus	20.0^{c}	20.1^{cd}	21.7	18.6	23.4	27.8^{cd}	27.0^{a}
Winfred	15.0^{ab}	14.0^{ab}	18.4	17.8	19.3	19.6^{ab}	25.4^{a}
Chicory	16.6^{bc}	15.4^{ab}	15.3	22.3	19.4	26.8^{bcd}	24.7^{a}
Plantain	14.8^{ab}	16.3^{bc}	17.4	16.7	22.5	29.9^{d}	24.0^{a}
Lucerne	15.1^{ab}	13.3^{a}	13.8	16.2	20.0	23.5^{abc}	35.9^{b}
Ryegrass	11.5^{a}	12.0^{a}	15.8	17.5	18.4	23.8^{abc}	27.8^{a}
P-value Group	0.056	<0.001	<0.001	0.136	0.56	0.122	0.017
P-value Group.treatment	0.048	<0.001	0.087	0.668	0.182	0.005	<0.001
LSD P=0.05 (within brassica group)	4.35	2.98	3.43	5.35	5.35	5.16	3.98
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	4.35	2.98	3.43	5.35	5.35	5.16	3.98
LSD P=0.05 (max. all other comparisons)	4.46	2.98	3.43	6.46	5.60	5.16	3.98
	Experiment 3 (2016)						
	21 Jan	25 Feb	9 Mar	21 Mar	1 Apr	6 Jun	
Hyola971CL	14.1^{c}	15.9^{bc}	16.2^{b}	13.3^{a}	14.0^{a}	13.8^{ab}	
Brazzil	11.5^{bc}	18.4^{cd}	18.2^{bc}	20.7^{b}	20.5^{a}	20.1^{bc}	
Winfred	15.0^{c}	17.2^{bc}	17.4^{bc}	19.8^{ab}	19.6^{a}	20.2^{bc}	
Chicory	10.0^{b}	12.5^{a}	12.2^{a}	13.6^{a}	13.4^{a}	12.5^{a}	
Plantain	12.2^{bc}	18.0^{bd}	17.9^{bc}	18.8^{ab}	18.2^{a}	19.3^{bc}	
Lucerne	14.0^{c}	14.7^{ab}	14.8^{ab}	30.9^{c}	29.9^{b}	30.2^{d}	
Ryegrass	5.4^{a}	20.4^{d}	20.6^{c}	22.6^{b}	21.2^{a}	23.7^{cd}	
P-value Group	0.022	0.008	0.008	0.001	0.011	<0.001	
P-value Group.treatment	<0.001	0.009	0.016	0.006	0.029	0.013	
LSD P=0.05 (within brassica group)	3.08	3.19	3.42	6.81	7.90	6.70	
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	3.35	3.19	3.42	6.81	7.90	6.70	
LSD P=0.05 (max. all other comparisons)	3.51	3.30	3.53	6.81	7.90	6.70	

On 21 January 2016, the perennial ryegrass treatment had much lower CP than all the other treatments, and the Winfred had higher CP than all other treatments except the canola cv. Hyola971CL and lucerne. CP content of green ryegrass recovered during February; by 25 February 2016 the chicory had the lowest CP concentration with the perennial ryegrass, Brazzil, Winfred and plantain treatments having higher CP concentrations. On 21 March 2016, chicory and canola cv. Hyola 971CL had the lowest and lucerne the highest CP concentrations; lucerne CP remained extremely high thereafter. By the end of Exp. 3, the Hyola 971CL and chicory had the lowest and the lucerne and perennial ryegrass the highest CP concentrations.

Water soluble carbohydrate (WSC)

Water soluble carbohydrate concentrations decreased over time in Exp. 1 but not in Exp. 3 (Table 6.5). Lucerne had lower WSC concentration than all other forages on most of the sampling dates (Table 6.5). Chicory, plantain and perennial ryegrass all had sampling dates where WSC concentrations were lower than those of the brassicas, but this effect was not consistent with treatments often not differing in WSC concentration or effects changing between successive sampling dates.

Table 6.5. Pre-grazing water soluble carbohydrate (%DM) during the pre-joining and joining periods in summer and autumn 2014 and 2016. Data are for the green component of the herbage only; means with different superscripts are statistically different (i.e. P<0.05).

Treatment	Experiment 1 (2014)						
	22 Jan	21 Mar	10 Apr	17 Apr	5 May	19 May	2 Jul
Hyola 971CL	18.2^{c}	12.3^{c}	11.3^{b}	10.7^{bc}	11.0^{de}	9.4^{de}	12.5^{c}
Taurus	17.5^{c}	11.8^{c}	11.5^{b}	8.9^{abc}	7.5^{bc}	8.6^{d}	12.7^{c}
Winfred	18.0^{c}	14.6^{d}	12.4^{b}	12.5^{cd}	11.8^{e}	11.8^{e}	13.9^{c}
Chicory	11.2^{ab}	8.8^{b}	11.0^{b}	7.2^{ab}	5.9^{b}	3.1^{ab}	10.2^{bc}
Plantain	13.5^{b}	12.7^{cd}	10.9^{b}	12.2^{cd}	7.9^{bc}	4.7^{bc}	8.6^{b}
Lucerne	8.9^{a}	5.2^{a}	6.1^{a}	5.7^{a}	3.2^{a}	1.8^{a}	4.5^{a}
Perennial ryegrass	19.2^{c}	20.1^{e}	16.4^{c}	15.2^{d}	9.0^{cd}	5.8^{c}	7.8^{b}
P-value Group	0.001	0.004	0.711	0.059	<0.001	<0.001	0.004
P-value Group.treatment	<0.001	<0.001	<0.001	<0.001	<0.001	0.010	0.041
LSD P=0.05 (within brassica group)	2.74	1.86	2.90	3.94	2.63	2.62	3.23
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	2.74	1.86	2.90	3.94	2.63	2.62	3.23
LSD P=0.05 (max. all other comparisons)	3.09	2.22	2.90	3.94	2.63	2.62	3.55
	Experiment 3 (2016)						
	21 Jan	25 Feb	9 Mar	21 Mar	1 Apr	6 Jun	
Hyola 971CL	11.0^{ab}	13.5^{de}	13.3^{bc}	16.2^{d}	16.3^{d}	16.2^{d}	
Brazzil	13.2^{b}	13.8^{e}	13.8^{c}	14.3^{cd}	15.0^{cd}	14.4^{cd}	
Winfred	9.8^{ab}	13.1^{ce}	13.0^{bc}	14.9^{cd}	13.8^{c}	13.7^{cd}	
Chicory	8.6^{a}	5.9^{a}	6.1^{a}	4.1^{a}	4.5^{a}	3.8^{a}	
Plantain	12.8^{ab}	10.4^{c}	10.7^{b}	12.5^{c}	12.4^{c}	12.6^{c}	
Lucerne	8.5^{a}	6.2^{a}	6.2^{a}	3.7^{a}	4.2^{a}	3.6^{a}	
Perennial ryegrass	18.4^{bc}	10.6^{cd}	10.6^{b}	8.4^{b}	8.2^{b}	7.4^{b}	
P-value Group	0.033	<0.001	<0.001	<0.001	<0.001	<0.001	
P-value Group.treatment	<0.001	0.040	0.019	<0.001	<0.001	<0.001	
LSD P=0.05 (within brassica group)	3.43	2.95	2.79	2.77	2.16	2.65	
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	3.96	2.95	2.79	2.77	2.16	2.65	
LSD P=0.05 (max. all other comparisons)	3.76	2.95	2.79	3.49	3.47	3.37	

On 21 January 2016, the WSC concentration of the perennial ryegrass was higher than all other treatments. On 25 February 2016, 9 and 21 March 2016, 1 April 2016 and 6 June 2016 the chicory and lucerne had the lowest WSC concentrations while the brassica treatments had the highest WSC concentrations and the perennial ryegrass was intermediate.

Ryegrass endophyte alkaloids

Peramine concentrations in the perennial ryegrass pastures ranged from 5.4 to 10.4 mg/kg during Exp. 1, and ergovaline concentrations from 0.24 mg/kg to 1.04 mg/kg (Fig. 6.1). Samples from Exp. 1 did not contain measurable levels of lolitrem B. In Exp. 3 the range in plot average concentrations for peramine, ergovaline and lolitrem B in the perennial ryegrass samples were 2.5 to 8.7 mg/kg, 0.10 to 0.54 mg/kg and 0.08 to 0.55 mg/kg, respectively.

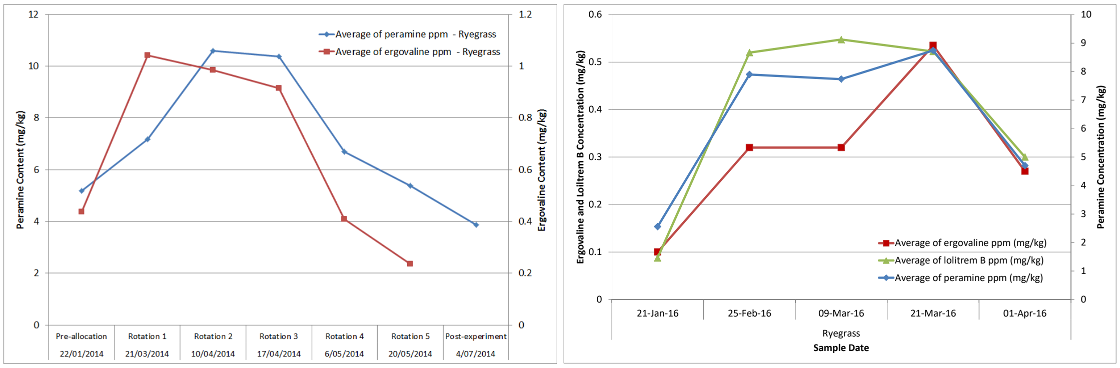

Fig. 6.1. Peramine, ergovaline and lolitrem B concentrations in the ryegrass samples collected during experiments 1 and 3.

Botanical composition

Throughout March and April 2014, the lucerne treatment had a lower sown species proportion than all other treatments, with plots containing on average 46 to 53% lucerne (Table 6.6). The perennial ryegrass treatment contained 81-99% sown species, while the other treatments contained 70-90% sown species. By May 2014, the sown species content of the lucerne did not differ from the canola cv. Taurus, plantain or chicory.

Table 6.6. Sown species proportion (%DM) in the sward during the pre-joining and joining periods in summer and autumn 2014 and 2016. Means with different superscripts are statistically different (i.e. P<0.05).

Treatment	Experiment 1 (2014)					
	21 Mar	10 Apr	17 Apr	6 May	20 May	
Hyola 971CL	77^{b}	76^{bc}	81^{b}	91^{bc}	91^{b}	
Taurus	78^{b}	80^{bc}	87^{b}	84^{ab}	82^{a}	
Winfred	75^{b}	77^{bc}	71^{ab}	92^{bc}	93^{b}	
Chicory	73^{b}	76^{bc}	73^{ab}	76^{a}	80^{a}	
Plantain	72^{b}	68^{b}	71^{ab}	87^{b}	78^{a}	
Lucerne	53^{a}	46^{a}	50^{a}	79^{a}	80^{a}	
Perennial ryegrass	99^{c}	84^{c}	81^{b}	96^{c}	91^{b}	
P-value Group	0.815	0.022	0.274	<0.001	0.021	
P-value Group.treatment	<0.001	<0.001	0.017	<0.001	0.006	
LSD P=0.05 (within brassica group)	18	9	20	7	8	
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	18	9	20	7	8	
LSD P=0.05 (max. all other comparisons)	18	12	23	7	8	
	Experiment 3 (2016)					
	1 Feb	25 Feb	9 Mar	21 Mar	4 Apr	1 Jun
Hyola 971CL	70^{a}	83	92	75	78	91
Brazzil	73^{a}	85	96	78	91	91
Winfred	79^{ab}	85	95	78	93	95
Chicory	88^{b}	97	98	87	90	78
Plantain	89^{b}	90	98	83	93	92
Lucerne	82^{ab}	81	95	76	93	67
Perennial ryegrass	69^{a}	83	96	96	93	64
P-value Group	0.104	0.138	0.040	0.125	0.63	0.019
P-value Group.treatment	0.011	0.62	0.20	0.07	0.37	0.09
LSD P=0.05 (within brassica group)	11	14	4	15	18	23
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	11	14.06	4	15	18	21
LSD P=0.05 (max. all other comparisons)	14.	16	4	15	19	21

There were some initial differences in sown species proportions in Exp. 3. (Table 6.6), but at all subsequent dates there were no differences in sown species proportions between treatments, with the sown species generally above 70% of the available forage.

6.2 **Performance of weaner ewes grazing summer forages**

Live weight and live weight gain

Live weight of ewe weaners did not differ between treatments on any measurement date in Exp. 1 (Table 6.7), and ewe weaners reached the desired threshold weight of 40 kg by the start of joining in all treatments and in both years.

Live weight gain did vary between treatments when averaged over multiple weighing intervals (Table 6.8). Between allocation and the start of joining in Exp. 1, live weight gain of ewes on canola cv. Hyola 971CL and Winfred was lower than that on cv. Taurus; all other treatments were intermediate. During joining in Exp. 1, live weight gain of ewes on canola and Winfred were higher than ewes on the perennial ryegrass. When averaged over the entire experimental period, the perennial ryegrass treatment had lower live weight gain (at P=0.05) than the brassica and plantain treatments.

At allocation of the ewes to plots in Exp. 3, there were no differences in ewe live weights between the forage treatments (Table 6.7). At the next weighing on 26 February 2016, however, ewes on the plantain treatment had lower live weights than the ewes on any other treatment. During March 2016, ewes on the plantain treatment had lower live weights than all other treatments but there were no differences between the other treatments. On 5 April 2016, ewes on the plantain treatment had significantly lower live weights than all other treatments, with the three brassica treatments, the lucerne and the perennial ryegrass treatments not differing in live weight. On 29 April 2016, ewes on

Table 6.7. Ewe live weights (kg) during the pre-joining and joining periods in summer and autumn 2014 and 2016. Means in 2016 with different superscripts within columns are statistically different (i.e. P<0.05). Live weights at the start of joining are shown in red.

Treatment	*Experiment 1* (2014)							
	27 Feb	17 Mar	25 Mar	9 Apr	23 Apr	6 May	21 May	5 Jun
All treatments	39.7	41.7	38.8	41.5	44.0	44.5	46. 1	47.4
	Experiment 3 (2016)							
	15 Feb	26 Feb	11 Mar	23 Mar	5 Apr	29 Apr		
Hyola 971CL	41.4	42.0^{b}	44.9^{b}	47.1^{b}	49.7^{bc}	49.6^{cd}		
Brazzil	40.2	40.8^{b}	44.6^{b}	48.3^{b}	51.0^{cd}	52.3^{de}		
Winfred	40.5	40.8^{b}	44.5^{b}	48.1^{b}	51.0^{c}	51.0^{de}		
Chicory	40.4	42.4^{b}	45.4^{b}	46.6^{b}	47.6^{b}	42.1^{a}		
Plantain	41.2	38.7^{a}	40.7^{a}	42.2^{a}	44.7^{a}	45.8^{b}		
Lucerne	40.3	42.2^{b}	46.4^{b}	47.2^{b}	50.1^{c}	49.0^{c}		
Perennial ryegrass	40.7	42.4^{b}	45.0^{b}	45.9^{b}	48.4^{bc}	44.6^{ab}		
P-value Group	0.80	0.13	0.24	0.010	<0.001	<0.001		
P-value Group.treatment	0.15	<0.001	<0.001	0.010	0.001	0.037		
LSD P=0.05 (within brassica group)	1.3	1.6	2.0	2.6	2.3	3.1		
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	1.3	1.6	2.0	2.6	2.3	3.1		
LSD P=0.05 (max. all other comparisons)	1.3	1.6	2.1	2.6	2.3	3.1		

Table 6.8. Ewe live weight gain (g/day) during the pre-joining and joining periods and over the total experimental period in summer and autumn 2014 (Exp. 1) and 2016 (Exp. 3). Means with different superscripts are statistically different (i.e. P<0.05).

Treatment	Live weight gain (pre-joining)	Live weight gain (joining)	Live weight gain (total)
Experiment 1 (2014)			
Hyola 971CL	146^{a}	147^{c}	146^{a}
Taurus	235^{b}	93^{bc}	150^{a}
Winfred	167^{ac}	137^{c}	149^{a}
Chicory	215^{bc}	27^{ab}	103^{ab}
Plantain	206^{bc}	101^{bc}	143^{a}
Lucerne	164^{ac}	51^{ab}	96^{ab}
Perennial ryegrass	184^{ab}	2^{a}	75^{b}
P-value Group	0.29	0.025	0.07
P-value Group.treatment	0.018	0.012	0.05
LSD P=0.05 (within brassica group)	54.1	56.6	43.4
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	54.1	56.6	43.4
LSD P=0.05 (max. all other comparisons)	54.1	79.3	54.2
Experiment 3 (2016)			
Hyola 971CL	152^{b}	93^{cd}	112^{b}
Brazzil	185^{b}	154^{e}	164^{c}
Winfred	168^{b}	129^{e}	141^{bc}
Chicory	209^{b}	-66^{a}	23^{a}
Plantain	-25^{a}	102^{cd}	61^{a}
Lucerne	252^{b}	58^{bc}	119^{bc}
Perennial ryegrass	180^{b}	-7^{b}	54^{a}
P-value Group	0.24	<0.001	0.002
P-value Group.treatment	<0.001	0.001	0.012
LSD P=0.05 (within brassica group)	70.3	47.0	47.6
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	70.3	47.0	47.6
LSD P=0.05 (max. all other comparisons)	100.4	55.7	54.4

the chicory and perennial ryegrass had lower live weight than all other treatments, except the plantain. The plantain also had lower live weight than the brassica treatments. The live weights of ewes on the brassicas and the lucerne treatments did not differ.

Ewes on the plantain treatment had significantly lower live weight gain than all other treatments during the four-week pre-joining period in Exp. 3 (Table 6.8), with the other treatments not differing from each other. During the six week joining period in Exp. 3, ewes on chicory and perennial ryegrass had lower live weight gains than all other treatments except the lucerne. When averaged across the entire experimental period, live weight gains from the ewes on the plantain, chicory and perennial ryegrass did not differ and were significantly lower than the live weight gains from all the other treatments.

Ultrasound fat and muscle depth

The ultrasound muscle and fat depth did not vary between forage treatments when measured at the start of joining in 2014 (Table 6.9). When measured at the end of joining in 2016 the ewes from the perennial ryegrass, plantain and chicory treatments had lower fat depth than those from the lucerne and brassica treatments. These differences were also reflected in eye muscle depth measurements.

Table 6.9. Ultrasound fat and muscle depth measured at the C-site of ewe lambs at the start of joining in 2014 (experiment 1) at joining and at the end of joining in 2016 (experiment 3). Means in 2016 with different superscripts are statistically different (P<0.05).

Treatment	C site Fat Depth C fat	Eye Muscle Depth (mm)
Experiment 1 (2014)		
All treatments	3.2	29.9
Experiment 3 (2016)		
Hyola 971CL	4.6^{ac}	32.6^{b}
Brazzil	5.2^{a}	34.4^{a}
Winfred	5.0^{ac}	33.6^{ab}
Chicory	2.9^{b}	29.3^{c}
Plantain	3.5^{b}	30.3^{c}
Lucerne	4.3^{c}	32.2^{b}
Perennial ryegrass	3.3^{b}	30.4^{c}
P-value Group	<0.001	<0.001
P-value Group.treatment	0.007	0.037
LSD P=0.05 (within brassica group)	0.6	1.7
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	0.6	1.7
LSD P=0.05 (max. all other comparisons)	0.7	1.9

Table 6.10. Average conception rate (proportion of ewes joined that conceived) and average reproduction rate (number of foetuses scanned per ewe joined) in Experiment 1 and 3. Means with different superscripts are statistically different (i.e. P<0.05).

Treatment	Conception rate		Reproduction rate	
	Exp. 1 (2014)	Exp. 3 (2016)	Exp. 1 (2014)	Exp. 3 (2016)
Hyola 971CL	0.89	0.77	1.46^{b}	1.12
Taurus	0.93		1.45^{b}	
Brazzil		0.67		1.08
Winfred	0.86	0.81	1.28^{ab}	1.06
Chicory	0.95	0.50	1.44^{b}	0.83
Plantain	0.84	0.70	1.29^{ab}	0.94
Lucerne	0.96	0.75	1.51^{b}	0.93
Perennial ryegrass	0.85	0.85	1.03^{a}	1.24
P-value Group	0.27	0.07	0.53	0.39
P-value Group.treatment	0.07	0.41	0.039	0.63
LSD P=0.05 (within brassica group)	0.10	0.25	0.31	0.46
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	0.10	0.25	0.31	0.46
LSD P=0.05 (max. all other comparisons)	0.11	0.27	0.39	0.46

Ewe conception and reproduction rate

In Exp. 1 there were no treatment differences in conception rate (Table 6.10); 90% of ewe weaners conceived. The reproduction rate of 1.03 lambs/ewe on the perennial ryegrass treatment was lower than on canola, chicory or lucerne, which averaged 1.47 lambs/ewe; the reproduction rates on Winfred (1.28) and plantain (1.29) was not significantly different from either the perennial ryegrass treatment or the high-reproduction group. In Exp. 3, there was no effect of forage treatment on either conception rate (average 0.72) or reproduction rate (1.03 lambs/ewe), but both were much lower than in Exp. 1 (Table 6.10).

Plasma progesterone and prolactin

Progesterone and prolactin concentrations collected at the start of the experiment represent the control, non-pregnant values; progesterone and prolactin concentrations collected at the end of the experiment values were from sheep that were a mixture of cycling and pregnant. At the start of the experiment and at the start of joining, there were no observed differences in progesterone levels between forage treatments or forage groups (Table 6.11). At the end of the experiment, maiden ewe lambs joined on the brassica plots had significantly lower progesterone levels than maiden ewe lambs joined on the other forage groups in the design.

Prolactin levels did not differ between treatments at the start of Exp. 1, but at the start of joining there was an effect of treatment on prolactin: ewes in the group of treatments containing plantain, lucerne and perennial ryegrass had lower prolactin than the other forage groups (P=0.04). It appears that the perennial ryegrass treatment was the primary driver of this result, as it had a significantly lower prolactin than all forage treatments except for the lucerne and plantain. There was also a significant effect on prolactin at the end of joining, with the perennial ryegrass treatment being significantly lower than the Winfred forage and the plantain. All other forages were intermediate in the level of prolactin at the end of joining.

Table 6.11. Plasma progesterone levels (ng/ml) and plasma prolactin levels* (ng/ml) at the start of the experiment (18 March), start of joining (22 April) and end of joining (4 June) during Experiment 1 (2014). Means with different superscripts are statistically different (P<0.05).

Treatment	Progesterone			Prolactin		
	Start of Exp. 1	Start of joining	End of joining	Start of Exp. 1	Start of joining	End of joining
Hyola 971CL	0.90	1.36	3.76	139.3 (2.14)	231.5 (2.36)	232.8 (2.37)^{ab}
Taurus	1.05	1.84	3.98	140.5 (2.15)	249.4 (2.40)	221.9 (2.35)^{ab}
Winfred	1.06	1.97	4.15	124.3 (2.09)	162.7 (2.21)	513.9 (2.71)^{a}
Chicory	0.98	2.16	4.79	141.8 (2.15)	156.3 (2.19)	333.8 (2.52)^{ab}
Plantain	0.92	1.57	4.30	136.3 (2.14)	145.1 (2.16)	372.5 (2.57)^{a}
Lucerne	0.80	1.86	5.22	170.2 (2.23)	129.9 (2.11)	228.5 (2.36)^{ab}
Perennial ryegrass	1.08	1.58	4.67	114.6 (2.06)	62.7 (1.80)	173.5 (2.24)^{b}
P-value Group	0.914	0.195	0.021	0.96	0.041	0.64
P-value Group.Treatment	0.367	0.434	0.216	0.09	0.16	0.021
LSD P=0.05 (within brassica group)	0.369	0.832	0.914	(0.14)	(0.37)	(0.31)
LSD P=0.05 (within perennial ryegrass, plantain, lucerne)	0.369	0.832	0.914	(0.14)	(0.37)	(0.31)
LSD P=0.05 (max. all other comparisons)	0.4955	0.725	0.91	(0.21)	(0.38)	(0.39)

*Mean plot prolactin concentrations were log-transformed. The values presented are the back-transformed means but all statistical comparisons are made on the log-transformed values (shown in brackets).

6.3 Canola crop production

Effects of grazing on phenological development

Grazing resulted delayed phenological development of canola in both Exp. 1 and Exp. 3 (P<0.05, Table 6.12) as measured in July of each experimental year. There was some variation in growth stage due to variety in response to grazing in Exp. 3, with grazed cv. Brazzil being at an earlier growth stage than grazed cv. Hyola971CL.

Table 6.12. Growth stage of the two canola varieties on 7 July 2014 and 18 July 2016 showing the areas that were grazed by the ewe lambs and areas that had never been grazed since being sown. Means with different superscripts are statistically different (i.e. P<0.05).

Canola Variety	Grazing Treatment	Growth stage	Description
		Experiment 1 (2014)	
Hyola 971CL	Grazed	3.2^{ab}	Flower buds present but enclosed by leaves
Hyola 971CL	Ungrazed	4.5^{c}	50% all buds on raceme flowering or flowered
Taurus	Grazed	2.3^{a}	Twenty internodes detectable
Taurus	Ungrazed	4.0^{bc}	More than half flower buds on raceme yellow
P-value (variety)		0.080	
P-value (variety.grazing treatment)		0.013	
LSD P=0.05 (LSD max., variety.grazing treatment)		0.99	
		Experiment 3 (2016)	
Hyola 971CL	Grazed	3.5^{b}	Flower buds raised above leaves
Hyola 971CL	Ungrazed	4.2^{c}	20% all buds on raceme flowering or flowered
Brazzil	Grazed	3.1^{a}	Flower buds present but enclosed by leaves
Brazzil	Ungrazed	4.2^{c}	20% all buds on raceme flowering or flowered
P-value (variety)		0.006	
P-value (variety.grazing treatment)		<0.001	
LSD P=0.05 (LSD max., variety.grazing treatment)		0.20	

Table 6.13. Grain yield (t/ha), individual seed weight (mg), number of seeds per pod, and number of primary and secondary branches from spring sown canola in 2014 and 2016. Results are given for sub-plots were ungrazed, grazed during autumn or grazed during both autumn and winter and then cut for silage (Exp. 1) or grazed through to early spring (Exp. 2). Data are presented for the two canola varieties used in each experiment. Means with different superscripts are statistically different (P<0.05).

Canola Variety	Grazing Treatment	Grain yield (t/ha)	Individual seed weight (mg)	No. of seeds per pod	No. of primary branches	No. of secondary branches
		Experiment 1 (2014)				
Hyola 971CL	Ungrazed	2.66^{b}	3.92	20.1	4.00	3.4
Taurus	Ungrazed	2.19^{b}	3.44	20.8	4.60	7.0
Hyola 971CL	Autumn grazed	2.32^{b}	3.73	20.9	3.41	5.9
Taurus	Autumn grazed	2.13^{ab}	3.21	21.7	5.27	9.4
Hyola 971CL	Autumn/winter grazed, then ensiled	0.96^{a}	3.37	21.3	3.61	5.6
Taurus	Autumn/winter grazed, then ensiled	0.83^{a}	3.28	19.6	4.71	8.7
P-value (variety)		0.69	0.053	0.91	0.030	0.033
P-value (variety.grazing treatment)		0.001	0.139	0.74	0.55	0.33
LSD P=0.05 (LSD max., variety.grazing treatment)		1.83	0.69	4.1	1.74	5.49
		Experiment 3 (2016)				
Hyola 971CL	Ungrazed	1.87^{bc}	2.70^{d}	18.6^{b}	3.98	4.00^{a}
Brazzil	Ungrazed	1.90^{bc}	2.67^{d}	17.5^{a}	4.28	4.15^{a}
Hyola 971CL	Autumn grazed	2.14^{c}	2.55^{c}	18.2^{b}	4.30	6.10^{b}
Brazzil	Autumn grazed	1.74^{b}	2.52^{bc}	18.2^{b}	3.98	6.30^{b}
Hyola 971CL	Autumn/winter grazed, then grazed into early spring	0.41^{a}	2.44^{a}	17.5^{a}	3.80	4.69^{ab}
Brazzil	Autumn/winter grazed, then grazed into early spring	0.39^{a}	2.43^{ab}	17.1^{a}	4.50	5.42^{ab}
P-value (variety)		0.69	0.59	0.025	0.66	0.94
P-value (variety.grazing treatment)		<0.001	<0.001	0.014	0.78	0.036
LSD P=0.05 (LSD max., variety.grazing treatment)		0.39	0.10	0.8	1.59	2.25

Table 6.14. Oil, protein and glucosinolate concentration of spring sown canola that was ungrazed, grazed during autumn or grazed during autumn and winter then cut for silage. Data are presented for the two canola varieties used in each experiment. Means with different superscripts are statistically different (i.e. P<0.05).

Canola Variety	Grazing Treatment	Oil (% in whole seed at 6 % moisture)	Protein (% in oil free meal at 10 % moisture)	Glucosinolates (µmol/g in whole seed at 6 % moisture)
		Experiment 1 (2014)		
Hyola 971CL	ungrazed	44.1	32.5	18.1^{c}
Taurus	ungrazed	45.1	34.2	16.6^{bc}
Hyola 971CL	autumn grazed	45.0	30.8	16.4^{bc}
Taurus	autumn grazed	45.2	32.3	13.6^{ab}
Hyola 971CL	autumn/winter grazed, then ensiled	43.4	32.6	13.2^{ab}
Taurus	autumn/winter grazed, then ensiled	47.1	31.1	10.0^{a}
P-value (variety)		0.16	0.57	0.030
P-value (variety.grazing treatment)		0.23	0.11	0.005
LSD P=0.05 (LSD max., variety.grazing treatment)		4.4	6.8	3.7
		Experiment 3 (2016)		
Hyola 971CL	ungrazed	40.1^{a}	39.1^{b}	16.17
Brazzil	ungrazed	45.6^{c}	37.9^{b}	14.00
Hyola 971CL	autumn grazed	40.1^{a}	38.1^{b}	15.67
Brazzil	autumn grazed	44.3^{bc}	38.9^{b}	13.33
Hyola 971CL	autumn/winter grazed, then grazed into early spring	43.1^{b}	32.8^{a}	12.83
Brazzil	autumn/winter grazed, then grazed into early spring	46.9^{cd}	34.1^{a}	12.00
P-value (variety)		0.002	0.78	0.09
P-value (variety.grazing treatment)		0.004	0.002	0.16
LSD P=0.05 (LSD max., variety.grazing treatment)		1.4 (1.6 within variety)	3.4 (2.8 within variety)	2.8 (3.2 within variety)

Canola grain yield and seed/oil quality

In both Exp. 1 and Exp. 3, grazing the canola during autumn resulted in no canola seed yield penalty relative to the ungrazed control (Table 6.13). Grazing the canola during winter and then cutting the canola for silage or grazing the canola through to early spring did however result in a significant canola seed yield penalty, with canola seed yields in the silage plots reduced by approximately 65% (Exp. 1) and the plots grazed through to early spring reduced by approximately 80% (Exp. 3) relative to the ungrazed controls.

In Exp.1 there was no effect of grazing on seed weight, seeds per pod or branching although the level of primary and secondary branching was different between the Taurus and Hyola971CL varieties (Table 6.14). In Exp. 3, individual seed weight and seeds per pod were reduced by late grazing into early spring. Autumn grazing also increased the number of secondary branches in Exp.3 but ungrazed and the late grazed treatments did not differ (P<0.05).

Analysis of seed/oil quality from the canola crops is shown in Table 6.14. Oil and protein concentration was unaffected by variety or grazing treatment in Exp. 1, with glucosinolate concentration reduced by late grazing of cv. Taurus which also had lower glucosinolate concentration compared to cv. Hyola 971CL. Glucosinolate concentration was not affected by grazing or canola variety in Exp. 3. Late grazing of the canola into early spring decreased the protein concentration of both varieties, but increased oil concentration of cv. Hyola 97CL relative to ungrazed or autumn-grazed plots. This effect on oil concentration did not occur in the Brazzil canola.

6.4 Economic Analysis

For the prime lamb case study farm in south west Victoria, and based on the assumptions used, mating replacement ewes at seven months of age was more profitable than mating ewes to lamb as 2 year olds in a conventional prime lamb production system (Table 6.15; Fig. 6.2; $295/ha vs $224/ha). Mating ewe lambs to lamb as 1 year olds reduced business and financial risk (Fig. 6.3) compared to the base case option (1) of joining ewes to lamb as two year olds.

Augmenting perennial ryegrass/clover pastures in summer with supplementary feed (option 2), forage brassica (option 3), spring-sown canola (option 4) or lucerne (option 5) all generated similar levels of profit and rate of return on investment (Table 6.15; Fig. 6.4). Increasing the average lamb marking percentage of ewe lambs by 10% (option 6) only provided a small increase in whole net profit of $14/ha, as the ewe lambs only represent a small portion of the flock.

Using spring-sown canola in the feedbase reduced the level of variability around rate of return (as measured by the standard deviation; Fig. 6.5). The contribution of income from canola was one reason for the reduction in variability around the rate of return. Putting variation around rate of return in proportion to returns achieved for each option (coefficient of variation, CV; Fig. 6.5) showed that using spring-sown canola or lucerne in the feedbase offered the best returns for the least risk (CV).

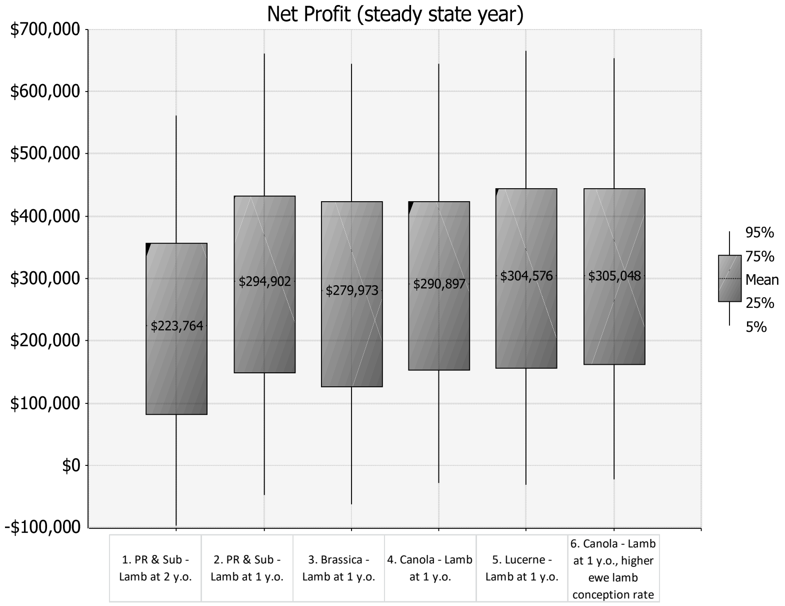

Fig. 6.2. The net farm profit for different modelled farm options comparing age of ewe lambing (2-year-old, option 1 and 1-year-old option 2) using supplements on conventional perennial ryegrass and sub-clover pastures (option 2) against forage brassica (option 3), spring-sown canola (option 4), and lucerne (option 5). The final option (6) represents a scenario where a further 10% increase in average ewe lamb marking rate is achieved within the spring-sown canola forage system.

Table 6.15. Summary of results – production data, profit and loss, economic and wealth analysis – comparing different dual-purpose crops in the feed-base – brassica, canola and lucerne – for a prime lamb farm in south west Victoria

Dual-purpose crops in the feed-base:												
Production and Economic analysis of a farm system	**Option 1**		**Option 2**		**Option 3**		**Option 4**		**Option 5**		**Option 6**	
Farm area: 1,000 ha	PR & Sub -		PR & Sub -		Brassica -		Canola -		Lucerne -		Canola - Higher ewe	
Analysis period: 1985 to 2014	Lamb at 2 y.o.		Lamb at 1 y.o.		Lamb at 1 y.o.		Lamb at 1 y.o.		Lamb at 1 y.o.		lamb conception rate	
Average annual rainfall: 710 mm												
	mean	*stdev*	***mean***	*stdev*	***mean***	*stdev*	***mean***	*stdev*	***mean***	*stdev*	***mean***	*stdev*
Production Data - Prime Lamb Enterprise												
Average stocking rate (DSE/ha)	22.0	*0.8*	22.4	*0.9*	22.4	*0.8*	22.4	*0.7*	22.5	*0.8*	22.6	*0.7*
Feed budget - pasture growth (kg DM/ha)	12,698	*2,675*	12,623	*2,663*	12,571	*2,723*	12,604	*2,718*	12,701	*2,661*	12,571	*2,715*
- animal intake (kg DM/ha)	6,390	*366*	6,473	*386*	6,373	*360*	6,321	*343*	6,515	*364*	6,370	*356*
Utilisation	52%	*9%*	53%	*9%*	53%	*10%*	52%	*10%*	53%	*9%*	53%	*10%*
Supp. feed - ewes (mature & 1-2 y.o.) (t)	113	*217*	120	*211*	144	*224*	125	*204*	105	*187*	130	*211*
(grain) (kg/hd)	15.9		17.6		21.7		19.8		15.5		20.7	
- lambs (t)	61	*92*	75	*110*	52	*95*	48	*94*	76	*106*	53	*96*
- replmt. ewe lambs - pasture (t)			18	*19*					15	*18*		
- replmt. ewe lambs - forage crops (t)					20	*9*	28	*10*			29	*10*
Ewe mating no. ewes weaners	0	*0*	1,584	*54*	1,548	*65*	1,473	*65*	1,582	*52*	1,474	*69*
1-2 y.o.	1,573	*40*	1,519	*53*	1,480	*65*	1,408	*64*	1,515	*49*	1,410	*68*
mature	5,567	*66*	5,289	*88*	5,145	*86*	4,900	*93*	5,278	*65*	4,897	*103*
Lamb marking % (lambs per ewe)	129%	*10%*	120%	*9%*	123%	*8%*	124%	*8%*	122%	*8%*	126%	*8%*
No. wether lambs sold	4,550	*335*	4,992	*358*	4,975	*314*	4,754	*294*	5,031	*340*	4,836	*291*
Weight of wether lambs sold (kg lwt)	48.1	*0.0*	48.1	*0.0*	48.1	*0.1*	48.1	*0.0*	48.1	*0.0*	48.1	*0.1*
No. ewe lambs sold	2,891	*318*	3,387	*346*	3,401	*298*	3,258	*266*	3,428	*314*	3,338	*281*
Weight of ewe lambs sold (kg lwt)	46.8	*0.5*	46.8	*0.5*	46.9	*0.5*	46.9	*0.5*	46.8	*0.5*	46.9	*0.5*
Lamb production (kg cwt)	162,874	*14,310*	183,342	*15,400*	183,355	*13,268*	175,388	*12,155*	185,060	*14,337*	178,948	*12,348*
Lamb production (kg cwt/ha)	162.9	*14.3*	183.3	*15.4*	183.4	*13.3*	184.6	*12.2*	185.1	*14.3*	188.4	*12.3*
Wool production (kg cfw/ha)	31.0	*0.8*	31.4	*0.8*	32.2	*0.9*	32.3	*0.9*	31.4	*0.8*	32.5	*0.8*
Production Data - Canola Enterprise												
Area (ha)							50				50	
Average rainfall (mm; growing season Apr to Nov)							547	*100*			547	*100*
Yield (t/ha)							2.4	*0.5*			2.4	*0.5*
Total wheat production (t)							120	*26*			120	*26*
Whole Farm Profit and Loss (steady state year)	*(in Real terms)*											
Prime Lamb Gross Income	$1,091,000	$191,000	$1,193,000	$206,000	$1,189,000	$202,000	$1,134,000	$191,000	$1,202,000	$206,000	$1,157,000	$196,000
Variable Costs	$443,000	$59,000	$464,000	$62,000	$480,000	$67,000	$450,000	$60,000	$463,000	$56,000	$456,000	$65,000
Gross Margin - total	$649,000	$203,000	$729,000	$217,000	$709,000	$216,000	$684,000	$203,000	$740,000	$216,000	$700,000	$208,000
- per DSE	$29	$9	$32	$9	$32	$9	$32	$9	$33	$9	$33	$9
- per Ha	$649	$203	$729	$217	$709	$216	$720	$213	$740	$216	$737	$219
Cropping Gross Income							$59,000	$17,000			$59,000	$17,000
Variable Costs							$25,000	$426			$25,000	$428
Gross Margin - total							$35,000	$17,000			$35,000	$17,000
- per Ha							$694	$339			$694	$338
Total Gross Income	$1,091,000	$191,000	$1,193,000	$206,000	$1,189,000	$202,000	$1,193,000	$191,000	$1,202,000	$206,000	$1,216,000	$196,000
Total Variable Costs	$443,000	$59,000	$464,000	$62,000	$480,000	$67,000	$474,000	$60,000	$463,000	$56,000	$481,000	$64,000
Total Gross Margin - total	$649,000	$203,000	$729,000	$217,000	$709,000	$216,000	$719,000	$203,000	$740,000	$216,000	$735,000	$209,000
- per Ha	$649	$203	$729	$217	$709	$216	$719	$203	$740	$216	$735	$209
Overhead Costs	$118,000	$0	$118,000	$0	$118,000	$0	$118,000	$0	$118,000	$0	$118,000	$0
Owner/Operator Allowance	$144,000	$0	$144,000	$0	$144,000	$0	$144,000	$0	$144,000	$0	$144,000	$0
Operating Profit (EBIT) - total	$386,000	$203,000	$466,000	$217,000	$447,000	$216,000	$456,000	$203,000	$477,000	$216,000	$472,000	$209,000
- per Ha	$386		$466		$447		$456		$477		$472	
Interest Costs Loan (20 yrs @ 7%)	$97,000	$0	$93,000	$0	$91,000	$0	$88,000	$0	$93,000	$0	$88,000	$0
Tax Payable	$65,000	$30,000	$78,000	$33,000	$76,000	$32,000	$77,000	$31,000	$80,000	$33,000	$80,000	$31,000
Net Profit - total	$224,000	$201,000	$295,000	$215,000	$280,000	$215,000	$291,000	$203,000	$305,000	$215,000	$305,000	$208,000
- per Ha	$224		$295		$280		$291		$305		$305	
Economic Analysis (over seven years)	*(in Real terms)*											
Net Present Value at 5% discount rate	$376,000	*$428,000*	$814,000	*$455,000*	$717,000	*$444,000*	$782,000	*$424,000*	$874,000	*$449,000*	$863,000	*$439,000*
Modified Internal Rate of Return (MIRR)	5.7%	*1.1%*	6.8%	*1.2%*	6.6%	*1.2%*	6.8%	*1.1%*	7.0%	*1.2%*	7.0%	*1.2%*
Wealth Analysis (at the end of seven years)	*(in Real terms)*											
Increase in Equity/ End Wealth (in Present Value terms)	$2,154,000	*$459,000*	$2,627,000	*$487,000*	$2,523,000	*$475,000*	$2,597,000	*$453,000*	$2,691,000	*$480,000*	$2,684,000	*$471,000*

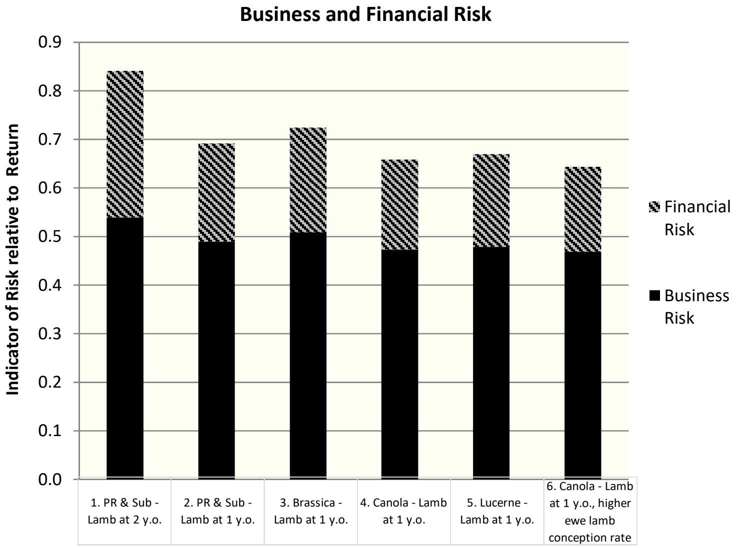

Fig. 6.3. The business and financial risk for different modelled farm options comparing age of ewe lambing (2-year-old, option 1 and 1-year-old option 2) using supplements on conventional perennial ryegrass and sub-clover pastures (option 2) against forage brassica (option 3), spring-sown canola (option 4), and lucerne (option 5). The final option (6) represents a scenario where a further 10% increase in average ewe lamb marking rate is achieved within the spring-sown canola forage system.

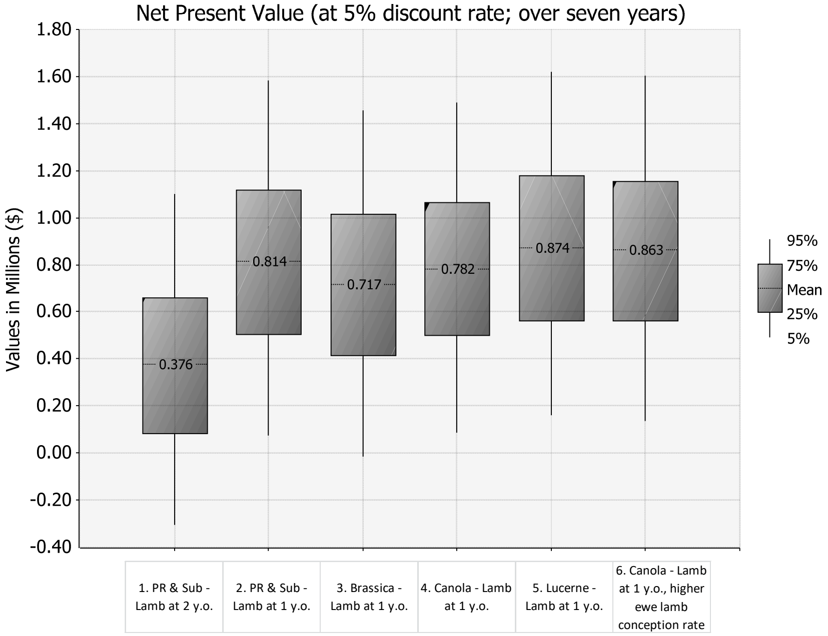

Fig. 6.4. The net present value (at 5% discount rate, over 7 years) for different modelled farm options comparing age of ewe lambing (2-year-old, option 1 and 1-year-old option 2) using supplements on conventional perennial ryegrass and sub-clover pastures (option 2) against forage brassica (option 3), spring-sown canola (option 4), and lucerne (option 5). The final option (6) represents a scenario where a further 10% increase in average ewe lamb marking rate is achieved within the spring-sown canola forage system.

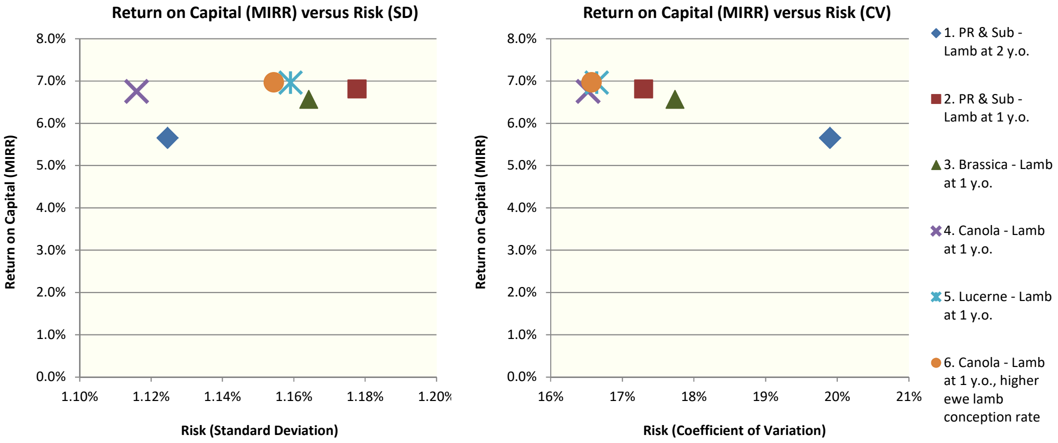

Fig. 6.5. The return on capital (measured as the marginal internal rate of return, MIRR) related to the standard deviation of MIRR (left hand panel) or its coefficient of variation (right hand panel) for different modelled farming systems. Comparisons are age of ewe lambing (2-year-old option 1 and 1-year-old option 2) using supplements on conventional perennial ryegrass and sub-clover pastures (option 2) against forage brassica (option 3), spring-sown canola (option 4), and lucerne (option 5). The final option (6) represents a scenario where a further 10% increase in average ewe lamb marking rate is achieved within the spring-sown canola forage system.

7 Discussion

7.1 Winter crop forage in the Tablelands region can support a step change in livestock production

The Canberra systems experiment showed that, over 4 years, the WCG breeding ewe system on a feedbase that combined perennial pastures, ley pastures and dual-purpose crops was able to turn off 11% more weight of lambs than the same sheep production system based on perennial pastures only, at the same time as yielding additional income from grain production and with a lower supplementary feeding requirement (Table 7.1). As a result, the 4-year mean gross margin of the WCG system was over 50% higher than that of the control system. Given that the control treatment was conceived and managed as representing local best practice for pasture-based livestock production, our results provide strong experimental confirmation that adding dual-purpose wheat and canola to a well-managed pasture feedbase can enhance productivity.

Table 7.1. Lamb production per hectare, supplementary feeding requirement and gross margins of the 3 livestock production systems in the Canberra experiment, averaged over 4 years.

Parameter	Control	ECG	WCG
Total sale weight of lambs (kg/ha/year)	205	206	228
Total supplementary feeding requirement (GJ/ha/year)	3.16	1.84	1.53
Farmlet gross margin ($/ha/year)	476	660	743

A full-system grazing experiment was necessary to properly reveal this finding. The financial analysis showed that the WCG system was significantly more profitable than the control system in each year, but the cause of this higher profitability differed over the years: in 2013, a poor year for forage supply, the crop-grazing treatments exhibited a large saving in supplementary feeding. In 2014, on the other hand, lamb turnoff per hectare was high in all treatments owing to a long pasture growing season but the crop-grazing treatments produced large amounts of grain from land that in the control system was used to grow excess, unused forage. In 2015, a failure of the wheat crops was ameliorated by unexpectedly high canola yields and excellent growth of weaners on the dual-purpose crops, and in 2016 both meat and grain production contributed to the greater gross margin in the WCG system.

The impact of crop grazing on lamb sale weights is an important outcome from this experiment and provides a unique comparison between alternate uses of dual-purpose crops. Weaning weights of lambs from the ECG and WCG treatment did not differ significantly (Table 4.9) but were significantly heavier per head than lambs born in the control treatment. By the time the yearling lambs exited the experiment (i.e. were sold), lambs in the WCG treatment were on average 5 kg heavier than lambs from the ECG and control treatments. In the comparison between crop grazing treatments this difference was due to higher growth rates of WCG lambs on crops compared to the ECG lambs, with the latter grazing pastures during the winter. Furthermore, supplementary feeding requirements of weaners were higher in the ECG treatment compared to the WCG treatment in two out of four years (Table 4.11). Prioritising crops for grazing by weaners will therefore increase meat production and reduce supplementary feeding to carry-over weaners, although costs saved in feeding weaners may be somewhat offset by higher supplementary feeding costs to ewes.

Another advantage of prioritising crop grazing for weaners is the potential to utilise crops for grazing by other livestock classes in response to seasonal opportunities. The lower feed requirements for weaners meant that the second cropping sub-paddock in the WCG treatment was available for grazing by trade wethers in 2014 and by ewes in 2013, 2015 and 2016. For wethers this generated additional income for this system. For the ewes this likely reduced the supplementary feeding requirements in the WCG treatment in these years, although amount of supplement per ewe was still higher in the WCG treatment compared to the ECG treatment in 2016 (Table 4.11).

Allowing Merino ewes to graze dual-purpose crops in the Canberra experiment did have some advantages for livestock production, however the effect was not always consistent and was affected by seasonal conditions. Priority grazing of ewes on crop reduced supplementary feeding when seasonal conditions were poor, and increased wool production by 16% or 0.7 kg GFW per head compared to the control; however, sale weight of lambs was not increased compared to the pasture-only feedbase. Overall we can conclude that the "easy-care" option for crop grazing – using them to accelerate growth of retained young stock – is also the most economically efficient approach.

7.2 Combining dual-purpose wheat and canola to fill the winter feed gap

Sowing one third of the farmlets in the Canberra experiment to dual-purpose crops that could be grazed in sequence resulted in a significant portion of the year when sheep were not grazing pastures. An important observation in 2015 was the ability of canola to still provide grazing and grain yield despite the late germination following dry conditions after sowing, and the benefits of sowing multiple dual-purpose crop species.

In 2013, 2014 and 2016 the canola was grazed first in sequence. This concurs with the results of Sprague *et al.* (2015a), who suggested that the higher early growth of canola would result in it being available for grazing first. Early grazing also provides additional time for recovery of the canola plants to minimise the impact of grazing on grain yield, given the low winter production of canola (Sprague *et al.* 2015a). The germination and early production of wheat was sufficient to allow grazing by ewes (ECG treatment) and weaners (WCG treatment) by early May 2015 in the current study. Thus sowing a cereal as well as a brassica for grazing in winter provided a level of insurance against poor early germination of one crop. Other experiments have also demonstrated that growth rates of canola can be reduced compared to wheat under drier autumn conditions (Sprague *et al.* 2015a).

7.3 "Pasture spelling" during winter

Crop grazing provided a long rest period for pastures during the late autumn and winter. Previous experiments have reported that one of the key benefits of grazing crops can be a "pasture spelling" effect, where pastures can accumulate biomass during the crop grazing period, making additional biomass available for grazing in spring compared to systems where livestock continually graze pastures (Virgona *et al.* 2008; Dove *et al.* 2015). In the latter experiment the benefits of pasture spelling were very important, with a substantial part of the benefit of dual-purpose crops for livestock production being attributed to this effect; the extra pasture growth during the crop grazing phase contributed 40% of the total benefit in terms of extra sheep grazing days per hectare associated with inclusion of dual-purpose crops in the system (Dove *et al.* 2015). Extrapolation from this data suggested that, with the exception of very small areas sown to canola, the number of whole-farm sheep grazing days would be reduced if the effect of pasture spelling was not included (Bell *et al.* 2015a).

In our current experiment, feed availability in pasture at the end of winter (at the conclusion of the crop grazing period) was higher in the crop grazing treatments in 2013, but not in any other year (Table 4.2). Instead of pasture spelling from the same initial mass resulting in a higher feed on offer after crop grazing, pasture mass at the start of crop grazing was lower (Table 4.2) and the spelling of pastures during late autumn and winter enabled the pastures to recover to the same level in spring. Once again, this change in the pattern of feed supply – which alters the rationale for dual-purpose crops in the feedbase – was not, and could not be, detected until a whole-system grazing experiment was undertaken. In the 2013 season, the lower availability in the control treatment at the end of the crop grazing period was likely due to the higher stocking rate per hectare of pasture used in that year as well as the poor seasonal conditions.

Resting of pastures over winter does allow accumulation of feed in pasture paddocks, however this will not necessarily result in higher feed availability in those pasture paddocks during late winter and spring, the period immediately following when sheep are removed from dual-purpose crops. However, the spelling effect may allow pastures in systems that include dual-purpose crops to “catch up” following a feed deficit in autumn. The impact of pasture spelling on the overall feedbase is likely to be affected by the proportion of land sown to dual-purpose crops; in the experiments reported here we used a relatively high area for the Tablelands region.

7.4 How does incorporating dual-purpose crops affect composition of permanent pastures?

In the Canberra systems experiment we were able to follow the composition of the permanent pastures over a 4-year period (Fig. 4.6). The legume content in the pastures showed a typically high level of variability but did not differ significantly between the treatments. Legumes are an important component of perennial grass-based pastures, providing high quality feed as well as fixing nitrogen in the soil for use by the grass species, so maintenance of the legume component is important for both livestock production and pasture quality and persistence; the experimental data give no grounds for concern on this front.

The evidence regarding the balance of perennial grasses and weeds is less straightforward. Over the 4 years, the average perennial grass content of the crop-grazing farmlets was lower and the weed content was higher than in the control farmlets, and a barley grass (*Hordeum vulgare*) infestation in one permanent pasture sub-paddock in one of the crop grazing farmlets in 2015 resulted in that sub-paddock being removed from the experiment and replaced by a different sub-paddock. Annual grasses (*Lolium* spp., *Hordeum* spp. and *Vulpia* spp.) were the main weeds in pastures in early spring while other species (mainly *Chenopodium spp.* and *Rumex spp.*) were the main weeds observed in pastures in autumn. The higher stocking rates per hectare of pasture at times of the year may have allowed greater weed infestation in the cropping treatments. On the other hand, the crop-grazing farmlets averaged 70% desirable species in the spring of 2016; there was no apparent trend in perennial grass content between 2013 and 2016; and a need to renovate a permanent pasture in 1 of 24 paddock-years in the crop-grazing treatments can be interpreted as a financially viable level of perennial grass persistence.

There is some reason to suspect that higher autumn stocking densities associated with replacing permanent pasture with dual-purpose crops (the crop penalty) could result in deterioration of permanent pastures. Virgona *et al.* (2000) demonstrated that resting of phalaris pastures during autumn and winter was beneficial for maintaining or increasing the proportion of the perennial grass in the pasture. Therefore, it could be expected that heavy grazing during this period could have the reverse effect and thus allow greater invasion by annual species.

Real-world production systems with dual-purpose crops should place less grazing pressure on permanent pastures in autumn than our experimental system did. First, the area of land that can be placed under arable crop-pasture rotation is likely to be lower than in the experiment. Second, the first-year ley pastures in our experiment were not grazed at all during autumn, further increasing the average stocking density on the permanent pastures after the end of stubble grazing. In real production systems, the ley pasture phase on arable land will almost certainly be longer than 2 years; this will reduce the “crop penalty”, i.e. the area unavailable for grazing because it is in transition from pasture to crop or from crop to pasture.

It seems reasonable to conclude – provisionally – that at farm scale, it should be possible to maintain the perennial grass component of well-fertilized grass-clover pastures with little or no reduction in whole-farm stocking rates. The potential negative impact on pasture composition of including dual-purpose crops in the system is worthy of further investigation, however, given that the cost of re-establishing permanent pastures is high.

7.5 Winter crop forage in the Tablelands region improves ewe wool production and live weight during spring

Ewes in the ECG and WCG treatments were mostly able to either maintain or increase their condition between pregnancy scanning and lamb marking, whereas ewes in the pasture-only treatment lost weight and condition during this period in 2015 and 2016 and overall tended to have lower live weights than ewes in the crop grazing treatments during spring. These results suggest that ewes in the crop grazing treatments had better nutrition during late pregnancy and lambing compared to the pasture only treatment. A recent modelling study identified that the most profitable approach to managing ewe weight in south-western Victoria in an ‘average’ season was to allow all ewes to lose 4 kg from joining to scanning; single-bearing ewes to gain 4 kg from scanning to lambing and twin-bearing ewes to gain 8 kg from scanning to lambing (Young *et al.* 2016). The pattern of weight change in ewes in the crop grazing treatment most closely reflected these recommendations, whereas the pattern of weight change was different in the pasture-only system when lambing in winter, with ewes often losing weight during late-pregnancy and lambing.

The implications of losing body condition during late pregnancy include a potential increase in lamb mortality and morbidity. Research in Western Australia and Victoria identified that ewe condition score at about day 100 of pregnancy and ewe nutrition from day 100 to lambing can have a small but significant impact on lamb birthweight (Oldham *et al.* 2011), and low lamb birth weight is a risk factor for poor lamb survival outcomes (Atkins 1980; Knight *et al.* 1988; Oldham *et al.* 2011). Although significant differences in birth weight and survival were not detected in the current experiment, lamb weaning weights were higher in crop grazing treatments, suggesting suckling lambs had higher growth rates associated with the crop grazing treatments. This is likely due at least in part to improved nutrition of ewes during the winter, given in most years there was no differences in feed on offer in pastures in early spring (Table 4.2). Ewes were heavier in spring in the crop grazing treatments, and ewe condition has been correlated with higher milk production and weaning weights in some studies as reviewed by Kenyon *et al.* (2014).

Improved nutrition of ewes in the crop grazing treatments from late autumn through to spring also increased wool production, with GFW and CFW both being significantly heavier in the crop grazing treatments compared to the control (Table 4.7). This has direct financial implications for producers, increasing farm income, assuming that stocking rates per farm hectare are equivalent. The financial benefit also extends to ewe weights: sale weights of ewes post-shearing was on average 4.1 kg per head heavier in the crop grazing treatments compared to the control; therefore, it could be expected that income from sale of cast-for-age ewes post-shearing would be higher when dual-purpose crops are included in the system.

The decline in ewe weight and condition during late pregnancy and lactation in the control treatment during 2015 and 2016 conceivably could have been avoided in these years by increasing the supplementary feeding of ewes during the winter. However supplementary feeding in these years was low, with minimal supplementary feeding to control ewes in winter 2015, and although there was supplementary feeding of control ewes in 2016 the amount of supplement fed to ewes in the control was not significantly different to ewes in the ECG treatment and was less than to ewes in the WCG treatment (Table 4.11). Therefore, although no impact of a feed gap was observed in 2015 and 2016 in terms of additional supplementary feeding requirements in the pasture-only system, a potential impact of poorer ewe nutrition in the pasture-only treatment was evident in lower ewe weights during spring.

Scanning rate can be improved by ewe nutrition and condition at joining (Kleemann and Walker 2005; Kenyon *et al.* 2014). Ewe live weight and body condition score did not differ significantly between treatments at scanning (Table 4.6); therefore, similar scanning rates between control and crop grazing treatments was expected. The lower scanning rates of WCG ewes in 2013 and 2016 cannot be explained, although accuracy of scanning is questionable given the number of foetuses born per ewe was lower than the number of lambs born per ewe in the WCG treatment. The lower apparent scanning rates in the WCG treatment did not affect meat production from this system, as total live weight of lamb weaned per farmlet did not differ significantly between treatments (Table 4.9). This may be partly explained by higher survival and weaning weights of single-born lambs; given in three of the years there were no ewes scanned as empty, and a higher scanning rate implies more twin-born lambs which may have lower survival compared to single-born lambs. Lambing in July would be expected to have lower lamb survival compared to lambing later in the season, particularly for twin-born lambs, due to the colder conditions. Severe weather conditions in July 2013 were associated with a spike in lamb deaths at that time.

Grazing dual-purpose canola is a relatively recent phenomenon in Australia, with only a small number of studies demonstrating the use of this forage source, with most livestock production research focussed on young sheep (Dove *et al.* 2012; Dove *et al.* 2015). Ewes lambed on wheat in three years and canola in one year, with the delay in grazing the canola crop being due to slow germination. One possible concern for grazing ewes on canola is the reported lag phase when sheep are first introduced to canola, where animal growth rates are low when first introduced to canola forage (Dove *et al.* 2012), implying a possible reduction in intake during the initial grazing period. No adverse effects of grazing canola during the lambing period were observed in the experiments near Canberra or Wagga Wagga, and no mineral supplements or hay were fed to ewes in either study. Safe grazing of ewes on canola during late pregnancy and lambing allows consideration of the optimal lambing time when dual-purpose canola and wheat are both included in the system, and may allow consideration of an earlier lambing time given that canola is often available for grazing earlier than wheat (Table 4.1; Sprague *et al.* (2015a)).

Seasonal conditions were influential on livestock weights and supplementation in the current study. The poor season in 2013 resulted in high supplementation and low ewe weight compared to the better season in 2014. This effect was most pronounced in the control treatment, and was exacerbated by the smaller control farmlet size in 2013. The dry start to the season in 2016 resulted in higher supplementary feeding in the crop grazing treatments compared to the previous year.

In conclusion, prioritising dual-purpose crops for grazing by weaners for a Merino-maternal system where lambs are sold as yearlings appears to have advantages compared to prioritising crops for ewes or a pasture-only system. The benefits of dual-purpose crops for wool production were observed in both ECG and WCG systems, and the WCG system also increased meat production compared to the other systems due to higher pre-weaning growth compared to the control, and superior growth rates compared to both ECG and control yearling lambs during the crop grazing period in the following autumn and winter. The lower utilisation of crops by weaners in comparison to reproducing ewes also provides the potential for ewes in a WCG system to graze crops during winter when seasonal conditions allow.

7.6 Advantages and disadvantages of White Dorper-cross lamb production with dual-purpose crops

7.6.1 Seasonal conditions

Seasonal conditions during autumn and winter in 2013 and 2014 had important implications for the experiments. 2013 was characterised by low rainfall in April (Fig. 7.1), with crops being dry sown and emerging following rain in May. Ewes required supplementary feeding in June and there was a low starting biomass when ewes commenced grazing the dual-purpose wheat crop in late June (Table 5.4). Excellent growing conditions during autumn in 2014 resulted in a high crop biomass at the commencement of grazing, and ewes were in higher condition score during lambing in 2014 (Figure 5.6), resulting in a significant incidence of dystocia. In addition, a heavy barley grass infestation in 2014 required heavy grazing of lucerne plots by non-experimental animals during the winter period to allow effective spraying of the barley grass; a period when this pasture had planned to be spelled for grazing post-lamb marking. As a result of this and the dry conditions in July and August (Fig. 7.1), the replicated experiment ended on 12 September 2014 to avoid limiting weaning weights, with ewes and lambs run as a single mob from that date.

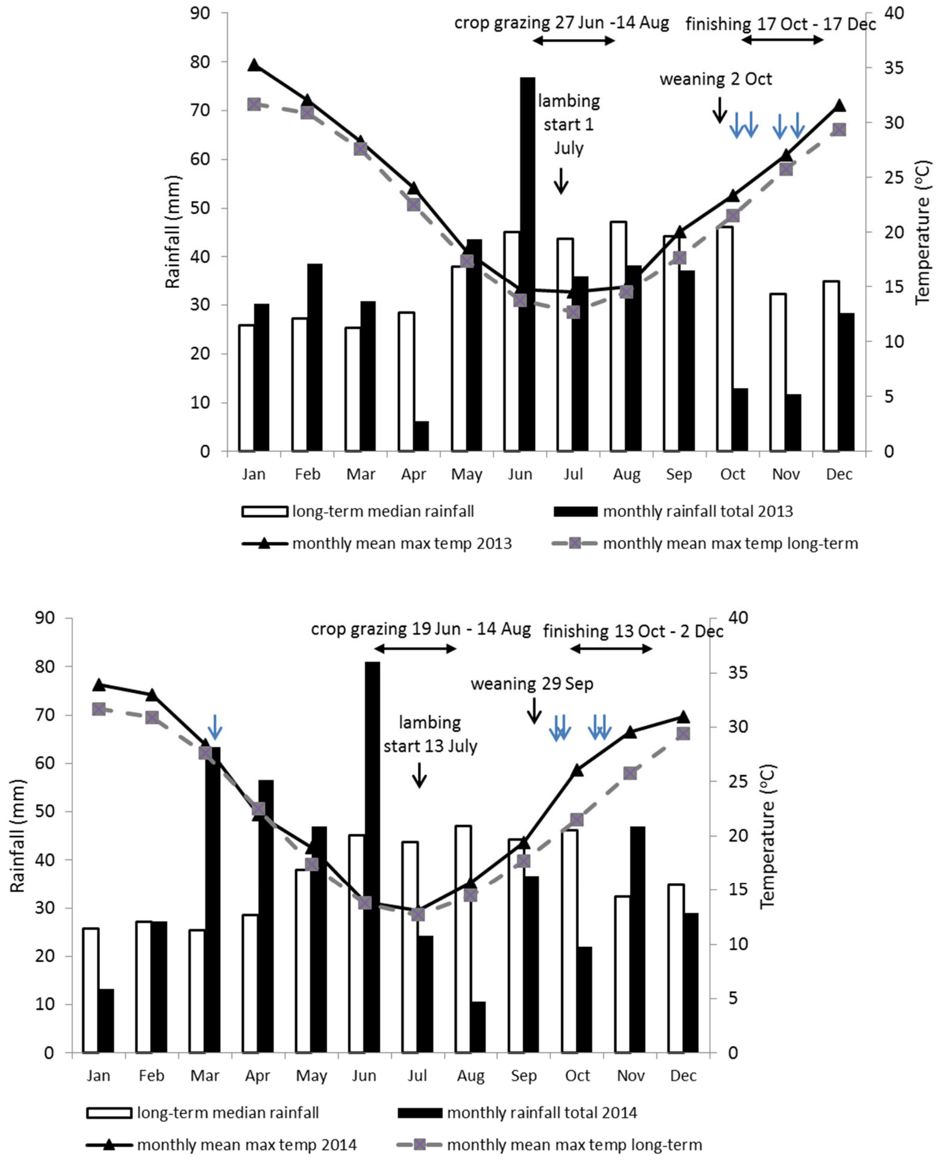

Fig. 7.1. Monthly rainfall (Wagga Wagga Agricultural Institute) and mean maximum monthly temperatures (Wagga Wagga AMO) totals in 2013 (top panel) and 2014 (bottom panel) compared to long term median. Blue arrows represent each irrigation event on pasture plots for the lamb finishing experiment.

Below median rainfall and above median temperatures were recorded during late winter and early spring in both years (Figure 7.1). Irrigation of pasture plots for the "finishing" experiment was necessary to allow the genotype x pasture comparison to proceed. Although this is not representative of how dryland pastures would have performed in those seasons, the comparisons of how lamb growth rates are affected by the different rates of senescence of the annual pastures and compared to perennial pasture is valid.

7.6.2 **Feed on offer and diet quality**

For late-pregnant ewes grazing pasture, a minimum pasture mass of 1000 kg green DM/ha for single-bearing ewes and 1200 kg green DM/ha for twin-bearing ewes is recommended during late-pregnancy and lactation (Hatcher 2006; Court *et al.* 2010). From five years of crop grazing experiments the feed on offer at the commencement of grazing experiments in the Riverina/south-west slopes was highly variable (Table 7.2), and in 2010 and 2013 the starting feed on offer was well below this benchmark for ewes. Despite this, ewes in both years were generally able to maintain their condition. In other experiments with pregnant ewes grazing dual-purpose wheat the starting biomass of 500 kg DM/ha was maintained throughout and no adverse implications for animal health or production were reported (Virgona *et al.* 2006). The key point is that late pregnant and lambing ewes can be grazed on crops with low starting feed on offer, provided they are stocked accordingly.

Height and biomass data from the field experiment (section 5.1) was inputted into GrazFeed to demonstrate that ewes grazing dual-purpose wheat can satisfy a higher proportion of potential intake at lower pasture biomass compared to ewes grazing a pasture such as annual ryegrass, due to the higher height: biomass ratio in sown wheat crops. For example, ewes were predicted to satisfy 91% of predicted maximum intake at a FOO of 500 kg DM/ha when grazing wheat, which was equivalent to grazing an annual ryegrass pasture at FOO of 1500 kg DM/ha (Fig. 7.2). In the field experiments in 2013, lambing ewes grazing dual-purpose wheat with mean starting biomass 330 kg DM/ha maintained condition during the grazing period despite a low biomass when compared to recommendations for ewes grazing pasture.

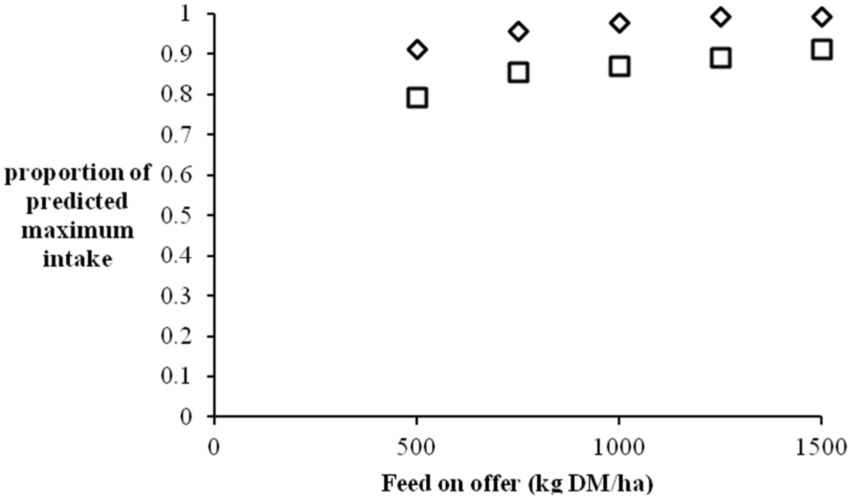

Fig. 7.2. Proportion of predicted potential intake for a pregnant medium Merino ewe (maternal weight 50 kg; body condition score 3 at day 132 of pregnancy) carrying two foetuses and grazing wheat (diamond) or annual ryegrass (square). Height data for wheat and pasture is predicted height from (Appendix 2, Figure 1). Dry matter digestibility of 80% DM and crude protein 25% DM were used for both wheat and annual ryegrass.

Our experiment demonstrated that using high stocking rates to rapidly graze down crops, particularly late in the season, may reduce the quality of the diet of sheep, resulting in lower production from livestock than expected. This is likely associated with sheep removing the leaf in preference to other parts of the plant (Virgona *et al.* 2006; De Mattia 2013), and may explain why other researchers have also observed a decline in lamb growth rates below 1000 kg DM/ha (Dove and McMullen 2009; Miller *et al.* 2010). The field studies observed that there was a decline in digestibility, and therefore energy density, of dual-purpose wheat from the commencement of grazing (typically June/July) to the cessation of grazing (typically August), even if grazing terminates prior to stem elongation (Growth Stage 31), although under moderate stocking rates the decline in digestibility and crude protein should not result in these traits being limiting to ewes grazing crops (Table 5.9). Other researchers have shown a large decline in energy density and crude protein in wheat crops after GS 31 (Jacobs *et al.* 2009), although it is not recommended to graze beyond GS 30 due to grain yield reductions.

The recommendation therefore is that stocking rates for late-pregnant and lambing ewes should be moderate to avoid rapid reduction in crop biomass, particularly if the starting biomass is low. Using stocking rates that eat down the crop may reduce leaf blade availability and therefore quality of the diet.

Table 7.2. Starting feed on offer (FOO; t DM/ha)) of crops grazed in experiments in the Riverina and south-west slopes 2010-2014.

Year	Location	crop	Sow date	Sowing rate (kg/ha)	Row spacing (cm)	Start crop grazing	FOO at start (t/ha)	Livestock class	Initial stocking rate (sheep/ha)
2010	Balldale[A]	wheat	16 Apr	70	30	15 Jun	0.6	lambing ewes	11.4
2011	Cookardinia[A]	wheat	Apr	75	22.5	22 Jun	1.1	late-preg ewes	11
2012	Wagga	wheat	22 Apr	73	35	16 Jul	1.0	2nd-cross lambs	various
2012	Wagga	wheat	22 Apr	75	17.5	16 Jul	1.3	2nd-cross lambs	various
2013	Wagga	wheat	18 Apr[B]	85	17.5	28 Jun	0.3	lambing ewes	10
2014	Wagga	wheat	9 Apr	80	17.5	19 Jun	2.6	late-preg ewes	13
2014	Wagga	canola	8 Apr	4.1	17.5	19 Jun	2.3	late-preg ewes	13

[A] McGrath *et al.* (2015)
[B] crop sown dry in 2013.

7.6.3 **Systems considerations**

The ability of ewes to safely graze dual-purpose canola and wheat during late pregnancy and lambing may present opportunities for mixed-farms. Modelling of a farm at Wagga Wagga NSW demonstrated that stocking rate could be increased when lambing in autumn, but the optimum time of lambing (defined as the lambing month achieving the highest median gross margin over the long-term) was not changed when ewes were allowed to graze a dual-purpose wheat crop compared to when they grazed pasture only (Section 5.3). Dual-purpose canola may be better suited to earlier grazing than dual-purpose wheat, and grazing the two crops in sequence may widen the grazing window (Sprague *et al.* 2015a). The implications for lambing time, stocking rates and producer returns of allowing reproducing ewes to graze both crops in sequence needs to be further explored.

7.6.4 **Considering the benefits – gross profit analysis**

Dorper-based maternal systems (Dorper or White Dorper ewes) produce lambs but have no income from wool. To achieve comparable returns to a Merino system producing first-cross lambs and wool, the Dorper system must therefore produce more kilograms of lambs from the equivalent area of land. Modelling has suggested that non-wool sheep require a 40–50% increase in reproduction rate to have a similar profitability to Merinos (Thompson and Young 2014). In the current study, the number of lambs weaned to ewes scanned pregnant was similar for the three maternal systems, and the gross returns from the Merino system based on the scenario of store lambs being sold at weaning, were higher in both years due to additional wool income. Other studies in Australia have also found that Dorper systems do not consistently have a significant advantage in terms of reproduction rates (Kilminster and Greeff 2011). The implication is that using non-wool breeds may provide an opportunity for mixed-farmers who are not interested in wool or want a livestock system with lower input costs to retain sheep in their system; although returns may be lower unless genetic improvement or management (such as accelerated lambing) allows higher reproduction rates in such breeds, or significantly faster growth rates are achieved.

Table 7.3. Lamb production and gross return per ewe for White Dorper x White Dorper (WD x WD), White Suffolk x White Dorper (WS x WD) and White Suffolk x Merino (WS x M) systems with lambs sold at weaning

		Lamb genotype		
	Year	WD x WD	WS x WD	WS x M
no. ewes joined	2013	35	35	40
	2014	49	49	54
number ewes scanned pregnant	2013	28	27	29
	2014	39	48	49
number lambs weaned	2013	34	36	36
	2014	48	58	61
mean weaning weight of lambs	2013	35.4	40.3	36.4
	2014	28.0	30.9	28.7
Income from lambs sold at weaning [A]	2013	\$2,596	\$3,129	\$2,826
	2014	\$2,898	\$3,869	\$3,775
Income from wool [B]	2013	-	-	\$922
	2014	-	-	\$1229
Gross income				
per head joined	2013	\$74	\$89	\$94
	2014	\$59	\$79	\$93
	average	\$67	\$84	\$93
per hectare pasture [C]	2013	\$593	\$715	\$750
	2014	\$473	\$631	\$741
	average	\$533	\$673	\$746

[A] store lamb sale price @ \$2.27/kg LW less selling costs (5%)

[B] includes value of wool @ \$9/kg CFW less cost of shearing (\$6.60/head) and selling costs (4%)

[C] stocking rate 8 ewes per hectare of pasture

Selling lambs at weaning

The mean weaning weights of White Suffolk x White Dorper lambs was significantly higher than other genotypes in both years, demonstrating potentially higher lamb production from the non-wool system is possible with the right genetics. The low weaning weights of White Dorper x White Dorper lambs in 2014 was in part affected by the younger average age of lambs at weaning; however even when adjusted for age the weaning weight of White Dorper lambs was lower. Breeding values were not available for the White Dorper sheep used in the experiment so it is possible that the genetic merit for growth of White Dorpers used in this experiment was sub-optimal. The more appropriate comparison might therefore be the production when White Dorper ewes were joined to White Suffolk rams. When applying the financial costing it was not possible to analyse the data statistically because (a) not all ewes that were scanned pregnant were included in the crop grazing experiments and (b) not all lambs born in the crop grazing experiments were used in the lamb finishing experiments.

The average weaning weight of White Suffolk x White Dorper lambs was higher than White Suffolk x Merino lambs, and therefore returns from lambs at weaning were higher. At the commodity prices used, overall returns for the system with Merino ewes joined to a terminal sire remained higher due to income from wool ($4.31-13.80 per ewe higher than White Suffolk x White Dorper system over the two years, Table 2). If pasture is stocked at the optimal stocking rate (8 ewes per hectare pasture; Section 5.3) White Dorper ewes joined to White Suffolks would need to produce 16 - 51 kg of lamb per hectare (5-18% increase) more than achieved in the current experiments to achieve the same return per hectare as the Merino system, based on sale of lambs at weaning. An increase in reproduction rate and/or weaning weight would be required to achieve this.

Table 7.4. Comparison of income from systems based on White Dorper ewes joined to White Dorper rams (WD x WD), White Dorper ewes joined to White Suffolk rams (WS x WD) or Merino ewes joined to White Suffolk rams (WSM) with lambs sold in December

			lamb genotype	
	Year	WD x WD	WS x WD	WS x M
Additional weight gain (kg)	2013 [A]	11	14	13.3
	2014 [B]	11.5	12.8	11.7
Lamb net sale value [C]		$112	$129	$116
		$99	$107	$98
Income (per head joined) [D]	2013	$109	$133	$128
	2014	$97	$127	$134
	Mean	$103	$130	$131
Income (per ha pasture) [E]	2013	$873	$1,060	$1,023
	2014	$777	$1,016	$1,071
	Mean	$825	$1,038	$1,047

[A] mean weight gain grazing lucerne

[B] mean weight gain grazing chicory/arrowleaf clover

[C] sale price $5/kg DW less 5% selling costs; used mean dressing percentages for Dorper cross and Merino cross lambs in each year. Includes skin value $7/head for Merino cross and $1.50/head for Dorper and Dorper cross lambs

[D] includes income from wool from Merino ewes

[E] based on stocking rate of 8 ewes per hectare of pasture

Selling lambs at the end of the pasture growing season

If post-weaning growth rates of lambs born to White Dorper ewes are higher than lambs born to Merino ewes, the difference in returns from the two systems will be reduced. In Year 1, all White Dorper x White Dorper lambs used in the post-weaning experiment were of the same bloodline and growth rates were lower compared to White Suffolk x Merino lambs grazing lucerne, subterranean clover or subterranean clover + biserrula. In Year 2 the additional White Dorper x White Dorper lambs sourced for the experiment came from a local commercial producer and finished weights were at least as high as White Suffolk x Merino lambs across all treatments. This suggests that the lambs sourced from the CSU flock may have been of lower genetic merit, thus impacting post-weaning live weight gains; therefore, a comparison of White Suffolk x Merino to White Suffolk x White Dorper lambs may be more appropriate.

Post-weaning growth rates of White Suffolk x White Dorper lambs did not differ significantly from White Suffolk x Merino lambs grazing lucerne in 2013 but were significantly higher when grazing arrowleaf clover/chicory or lucerne in 2014. The key advantage in the finishing systems was that the dressing percentages of White Dorper and White Suffolk x White Dorper lambs were significantly higher than White Suffolk x Merino lambs, although skin values were lower ($1.50/head v. $7/head). The gross returns for lambs sold at the end of the pasture growing season (December) were calculated using mean weight gain on lucerne (2013) or arrowleaf clover/chicory (2014) and mean dressing percentages and skin values for each genotype. There was only a small difference in returns per hectare, with the average advantage per hectare for White Suffolk x Merino system being $9 per hectare over the White Suffolk x White Dorper system over the two years, and returns from the White Suffolk x White Dorper system were actually higher in 2013 (Table 7.4).

7.6.5 **Conclusion**

The field studies conducted in the medium rainfall zone have demonstrated that reproducing ewes can graze crops with a low starting biomass if moderate stocking rates are used to avoid grazing down the crop. Late-pregnant and lambing ewes can graze dual-purpose wheat or dual-purpose canola. More research is required to determine if providing hay or straw to ewes grazing canola is beneficial for ewes grazing canola; however, our experiment did not identify any requirement to supply mineral supplements when grazing this crop based on the mineral profile of the forage.

Non-wool breeds such as White Dorpers offer an opportunity for producers to retain sheep in the system while reducing labour costs; however, returns from this system are likely to be lower compared to Merino ewes joined to terminal sires and depend on current sale prices for wool and lambs. A 5-18% increase in lamb production per hectare compared to that observed in the current study is required to achieve commensurate returns to the Merino-maternal system if lambs are sold as store lambs at weaning; however the difference between the systems was minor if lambs were finished on pasture at the commodity prices used.

The meat-only breed did not appear to have any rumen physiological advantage compared to Merinos on any of the feedbases tested except perhaps when grazing stubble; although it was not clear if this would result in any production advantage. The opportunity to increase the lamb produced/ha of White Dorper ewes by lambing more often than annually was not explored in this study; however, if this breed does have an increased ability to utilise stubble, this may present an opportunity in mixed-farming systems seeking to increase the lamb produced/ha. An important finding was that similar stocking rates on crop are possible for Merino and White Dorper ewes, however this should be confirmed by direct measurement of intake, for example in animal house studies or using marker technology. Studies such as this are limited by the genetic value of the sheep used, and the genetic potential of Dorper and White Dorper sheep may not yet have been fully explored in Australia given the relatively recent arrival of this breed in Australia.

7.7 Finishing lambs born onto dual-purpose crops in the Riverina

Given sufficient moisture availability, a specialist pasture such as the chicory/arrowleaf clover mixture can improve spring lamb production compared to lucerne, increasing the weight of lambs turned off and the number of lambs reaching a finished weight.

In vitro nutritive value of biserrula was at least as high as subterranean clover during the spring; however growth rates of lambs grazing biserrula were significantly lower that lambs grazing lucerne or subteranean clover. The reason for this requires further investigation. Providing lambs a choice of biserrula and subterranean clover had a positive effect, with growth rates of lambs at least as high as grazing subterranean clover as a monoculture.

White Suffolk x White Dorper lambs had an advantage compared to White Dorper or White Suffolk x Merino lambs in terms of growth rates on the better pastures where lambs continued to grow throughout the experiment. White Dorper x White Dorper lambs appeared to have some weight gain advantage compared to other genotypes as pastures senesced.

White Suffolk x Merino lambs had significantly higher growth rates compared to White Dorper x White Dorper lambs in Year 1 when grazing lucerne, subterranean clover or subterranean clover + biserrula; however in Year 2 growth rates of White Dorper x White Dorper lambs were at least as high as the White Suffolk x Merino lambs across the treatment, and were higher when grazing French serradella and Lucerne/phalaris. This may be due to the higher genetic value of the White Dorper lambs sourced from a commercial producer in Year 2 compared to the White Dorpers from the CSU flock.

In conclusion, using a more diverse feedbase presents an opportunity to increase lamb production from pasture in mixed-farming systems. A high value pasture such as chicory and arrowleaf clover can increase growth rates of lambs compared to those achieved on lucerne in late-spring given sufficient moisture and if biomass is not limiting. The increase in production from this more diverse feedbase may be greater than that achieved from altering the lamb genotype.

7.8 Increasing lifetime conception rates using spring canola forage

7.8.1 Dry matter production & nutritive characteristics

The canola and forage brassicas had higher feed on offer levels than lucerne, chicory and plantain throughout most of experiment 1 and also had higher feed on offer than the perennial ryegrass during January and February 2014. Previous research has indicated that summer brassica crops (*B. napus* and *B. campestris* subsp. *rapifera* and *oleifera*) in south west Victoria can produce between 4.2-5.4 t DM/ha (Chin *et al.* 1993). Our research has shown that spring-sown canola crops can produce between 2.0-4.1 t DM/ha of feed on offer during summer and this feed can be retained into autumn to provide a source of accumulated green forage for joining ewes. In experiment 1, the lucerne, chicory and plantain in our research produced lower levels of feed on offer than is their potential in this environment, with previous research indicating that established lucerne and chicory swards can produce 1.5-3.0 t DM/ha during the summer and autumn period (Ward *et al.* 2013). It is likely that the recent establishment, wet conditions during sowing, which resulted competition from weed species, followed by drier than average conditions throughout December 2013 to March 2014, resulted in the feed on offer potential of the lucerne, chicory and plantain not being realised in experiment 1.

The DM production advantage of the brassica forages was not repeated in experiment 3 because the perennial forages were well established and were able to respond to seasonal conditions. Nevertheless, the canola and Winfred brassica offered generally similar levels of DM during experiment 3 when compared to the established perennial forages and there was some evidence of quicker regrowth in late autumn/early winter based on the feed on offer measures for the 1 June 2016.

The nutritive characteristics of the canola treatments were generally similar to the Winfred brassica in both experimental years. Metabolizable energy concentrations were generally higher than all the other forages, in the order of 12.0-13.5 MJ /kg DM, whilst CP concentrations were mostly moderate and similar to the other forages except for the lucerne. This indicates the canola forage is suitable forage for achieving good growth rates from young sheep. Neutral detergent fibre concentration was consistently lower for brassica forages than the other forage treatments in both experimental years and ranged from about 17% to 28%. The lower end of this range may lead to digestive problems particularly during the adaptation phase where the provision of supplementary fibre sources may aid adaptation and live weight gain, although the evidence for improved growth rates in sheep supplemented with hay is limited (Reid *et al.* 1994, Cassida *et al.* 1994).

7.8.2 Ewe live weight gain

At the start of joining, the live weight of the ewe lambs did not differ between forage treatments in both experiments, except the plantain treatment that was lower in experiment 3. There was some evidence that condition score of ewes on the brassica treatments was improved for joining in experiment 3. For both experiments the ewe lambs on the canola and Winfred had higher daily live weight gains than ewe lambs on the perennial ryegrass and pellet treatment. This was primarily driven by differences during the joining period in both experiments rather than the pre-joining period where growth rates were mostly similar across all forages. Our research, has produced weight gain on the brassica forages of between 93-147 g/day in 2014 and 93-154 g/day in 2016 during the joining period for ewe lambs. Across both experimental years growth rates for canola and brassica varied from 93 g/day to 235 g/day with most growth rates averaging in the range of 130-160 g/day. Given the excellent nutritive characteristics of the canola and brassica forages and the high feed on offer it might be expected that relatively young lambs growing on these forages should grow at higher rates. The levels of ME and CP were not limiting and this indicates that perhaps other factors are limiting the growth of lambs on these forages and this could merit further research.

Live weight gain on the other summer/autumn forage options lucerne and chicory were generally satisfactory in both years except when DM became limiting. In contrast, while the performance of the ewes on plantain was good in experiment 1, growth rates in experiment 3 were below those achieved by other treatments and were symptomatic of poor palatability of plantain under summer/autumn dry conditions presumably due to an increased number of seed heads. Previous research has shown that apparent intake of plantain is reduced during these periods (Raeside *et al.* 2017a; Raeside *et al.* 2017b) and as such plantain should not be recommended as summer/autumn forage for improving the growth rate of young animals during summer and autumn without regular grazing management to reduce seed head production.

7.8.3 Ewe reproductive performance

Previous research has shown that very high levels of nutrition can negatively affect the conception rates of ewe hoggets (Mulvaney *et al.* 2010; Kenyon *et al.* 2008). Kenyon *et al.* (2008) compared ewe hoggets with live weight gains of 134 and 223 g/d, while Mulvaney *et al.* (2010) compared ewe hoggets with live weight gains of 153 and 208 g/d. Both studies found that a higher proportion of the 'high live weight gain' ewes did not conceive in the first cycle, but there was no difference in overall pregnancy scanning data or the percentage of hoggets that subsequently lambed. Our results in both experiment 1 and 3 showed no disadvantage due to high growth rate on any of the brassica forages.

Ewes grazing the perennial ryegrass forage treatment in experiment 1 had significantly lower reproduction rate than those grazing canola, chicory or lucerne forages. The perennial ryegrass treatment was based on a normally dormant temperate grass pasture with supplementary feeding of pellets and represents a common system for grazing in south west Victoria. At the start of joining in 2014 there was no significant difference between this treatment and other forage treatments in ewe live weight. Having ewe lambs on a rising plane of nutrition leading up to joining, such that the ewe lambs reach a critical live weight of 40 kg at joining, increases the likelihood of successful conception and the rate of twinning (Coop 1962) and the effect of ewe live weight and growth on joining performance is well known (see review by Kenyon *et al.* 2014). Given that ewes in all forage treatments had a live weight above 40 kg at joining the much lower reproduction rates of ewes on the perennial ryegrass treatment in experiment 1 was unexpected. The difference in reproduction rate due to forage could be due to flushing effects on ewe lambs from the other forage treatments, as has been found previously with lucerne and chicory (King *et al.* 2010). However, these dynamic effects of flushing often occur in animals of lower live weight and poorer condition score which was not the case in the current study.

The possible reasons for the differences in reproductive performance in experiment 1 were therefore further investigated. Parr *et al.* (1987) found that feeding two times maintenance resulted in reduced conception rates in adult Merino ewes. However, reproduction rates in the experiment 1 were actually higher for ewes fed canola forages than the perennial ryegrass treatment which had the lowest reproduction rate. This indicates that while progesterone levels may vary between the treatments, the levels in this experiment were still sufficient to support maintenance of pregnancy and thus progesterone is unlikely to be having a causal influence in the results from experiment 1.

The Banquet II perennial ryegrass with the endophyte strain (Endo 5) that was originally sown into the experimental plots is known to produce small amounts of ergovaline that protects from insect predation (Popay and Hume 2011, Thom *et al.* 2012, Nicol and Klotz 2016). Analysis of perennial ryegrass pasture samples collected from experiment 1 suggested that there were clinically significant levels of ergovaline in the pasture (Figure 6.1). This may due to the variety/endophyte combination or because some recruitment of wild type endophyte perennial ryegrass occurred over the years since sowing. The concentrations of the endophyte alkaloid, ergovaline, were at levels typical of perennial ryegrass pastures in south west Victoria (Reed *et al*. 2004) and reached levels higher than 0.5 mg/kg which is required to induce clinical symptoms of toxicosis in cattle (Hovermale and Craig

2001). Endophyte alkaloids such as ergovaline have been associated with reduced ovulation rate in ewes (Kramer *et al.* 1999). Ergovaline is also known to significantly reduce circulating prolactin concentrations in many species including sheep (Debessai *et al.* 1993 and Kramer *et al.* 1999). Circulating prolactin concentrations were assessed to see whether there was a possible effect of the ergovaline concentration of the pastures in the ewes. There was a trend for reduced prolactin levels in experiment 1 for the perennial ryegrass forage treatment at the start and end of joining. This is a possible indication that the ergovaline concentration of the pasture was sufficiently large to have had a physiological effect on the ewes in this experiment despite an absence of clinical symptoms of ryegrass toxicity in the form of staggers. Ryegrass staggers is more generally associated with lolitrem B concentration; however this was not at detectable levels in experiment 1.

Prolactin is an important hormone in the reproductive system of sheep and plays a role in maintaining the progesterone secreting function of corpus luteum together with luteinising hormone. However, a reduction in the levels of prolactin itself may not be the mechanism by which reproduction rate and conception was reduced in the perennial ryegrass treatment and the exact mechanism for the effect in experiment 1 is unclear. Other factors such as heat stress due to the combination of higher ambient temperatures and the potent vasoconstrictive properties of ergovaline (Rhodes *et al.* 1989) may also have been sufficient to reduce reproductive performance in both ewes and rams. For example, heat stress can affect the survival of the embryo and foetus in the ewe (Cockrem and McDonald 1969, Bell *et al.* 1989) and negatively affects spermatogenesis in the ram (Cameron *et al.* 1984).

However, prolactin also has a role in regulating feed intake of sheep and heat stress is well known to reduce feed intake and feed efficiency in lambs (Ames and Brink 1977). Sheep growth rate was reduced in the perennial ryegrass treatment compared to the brassica treatments during joining despite ewes being at similar weights at the start of joining. This may mean that feed intake was reduced in these sheep compared to other forage treatments. However, feed on offer for the perennial ryegrass treatment was similar to other forages and both the lucerne and chicory treatments also had low sheep growth rates that were not statistically different to the perennial ryegrass treatment during joining. Despite this both these treatments had significantly higher reproduction rates when compared to the perennial ryegrass treatment. Taken together this means that the forage treatment differences observed for reproduction rate in experiment 1 are unlikely to be entirely due to the well-known dynamic and static effects of ewe live weight at joining but are also the result of some other distinctly forage based effect of the perennial ryegrass treatment.

While the actual causal mechanisms for the effect on reproduction rates remain unclear the results from experiment 1 are consistent with the results of Kramer *et al.* (1999) where endophyte infected tall fescue producing ergovaline reduced fertility of ewes at joining. These results have wider implications for all ewe reproduction and in particular ewe lambs that are being mated during late summer and autumn on wild-type endophyte infected perennial ryegrass pastures in south-west Victoria and other temperate sheep zones where wild-type endophyte infected ryegrass pastures are present. The results present a *prima facie* case to more closely examine ewe reproduction and the mechanisms by which wild type endophyte infected perennial ryegrass pastures may reduce reproductive performance in ewes (and possibly rams) at joining.

Reproduction rate and conception rate of ewe lambs were unaffected by forage treatment during the 2016 joining. This may be due to ewe lambs being mated earlier in the calendar year in 2016 when not as many were cycling naturally. There may also have been seasonal differences in the nutritive value and/or endophyte alkaloid content of the pastures. The ergovaline content of the perennial ryegrass pastures in experiment 3 was generally lower than in experiment 1. Additionally, it may also be a function of the reduced precision in the experiment due to the reduced animal numbers that could be used in experiment 3 under the seasonal conditions of that experiment. Further work may be warranted on the optimum time for mating maternal composite ewe lambs during summer/autumn in south west Victoria given the average conception and reproduction rates were substantially different between 2014 and 2016 experiments.

7.8.4 Stage of grazing and the yield of canola

Previous research has indicated that canola seed yields in south west Victoria can be between 1.1-4.8 t DM/ha (Riffkin *et al.* 2012). While the seed yields obtained in this experiment are at the lower end of this range, grazing was not the cause of the yield reduction. Further research is needed to compare the canola seed yields obtained from spring sowing canola with traditional autumn-sown crops.

Grazing throughout autumn did not result in a canola seed yield penalty or markedly change the oil concentration of the seed. Grazing further into spring or cutting for silage did however reduce seed yield and protein concentration in experiment 3. This is likely due to the phenological stage of the canola at the time of grazing and the intensity of the grazing. Once the canola has commenced reproductive development, in early to mid-July, grazing can remove the elongating flower buds from which the crop does not fully recover. Grazing the canola to very low levels of herbage mass (<1000 kg DM/ha) in early July may also penalise the crop due to the time taken for the crop to recover before reproductive development can commence. The glucosinolate concentration of the whole seed was reduced by later grazing in experiment 1 suggesting grazing may improve this aspect of canola seed quality.

7.8.5 Economic benefit of spring sown dual–purpose canola

Previous economic modelling (Young *et al.* 2010) had shown mating ewe lambs to lamb as 1 year olds was profitable, increasing profit by up to $100/ha if weaning percentages of 83% can be achieved. Modelling the impact of changing mating and lambing practices to 1-year-old ewe lambing from two-year-old lambing for our case study farm showed similar changes in net profit ($71/ha) acknowledging however that the costs for achieving these changes in management have been included in our modelling. Increasing lamb marking percentages from our ewe lambs by 10% provided a similar increase in farm profit per hectare ($14/ha) as that modelled by Young *et al.* (2010) ($12/ha). This study has shown that both business and financial risk is reduced by the introduction of ewe lamb mating for 1-year-old lambing. This finding, however needs to be considered alongside the increase management complexity that occurs with the need to meet the nutritional requirements of ewe lambs prior to and during joining and also during pregnancy and lactation.

Young *et al.* (2010) did not investigate options for achieving the change to ewe lamb mating and lambing within the farm system. The primary aim of the practice of using spring-sown dual-purpose canola is to provide out of season forage of high nutritive value suitable for increasing live weight gain in sheep. Therefore, spring-sown dual-purpose canola offers one possible option for achieving reliable conception and reproduction rates from ewe lambs. Using dual-purpose canola offered similar levels of profit and rates of return to other practices such as increased supplementary feeding, using a forage rape or using lucerne. However using the perennial option of lucerne or cropping with spring-sown dual-purpose canola had the advantage of reducing variability in the rate of return with both options providing the highest returns at the least risk.

7.9 Bringing it all together: dual-purpose crops and livestock enterprise risk

7.9.1 Livestock enterprise risk is reduced by including dual-purpose crops in the system

This project has demonstrated that including dual-purpose crops in the system reduced the livestock enterprise risk by increasing production and decreasing costs associated with livestock production. Dual-purpose crops sown in late summer and autumn increased production and income by increased wool production and increased meat production by higher weaning weights per hectare and, in the case of priority grazing of dual-purpose crops by weaners, increased sale weight of lamb per hectare. Dual-purpose crops also may provide the opportunity to increase weight of cast-for age ewes following shearing in the spring. Dual-purpose crops reduced production costs by reducing supplementary feeding in a year where feed supply from pasture was low and, in the case of spring-sown canola, reduced the amount of supplementary feeding to ewe lambs during summer when these sheep were otherwise grazing senesced perennial pastures to get them to joinable weight. The ability to graze crops at relatively low feed on offer provides the opportunity to graze crops early, providing they are sufficiently anchored, alleviating feed shortage earlier in autumn. Further, sowing both a cereal crop and canola crop for grazing in sequence can make use of fast early growth rates of canola for early feed, but also mitigating against establishment risk in case of poor initial emergence or growth rates in one crop.

A key result from the simulation modelling of grazing systems was the importance of the distinction between *variability* and *risk*. Including dual-purpose crops in a grazing system while maintaining farm-level stocking rate will increase the financial variability over a run of years (both because crop yields are inherently more variable, and because the frequency of supplementary feeding will increase). Because these systems are substantially more profitable on average, however, their downside risk is lower – at least when lambing times are in winter.

The modelling analysis of the Tablelands grazing system indicates that as long as the current high prices for lamb (and especially the high ratio of lamb price to the price of supplementary feed) continues, earlier lambing dates in the southern Tablelands are likely to be more profitable than the mid-late July lambing that was tested in the field experiment. However, adopting the combination of dual purpose crops and earlier joining is likely to be more risky – as well as more profitable – than adopting either alone.

7.9.2 Risks and risk management for spring sown dual-purpose canola.

Establishment failure is a key risk associated with spring sowing of any pasture or crop. Particularly in years when variable spring rainfall results in low rainfall totals during October, November and December. This occurred in 2014 with experiment 2 at Hamilton. A mitigation strategy involves trying to sow earlier in the year before conditions dry off. For example, in experiment 3 sowing occurred in September and despite 2015 having a dry spring and lower total annual rainfall, the forages established and grew sufficient feed to allow for grazing. This does show some resilience in the system provided sowing occurs early enough to allow a good germination and plant establishment to occur. Sowing too early raises the risk of the canola vernalising and setting seed early, but in our experiment 3 sowing in September was effective, with the canola not running to head early.

A second risk for spring sown canola is the level of production risk associated with seasonal variation in the feed on offer and nutritive value. Biophysical modelling of various feeding and forage options using data and assumptions based on our project showed that spring-sown canola was equivalent in risk (CV of rate of return) to the perennial option of lucerne was equivalent in risk (CV of rate of return) to lucerne and reduced risk relative to other options such as a conventional forage rape or using grain based supplement to achieve ewe lamb mating weight. It is likely that at least part of the reduction in risk occurs due to the diversification in income from the canola produced as part of the system.

7.10 Bringing it all together: has the key feed gap shifted to autumn?

Pasture availability in the Canberra systems experiment was often higher in control treatments compared to the crop grazing treatments in the period February-May (Table 4.2), corresponding to the period when crops were being established. The decision to replace permanent pasture with an annual crop such as dual-purpose wheat or canola comes at a cost or “cropping penalty” (Dove 2002), with reduced grazing area during the period of crop establishment increasing grazing pressure on the rest of the farm while the crop is established (Dann *et al.* 1974; Dove 2002). The cropping penalty also resulted in extended supplementary feeding of sheep during the late summer and autumn period (Figure 4.8). These results suggest that the period of lowest feed availability in a system that includes dual-purpose crops sown in late summer and autumn (i.e. excluding the spring-sown canola opportunity discussed above) is during the late-summer and autumn period, and highlights the importance of taking early sowing opportunities for crop establishment to allow early grazing of crops.

Inclusion of dual-purpose crops in the system changed the availability of feed to livestock through the year. The early sowing dates during the period 2013 to 2016 provided the opportunity to graze crops early, with sowing of crops occurring no later than 7 March and grazing commencing in the period from late April, with the latest date for commencement of grazing being 19 May across the four years. This was an important occurrence given the lower pasture availability in the crop grazing treatments in autumn (Table 4.2). Experiments in 2010 and 2011 at the same site reported sowing dual-purpose crops on 11-12 March 2010 and 28-29 March 2011, with first grazing of crops occurring on 11 May 2010 and 21 June 2011 (Sprague *et al.* 2015a) while crops for grazing experiments in 2009 were not sown until 21 April with grazing commencing on 13 July (Dove *et al.* 2012). In fact, the site has been used for dual-purpose crop experiments since at least 2004, with sowing dates ranging from early March through until late May. The current experiment had an emphasis on early and timely sowing of crops, reflecting growing confidence by researchers in consistently target early sowing opportunities for crops other than oats (which has traditionally been sown early in this region); a confidence that is also now being reflected by industry practice (John

Kirkegaard, personal communication). This also demonstrates the importance of running experiments over a number of years, and how a systems experiment focused on whole-farm feed supply may demonstrate the benefits of pushing the system harder than may have been traditionally attempted.

The impact of low feed availability in autumn when dual-purpose crops are incorporated into the system means that producers in this system are likely to want to be able to graze crops as early as possible. The feed on offer in wheat crops at the commencement of grazing in the Canberra systems experiment (Table 4.3) was high compared to other studies where ewes have safely grazed wheat crops (Table 7.2; McGrath *et al.* 2015; McGrath *et al.* 2016a), although in the only other study where lambing ewes have grazed canola the FOO in canola was also high (Table 7.2; McGrath and Friend 2015; Section 5.2). In the current study, sheep went onto crops following pregnancy scanning, however conceivably they could have grazed crops earlier. One constraint in the current project was withholding periods on herbicides (12 weeks) applied at sowing in 2013 and 2014. Crop grazing ceased at Growth Stage 31 (wheat) or Growth Stage 3.0 (canola) to minimise the impact of grazing on grain yields in all years of the experiment, not because crop biomass was insufficient to meet livestock needs. Allowing ewes to graze the crops slightly earlier would have reduced supplementary feeding requirements during autumn and increased utilisation of the crops.

7.11 Achievement of the project objectives

The project had two key objectives:

1. To demonstrate that significantly higher utilisation rates and production of meat per kilogram of pasture eaten (at farm scale) are achievable when winter and summer feed gaps are reduced by grazing dual-purpose crops.

The biophysical modelling of grazing systems with and without dual-purpose wheat+canola (section 4.8) demonstrated that pasture utilization rates could be increased by about 20% and that the conversion rate of pasture eaten to lamb live weight could be increased by about 13% at the same time by the inclusion of dual-purpose crop forage as a supplement to the forage supply during winter and (to a lesser extent) summer. These increases in the efficiency of use of pasture almost completely compensate for the reduction in area of pasture grown when crops are introduced – or even over-compensate for it, if our experimental results for the weaner crop-grazing system can be replicated at farm scale.

2. To rigorously evaluate the changed production risk environment associated with livestock production systems that exploit the higher forage production and potentially greater conversion of pasture to meat that arise from inclusion of dual-purpose crops in the feedbase.

The changed production risk environment has been rigorously evaluated using field experiments across multiple regions and production systems and using biophysical modelling. The change in feed availability was clearly identified by the systems experiment at the Canberra node, where crops were consistently available to graze by early May, alleviating the feed gap in late-autumn and winter; however, a feed gap was apparent from late summer through to mid-autumn, during the time of crop establishment. Inclusion of dual-purpose crops increased meat and wool production, with the benefits of increased meat production particularly notable when crop grazing was prioritised for carry-over weaners resulting in higher conversion of pasture to meat. The input costs for systems that included dual-purpose crops were higher, but returns were also higher and business risk was reduced. The study in South West Victoria demonstrated that using spring-sown dual-purpose canola offers one possible option for achieving reliable conception and reproduction rates from ewe lambs. Using dual-purpose canola offered similar levels of profit and rates of return to other practices such as increased supplementary feeding, using a forage rape or using lucerne. However, using the perennial option of lucerne or cropping with spring-sown dual-purpose canola had the advantage of reducing variability in the rate of return with both options providing the highest returns at the least risk. The study has shown that both business and financial risk is reduced by the introduction of ewe lamb mating for 1-year-old lambing, but this needs to be considered alongside the additional management complexity of the system. At the Wagga node data from White Dorpers found no great advantages for this breed in terms of high reproduction rates or metabolism in comparison to a Merino-maternal system, and thus the non-wool breed was not able to better exploit the additional winter and spring feed and returns were lower compared to the dual-purpose system producing wool and meat.

8 Conclusions and Recommendations

8.1 Implications for the red meat industry

- Timely sowing of crops is important to minimise establishment risk (if spring sowing) and maximise the grazing opportunity
- Sowing both dual-purpose cereal and brassica crops can increase the sheep grazing days on crops and also mitigate against poor establishment or slower autumn growth rates of one species.
- Replacing permanent pasture with dual-purpose crops can provide a large amount of nutritious feed during late autumn and winter, allowing pastures to be rested and higher livestock production, however this may create a feed gap during the late summer and autumn while the crops are being established.
- Dual-purpose crops can increase meat and wool production. Prioritising grazing for young growing livestock may be more beneficial as meat production is increased and the lower intakes of young livestock may allow other livestock classes also graze crops for at least part of the winter.
- Spring sown canola can be used as a summer/autumn forage for grazing ewe lambs prior to and during joining. This practice can be used as a direct replacement for the sowing of typical forage brassica (such as Winfred) for grazing and will give similar performance in terms dry matter production, nutritive value and live weight growth and reproduction.
- There appear to be no negative effects of grazing brassica forages on ewe reproductive performance prior to and during joining. Gains in live weight during this period will improve reproduction and forage brassicas are able to produce good live weight gains at a time of year when perennial grass pastures are usually dormant. The brassica forage treatments also produced similar or better levels of dry matter compared to other possible summer/autumn forage options such as chicory and plantain.

- Grazing of spring-sown canola during summer and autumn will not affect canola seed yield at harvest providing grazing is stopped before the plants start producing flower buds.
- Use of spring-sown canola within a farm system will require careful consideration of the sowing risks, costs, increased management complexity and additional animal health management requirements.
- Lucerne and chicory are viable alternatives for summer forage generally achieving similar live weight gain and reproductive performance to the brassica forages.
- Plantain should not be recommended as summer/autumn forage due to possible effects on feed intake and live weight gain through poor palatability in summer/autumn.
- Including dual-purpose crops in the livestock system can increase farm returns and reduce risk. However, there is an added level of management complexity added to the system by adopting dual-purpose crops.

8.2 Recommended development & adoption activities

Three sets of producer guidelines have been generated from this project and should be made publically available as a first step to informing advisers and producers regarding potential use of dual-purpose crops to increase meat production and farmer returns. The main guideline incorporates results from all nodes but has a particular focus on using dual-purpose crops to address the autumn/winter feed gap common in southern Australia due to cold temperatures restricting pasture growth rates and hence feed availability. The guideline produced by Agriculture Victoria (Hamilton node) has a focus on spring-sown dual-purpose canola to address the feed quality gap in summer and early autumn. The third guideline disseminates results from the Riverina node, with a key focus of summarising the experimental results and their meaning for producers in the mixed-farming zone.

The project aligns well with MLA’s producer demonstration sites model. There are currently several producer focus groups which include a component on dual-purpose crops, however as these have either concluded or are about to conclude there is limited opportunity to disseminate the results through these focus groups. However, there will be future calls for Producer Demonstration sites which will provide an opportunity for interested farming groups to incorporate and test the findings from this project on-farm.

MLA is currently contracting production of a series of fact sheets as a mechanism to summarise and disseminate knowledge generated from projects such as this which can be easily read and applied on farm. It is recommended that utilisation of dual-purpose crops be included as part of this fact sheet series, providing the opportunity to further drive adoption practices.

Finally, there is an opportunity for MLA to facilitate adviser updates in key regions as a mechanism to provide key influencers with the latest information generated from MLA funded projects. Inclusion of this project as part of the adviser updates would be another opportunity to disseminate information and increase adoption.

8.3 Future R&D opportunities

8.3.1 Spring-sown dual-purpose canola

Further research is required into the vernalisation requirements of spring-sown canola with canola in south west Victoria showing evidence of unseasonal reproductive development. Sowing in spring also presents establishment risks associated with failed spring rains and increasing temperatures. Modelling and/or the development of tools to determine optimum sowing windows and risks could be beneficial.

8.3.2 Optimising lamb growth from brassica forages

The data from this experiment suggest that the forage nutritive value and DM production of the brassicas used in this experiment should have enabled higher growth rates than was achieved experimentally. Further research is therefore needed to determine if the growth rates of lambs on canola or forage brassicas can be improved and if higher growth rates than those achieved in this experiment are detrimental to ewe lamb performance. Our results to date and those of other Australian studies would suggest that higher growth rates during joining of ewe lambs are advantageous for reproductive success and that spring-sown canola can fulfil this requirement in the south west Victoria.

8.3.3 Ewe lamb reproduction

The results from these studies show that mating ewe lambs can result in high reproduction rates where nutrition and breeding season is well matched (experiment 1 Hamilton). The results from experiment 3 were less attractive in terms of conception and reproduction rate and this may have been due to the earlier joining time resulting in reduced cycling of the ewe lambs. Further research is warranted on optimising the joining time of ewe lambs to optimise reproductive performance the benefits from this change in management practice.

There is also circumstantial evidence to suggest that sub-clinical perennial ryegrass toxicosis could be negatively impacting on the reproductive performance of ewe lambs when grazing perennial ryegrass pastures producing ergovaline during summer and autumn. Further research is recommended to determine whether this effect is consistent and whether it can be mitigated through supplementation treatments that bind and reduce the activity of this alkaloid.

8.3.4 Other forage options

Further research is required on the factors influencing the palatability of plantain as a summer/autumn forage. Plantain has the potential to be an important forage through good DM production and persistence but the results in experiment 3 at Hamilton are the second time we have observed poor live weight gain of lambs grazing plantain during summer and autumn. It may be that management actions to manage the age of the sward and level of seed head could improve palatability or that breeding may be required to reduce anti-nutritive factors, if they are present.

Biserrula is another pasture species that may have potential in Australian farming systems, however further research is required to address management of the plant for livestock production. Some general rules have emerged suggesting that biserrula should not be grazed around flowering; however, to date there is a lack of experimental evidence to back claims that this species can produce high production rates per hectare or extend the growing season. Further research may also address breeding to identify and breed-out the compounds causing photosensitisation in livestock grazing biserrula.

8.3.5 Effect of incorporating dual-purpose crops on composition of permanent pastures

Our data from the Tablelands node indicated that annual species had a higher prevalence in systems that included dual-purpose cropping, and we have speculated that this could be due to the higher stocking densities on pastures in the autumn when dual-purpose crops are included in the system. However apart from the removal of one sub-paddock from the system due to heavy infestation by annual grasses, the data does not indicate a deterioration in the pastures. Further, this system used a high proportion of land sown to dual-purpose crops, and a tight cropping rotation which increased the stocking density on permanent pastures during the autumn. Pasture renovation is an expensive undertaking, costing $400-500/ha, and has a long pay-back period. Understanding the impact of dual-purpose crops on longer-term pasture dynamics is an important question requiring further research.

9 Key messages

- **Dual-purpose crops alter the feed supply.** Dual-purpose crops sown in late summer and autumn can supply a large amount of high quality feed during late autumn and winter. For systems that use autumn-sown crops, however, the main deficit in feed is during late summer and autumn, the period when crops are being established, and additional supplementary feeding may be required during this period. Consequently, the deferment effect of crops may not be extra feed availability in winter, but rather that resting pastures over winter allows them to ‘catch-up’ in comparison to systems that do not have dual-purpose crops.
- **Sow dual-purpose crops early – whether in late-summer/early autumn or in spring.** Sowing early in late-summer or autumn, when soil moisture is sufficient, can allow early establishment of crops and increase the grazing opportunity during autumn and winter. In environments suitable to spring sowing of canola, crops should be sown as soon as tractors can get onto paddocks in early spring to mitigate against dry spring conditions, however producers also need to be mindful not to sow too early to avoid vernalisation of the crops. Local advice should be sought.
- **Grazing brassica and cereal crops in sequence – an opportunity to increase the period grazing crops and hedge against poor initial establishment or slow growth rates in one species.** Where growing conditions are good, canola will have higher growth rates than wheat and can be expected to be ready for grazing first. The added advantage of grazing canola first is that it provides more time post-grazing for canola to recover. In more marginal moisture conditions wheat may have better establishment and higher initial growth rates than canola, and therefore may be available to graze earlier if canola growth rates are initially slow. Grazing crops in sequence (e.g. canola then wheat) can increase the time that livestock are grazing crops and pastures are being rested.

- **Greatest opportunities for utilising dual-purpose crops are likely to be through prioritising crop grazing for young livestock**. The high nutritive value and availability (ease of consumption) of dual-purpose crops can increase winter growth rates of young livestock compared to those grazing pastures, increasing sale weights and producer returns. Further, the lower per-head consumption of young sheep compared to reproducing ewes means that other livestock classes may also be able to utilise the crops (e.g. reproducing ewes, agistment or trading livestock), even if for a reduced period, or a smaller area of land can be devoted to dual-purpose crops if targeted specifically at young livestock. Spring-sown canola also provides an opportunity to increase growth rates of ewe lambs to allow joining as one year olds, or potentially for other young livestock.
- **Including grazing crops can increase wool production.** On farms where wool production is an important component of income, inclusion of dual-purpose crops can increase wool production per ewe. (It is not clear whether this is just due to improved nutrition during winter, or may also be affected by other factors such as reducing the worm burden in ewes.) An additional benefit is that ewe live weights may be heavier in spring, increasing the sale weight of cull ewes.
- **Cereal crops can be grazed at low initial biomass, but beware chemical withholding periods.** Dual-purpose wheat can be grazed at a starting biomass as low as 330 kg DM/ha, but using moderate stocking rates that allow the crop to continue to get ahead. Exploiting this opportunity may allow crops to be grazed early in tight seasons. Producers need to be mindful that withholding periods on chemicals applied at sowing may prevent early grazing of crops.
- **Dual-purpose crops increase farm returns – but input costs are higher.** The increased livestock production, reduced supplementary feeding costs and income from grain can increase returns when dual-purpose crops are included in the system. Input costs associated with crop establishment and management are higher compared to pasture-only systems. There may also be additional costs compared to grain only systems, such as additional fertiliser applications.
- **Dual-purpose crops reduce business and financial risk – but complexity of management is increased.** Business and financial risk and the variability of returns are reduced by including dual-purpose crops in the system, however producers also need to be prepared to deal with the extra management complexity involved with sowing and managing crops to maximise livestock production while minimising the effects of grazing on grain yield.

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Appendix 1: Curation of project data

Milestone 11 of the project contract requires that experimental data sets from all nodes be made publically available.

- Datasets from the Riverina node experiments were provided to MLA in April 2016 in satisfaction of Milestone 9. These datasets will become available via CSIRO's Data Access Portal on 1 April 2019 (in order to allow time for publication of the experiments).
- The full dataset from the Canberra systems experiment has been collated into a single Microsoft Access database. This data file accompanies the project report in satisfaction of milestone 11. In addition, the dataset will be uploaded to CSIRO's Data Access Portal once the two experimental papers have been accepted for publication.
- The full dataset from Experiments 1 and 3 of the Hamilton node has been collated as a set of Microsoft Excel spreadsheets. These data files accompany the project report in satisfaction of milestone 11.

Appendix 2: Communications from the project

Journal and conference publications

Refereed journal and conference publications

McGrath SR, Virgona JM, Friend MA (2013) Describing the sward structure of wheat and annual ryegrass swards grazed by lambs in southern NSW. *Proceedings of the 22nd International Grassland Congress*, pp 978-979.

McGrath SR, Virgona JM, Friend MA (2014) Modelling the effect on stocking rate and lamb production of allowing ewes to graze a dual-purpose wheat crop in southern New South Wales. *Animal Production Science* **54**, 1625-1630

Pinares-Patiño CS, McDonald SE, Kirkegaard JA, Dove H, Hunt JR, Simpson RJ, Moore AD (2015) Influence of winter-grazed dual-purpose wheat and canola crops on the forage availability in a pasture-based system. In 'Building productive, diverse and sustainable landscapes.' 17th Australian Agronomy Conference, Hobart, 20-24 September 2015. (Ed. TL Botwright Acuna) (Australian Society of Agronomy: Hobart)

McGrath SR, Friend MA (2015) Dual-purpose crops: comparison of maternal systems grazing canola or wheat during late pregnancy and lambing then lucerne-based pasture until weaning. In 'Building productive, diverse and sustainable landscapes.' 17th Australian Agronomy Conference, Hobart, 20-24 September 2015. (Ed. TL Botwright Acuna) (Australian Society of Agronomy: Hobart)

McGrath SR, Virgona JM, De Mattia TA, Friend MA (2015). Forage quantity and quality of dual-purpose wheat: changes during grazing and implications for livestock production. In 'Building productive, diverse and sustainable landscapes.' 17th Australian Agronomy Conference, Hobart, 20-24 September 2015. (Ed. TL Botwright Acuna) (Australian Society of Agronomy: Hobart)

McGrath SR, Sandral G, Friend MA (2015) Lamb growth rates on pasture: assessing options for finishing lambs in spring. In 'Building productive, diverse and sustainable landscapes.' 17th Australian Agronomy Conference, Hobart, 20-24 September 2015. (Ed. TL Botwright Acuna) (Australian Society of Agronomy: Hobart)

Raeside, M, Byron, J, MacDonald, C, Cameron, F and Behrendt, R (2015). Joining ewe lambs on dual purpose canola in Southern Australia. 17th Australian Agronomy Conference, Hobart, 20-24 September 2015. (Ed. TL Botwright Acuna) (Australian Society of Agronomy: Hobart)

In addition, the following papers used samples collected from White Dorper lambs from the Wagga Wagga site, although the research was not funded under this project:

De Brito GF, McGrath SR, Holman BWB, Friend MA, Fowle, SM, van de Ven RJ, Hopkins DL (2016) The effect of forage type on lamb carcass traits, meat quality and sensory traits. *Meat Science* **119**, 95-101.

De Brito GF, McGrath SR, Holman BWB, Friend MA, Fowler SM, van de Ven RJ, Hopkins DL (2016) The effect of forage type on lamb carcass traits, meat quality and sensory traits. *Meat Science* **119**, 95-101.

Journal manuscripts in preparation

The following manuscripts have been drafted for journal submission. Copies of each draft manuscript have been provided as separate documents:

McGrath SR, Sandral GA, Sundermann L, Quinn JC, Weston LA Friend, MA. (in preparation) Growth and carcase performance of lambs grazing lucerne, subterranean clover, biserrula or a choice of legume in southern Australia. To *Grass and Forage Science*.

McGrath SR Virgona JM, Friend MA (in preparation) Comparison of growth rate of lambs grazing dual-purpose wheat sown at narrow or wide row spacing with annual ryegrass pasture. To *Grass and Forage Science.*

McGrath' SR, Pinares-Patiño CS, McDonald SE, Kirkegaard JA, Simpson RJ, Moore A.D. (in preparation) Utilising dual-purpose crops in a high-rainfall livestock system to increase meat and wool production: 1. Pasture production and crop yields. To *Animal Production Science.*

McGrath' SR, Pinares-Patiño CS, McDonald SE, Simpson RJ, Moore A.D. (in preparation) Utilising dual-purpose crops in a high-rainfall livestock system to increase meat and wool production. 1. Pasture production and crop yields. To *Animal Production Science.*

McGrath' SR, Behrendt R, Raeside MC, Friend MA, Moore AD (in preparation) Can dual-purpose crops increase meat production economically whilst reducing risk? To *Animal Production Science*.

Raeside MC, Byron J, Cameron F, MacDonald C, Behrendt R (in preparation) Improving ewe lamb reproduction using dual purpose canola in southern Australia. 1. Herbage mass, nutritive characteristics and botanical composition of grazed forage. To *Animal Production Science*.

Student theses

De Mattia T (2013) Winter wheat: Does a change in row spacing affect liveweight gain in lambs? BSc (Hons) thesis, Charles Sturt University.

McGrath SR (2015) 'Studies on the utilisation of dual-purpose wheat by sheep in southern NSW'. PhD thesis, Charles Sturt University.

Sundermann L (2014) 'The preference, voluntary intake and herbage digestibility of biserrula (*Biserrula pelecinus* L.) and subterranean clover (*Trifolium subterraneum* L.) grazed by two lamb genotypes.' BSc (Hons) thesis, Charles Sturt University.

Producer guidelines

Three producer guidelines have been prepared and are provided as separate documents:

- A guideline for producers that outlines the underpinning management principles and activities that enable higher utilisation rates and production of meat per kilogram forage eaten (at farm scale) from grazing dual-purpose crops
- 'Grazing of spring sown canola for lamb and canola production'
- 'Step changes in meat production systems from dual-purpose crops in the feed-base: Riverina'

Other conference papers, posters and presentations to industry

Conference papers

McGrath SR, Sandral GA, Sundermann L, Friend MA (2015). Lambs grazing a choice of biserrula and subterranean clover have higher growth rates in spring than lambs grazing a biserrula monoculture. In 'Making Pasture Pay: Proceedings of the 29th Annual Conference of The Grassland Society of NSW Inc.' Goulburn NSW, 14-16 July 2015, pp. 110-112.

McGrath SR, Street SH, Krebs GL, Friend MA (2016) Turning dual-purpose wheat into meat: comparison of Merino and White Dorper maternal systems on a mixed-farming feedbase. Australian Society of Animal Production, Adelaide, July 2016.

Pinares-Patiño, CS, McDonald, SE, Kirkegaard, JA, Simpson, RJ and Moore, AD (2016). Influence of integration of dual-purpose wheat and canola crops in a pasture system on liveweight of Merino sheep. Australian Society of Animal Production, Adelaide, July 2016.

Pinares-Patiño, CS, McDonald, SE, Kirkegaard, JA, Simpson, RJ and Moore, AD (2016). Methane emission from Merino weaners on pasture systems that include grazing dual purpose crops in winter. International Symposium on Energy and Protein Metabolism and Nutrition, Krakow (Poland), September 2016.

Pinares-Patiño, CS, McDonald, SE, Kirkegaard, JA, Simpson, RJ and Moore, AD (2016). Effects of winter-grazed dual-purpose crops integrated in the pasture system on liveweight of Merino sheep. 26th General Meeting of European Grasslands Federation, Trondheim (Norway), September 2016.

Pinares-Patiño, CS, McDonald, SE, Kirkegaard, JA, Dove, H, Hunt, JR, Simpson, RJ, Moore, AD (2015) Influence of winter-grazed dual-purpose wheat and canola crops in a pasture system on the performance of Merino sheep. In 'Making Pasture Pay: Proceedings of the 29th Annual Conference of The Grassland Society of NSW Inc.' Goulburn NSW, 14-16 July 2015.

Raeside M, Behrendt R, MacDonald C, Byron J, Zollinger R, Cameron F, Partington D, Knight M (2014) Increasing the reproductive performance of ewe lambs by grazing spring sown canola as an autumn forage crop. 18th Australian Research Assembly on Brassicas, Tanunda, 29 September-2 October 2014.

MLA magazine articles

1. Dual-purpose crops pass first test (*Feedback* June 2014)
2. Planning cash crops (19 February 2015)
3. Making the most from dual-purpose crops (4 June 2015)
4. Five things to know about dual-purpose crops (23 July 2015)
5. Seeing double (*Feedback*, July 2015)
6. Three things you need to know when grazing crops (9 June 2016)
7. How to maximise the benefits of grazing crops for ewes (1 July 2016)
8. Getting the crop-to-pasture ratio right (*Feedback* August 2016)
9. Incorporating dual-purpose crops in your pasture feedbase system (15 July 2016)
10. Dual-purpose crops outperform pasture-only alternative/Dual-purpose crops boost pasture-only system (Feedbase Focus 29 May 2017; Friday Feedback 2 June 2017)

Industry communications

- June 2017: 'Dual-purpose crops: a flexible option for Southern Tablelands sheep producers'. The Innovator (Charles Sturt University and NSW Department of Primary Industries), Winter 2017 Edition.
- 2 August 2016: A group of 15 farmers from Argentina visited the Hamilton site and were presented with a project overview, key results and provided with a handout.
- 1-2 August 2016: A trade display was presented at SheepVention, Hamilton's local field day attracting around 30,000 visitors with a focus on sheep production and rural industries. Posters and handouts were available and the stalls staffed so that farmers could ask questions and be provided with information regarding the use of brassica crops.
- 21 July 2016: A group of 25 Agriculture TAFE teachers visited the Hamilton (Victoria) site and were given an overview of the project, key results and provided with a handout.
- 24 June 2016: Cesar Pinares Patino presented to a Brazilian delegation visiting CSIRO Black Mountain. Title: 'Dual-Purpose Crops in the Pastoral Feedbase System'
- 10 June 2016: A group of twenty Year 9 agriculture science students from Hamilton College visited the Victoria site.
- 1 June 2016: Cesar Pinares Patino presentation 'Mixed farming Systems: Dual-Purpose Crops) at the Producer Research Site Workshop (Melbourne).
- 15 May 2016: A group of 25 students from University of South Dakota visited the Hamilton (Victoria) site and were given an overview of the experiment, key results and provided with a handout.
- 8 April 2016: A group of 20 livestock producers visited the Hamilton (Victoria) site as part of the Victorian High Country Beef Producers Group. A site overview was presented, with key results and the group were provided with a handout.
- September 2015: Presentation by S. McGrath 'The effect on lamb growth rates of grazing a row crop' at the Graham Centre Field day, Wagga Wagga.
- September 2015: Article "Assessing options for finishing lambs on pasture in spring" by S. McGrath: The Innovator (Charles Sturt University and NSW Department of Primary Industries), Spring 2015 Edition. pp. 12-15. http://www.csu.edu.au/__data/assets/pdf_file/0008/1710485/Spring-2015-email.pdf
- 6 August 2015: Field Day on Dual-Purpose Crops, Ginninderra Experiment Station (CSIRO, Canberra). Attendees: 60+
- August 2015: A poster displaying the results from Experiment 1 at the SW Victoria node was displayed at SheepVention.
- 14-16 July 2015: Two posters (C. Pinares-Patino *et al.* and S. McGrath *et al.*) displayed at the 29th Annual Conference of the Grasslands Society of NSW, Goulburn, NSW. Attendees: 200+.
- 10 July 2015: Poster 'Lambs grazing a choice of biserrula and subterranean clover had higher growth rates in spring than lambs grazing a biserrula monoculture' by S. McGrath *et al.*, presented at the Graham Centre Sheep Forum, Graham Centre, Wagga Wagga
- July 2015: Presentation by S. McGrath to Merino Sheep Breeders Council on 'Grazing ewes on dual-purpose crops', Graham Centre, Wagga Wagga.
- 2-3 June 2015: M. Raeside, S. McGrath, A. Moore and C. Pinares-Patino attended the MLA Feedbase Investment Plan Symposium at Mercure Hotel, Sydney.
- February 2015: 'Finishing lambs on perennial and/or annual pastures in spring', a presentation at the MLA Feedbase Investment Plan Pillar Meeting – Alternative Legumes, Sydney.
- Cesar Pinares-Patino and Scott McDonald attended the farmer's event 'Grazing crops & animal health update' organised by NSW DPI at Cowra, where Drs. J Kirkegaard and S. Sprague

presented the presentation ‘Optimising the grazing and yield potential of dual-purpose crops’. The attendees engaged in discussion with the CSIRO staff regarding their interest on DPC.

- October 2014-March 2015: Three field-day presentations on the "Use of summer-autumn fodder crops for improved reproductive performance in ewe lambs" were delivered at MLA and GSSA Pasture Updates held at Warrmabeen, Bairnsdale and Stawell (Victoria), on 8 October 2014, 22 October 2014 and 24 March 2015, respectively. The presentations highlighted DEPI Victoria research on dual-purpose canola crops in comparison to forage brassica and other forage options such as lucerne, plantain and chicory. Approximately 30 people attended each field day comprising agribusiness and producers.
- August-September 2014: Financial analysis of 2013 results at the NSW Tablelands node was included in presentations to GRDC Farm Business Updates on “Integrated farming systems for a sustainable future – what is the role of mixed farming?” at Wagga Wagga (August) and Horsham (September).
- August 2014: A media release on the results from Experiment 1 of the SW Victoria node was submitted to local and regional media (‘Country Hour’, ‘Warrnambool Standard’, ‘Hamilton Spectator’, ‘Colac Herald’ and ‘Stock and Lamb’).
- August 2014: A poster display and presentation of results from the SW Victoria node was delivered at Sheepvention (the largest field day for sheep producers in south-east Australia).
- July 2014: A report on the project was provided to the Industry Leaders Group Conference held at Hamilton.
- September 2013: Preliminary results from the modelling study (NSW Riverina node) presented at a producer field day at Burrumbuttock (NSW) to approximately 80 producers.
- July 2012 – NSW Grasslands Society tour visited the Wagga Wagga site at Charles Sturt University. Shawn McGrath described the approach and aims of the 2012 trial at Wagga and fielded questions from the group.

Appendix 3: Details of crop and pasture management at GES 2013-2016

Table 15.1. Details of crop and pasture management at Ginninderra Experimental Station, ACT 2013-2016

Crop	Pre-emergent	Sowing date and details	Post-sowing	Harvest
2013				
Wheat - 'Revenue'	KNOCKDOWN 1.2 L/ha glyphosate 450 45 ml/ha Hammer 1.0 L/ha Lorsban 1% ammonium sulphate	7 March – Sowing rate 100 kg/ha with Granulock15 @ ~100 kg/ha. Imidicloprid	POST SOWING PRE-EMERGENT 250 ml/ha Dual Gold 150 ml/ha Fastac Duo 8 April Herbicide: 670 ml/ha Velocity + 1 % Hasten 12 September – urea @ 200 kg/ha	4 Jan
Canola – 'Hyola 971CL'	KNOCKDOWN 1.2 L/ha glyphosate 450 300 ml/ha Lontrel 45 ml/ha Hammer 1% ammonium sulphate PRE-EMERGENT IBS 3.0 L/ha trifluralin 1.0 L/ha Lorsban	7 March – Sowing rate 5 kg/ha with Granulock15 @ ~100 kg/ha	POST SOWING PRE-EMERGENT 250 ml/ha Dual Gold 150 ml/ha Fastac Duo 27 March – urea @ 83 kg/ha 2 April – Herbicide: 750 ml/ha Intervix+500 ml/ha Select (clethodim) 0.5% Supercharge or 1% Hasten 15 July – 3 plots urea @ 108 kg/ha 12 September – plots that were not top-dressed in July @ 200 kg/ha; plots top-dressed in July @ 100 kg/ha	20 Dec
Ley Pastures		8 March – Pastures sown at 15 kg/ha with Granulock15 @ ~100 kg/ha.	4-5 June 2013 – triple super applied to ley and permanent pastures @ 110-129 kg/ha	
2014				
Wheat 'Manning'	KNOCKDOWN 3.0 L/ha glyphosate 450 0.3 L/ha Lontrel 45 ml/ha Hammer or 75 ml/ha Goal or Striker (oxyfluorfen) 1% ammonium sulphate 0.25% LI700 (or 0.2% non-ionic surfactant) PRE-EMERGENT IBS 118 g/ha Sakura	24 February- Sowing rate 100 kg/ha with 100 kg/ha Granulock 15 treated with flutriafol (Impact) at the high rate. Seed treated with Emerge and Rancona-C	19 March Post emergent sprays to control grasses and broadleaf: 100 ml/ha Hussar OD + 500 ml/ha Velocity + 1 % Hasten 17 April – urea @ 100 kg/ha 20 August – urea @ 270 kg/ha 1 September 2014 – Aphid sprayed with Pirimor aphicide (500 g/kg PIRIMICARB) @ 150 g/ha with Agral 20 October 2014 – Fungicide applied to wheat - 290 ml/ha Launch (430 g/L tebuconazole)	

Crop	Pre-emergent	Sowing date and details	Post-sowing	Harvest
Canola ‘Hyola 971CL	KNOCKDOWN 3.0 L/ha glyphosate 450 0.3 L/ha Lontrel 45 ml/ha Hammer or 75 ml/ha Goal or Striker (oxyfluorfen) 1% ammonium sulphate 0.25% LI700 (or 0.2% non-ionic surfactant) 160ml/ha Garlon	27 February - Sowing rate 5 kg/ha with 100 kg/ha Granulock 15 treated with flutriafol (Impact) at the high rate. Seed treated with Jockey and Cosmos	Post-sowing, pre-emergence: 0.25 L/ha Dual Gold 0.15 L/ha Fastac Duo 17 April – urea @ 100 kg/ha 20 August – urea @ 270 kg/ha 1 September 2014 – Aphid sprayed with Pirimor aphicide (500 g/kg PIRIMICARB) Canola @ 1 kg/ha with 0.018% Agral	21 Nov
Ley Pastures		1 April - Pastures sown at 15 kg/ha with Granulock15 @ ~100 kg/ha following a further spray of knock down herbicide.	26 May 2014 – Winter cleaning of second year pastures and weed control in 1st yr pastures 25 g/ha Broadstrike + 1.4 L/ha bromoxynil 200 g/l+ 0.2% wetter with primary aim to clean up shepherd’s purse and turnip weed Early June – Application of Verdict to second year pastures 22 October – 2nd year pastures sprayed out with 1% ammonium sulphate + 7 g/ha metsulfuron-methyl (Ally) + 3 L/ha glyphosate + 0.1% BS1000. 25 October – 2nd year pastures cut for hay Then post hay removal spray with 1.5 L/ha paraquat + 0.1% BS1000 26 October – 1st yr. pastures spray-topped with 360 ml/ha glyphosate + 1% ammonium sulphate + 0.1% BS1000 8 January 2015 – 2nd Yr. Pastures sprayed with glyphosate (with some MCPA) to clean up cocksfoot not killed earlier.	
2015				
Wheat ‘Manning’	KNOCKDOWN & IBS 1% ammonium sulphate 0.25% LI700 118 g/ha Sakura 1.2 L/ha glyphosate 450 gai	4 February – Sowing rate 100 kg/hectare treated with Granulock 15 @ 100 kg/ha. Seed treated with Emerge and Rancona	14 April 2015 – Urea @ 100 kg/ha	Not harvested
Canola ‘Hyola 970’	KNOCKDOWN & IBS 1% ammonium sulphate 0.25% LI700 1.0 L/ha Lorsban 3.0 L/ha trifluralin	11 February – Sowing rate 5 kg/ha with Granulock 16 @ 100 kg/ha. Seed treated with Impact for blackleg	Post-sowing PRE EMERGENT 0.25 L/ha Dual Gold 0.15 L/ha Fastac Duo	27 Nov

Crop	Pre-emergent	Sowing date and details	Post-sowing	Harvest
	1.2 L/ha glyphosate 450 gai			
Ley pastures	6 March 2015 - 1st yr. Pastures sprayed with glyphosate Further spray of knockdown herbicide (Glyphosate and Lontrel) pre-sowing as well as sprayed for cockchafers.	21 April 2015 – Pasture sown at 13 kg/ha with Granulock15 @ ~100 kg/ha following		
2016				
Wheat – 'Manning'	KNOCKDOWN & IBS 1% ammonium sulphate 0.25% LI700 118 g/ha Sakura 1.2 L/ha glyphosate 450 gai	12 February 2016 – Sowing rate 100 kg/ha with Granulock 15 @ 100 kg/ha. Seed treated with Emerge and Rancona	No top dress of N (urea) due to ground condition	4 Jan
Canola – 'Hyola 970'	KNOCKDOWN & IBS 1% ammonium sulphate 0.25% LI700 1.0 L/ha Lorsban 3.0 L/ha trifluralin 1.2 L/ha glyphosate 450 gai	15 February - Sowing rate @ 5 kg/ha with Granulock 15 @ 100 kg/ha treated with Impact for blackleg	POST SOWING PRE EMERGENT 0.25 L/ha Dual Gold 0.15 L/ha Fastac Duo No top dress of N (urea) due to ground condition	8 Dec
Ley Pastures	12 January 2016 - 2nd year pastures sprayed with glyphosate to control weed germination KNOCKDOWN Glyphosate and Lontrel; also sprayed for cockchafers.	21 March 2016 – Pasture sown at 15 kg/ha with Granulock15 @ ~100 kg/ha		